HYDROGEOLOGICAL AND HYDROCHEMICAL STUDIES OF THE PERIYAR RIVER BASIN, CENTRAL KERALA

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DOCTOR OF PHILOSOPHY

IN THE FACULTY OF MARINE SCIENCES

By

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FEBRUARY 2009

Declaration

I, **P. Balakrishnan**, do hereby declare that the thesis entitled **"HYDROGEOLOGICAL AND HYDROCHEMICAL STUDIES OF THE PERIYAR RIVER BASIN, CENTRAL KERALA" is an authentic record of research work done by me under the supervision of Prof. (Dr.) K.T. Damodaran, Former Director, School of Ocean Sciences and Technology, CUSAT. This work has not been previously formed the basis for the award of any degree or diploma of this or any other University/Institute.**

Kochi – 16
12th February, 2009. **P. BALAKRISHNAN**

****

Dedicated to my family

****

Certificate

This is to certify that the thesis entitled "HYDROGEOLOGICAL AND HYDROCHEMICAL STUDIES OF THE PERIYAR RIVER BASIN, CENTRAL KERALA" is an authentic record of research work carried out by Mr. P. Balakrishnan under my supervision and guidance in partial fulfillment of the requirements for the degree of Doctor of Philosophy and that no part thereof has been presented for the award of any degree in any University/Institute.

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P. Balakrishnan

WATER IN VEDAS

The Rig Veda identifies the Waters as the first residence or ayana of Nara, the Eternal Being and therefore water is said to be pratishtha, the underlying principle, or the very foundation of this universe. 'Water may pour from the heaven or run along the channels dug out by men; or flow clear and pure having the Ocean as their goal...In the midst of the Waters, is moving the Lord, surveying men's truths and men's lies. How sweet are the Waters, crystal clear and adjacent to the broken chain of cleansing...From whom... all the Deities drink exhilarating strength, into whom the Universal Lord has entered...'

(Satpatha Brahmanas).

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Chapter I

General Introduction

1.1 INTRODUCTION

Water is a prime natural resource essential for the subsistence of life and is a basic human need. About 70% of the Earth is covered by water. The total amount of water on the world is approximately 1.4 billion km^3 of which 97.5% is salt water and the rest is fresh water. Of the 35 million km^3 of freshwater on earth, about 24.4 million km^3 are locked up in the form of glacial ice or permanent snow. Groundwater and soil moisture account for 10.7 million km^3. Freshwater lakes and marshlands hold about 0.1 million km^3. Rivers, the most visible form of fresh water account for 0.002 million km^3 or about less than 0.01% of all forms of fresh water. The major source of fresh water is the evaporation on the surface of the oceans amounting to 505,000 km^3 a year. Another $72{,}000^3$ km evaporates from land surfaces annually. Approximately 80% of all the precipitation (about 458,000 km^3) falls on the oceans and the remaining 20% (119,000 km^3) falls over the land. The difference between precipitation onto land surfaces and evaporation from these surfaces is runoff and the groundwater recharge approximately is 47,000 km^3 per year. Of all fresh water not locked up in ice caps or glaciers, some 20% is in areas too remote for humans to access and of the remaining

80%, about three-quarters comes at the wrong time and place i.e., in monsoons and floods and is not always captured for use by people. The remainder is less than 0.08 of 1% of the total water on the Earth.

The estimated annual replenishable groundwater resource of our country is 432 BCM of which utilizable resource is 395.6 BCM and 325.6 BCM is allotted for agriculture. The estimated static resource is about 10350 BCM. The ultimate irrigation potential is 64 million hectors and the irrigation potential created so far is about 46 million hectors by developing nearly 160 BCM (Raju, 2006). With the present rate of groundwater development of about 160 BCM, in many arid, semi arid and drought prone areas of the country, groundwater development has exceeded the annual replenishment. The associated problems like steep declining of water levels and well yields, drying up of open wells and bore wells, deterioration in the quality of groundwater, sea water intrusion into coastal aquifers and shortage in the availability of fresh potable water, etc. are the threats due to over exploitation of groundwater. River basin based availability of groundwater should be estimated for groundwater development, management and sustainability of the resource. In Kerala, the annual replenishable groundwater resource of the state has been estimated as 6.84 BCM and the net annual groundwater availability is 6.23 BCM. The annual groundwater draft is 2.92 BCM and the stage of groundwater development in the state is 47% (CGWB, 2006).

Planning, development and management of this resource need to be governed by national perspectives. The accumulating hydrologic stresses and competing demands on our groundwater resources are making ground-water management increasingly complex. Hydrologic monitoring is critical to the management of a groundwater basin, as it provides information relating to the past and present state of the system, and can be used to signal necessary adjustments to the management plan. Source water protection and watershed management programs are vital to prevent the drinking water contamination. Success in any water resource management project lies in the application of an integrated approach considering the intrinsic characteristics of the domain. The occurrence and movement of groundwater is controlled by several factors such as climate, hydrology, geology, topography, ecology and soil distribution. These factors independently as well as collectively influence the functioning of the total water system. A systematic groundwater exploration includes the study of all the aforesaid factors. The first step in the development, conservation and optimum management of groundwater resources is a regional appraisal of the hydrogeologic conditions. Drainage basins or watersheds should be the unit of study area for better understanding of the hydrologic system and for accurate quantitative estimation of the resources. .

In India, development of groundwater in different parts of the country has not been uniform. Highly intensive development of groundwater in certain areas in the country has resulted in over exploitation leading to decline of groundwater levels and subsequently the sea water intrusion into the coastal aquifers. Development and management of this resource are planned on the basis of natural hydrologic boundaries and also on administrative boundaries. Application of an integrated hydrological methodology is a pre-requisite for any type of watershed development. To meet the two-fold challenge of increased water demands and reduced availability of fresh water in the country, the governments have promoted the practice of artificial recharge to groundwater including rain water harvesting. Impact assessment of the artificial recharge structures has shown arrest of declining trends, rise in groundwater levels, improvement in groundwater quality and increased sustainability of groundwater abstraction structures. Watershed based hydrological and hydrogeological studies are helpful in managing the water resources. Excessive pumping of our aquifers has resulted in an environmental catastrophe on many occasions. Groundwater is part of the longer hydrologic cycle that provides freshwater to lakes, rivers, and streams. Excessive groundwater exploitation disrupts this cycle and causes irreversible environmental damage.

Considering the aforesaid factors, Government of India, after a detailed deliberation over the water problems of the country, adopted a National Water Policy in 2002. The main objectives of this policy envisage the need for judicious and scientific water resource management and conservation. Water resource development and management will have to be planned for a hydrological unit such as drainage basin as a whole or for a sub-basin, multi-sectorally, taking into account surface and groundwater for sustainable use after incorporating quantity and quality aspects along with the environmental considerations. Water is a scarce and precious national resource to be planned, developed, conserved and managed as such on integrated and environmentally sound basis keeping in view the socio-economic aspects and the needs of the States. Exploitation of groundwater resources should be so regulated without exceeding the recharging possibilities. The detrimental environmental consequences of overexploitation of groundwater need to be effectively prevented by the Central and State Governments. Groundwater recharge projects should be developed and implemented for improving both the quality and availability of groundwater resource. Transfer of water from one river basin to another, especially to areas of water shortage may be required in certain cases. Monitoring of surface and groundwater quality and effluent treatment before releasing are also significant. Management of water resources for diverse use involves the participation of users, stakeholders and the government agencies.

1. 2 THE STUDY AREA

The Periyar River is the longest river of the State (PWD, 1974; CESS, 1984) and is indeed the life line of Central Kerala. Periyar was known as 'C*hhoorni nadhi*' (*nadhi* means *river*) in Sangham poetry. The activities along the long stretches of its banks are always hectic as life proceeds along with the flow of water downstream. The river is highly beneficial to Idukki and Ernakulam districts for irrigation, drinking and navigation. There are a series of dams and power stations in this river (Table1.1). The Idukki hydro-electric project is the most important scheme of its kind in Kerala. The river plays a very important role in the agricultural, industrial and commercial development of the State. The Periyar Valley Irrigation Project was capable of irrigating a net area of 30414 ha. The city of Cochin and the surrounding Municipalities and Grama Panchayats get their drinking water from the Periyar River.

The Periyar is sacred to the people around, materially, spiritually and creatively. It is not just a sacred river or Dakshina-Ganga or just a source for the State's drinking water and hydel power. It is also an inspiration for the writers, the muse of poets, the final destination of departed souls, the transmitter of culture and a source of income for the environmentally unfriendly who ravage it. The mountain ranges from where the Periyar originates and the serene beautiful lakes reflecting the nature around and along with the forest abounding in attractive wild life are all perennial attractions to the tourists. The Thekkady lake with boating facilities, the Bhoothathankettu reservoir and the beautiful wild life sanctuary adjacent to it, the natural beauty of Munnar etc., attract nature lovers and tourists from all over the world. The famous Malayattoor church, Kalady, the birth place of Sankaracharya, the greatest Advaitha Philosopher, is on the bank of the Periyar. Thattekkad bird sanctuaries, Aluva Sivarathri Manalpuram etc., are along the banks of the river Periyar.

1.2.1 Location

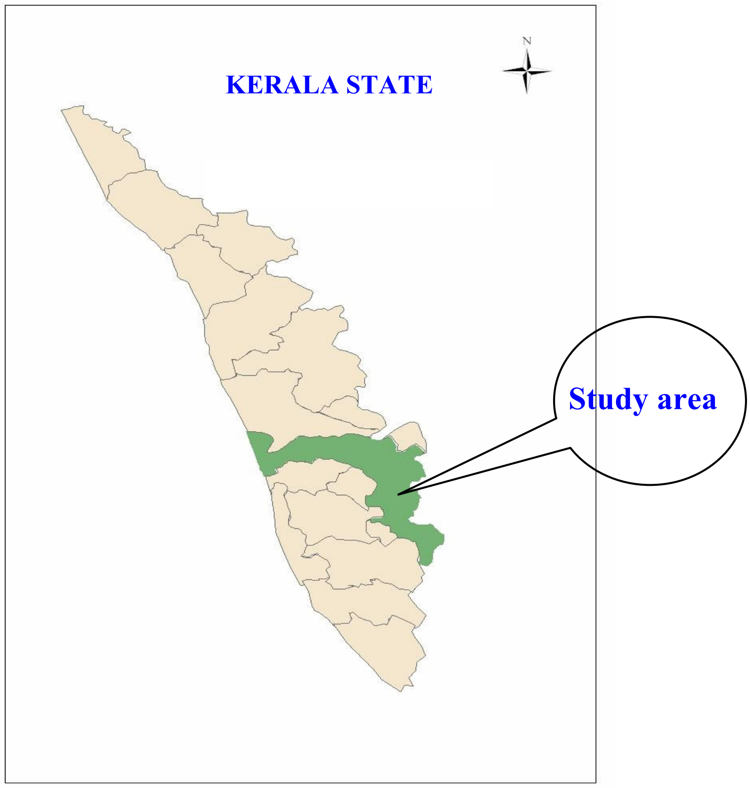
The area selected for the present study, the Periyar River Basin, falls within the central part of Kerala and lies between North latitudes 9°15’30” and

10°21’00”, East longitudes 76°08’38” and 77°24’32“ and spreads in the districts of Idukki, Thrissur and Ernakulam (Fig 1.1).

Table 1.1 Important Reservoirs in the Periyar River Basin

Sl. No.	Name of Reservoir	Year of completion	Height of Dam (m)	Length (m)	Volume of content (×1000m^3)	Reservoir			Designed spill way capacity (m^3/sec)
						Area at FRL (km^3)	Gross capacity (million m^3)	Effective capacity (million m^3)	
1	Kundala	1946	32.30	259	54	0.47	7.79	7.65	184.06
2	Mattupetty	1956	85.34	237	155	3.24	55.23	55.23	-
3	Sengulam	1957	26.80	144	18	0.29	0.71	0.71	70.80
4	Kallarkutty	1961	43.00	183	40	0.65	6.88	6.51	1982.40
5	Ponmudy	1963	59.00	294	181	2.79	51.54	47.40	1416.03
6	Anayirangal	1965	34.00	292	462	4.86	49.84	48.99	348.00
7	Idukki	1974	168.90	366	46	59.83	1996.30	1459.50	5100.50
8	Cheruthoni	1976	138.20	650	1700	59.83	1996.30	1459.50	5100.50
9	Kulamavu	1977	100.00	385	450	59.83	1996.30	1459.50	5100.50
10	Idamalayar	1985	12.20	58	4	0.25	0.79	0.77	1014.00
11	Kallar	1989	20.00	146	16	0.97	5.35	5.09	507.00
12	Erattayar	1989	102.80	373	880	28.30	1089.80	1017.80	3012.00
13	Lower Periyar	1995	39.00	244	140	0.45	5.30	4.50	14200.00

Source: KSEB (1996). FRL – Full Reservoir Level



THE PERIYAR RIVER BASIN

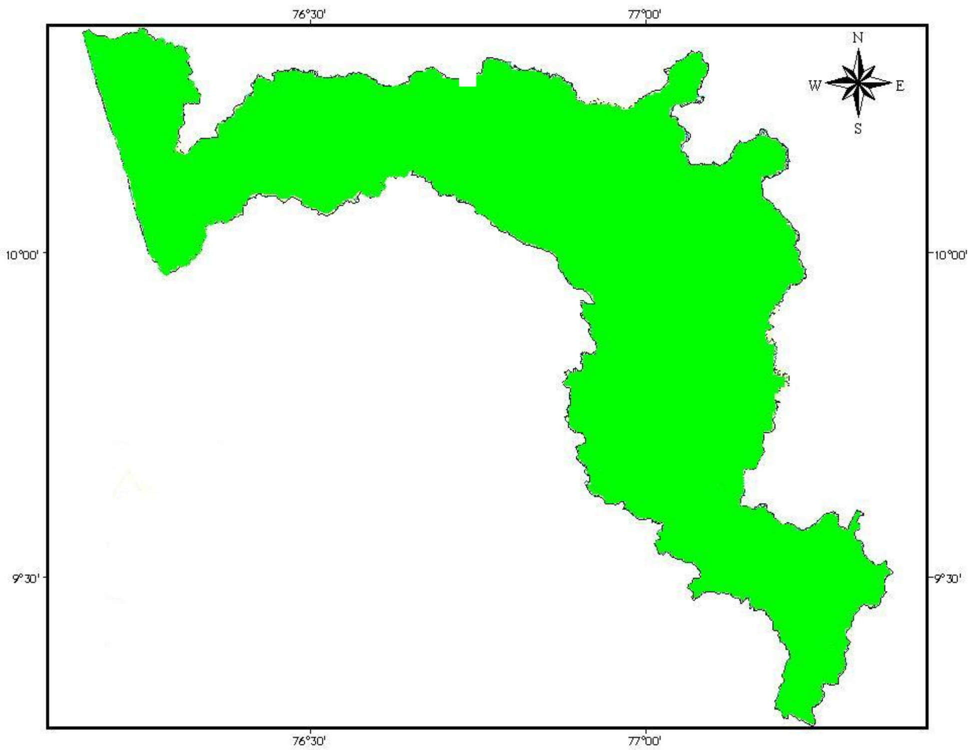


Fig. 1.1. Location map of the Study area.

1.2.2 CLIMATE

1.2.2 (a) Rainfall: The Periyar basin enjoys typical tropical humid climate. The high altitude area of this basin has a temperate climate. The average rainfall over a period of twenty years in the study area is 2809 mm of which 1785 mm is received during the southwest monsoon (June to August) and 704mm during the northeast monsoon (September to November). It is estimated that about 60% of the total rainfall is received during SW monsoon and about 25% during NE monsoon period.

1.2.2 (b) Temperature: The maximum, minimum and mean temperature of the basin is 32°C, 10°C and 27°C respectively. The maximum temperature is experienced during the month of March and the minimum during the month of December.

1.2.2 (c) Humidity: The study area has very high humidity. The mean humidity of the basin watershed is 83% at 8-30 hrs and 75% at 17-30 hrs.

1.3 PHYSIOGRAPHY

The study area exhibits varied physiographic features with elevation ranging from 1830m in the east to the sea level in the west (Fig.1.2). The study area is characterized by highly undulating topography with steeply dipping hill ranges, meadows, valleys and plains. Major part of the study area falls in the hilly ranges of the Western Ghats. The slope of the watershed ranges from nearly plain to steep sloping. Based on the elevation and the terrain features, the basin is divided into five physiographic units namely the lowlands, midlands, foothills, plateaus and the highlands.

1.3.1 Lowlands:

The lowlands occur as a narrow belt almost parallel to the present shoreline, with an elevation of less than 6m above the MSL. The width of the lowlands generally ranges from 8 to 15km. The landforms of this region are broad valleys, submerged lands with swamps and marshes and subdued sand dunes. Many parts of the area are directly connected to the backwaters with a network of canals.

1.3.2 Midlands:

To the east of the plains is the midland, which is approximately parallel to the coast, having an elevation ranging from 6 - 80m above MSL. The midlands are characterized by undulating topography with small hills separated by valleys and the general gradient is towards west. It is generally covered by thick laterite with good soil capping at the western part and with patches of crystalline rocks exposed on the surface in many places at the eastern part.

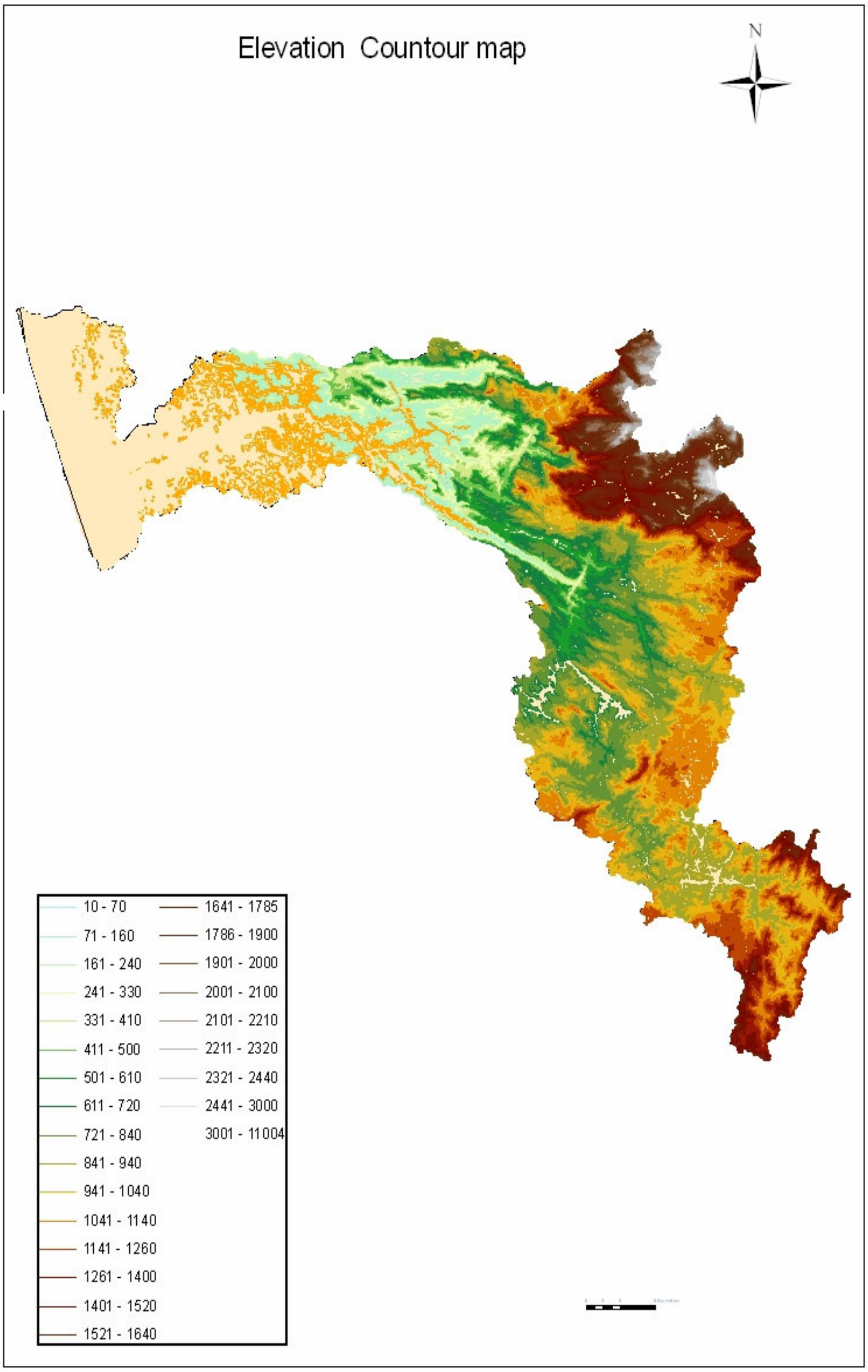


Fig. 1.2 Elevation map of the study area (in mtrs.).

1.3.3 Foot hills:

This is a narrow strip of land where midland region grades into the plateau region. The elevation of this region ranges from 80 to 500m above MSL and the sloping is very high ranging from 30 to 50%. The width of the foothill region ranges from 2 to 8 km. The area is characterized by high drainage density and small hillocks with steep slopes and deep cut valleys.

1.3.4. Plateaus :

This is characterized by a moderately sloping land with slope less than 30% and an elevation of less than 1500 m above MSL. This region is characterized by a number of deep-cut streams.

1.3.5 Highlands :

The highland region is characterized by roughly north-west trending ridges and high ranges of the Western Ghats with elevation exceeding 1500m above MSL and the maximum elevation reaches up to 2700m above MSL in Anamudi in the north-central part of the area. The highlands are characterized by highly undulating topography with hills separated by steep valleys. The foothills, plateaus and highlands are collectively classified as the highland region.

1.4 DRAINAGE

Periyar is the longest river of Kerala and also the largest in water discharge potential (Kerala State Gazetter, 1986) with a length of 244 km

(Fig.1.3). It originates from the Sivagiri malai (hills) in the Western Ghats at an elevation of 1830 m above MSL and finally drains into to the Lakshadweep Sea.

The river is perennial. The longitudinal profile of rivers is commonly used to identify the river morphological response to climate, lithology, structure, and tectonics (Brookfield, 1998). The drainage characteristics and the longitudinal profile of the river are exhibited in Figs. 1.3 and 1.4.

The analysis of the longitudinal profile of the basin suggests severe deepening in the upper-midland portion of the profile. The total drainage area is 5398 km^2, out of which 5284 km^2 is in Kerala and 114 km^2 is in Tamilnadu, covering 88 villages spreading over 103 grama-panchayats, 20 blocks and 3 districts. The Periyar watershed is divided into 183 sub-watersheds and 448 micro-water sheds (Fig. 1.5). The basin has an inverted " L" shape with a maximum width at the intersection. The length-width ratio is 6:1. The drainage pattern of the area has a direct control over the structure. Most of the streams flow in deep gorges with steep valleys along the highlands of the area. The general drainage pattern of the area is dendritic. At Pettoti, near Santhampara, some dome shaped hills with radial drainage pattern is noticed. The area from Idukki to Perinjakutty exhibits a parallel drainage pattern. The lithology also has a significant control over the drainage density of the area. The main tributaries of the Periyar River are Muthirapuzha, Mullayar, Panniyar, Puyankuttiyar, Cheruthoniyar, Perinjankutti and Edamalayar.

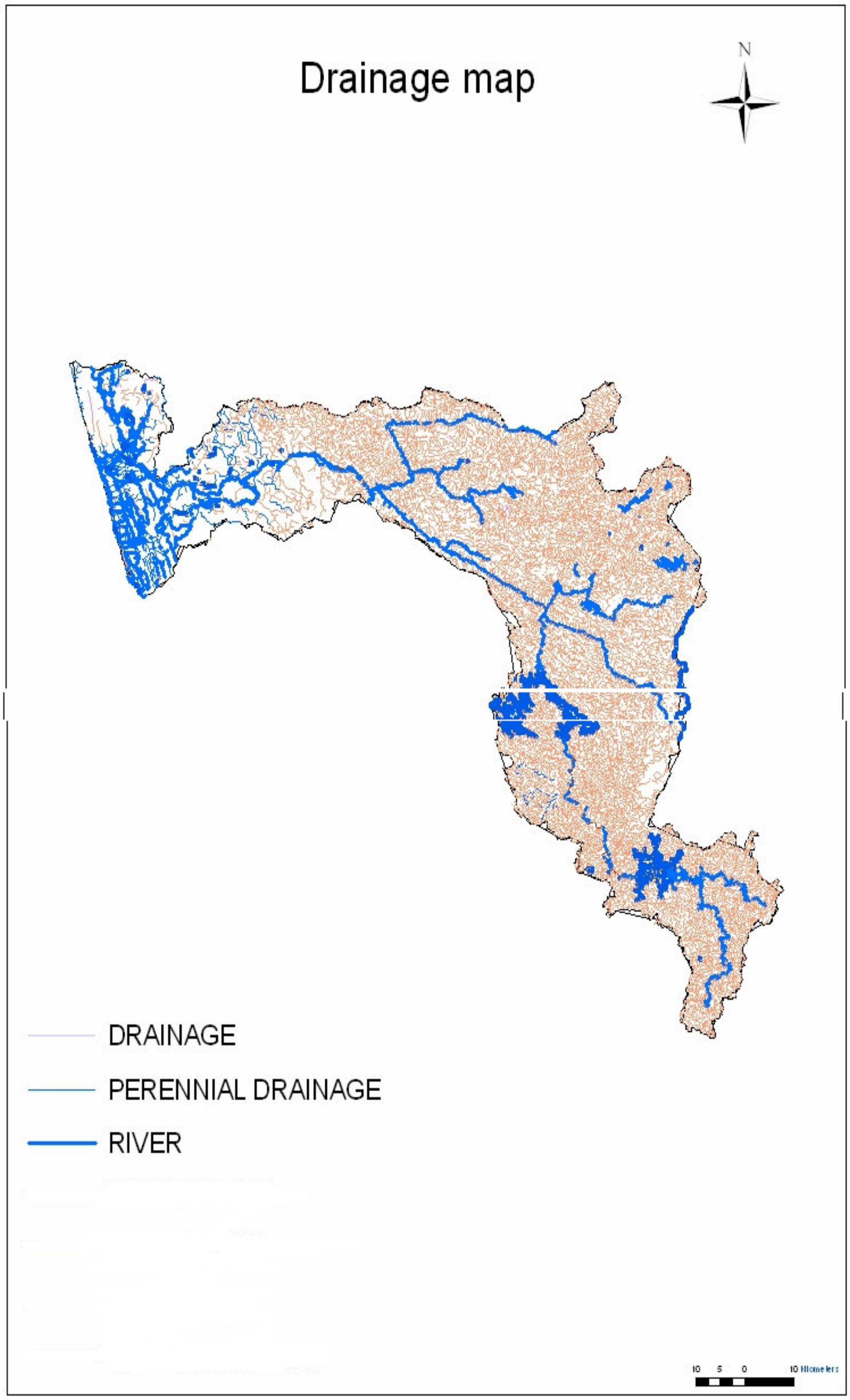


Fig.1.3 Drainage map of the Periyar River Basin.

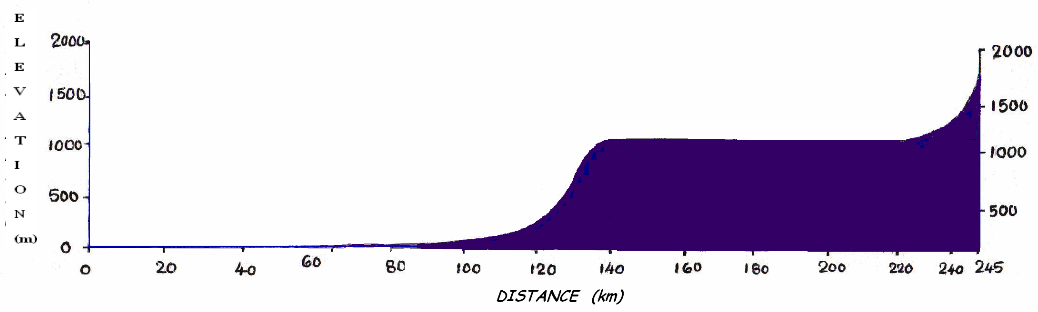


Fig.1.4 Longitudinal profile of the Periyar River Basin

The river bifurcates near Aluva into two major distributaries; one continue to flow through Desam, Mangalappuzha and finally drains into the Lakshadweep Sea. The Chalakkudy river also joins to the Periyar at Elanthikara, 10 km east of Kodungalloor and expands to its maximum width at Munambam. Maximum width of the river is 402m. The Marthandaverma branch flows southwards, again dividing into two near Kunjunnikkara Island, and finally drains into the Vembanad backwaters at Varapuzha. The Vembanad backwaters are connected to the Lakshdweep Sea at Cochin and Kodumgallur. The important reservoirs in the Periyar River Basin are Bhoothathankettu, Idamalayar, Lower Periyar, Mattupetty, Anayirangal, Kundla, Ponmudi, Kallarkutti, Idukki, Mullaperiyar etc.

1.5 LAND USE

The vegetal cover classification of the Periyar basin shows that around 30% of the area is dense in vegetation, 50% medium (35-75%) and the remaining (<35%) is low in vegetation (Fig.1.6).

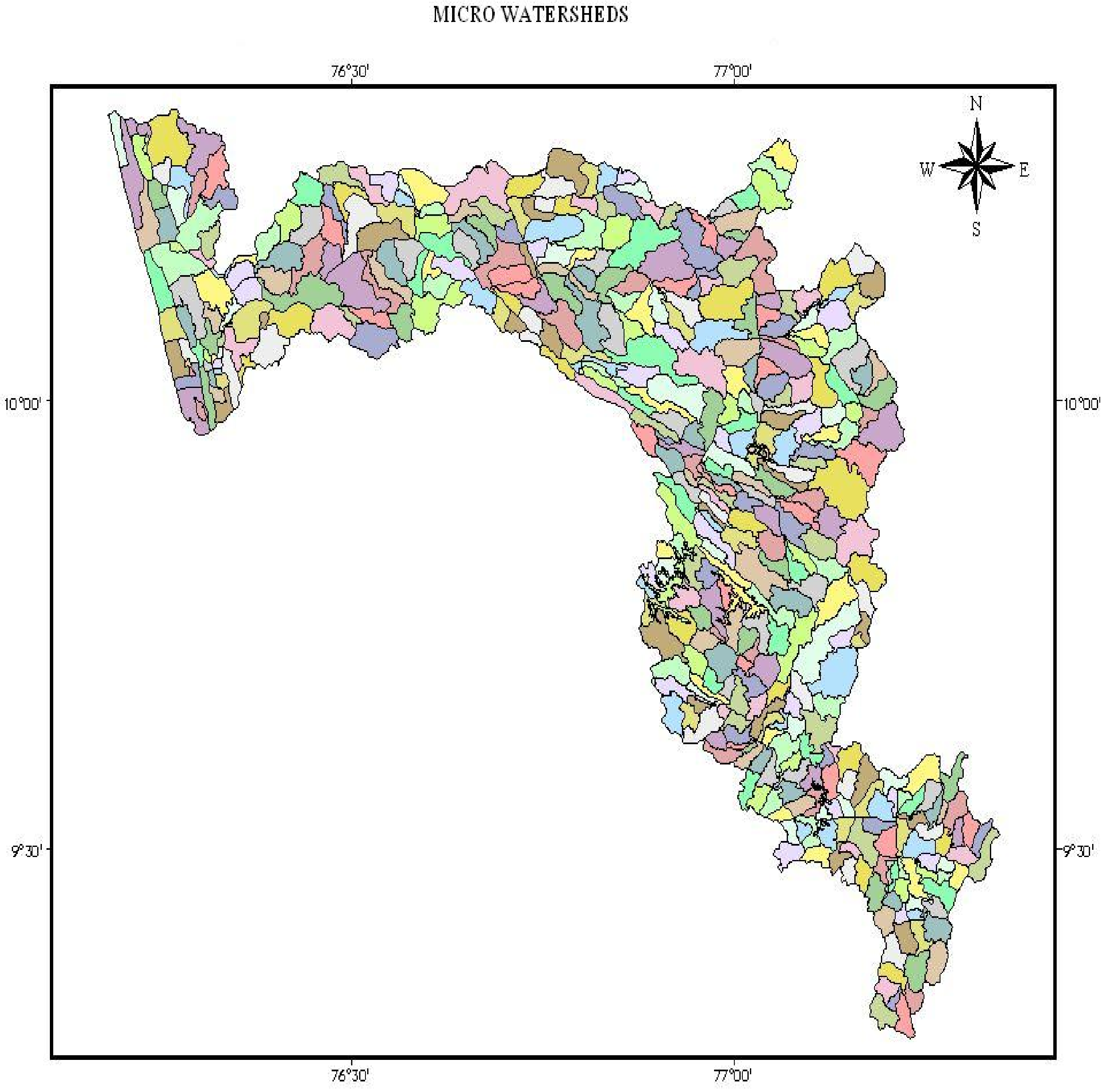


Fig. 1.5 Micro watersheds of the Periyar River Basin

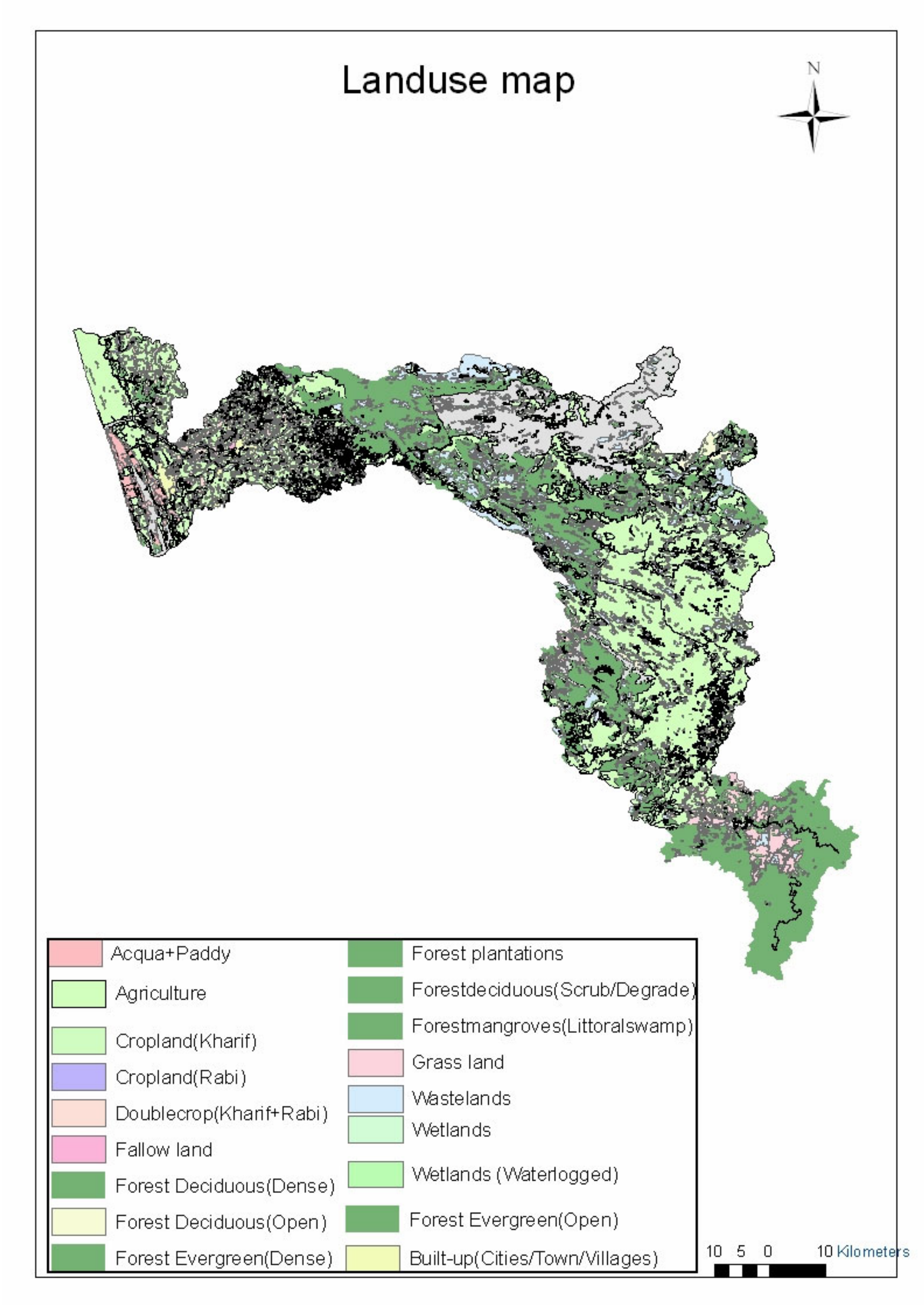


Fig. 1.6 Landuse map of the study area.

The upper reaches of the basin is utilized for plantation crops like tea, coffee, cardamom and rubber. The major share of the cardamom and tea production in the state is from this region. The maximum coverage of dense forest in the state is also occupied by the study area. Major crops being cultivated in the river basin includes rice, coconut, areca nut, banana, rubber, vegetables etc. The area under non-agricultural use is mainly water bodies, dwelling units and industrial areas. The steep sloping lands, barren crystalline area, highly undulating upland area and unutilized degraded forests are included in the category of wastelands. In the midland region, the main cultivations are paddy, mainly along the flood plains, coconut and other mixed crops along the valley portions and mainly rubber along the mounts and hill slopes. In the lowland region, the main cultivations are paddy, coconut and other mixed crops (Fig.1.6).

1.6 OBJECTIVES

1.6.1 The main objectives of the present investigation are:

(1) To study the seasonal variations (Pre-monsoon and Post-monsoon) in the groundwater resource and assessment of the groundwater balance of the study area.

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

(3) To study the seasonal variations (Pre-monsoon and Post –monsoon) in groundwater quality of the basin and thereby evaluate its suitability for various uses.

(4) To compare the different water quality parameters against the BIS and WHO standards.

(5) To study the impact of pollution on the ecosystem like salt water intrusion into the aquifers and to recommend practical measures to mitigate the same.

(6) To demarcate the groundwater potential zones through Geographic Information System (GIS) by the integration of the various data obtained as part of the study.

(7) To generate a scientific data base for the groundwater of the Periyar River basin.

(8) To suggest a set of recommendations for the proper water management in future of the basin based on the study.

1.7 PREVIOUS WORK ON THE STUDY AREA

Geological mapping was carrying out by the Geological Survey of India from 1965 and are being updated (Murthy et al, 2000; Soman, 1997). Detailed land survey of the basin area was carried out under the Periyar Valley Irrigation Project (PVIP) in 1981 for the construction of irrigation canals in the area. This is the major irrigation project of the study area. Under this project, mainly the midland region of the area is covered and being irrigated.

Reappraisal hydrogeological survey in the Periyar River Basin was carried out by the Central Groundwater Board in 1988 under the Coastal Kerala Groundwater Project (CGWB, 1988). According to the survey report, wells located along the valleys are found technically more yielding for domestic and irrigation purposes.

Studies were conducted to evaluate the quality of surface water at Kanakkankadavu, Purappallikavu, Pathalam and Manjummal stations, in the lower reaches of the Periyar River with a view to utilise them for drinking purposes (Ashraf and Mukundan, 2007). Mercury and lead were detected in the months of January and March of the sampling period at Kanakkankadavu. Trace levels of As, Se, Cr and Cd were detected in some samples during particular months of the study period. Significantly higher levels of magnesium and calcium were detected during the summer season. The hydrographic data revealed that all the sources have acidic pH, high turbidity, low salinity during monsoon and higher nitrate, sulphate and hardness during the summer months. Kanakkankadavu and Purappallikavu had extreme salinity and the presence of certain toxic metals during the summer months while the other stations recorded values well below the limits.

Studies were made on the surface water chemistry and dissolved nutrient flux of Periyar and Chalakudy rivers (Maya, 2005) and reported that the lower reaches of these rivers are affected by sea-water ingression from the Arabian Sea during the non-monsoon season. Human interference through agriculture, urbanization, and industrialization in the lower and middle stretches of the river basins induce marked concentration variations in the hydro-chemical parameters. Except for N & P, all other chemical constituents exhibit high values during the non-monsoon season. Industrial contaminants in specific locations of the Periyar River reduce the pH to lower levels (Maya, 2005).

Water quality survey conducted by the Central Pollution Control Board (CPCB, 2000) revealed that a high level of fecal contamination is noticed in the lower reaches of the river. The pH of the river water is found to be very low in the lower reaches of Udyogmandal industrial area, indicating the impact of pollution due to industrial waste disposal. Excessive sand mining from the river is affecting the water quality. Discharge of effluents from industries is affecting the water quality downstream of Eloor. A network design of rain gauging stations has been attempted for the seven adjacent rivers including Periyar using spatial correlation technique to study the number of rain gauge stations to be established in the area (Aswani Kumar and Sreedharan, 1999).

1.8 REVIEW OF LITERATURE

The branch of earth science which deals with the occurrence and movement of subterranean water is termed 'Hydrogeology' (Mead, 1919). The relevance of the science of Hydrogeology is becoming all the more important today especially in India, where overexploitation, declining groundwater levels and groundwater quality are affecting the lives of most of the population. The active role of groundwater in nature is its ability to interact with the ambient environment and the systematized spatial distribution of its flow (Toth, 1966). The "hydrogeologic environment" is a conceptual system of the morphologic, geologic and climatologic parameters that determine the principal attributes of the “groundwater regime” in a given area (Toth, 1970). 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 area also. Climate change is probably one of the most challenging pressures facing the hydrogeological systems and water resources (Brouyere et al., 2004). Groundwater transit times are of the interest for the management of water resources, assessment of pollution from non-point sources, and quantitative dating of groundwater by the use of environmental isotopes (Etcheverry and Perrochet, 2000). The Third World Water Forum was held at Osaka in Japan on 18-19 March 2003. This was the first major International conference to strongly feature groundwater within an overall water contest and was devoted the entire sessions specifically to moving “Groundwater – from development to management” (Kemper, 2003). Reliability and validity of groundwater analysis strongly depend on the availability of large volumes of high quality data. Putting all the data into a coherent and logical structure supported by a computing environment which helps to ensure validity and availability and provide a powerful tool for hydrogeological studies.

Watershed development programme provide an opportunity for sustainable management strategies, although currently they remain largely ‘supply side’ mechanism of water resources development. Hydrogeological conditions, community participation and status of groundwater usage are important in evolving strategies on ‘demand side’ groundwater development (Kulkarni and et al.., 2004; Chebaane et al., 2004; Sandoval, 2006). Watershed development in India is being adopted increasingly as an integrated mechanism of addressing ecological concerns, particularly in dry land areas. Increasing groundwater recharge constitutes one of the principal objectives of watershed development programme (Pakhmode et al., 2003). Implementing groundwater management and protection measures needs quantitative appraisal of aquifer evolution and effects based on detailed multidisciplinary studies which have to be supported by reliable data (Custodio, 2002).

Drainage pattern is one of the most important indicators of hydrogeological features as its texture and density are controlled in a fundamental way by the underlying lithology. In addition, the stream pattern is a reflection of the rate that precipitation infiltrates compared with the surface runoff. The infiltration/runoff relationship is controlled largely by permeability, which in turn is a function of the rock type and fracturing of the underlying rock or surface bed rock (Edet et al., 1998; Prasad et al., 2008). Slope of any terrain is one of the factors controlling the infiltration of groundwater into subsurface; hence is an indicator for groundwater prospect (Prasad et al. 2008).

Hypsometry, by definition, is an area-altitude analysis of a given territory and hypsometric curve depicts distribution of area according to altitude. The shape of the hypsometric curve provides important clues to decipher the type of erosional process controlling the landform development (Chattopadhyay et al., 2006).

The Exploration of groundwater is normally carried out following either a single method or a combination of a few methods (Karanth, 1987) namely, geological and hydrogeological methods, surface geophysical methods, hydrogeological well logging as tracer techniques as stated by Sharma (1987). Philip and Singhal (1991) have compared the groundwater levels of different geomorphologic features. Their study reveals that the wells located on erosion valleys have deeper water levels, varying from 3.4 to 6.5m below ground level as compared to other land forms. Karanth (1987) has also pointed out that water level fluctuation maps 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 influence on groundwater levels including meteorology, tidal phenomena, urbanization, earthquakes and external loads. Todd (1980) suggested that the land subsidence could occur due to changes in groundwater conditions. Within the type of hydrogeological environment in hard rock terrain, overwhelming heterogeneity in the properties is noticed. A parameter such as hydraulic conductivity which is determined by field methods, normally varies by several orders of magnitude within the same rock unit often within a short distance (Gustafson and Krasny, 1994). Suzhou city is one of the few cities in China which suffers from severe ground settlement. An examination of the historical records of groundwater extraction, water levels and ground settlement shows that the ground subsidence is associated with the continuously increasing groundwater extraction in the deep confined aquifer (Chen et al. 2003). The fluctuation of water table influences the agricultural production, as it is closely related to the alteration of dry and wet periods. A model has been developed to estimate the fluctuation of the water table in the La Pampa province and in Buenos Aires province in Argentina. A forecast of the seasonal rainfall is produced using the SST anomalies in the Pacific Ocean as predictors. Using that forecast and based on the relationship between rainfall and water table levels, the prediction of water table fluctuation could be generated (Tanco and Kruse, 2001).

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). By conducting Schlumberger array electrical soundings, Worthington (1977) has attempted to evaluate groundwater resources of the Kalhari basin, South Africa. Verma et al. (1980) has used histograms, curve types and iso-apparent resistivity and Schlumberger sounding curves to investigate the groundwater potential in metamorphic areas near Dhanbad, India. Vertical Electrical Soundings (VES) are very useful for economical and reliable groundwater investigation and assessment. This can also be used for the direct assessment of aquifer parameters (excluding storativity), which in turn can be used for estimation of dynamic and static groundwater reserves (Paliwal and Khilnani, 2001). The above study reveals 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., (Sharma and Sarma, 1987; Balakrishna et al., 1984; Balasubramanian et al., 1985). Gradient profiling for investigation of groundwater is successfully utilized as preliminary tool to identify the fracture zones saturated with water especially in a hard rock terrain covered with a thin layer of soil (Yadav and Singh, 2008). Gravity method is also an effective tool for groundwater exploration in crystalline rocks. A comparison of relative gravity anomalies with the yield of bore wells in weathered zones reveals that the yield is directly proportional to the weathered thickness and inversely proportional to the residual gravity in weathered granitic regions (Murty and Raghavan, 2002).

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 aid of computers. However, the graphical and iso-line 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). Good operational data are especially important when dealing with wells in shallow, unconfined, fissure- flow aquifers, where the actual well performance may vary considerably from that predicted using a more analytical approach (Misstear and Beeson, 2000). Determination of unconfined aquifer parameters using Neuman and Streltsova methods are widely used in groundwater studies (Abdulaziz et al., 1993).

The topography and landforms have strong influence on the well yield, especially of shallow wells, as they influence the thickness of weathered zone (LeGrand, 1967; McFarlane et al., 1992; Henrikesen, 1995, Wilkes et al., 2004). Wells located in valleys have greater yield than that of those located on steep slopes, sharp ridges and inter-fluvial area. (Wilkes et al. 2004). Therefore, to a certain extent, the well yield 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 inselberges (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 yield 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 part 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. Within the type of hydrogreological environment in hard rock terrain, overwhelming heterogeneity in the properties is noticed. A parameter such as the hydraulic conductivity which is determined by field methods, normally varies by several orders of magnitude within the same rock unit often within a short distance (Gustafson and Krasny, 1994).

Groundwater typically has a large range in chemical composition (Hem 1970; Drever 1982; Mathess 1990). The chemical composition of groundwater is mainly related to rock weathering with respect to space and time (Raghunath,1987). The leaching of minerals, man can 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 disposal of effluent from the tanneries are the main source of the change in physical, chemical and biological characteristics of groundwater in Sempattu area, Thiruchirappalli (Manivel and Aravindan, 1997). The hydrogeochemistry and groundwater flow patterns in the vicinity of Stratford-Upon-Avon have been studied Lloyd (1976). He used Durov's diagram to differentiate the major ionic constituents of groundwater flow. The study further reveals that faulting has a dominant control on groundwater movement. Similar type of work has been attempted by Daly et al.(1980) for Castle Corner plateau, Ireland. Groundwater pollution is of a major concern today. Isotope techniques are effective for identifying the source of salinity or pollution. The International Atomic Energy Agency (IAEA) has a long tradition and wide experience in the use of isotope techniques for water resources studies and is acting as the international focal point in promoting the practical application of isotope method on a wider scale (Gaye, 2001).

A substantial body of research over nearly a century has indicated two potential impacts of afforestation on groundwater; (i) impact on the quantity of water percolating down to the water table, i.e. a potential reduction in recharge of groundwater and (ii) Impact on water quality, specifically acidification (i.e. reduced pH) and changes in nitrate levels in groundwater (Allen and Chapman, 2001). There is increasing need for reliable tools for groundwater management against the background of the more intensive use of groundwater resources. Therefore, numerical models of groundwater flow and solute transport become very important in planning sustainable resource utilization and the protection of groundwater quality (Grasle and Kessels, 2003).

A large number of microbial pathogens are known to contaminate or may plausibly contaminate groundwater. Most of these organisms are of fecal in origin and are transmissible via a fecal-oral route of exposure (Macler and Merkle, 2000). Variability in subsurface geochemical and hydrological conditions significantly influences subsurface microbial-community structure (Haack et al., 2000).

Now a days aerial photographs and satellite imageries are widely used to obtain both qualitative and geological information. Due to repetitive and synoptic coverage capability of satellite, vital regional information is generated which otherwise may not be possible through ground survey (Williams and Partheeban, 2004). Remote sensing with its advantage of spatial, spectral and temporal availability of data covering large and inaccessible area within short time has become a very rapid and cost-effective tool in assessing, monitoring and conserving groundwater resources. Geographical Information System (GIS) is a powerful set of tools for collection, storing, retrieving, transforming and displaying spatial data from the real world for a particular purpose (Prasad et al., 2008). A hydrogeological geographic information system (GIS) database that offers facilities for groundwater vulnerability analysis and hydrogeological modelling has been designed in Belgium for the Walloon region (Gogu et al., 2001).

The Geographic Information System has become the most promising technology for the integrated approach. This technology is capable of assembling; storing, manipulating and displaying geographically referred information (Williams and Partheeban, 2004).

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Chapter II
Methodology

2.1 INTRODUCTION

Groundwater investigations of river basins involve a variety of procedures and techniques. The methodology is dependant on the objectives of the work, terrain conditions, the availability of infra-structure, etc.

2.2 SOURCE OF DATA

Data pertaining to the study area were collected during the field investigation and from various organizations as listed below:

Base map of the study area was prepared from the toposheets published by the Survey of India in the 1: 50000 scale. The toposheets used were 58 B/3, 58 B/4, 58 B/7, 58 B/8, 58 B/11, 58 B/12, 58 B/15, 58 B/16, 58 C/1, 58 C/5, 58 C/6, 58 C/7, 58 C/9, 58 C/10, 58 C/11, 58 C/13, 58 C/14, 58 C/15, 58 F/3, 58 F/4, 58 F/7, 58 F/8, 58 G/1, 58 G/2, 58 G/3, 58 G/5, 58 G/6 and 58 G/7. These toposheets were made available by the Kerala State Groundwater Department.

To study the seasonal variations in the groundwater of the area, data of the National Hydrograph Stations(NHS) being maintained by the Groundwater Department, Government of Kerala were collected for the period from 1985 to 2006. For visual interpretation of satellite imagery, FCC of IRS LISS II and LISS III data, available with the State Groundwater Department were also collected. Meteorological data has been collected from the Kerala State Electricity Board and the State Groundwater Department. The details pertaining to the irrigation canals were collected from the State Water Resource Department.

2.3 FIELD INVESTIGATIONS

2.3.1 Hydrogeological investigation

Detailed hydrogeological investigation has been carried out in the Periyar River Basin taking the entire area as a study unit, as this helps in better understanding of the hydrologic system and accurate quantitative estimation of the groundwater resources of the area. The prime objectives of the hydrogeological investigation of river basin are to study there

- Principal hydrogeologic units and their distribution.
- Recharge and discharge areas.
- General groundwater potential of the area.
- Physical parameters of aquifers like transmissibility, storage co-efficient and specific yields.

- Groundwater quality in terms of chemical constituents and their relationship to geologic factors
- Depth of wells and their distribution.
- Water table fluctuation with respect to topography and time.
- Yield of wells.
- Draft of groundwater for different uses.
- Major problems related to groundwater development and management.

The different methods involved in the hydrogeological investigations include geomorphological, geological, hydrometeorological, geophysical, hydrogeochemical, remote sensing, GIS studies etc.

2.3.2 Geophysical investigation

To study the geo-electrical properties of the basin, electrical resistivity survey has been carried out in the area using the computerized resistivity meter, namely, Aquameter CRM 20. Electrical resistivity is one of the most widely used geophysical techniques, which gives good indication on the presence of subsurface fractures in rocks as well as quantity and quality of water. Resistivity prospecting aims at determining the resistivity of the formations (more precisely geoelectric sections) which in turn can be used to determine the subsurface structures of large groundwater basins, horizontal and vertical distribution of the aquifer, salt-fresh water boundaries, presence of buried channels, etc. The resistivity variations in the subsurface can be studied from surface observations. In electrical resistivity method, current is passed into the earth using two current electrodes, from an AC or DC source, and the resulting potential distribution is measured using two more electrodes called potential electrodes. If the current is passed into the isotropic and homogenous medium, then the resistivity obtained will be the ‘true resistivity’. However, the Earth is never homogenous and hence the resistivity obtained is called as ‘apparent resistivity’. The apparent resistivity is related to the geometry of the electrode configuration and parameters of the geoelectric section. The measured values of apparent resistivity at a point must not be directly associated with the electric resistivity of the ground immediately below the point. Vertical electrical soundings (VES) were carried out at the selected 105 locations distributed uniformly within the study area using the Schlumberger array for delineation of deeper layers. During the field survey, the apparent resistivities obtained for different electrode spacing were recorded. These apparent resistivities were plotted against current electrode spacing on as double log graph sheets having 62.5 modulus to get the field curves. The field curves were interpreted by curve matching technique. Iso-resistivity maps were prepared and these maps were correlated with the hydrogeological aspects of the basin.

2.3.3 Conducting of pumping test:

Groundwater extraction in the study area is mainly through open dug wells. The occurrence and movement of groundwater depends on the geohydrological characterstics of the subsurface formations. These natural deposits vary greatly in their lithology, texture and structure which in turn influence their hydrological characteristics. Pumping test has been carried out in the selected 14 open dug wells of the study area. The Pumping test serves two main objectives. Firstly, a pumping test is performed to determine the hydraulic characteristics of aquifers. Secondly, the pumping test can provide information about the yield and drawdown of the wells. These data is used to determine the specific capacity. The specific capacity gives a measure of the effectiveness or productive capacity of a well. Prior to the performance of an aquifer test, the necessary information on the subsurface geological and hydrological conditions, i.e. the lithologic character and the thickness of the aquifer and the aquifer boundaries have been studied. In selecting the site of an aquifer test, the following points have been followed.

(i) The hydrogeological condition of the site should not change over short distance and should be a representative of the area or a large part of the area under study.

(ii) The site should not be selected near road or railway line where passing trains and heavy traffic may produce measurable fluctuations of the water table.

(iii) The pumped water must be discharged in such a way that it does not return to the aquifer.

(iv) The gradient of the water table should be low.

(v) Manpower and equipment must be able to reach the site easily.

The capacity of the pump and the rate of discharge should be high enough to produce good measurable drawdown depending upon the aquifer conditions. When the hydraulic conductivity of the aquifer is high, the cone of depression induced by pumping will be wide and flat. When the hydraulic conductivity is low the cone of depression will be steep and narrow (Kruseman and deRidder, 1984).

The measurements taken during the pumping test fall into two groups, (i) measurement of the water level and (ii) measurement of the discharge rate. The most important part of a pumping test is the measurement of the depth to water table. These measurements were taken at fixed time intervals during the course of the test using a digital water level recorder (DWLR). The time intervals adopted during the pumping and recovery phase are given below.

Table 2. 1 Range of time intervals between water level measurements in the pumped well.

Time elapsed since pumping started (in minutes)	Time intervals in minutes
0 – 5	0.5
5 – 60	5
60-120	20
120 – Shut down of the pump.	60

To avoid complicated calculations, the discharge rate is kept constant throughout the test. The discharge was measured accurately and recorded periodically. Necessary arrangements were made from time to time to keep the discharge rate constant. A very simple and accurate method to measure the discharge is by computing the time required to fill a container of known capacity. This method was applied where the discharge rates were small.

The circular or orifice weir was used to measure the rate of discharge from a centrifugal pump where the discharge is high. The period of pumping depended on the type and yield of the aquifer to be tested.

After the pump was shut down, the water level in the pumped well started to rise. In the initial phase it has risen rapidly, but as time goes on, the rate of rise decreased. This rise was measured and this part of the pumping test is called the recovery test. The schedule for recovery measurements was the same as that adhered to during the pumping period. After the pumping test was completed, all the data collected is analyzed and the aquifer parameters were found out individually. Based on this result the area of high transmissivity, high permeability, and high storage coefficient and in areas of minimum water yield of the basin were delineated. The details of equations used and procedure of calculations are given in Chapter V.

2.3.4 Groundwater Sample collection

Based on the detailed hydrogeological investigation, a total of 72 open dug wells were fixed uniformly throughout the basin for detailed water quality studies. These include public wells as well as those owned by private individuals. Pre-monsoon and Post-monsoon water samples from these wells were collected at regular intervals and analysed to study the seasonal variations and the sample locations. Sampling was done during the year 2004, 2005 and 2006. The Pre-monsoon samples were collected during March and the Post-monsoon during October every year. Groundwater samples were collected in new polyethylene bottles. Prior to sampling, these bottles were cleaned with pure water and also rinsed thrice with the respective groundwater under sampling. The parameters such as pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured in the field itself using the pH meter (pH scan1), conductivity meter (CM-183) and TDS meter (CM-183) respectively. The values of TDS and EC were validated using the relationship, 1µS/cm = 0.65 mg/l. For fixing the total iron, samples were preserved in the field by adding dilute hydrochloric acid (2ml/1000ml) as a preservative agent and transported to the laboratory following the standard guidelines (APHA, 1985). For bacteriological analysis, the groundwater samples were collected separately in sterlised bottles, kept in ice box for maintaining the temperature at 4°C and transported to the laboratory. Bacteriological tests were conducted within 12 hours of sampling.

2.4 LABORATORY WORK

2.4.1 Chemical analysis

Groundwater samples collected from the representative 72 open dug wells from different parts of the study area during the three consecutive pre-monsoon and post-monsoon periods were subjected to physical, chemical and bacteriological analysis in the laboratory. The samples have been brought to the laboratory after pretreatment and analysed by following the standard methods for water analysis (APHA, 1985). The major parameters like Ca^{++}, Mg^{++}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{--}, Cl^{-}, F, NO_3^{-} and SO_4^{--} were analysed in the laboratory. Sodium and potassium in the samples were analysed using

Flamephotometer (Systronics FPM digital model). Calcium, magnesium and total hardness were estimated by EDTA (0.01M) titrimetric method. Chloride was determined by argentrometric titration using standard silver nitrate as reagent. Carbonate and bicarbonate concentration in the samples were determined titrimetrically against standard hydrochloric acid (0.01N). Sulphate concentration was carried out following the turbidity method using Spectrophotometer. Total iron and sulphate in samples were determined through a double beam UV-visible spectrophotometer (Hitachi model 2000). The fluoride concentration was analysed based on the colorimetric method using SPADNS reagent. The consolidated outline of the various methods employed are tabulated in Table 2.2.

Table 2. 2 Methods followed for determination of various physical and chemical parameters of groundwater.

Sl.No.	Parameters	Methods
1	pH, TDS and 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

2.4.2 Reporting the analysis

The most common method that is used as a unit of measure to report the ionic concentration of groundwater is:

(i) Parts per million (ppm) by weight.
(ii) Equivalent per million (epm) by weight.

2.4.3 Accuracy of analysis

The precision and accuracy of the analysis have to be determined. Error in analysis can occur due to the chemical reagents employed for analysis, human error while analysis, distilled water quality, etc. Richards (1954) has worked out a procedure to check the precision and accuracy of chemical analysis data. Summers (1972) suggested that the total weight of cations approximately equal to anion and the weight of two should be verified with the TDS to find the precision and accuracy of sample. The criteria for verifying the accuracy is given below:

TDS (ppm)	2500	2000	1500	1000	500	100
Permissible error (PE %)	1.5	2.0	2.5	3.0	4.02	8.0

The evaluation of data was carried out using several standard techniques of groundwater hydrochemistry. These techniques include graphical methods like (a) hydrochemical isocon maps (b) hydrochemical diagrams such as Hill-piper and Stiff diagrams. The suitability of water for irrigation was determined by U.S.S.L. (1954) diagram.

2.5 WATER BALANCE

Water balance studies of the river basin is useful for solving important theoretical and field hydrological problems such as quantitative evaluation of water resources, rational use, control and redistribution of water resources in time and space. The spatial and temporal availability, present utilization and future demand of water for various purposes were estimated based on the Groundwater Estimation Methodology 1997 (GEC-97). For more precision, the resource estimation of the basin was made based on each block as separate unit and the resource of the basin was estimated. In order to understand the changes in water storage of the basin, the temporal and spatial availability and demand for various purposes were worked out. Net groundwater availability of the basin has been worked out and based on this, the categorization of the basin for future groundwater development is made.

2.6 SATELLITE DATA COLLECTION AND IMAGE PROCESSING

An understanding of the geology and structure of a terrain is a prerequisite for exploration, exploitation and landuse planning. Satellite remote sensing, by virtue of its capability to provide synoptic view of large area with reference to time, has become an essential and effective tool for water resources assessment, planning and development. The potential of remote sensing technology to address various issues of watershed management for sustainable development is well established.

Sebastian et al(1995) have stressed for a holistic approach towards watershed management and upto date information about various factors such as size and shape of watershed, topography, soil and their characteristics, landuse/land-cover, drainage parameters etc. Remote sensing lends itself a powerful input media helping in the process of multidisciplinary approach for natural resources in a watershed for integrated development.

The satellite data of IRS-1C LISS III (1997, geocoded FCC and IRS-1D LISS III (1999, both digital and geocoded FCC) of the study area were used. The 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; in two 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). It has a special resolution of 23.5m in visible and near infra red region and 70.5m in short wave infra red region. A path row based full scene product covers an area of 141 × 141 km^2. The details of the satellite data are given below (Table 2.3)

Table 2.3 Details of Satellite data used.

Item	Details
Satellite data.	Path & Row: 100/67
IRS 1C LISS III	Date: 11.10.1997
IRS 1D LISS III	Date: 24.2.1999.

2.6.1 Data analysis

A number of procedures are available for image data manipulation (Jenso, 1986; Lillesand and Kiefer 1987; Hord, 1982; and Mather, 1987). The manipulation of remotely sensed data by image processing and analysis is found to be one of the most useful techniques in groundwater studies. There are two methods for interpreting satellite remote sensing data. They are visual interpretation and image interpretation. In the present study both the methodologies have been used.

2.6. 1. (a) Visual interpretation

Many scientists have used visual interpretation technique for the study of water 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 the quality of the images used. In the present work, thematic maps such as geomorphology, lineament, landuse etc., were prepared from visual interpretation of LISS III geocoded products.

Table 2. 4 Interpretation using Remote Sensing keys developed by NRSA.

Sl. No	Land use	Tone/colour	Size	Shape	Texture	Pattern	Location
1	Build-up land	Dark bluish green in the core and bluish on the periphery	Similar to Big	Irregular and discontinuous	Coarse and mottled	Scattered and non-continuous	Plains, on hill slopes, deserts water front, road, rail, canal etc.
2	Crop land	Bright red to red	Varying in size	Regular to irregular	Medium to smooth	Contiguous to non-contiguous	Plains, hill slopes valleys, cultivable and waste lands.
3	Degraded land	Light red to dark brown	Varying in size	Irregular and discontinuous	Coarse mottled	Contiguous to non-contiguous	Mountain slope isolated hills and foot slopes and within notified forest areas
4	Salt affected land	White to light blue	Small to medium	Irregular and discontinuous	Smooth to mottled	Dispersed. Non-contiguous	River plains, valleys, coastal lowlands, and desert plains.
5	Water logged area	Light blue to dark blue.	Varying in size	Irregular and discontinuous	Smooth to mottled	Dispersed. Non-contiguous	Flood plains/lowlands, coastal plains and long canals.
6	River/ stream	Light blue to dark blue.	Long narrow to wide	Irregular and discontinuous	Smooth to medium	Contiguous, non-linear to subdendritic/ dendritic etc.	Natural river streams

2.6.1.(b) Digital image processing

The following procedures were followed in the digital image processing. The 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 technique includes loading of satellite data, rectification and restoration, image enhancement and information extraction. The digital data from the CD ROM was imported to the hard disc following the data import option of the software ERDAS IMAGE. The 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 the Survey of India toposheets of the study area and field ground control points (GCPs). An area of interest (AOI) i.e. Periyar water shed 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 was also performed in order to confirm the protection of the procedure.

2.6.1 .(c) 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 step certain Ground control points (GCP) were identified and verified during field checks. With a minimum number of GCPs we can use a polynomial model to relate image and map coordinates and determine the polynomial coefficients by the least square 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 taken as a measurement of accuracy.

2.6.1.(d) 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 behavior of vegetation in the infra red and regions of the EM spectrum. Healthy vegetation reflects 40 to 50% of the incident NIR (0.7 to 1.1 µm). Segmentation of NDVI images helps in differentiating forest cover density and understanding the health of vegetation.

2.6.2 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 classifications are in use namely supervised and unsupervised.

2.6.2. (a) Unsupervised classification:

This is more computers 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.

2.6.2. (b) 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.

The compilation of the interpretation of remote sensing data is presented in the form of different maps.

2.7 GEOGRAPHIC INFORAMTION SYSTEM

Geographic Information System is a tool that enhance our ability to integrate, analyze, query and display spatial data that was collected at different times and scales. This data is often in a variety of formats; paper maps, tabular form, images and data stored in human memory. Integrating data from different formats, different times, and different scales is time consuming and expensive. GIS technology has brought advances in computer processing, graphics and database capabilities to help solve the problems of spatial data integration and to perform data analysis to solve spatial questions (Star, et al., 1990). The ultimate purpoe of most GIS projects is to combine spatial data from diverse sources together, in order to describe and analyse interactions, to make predictions with models, and to provide support for decision makers (Pratheeban et al., 2004).

2.7.1 Development of Groundwater prospect zones using GIS

After reviewing the capabilities of GIS in groundwater problem assessment, it is decided to use GIS in conjunction with geological, geomorphological and geophysical data and a detailed methodology is given in Fig 2.1. Most of the GIS systems do not, as such, support the complete analytical functionality to perform the groundwater analysis. The GIS software used for 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 etc. All the maps were scanned using CADIM scanning software. These scanned maps were then transferred to Arc/Info and edited using Arc tools. These edited maps were used for the analysis.

These maps were geo-referenced 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 database components and map representation of GIS derived data base are given in Table 2.5. The following steps have been performed to establish the required GIS database.

- Fixing the boundary line of the study area.
- Cleaning, data editing within the GIS for removing the dangles, gap in the scanned image.
- 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 converge in the standard format.

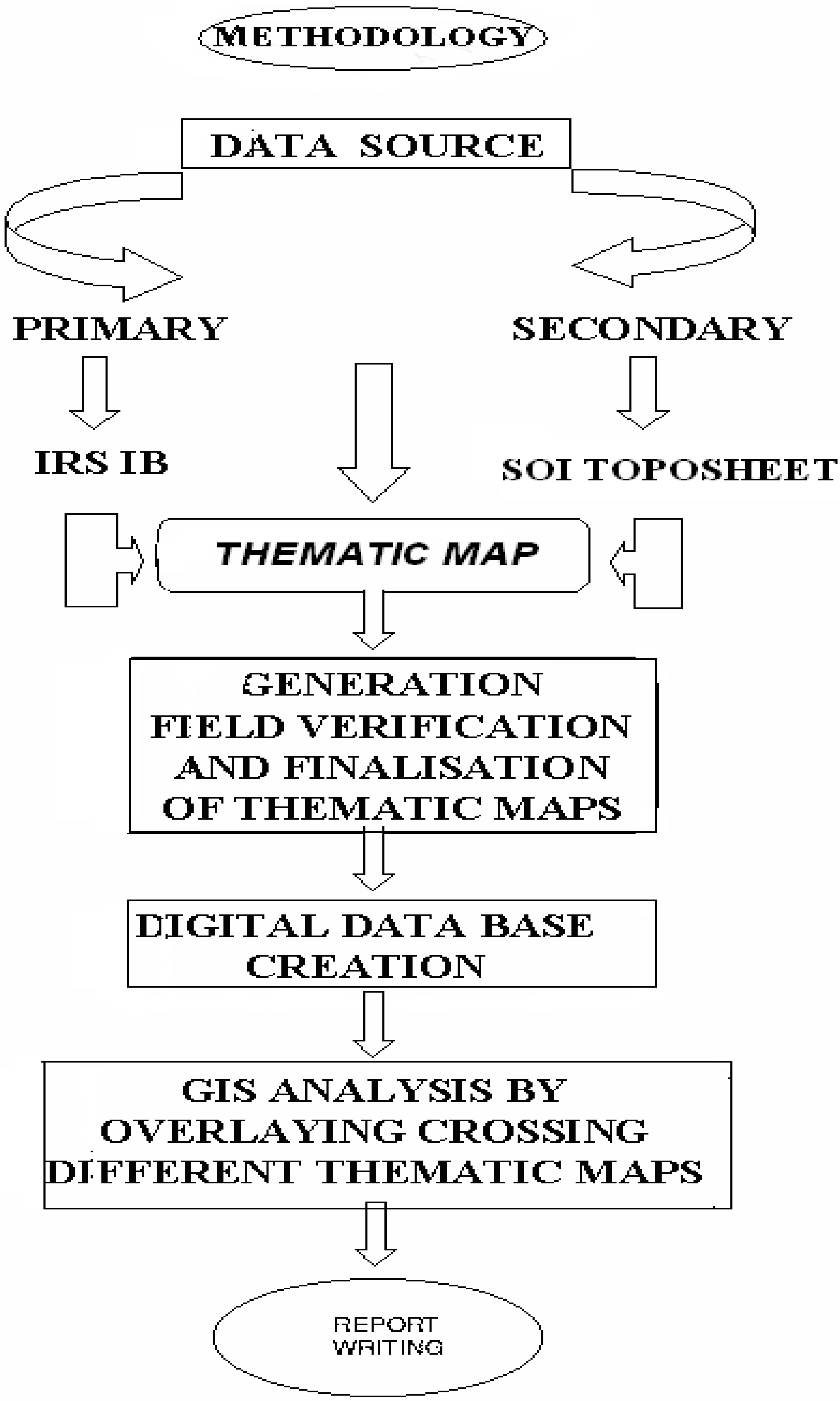

Fig. 2. 1 Generation of a GIS derived data base

Table 2. 5 GIS database components and their method of representation.

Data source	Database components	Method of representation
SOI topographic sheets in 1:50000 scale	Drainage and contours	Line
Geological map in 1;50000 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 2.6 Map representation of GIS derived database and the data format.

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

Different thematic maps of the study area were prepared in 1:50,000 scale from the conventional data and remotely sensed data to demarcate the groundwater potential zones. The thematic maps on (i) resistivity (ii) drainage (iii) lithology and (iv) contour were prepared using the Survey of India toposheets, the primary data obtained during the field investigation and also the secondary data collected. The maps on the (i) lineaments (ii) landuse and (iii) hydrogeomorphology were prepared using the Indian Remote Sensing Satellite (IRS – 1C), 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 unit in every theme map is assigned a knowledge based ranking depending on its significance to groundwater occurrence. The suitable weightage has been assigned after considering the characteristics listed below:

Polygon	***Characteristics***
Resistivity	Massive and consolidated nature in relation to high resistivity signals with reference to depths
Lithology	Rock type, weathering character, thickness of weathering, joints and fractures etc.
Geomorphology	Type of landforms, aerial extent, associated vegetation
Drainage density	Drainage density value
Lineament density	Lineament density value
Slope analysis	Based on the percentage of slope
Landuse	Based on the type of land cover

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

2.7.2 Integration of spatial and non-spatial data.

For developing a strong data base for the Periyar River Basin, the integration of spatial and non-spatial data was carried out. The methodology followed is shown in Fig. 2. In the present study, large volume of non-spatial data has been generated from hydrochemical data of 72 locations in the basin, which includes major cations, anions, total iron, fluoride etc. in GIS, this kind of non-spatial data can be put into feature attribute tables of respective coverage (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.

2.8 SOFTWARE USED

Arc/Info version 7.2.1 and Arc view 3.1 (GIS), Silicon Graphics workstation based ERDAS IMAGINE version 8.5 (DIP), HIS-GW/DES-II, IPI2win and Infinite Extent (version 3.1a) software were used for digitization of various thematic maps, processing of data and presentation of maps.

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Chapter III
Soils

3.1. INTRODUCTION

Soils represent one of the most complex and dynamic natural systems and are one of the three major natural resources, other than air and water. Knowledge of their chemical, physical and biological properties is a pre-requisite both for sustaining the productivity of the land, e.g. agriculture, and for conservation purposes. Soil is an integral part of a terrestrial ecosystem and fulfils numerous functions including the capacity to generate biomass and the filtering or buffering activities between the atmosphere and the groundwater in the biosphere. The word ‘soil’ means different things to different people but basically it may be defined as the solid material on the earth’s surface that results from the interaction of weathering and biological activity on the soil’s parent material or underlying hard rock. Soil is a three dimensional body with properties that reflect the impact of (1) climate (2) vegetation, fauna, man (3) relief on the soils (4) parent material over a variable and (5) time span. The nature and relative importance of each of these five 'soil forming factors' vary in time and space. With few exceptions soils are still in a process of change; their 'soil profile' shows signs of differentiation or alteration of the soil material incurred in a process of soil formation or 'pedogenesis'.

Soil is made up of three main components – minerals that come from rocks below or nearby, organic matter which is the remains of plants and animals that use the soil, and the living organisms that reside in the soil. The proportion of each of these is important in determining the type of soil that is present. But other factors such as climate, vegetation, time, the surrounding terrain, and even human activities (eg. farming, grazing, gardening, landscaping, etc.), are also important in influencing how soil is formed and the types of soil that occur in a particular landscape. The formation of soils can be seen as a combination of the products of weathering, structural development of the soil, differentiation of that structure into horizons or layers, and lastly, of its movement or translocation. In fact, there are many ways in which soil may be transported away from the location where it was first formed.

Soils have many important functions. Perhaps the best appreciated is the function to support the growth of agricultural and horticultural crops. Soil is the mainstay of agriculture and horticulture, forming as it does the medium in which growth and ultimately the yield of food producing crops occurs. Farmers and gardeners have worked with their soils over many centuries to produce increasing amounts of food to keep pace with the needs of a burgeoning world population. The soil's natural cycles go a long way in ensuring that the soil can provide an adequate physical, chemical and biological medium for crop growth.

As well as this agricultural and horticultural remit, soil also supports a wide range of trees grown for commercial purposes, e.g., plantations such as forests of commercially grown conifers. Soil type is a fundamental factor in deciding what to grow and where to grow it - or rather optimizing land use patterns. In addition to supporting world agriculture and horticulture, soil is also essential for maintaining natural and semi-natural vegetation, our forests, our grasslands and the huge breadth of species that occur worldwide. One of the best examples of this soil function is the tropical rain forest where more and more is now being learned of the important soil cycles that maintain this huge ecosystem.

As well as being essential to agriculture, horticulture, forestry and natural and semi-natural systems, soil also plays an important role for our fauna. The soil itself contains million of organisms, the exact nature and role of which we are still trying to determine. Undoubtedly, the soil flora and fauna play a vital role in cycles which are fundamental to the ability of the soil to support natural and semi-natural vegetation without additions of fertilizer and other support mechanisms. They breakdown plant debris, take in components from the atmosphere, aerate the soil together with many other functions that make the soil such an important medium.

Soils are much more difficult to identify and classify than other discrete bodies for two main reasons: (i) soil is more or less a continuum covering the land surface of the earth, not a set of discrete entities and (ii) most of the soil is below ground and therefore not readily visible. Soils grade into one another across the landscape usually without sharp boundaries between one type of soil and another. Over the years, there have been numerous attempts to give names to soils and to group them into natural classes, in much the same way as plants are named and classified. Classification is important in order to allow comparison between the soils of different regions, and to facilitate information transfer and organization of the growing knowledge about the main types of soil that occur around the region.

3.2 USDA CLASSIFICATION

The soil management support services of the United States Department of Agriculture (USDA, 1995) have classified the soils according to several parameters (most commonly their properties) and in several levels: Order, Suborder, Great Group, Subgroup, Family, and Series. There are 12 Orders identified in the world by the USDA. They are Alfisols, Andisols, Aridisols, Entisols, Gelisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, Vertisols and their important properties are given in Table 3.1.

The scientific classification of soils of Kerala is made based on the above classification system developed by USDA. Soil Taxonomy provides an elaborate classification of soil types according to several parameters and in several levels; Order, Suborder, Great Group, Subgroup, Family, and Series, of which 8 Orders are encountered in Kerala. They are Histosols, Spodosols, Vertisols, Ultisols, Mollisols, Alfisols, Inceptisols and Entisols (SSO, 2007).

Table 3.1. Name and important Properties of the main Orders. (USDA, 1995)

Order	Important Properties
Alfisols	Mineral soils relatively low in organic matter with relatively high base saturation. Contains horizon of illuvial clay. Moisture is available to mature a crop.
Aridisols	Mineral soils relatively low in organic matter. Contain developed soil horizons. Moisture is inadequate to mature a crop without irrigation in most years.
Entisols	Mineral soils lacking developed soil horizons. Moisture content varies.
Histosols	Soils composed mostly of organic matter. Moisture content varies.
Inceptisols	Mineral soils containing some developed horizons other than one of illuvial clay. Moisture is available to mature a crop.
Mollisols	Mineral soils with thick, dark surface horizons relatively high in organic matter and with high base saturation.
Oxisols	Mineral soils with no weatherable minerals. High in iron and aluminum oxides. Contain no illuvial horizons.
Spodosols	Soils that contain an illuvial horizon of amorphous aluminum and organic matter, with or without amorphous iron. Usually moist or well leached.
Ultisols	mineral soils with an illuvial clay horizon. Has low base saturation. Generally found in humid climates.
Vertisols	Clayey soils with deep wide cracks at some time in most years. Moisture content varies.
Gelisols	Soils of very cold climates which are defined as containing permafrost.
Andisols	Soils formed in Volcandanic defined as soils containing high proportions of glass and amorphous colloidal materials.

The Histosols occur as patches and are demarcated only on very detailed maps These are organic rich soils with organic matter. High acidity and high content of sulphide materials are associated with Histosols.

Spodosols occur sporadically on the raised coastal sandy beach deposits or the coastal sandy levees. The spodic horizon is a subsurface horizon with accumulation of organic matter and sesquioxides. Vertisols are confined to the Palghat gap and they extend eastward into Tamilnadu. These soils have uniform black or dark colour with more than 30 percent clay with the swell on wetting and shrink on drying. Ultisols are comparable with Alfisols except for having low base saturation due to advanced stages of weathering. They have low (<35%) base saturation and a clay enriched sub surface horizon. Mollisols have dark coloured well developed base-rich well-structured surface horizon, rich in organic matter. There are small areas of Mollisols in the Western ghats in the rain shadow regions which are predominantly east sloping. Alfisols are base-rich mineral soils of sub-humid and humid regions. Generally, the subsoil contains significant accumulations of illuviated silicate clays. These soils are developed from different type of parent material and at varied geomorphic position. Inceptisols are juvenile soils developed owing to the alteration of parent material and occupy similar geomorphic positions as that of Entisols. The major difference is that the land form is more stable. Entisols lack diagnostic horizons and occur on plains of recent to sub recent deposits and on the steep aspect of the hilly terrain. These have thin organic rich surface horizon resting on weathering rock material.

3.3 SOIL SERIES OF THE AREA

Soil ‘Series’ are the lowest category in taxonomic system. The soil series is named after the place from where it is identified first. If more than one soil series is identified in the same topographic unit, the soil series covering the minor extent is denoted as associated soil series. 82 soil series were identified as Bench Mark soils in the State. In the Periyar River Basin 12 Orders 6 sub orders and 12 soil series were identified.

In general, the soils of Kerala are dominated by lateritic soil and forest loams. Other soil types have developed in certain areas due to the local physiographic factors. On the basis of the morphological features and the physico-chemical properties, the Soil Survey Organisation under the Kerala State Agriculture Department has classified the soil of the districts of Ernakulam, Idukki and Thrissur into different groups (SSO, 2007). However in the area where the Periyar River and its tributaries drain through, 11 series of soil are identified, which are described below (Table 3.1). The soil map of the Periyar River is prepared based on the above classification. The major soils identified in each physiographic unit with minor soils and their characteristics are given in Table 3.2 and a soil map showing the major soils of the basin is given in Fig. 3.1.

3.3.1 Manathala Series

Manathala series is isohyperthermic, Ustic Quartzipsamments. These soils have yellowish brown to dark yellowish brown A horizon and greyish brown to brownish yellow sand C horizons. These soils are formed on coastal alluvial sediments on the coastal plains at an elevation of less than 20 m above MSL. These soils are characterised by the presence of oyster shells in the sandy profile. These soils are subject to flooding during monsoon. The thickness of this soil column is more than 150 cm often limited by water table.

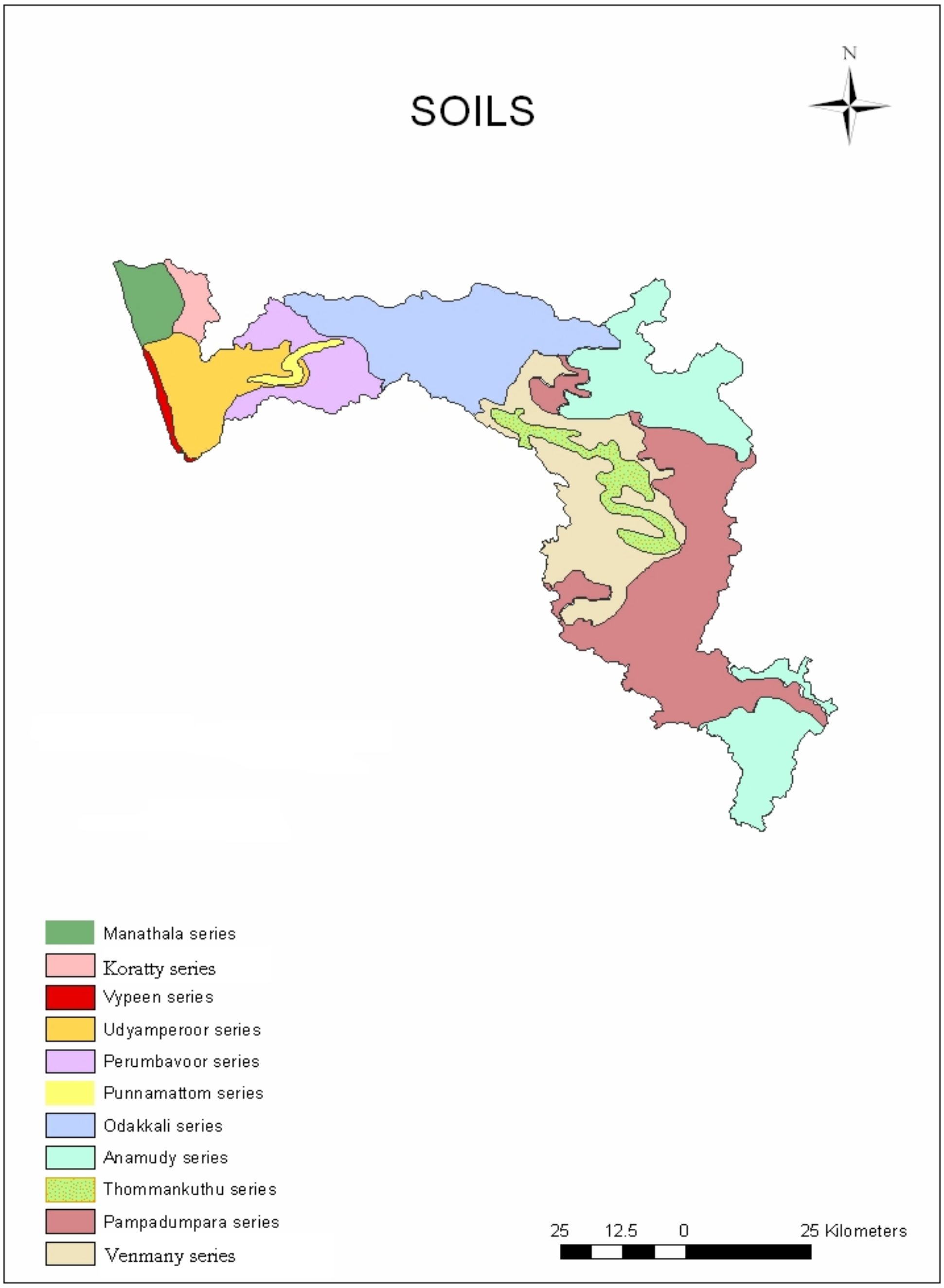

Fig. 3.1 Classification of soils of the Periyar River Basin.

Table 3.2 Soil Taxonomic Classification of Bench Mark Soils of the Periyar River Basin (SSO, 2007)

Sl.N	District	Soil Series	Order	Suborder	Great group	Subgroup	Family
1	Ernakulam	Vypeen	Entisols	Aquemts	Sulfaquents	Typic Sulfaquents	Fine, mixed, isohyperthermic.
2	Ernakulam	Ikkarnad	Entisols	Fluvents	Ustrothents	Oxyaquic Ustrothents	Fine, mixed, isohyperthermic.
3	Ernakulam	Punnamattom	Entisols	Fluvents	Ustrothents	Typic Ustrothen	Coarse-loamy, mixed, isohyperthermic.
4	Idukki	Thommankuthu	Ultisols	Humults	Palehumults	Ustic palehumult	Clayey, mixed, isohyperthermic.
5	Idukki	Pampadumpara	Ultisols	Humults	Kandihumults	Ustic Kandihumults	Clayey, mixed, isohyperthermic.
6	Idukki	Anamudi	Ultisols	Humults	Kandihumults	Typic Kandihumults	Clayey, mixed, isohyperthermic.
7	Ernakulam	Udayamperoor	Entisols	Orthents	Ustrothents	Oxyaquic Ustrothents	Coarse, loamy, mixed, isohyperthermic.
8	Thrissur	Manathala	Entisols	Psamments	QuartziPsamme ts	Ustic Quartzi Psamments	Isohyperthermic.
9	Idukki	Venmani	Inceptisols	Ustolls	Dystrustepts	Oxic Dystrustepts	Fine, mixed, isohyperthermic.
10	Ernakulam	Perumbavoor	Ultisols	Ustults	Plinthustults	Typic Plinthustults	Clayey skeletel, mixed, isohyperthermic.
11	Ernakulam	Odakkali	Inceptisosl	Ustults	Dystrustepts	Oxic Dystrustept	Clayey skeletel, mixed, isohyperthermic.
12	Thrissur	Koratty	Ultisosl	Ustults	Plinthustults	Typic Plinthustults	Clayey skeletel, mixed, isohyperthermic.

The texture is sandy to sandy loam. This series occupies mainly in Valappad grama panchayat of the study area.

3.3.2 Koratty series

Koratty series is a clayey skeletal, mixed, isohyper thermic, Typic Plinthustults. Koratty soils have red to yellowish red gravely sandy clay loam to gravely sandy clay A horizon and red to yellowish red gravely clay loam to gravely clay B horizons. The thickness of the solum is 50 to 100 cm these soils are formed on gneissic materials on gently sloping to moderate steep to steep low laterite hills of Chalakkudy block at an elevation of 20 m to 100 m above MSL.

3.3.3 Udayamperoor series

Udayamperoor series is coarse, loamy, mixed, isohyperthermic, Oxyaquic Ustorthents soils have yellowish brown to dark yellowish brown sand to loamy sand A horizon and reddish brown to light grey, sand to sandy loam C horizons. These soils are formed on alluvium on very gently sloping planes along the cost of Vembanad Lake in Ernakulam District, at an elevation of less than 5 m above msl. The thickness of soil column is more than 200 cm. The soil is mainly distributed in Parts of Paravur and Aluva taluks of the study area.

3.3.4 Vypeen series

Vypeen series is fine, mixed, isohyperthermic, Typic Sulfaquents. The soils have very dark grey to black clay A horizon and dark grey to black, extremely acid clay C horizons. Organic debris at advanced stages of decomposition is noticed in the lower layers. These soils are formed on coastal alluvium under ill drained conditions on coastal belts with flat to concave relief at an elevation of 1 to 1.5 m below MSL. The A horizon is 10 to 25 cm thick. The texture is predominantly clay. Sandy loam texture is noticed in some profiles in the subsoil. Organic debris at advanced stages of decomposition is noticed in the sub soil. The soils distributed in the Vypeen Block of Kochi taluk of the study area.

3.3.5 Ikkaranad series

Ikkaranad series is fine, mixed, isohypermeric, Oxyaquic, Ustifluvents. The soils have yellowish brown to yellow, strongly acid to medium acid, clay loam to clay A horizon and yellow to brown, medium acid to slightly acid, silty clay to clay C horizons. Frequent flooding during monsoon is common feature of these soils. These soils are widely used for brick making. These are formed in colluvio-alluvial deposits on low lying, level or nearly level paddy fields along the banks of rivers and streams at an elevation of 10 to 80 m above MSL. Thickness of the soil column is 150 to 160 cm often limited by water table. The texture is silty clay to clay.

3.3.6 Punnamattom series

Punnamattom series is coarse loamy, mixed, isohyperthermic, Typic Ustifuvents. These have yellowish brown to pale brown, slightly acid, loam to sandy clay loam A horizon and yellowish brown to strong brown, strongly acid sandy loam to sandy clay loam C horizon. Presence of mica flakes is a common feature observed in these soils. These soils are formed on alluvial sediments on gently sloping lands along the river banks and streams at an elevation of 20 m to 100 m above MSL. The thickness of the soil column is 160 to 180 cm. and the texture is sandy loam to sandy clay loam. This series occupies mainly in Koovappady grama panchayat along the banks of the Periyar River.

3.3.7 Perumbavoor series.

Perumbavoor series is clayey-skeletal, mixed, isohyperthermic, Typic Plinthustults. These have reddish brown to yellowish red, strongly acid, gravely clay loam gravely clay A horizon and red to yellowish red, very strongly acid, gravely clay B horizons. Fine gravels are present through out the solum. These soils are formed on gneissic rocks on gently sloping to moderately steep mounds and low hills at an elevation of 20 to 100 m above MSL. The thickness of this series is 90 to 100 cm. the texture is gravely clay loam to gravely clay. This series occupies mainly in Rayamangalam grama panchayat of Koovappady block.

3.3.8 Odakkali series

Odakkali series is clayey-skeletal, mixed, isohyperthermic, Oxic Dystrustepts. These have reddish brown to yellowish red, very strongly acid, gravely sandy clay loam to gravely clay A horizons and reddish brown to light reddish brown, very strongly acid to strongly acid, gravely clay loam to gravely clay B horizons. The B horizon is characterised by the presence of gneissic boulders in different stages of weathering. The C horizon is weathered gneiss. Many common relic mottling exhibiting variegated colours are seen in the subsoil. These soils are formed from gneiss rocks on moderately to steep sloping regions at an elevation of 20 to 300 m above MSL. The thickness of this series is 90 to 135 cm. the texture is gravely sandy clay loam to gravely clay. This series occupies major areas in Kunnathunad and Kothamanglam taluks of the study area.

3.3.9 Thommankuthu series

Thooankuthu series is a clayey, mixed, isohyperthermic, Ustic Palehumults. These have black to brown, gravelly loam to gravely clay loam A horizon and dark reddish brown to red, gravelly sandy clay loam to gravely clay B horizons. These soils are formed on weathering of the gneiss rocks on moderately to steep sloping foothills of Western Ghats in Devikulam, Udumbanchola and Peermade taluks at an elevation of 300 m to 600 m above MSL. The thickness of the solum is more than 200 cm.

3.3.10 Venmani Series

Venmani series is affine, mixed, isohyperthermic, Oxic Dystrustepts. These have reddish brown to dark reddish brown loamy to clay A horizon and reddish brown to red gravely sandy clay to gravely clay B horizons. Upper layer of B horizon is non-gravely. These soils are formed on the weathering of the gneissic rocks on moderately sloping to steeply sloping sides of hills of Idukki block, mainly in Kanjikuzhy grama panchayat and also in parts of Devikulam, Udumbanchola and Peermade taluks at an elevation of 600m to 900 m above MSL. The thickness of the solum is 150 cm.

3.3.11 Pampadumpara series

Pampadumpara series is a clayey, mixed, isohyperthermic, Ustic Kandihumults. These soils have dark reddish brown to dark brown silty clay to clay A horizons and yellowish red to red clay B horizons. These soils are formed on weathering of the gneissic rocks on steeply to very steeply slopping hills and hill tops of Pampadumpara gram panchayat and also parts of Peermade, Devikulam and Udumbanchola taluks at an elevation of 600 m to 1200 m above MSL. The thickness of the solum is more than 180 cm. lay.

3.3.12 Anamudi series

Anamidi series is a clayey, mixed, isothermic, Typic Kandhihumults. These soils have dark reddish brown to dark brown silt loam to clay loam A horizons and dark reddish brown to reddish yellow silty clay loam to clay B horizons. These are formed on weathering of the gneissic rocks on steeply sloping to very steeply sloping mountainous regions mainly are grama panchayat and northern part of Devikolam taluk, and some parts of Peermade and Udumbanchola taluks at an elevation of 1200 m above MSL. The thickness of the solum is more than 150 cm.

3.4 DISCUSSION

The relative predominance of the above described soil types is in the order Pampadumpara series (19%), Anamudi series (18%), Odakkali series (16%), Venmani series (17.5%), Perumbavoor series (12%), Udayamperoor series (11%), Thommankuthu series (2%), Kotatty series (1.75%), Manathala series 1.25%), Punnamattom series (1%), Ikarnad series and Vypin series (0.5%).

There is a direct relation between the soil profile and the occurrence and movement of groundwater. The Vypin series of soil is poorly drained and with low permeability. The groundwater of the area exhibit the chemical quality of the aquifer material and the water quality of the region is poor as per the BIS standards and WHO guidelines (Chapter V). This may be due to the direct influence of the chemical quality of the soil. The Manathala series adjacent to the coastal plains, the quality of water of the clayey sand aquifer is poor. The groundwater of the soils of Koratty, Perumbavoor, Ikarnad and Odakkali and Punnamattom series are of good quality, within the BIS standards and WHO guidelines. The soils of the region are highly porous and permeable and ideal for groundwater recharge. The thickness of soil is also high in these areas. The average thickness of soil in the area is 2 m underlain by laterite. This region is highly potential for the development of groundwater. The quality of groundwater of the region is generally good for all purposes.

The soils of Venmani series and Thommankuthu series are porous and permeable. The area is moderately potential for the development of groundwater. The quality of groundwater of the region is generally good for all purposes. The Anamudi and Pampadumpara soil series varies from 0.5 m to 1 m in thickness. The porosity and permeability of the soils of this region are poor and hence the surface and subsurface runoff is relatively high and correspondingly the rate of infiltration is also very less. Hence, the area covered with these soil types like the Vypin series, Anamudi series and the Pambadumpara series are generally poor for the development of groundwater. The relation between soil and geology of the study area is discussed in Chapter III, similarly the electrical conductivity variations in relation to soils is discussed in Chapter V.

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Chapter **IV**

Geology of the Area

4.1. INTRODUCTION

As mentioned in the foregoing chapters, the occurrence and movement of groundwater is controlled by several factors such as climate, hydrology, geology, topography, ecology soil-distribution, etc. These factors independently as well as collectively influence the functioning of the total water system and a systematic groundwater exploration includes the study of all the aforesaid factors. The geological formations play a major role in shaping the landscape. The mode of occurrence of groundwater is as varied as the rock types in which they occur and as intricate as the formation of the crust through geologic time.

From the available geological record of the Periyar River Basin it is evident that there is a prolonged history for the region starting from the Precambrian to the present. Geologically, the Periyar River Basin has three distinct formations; crystalline rocks of Precambrian age, the Tertiary formations and the Recent alluvium (Soman, 2002; GSI, 1976; Paulose and Narayanaswami, 1968) as given in Table 4.1 and in the geological map of the area (Fig. 4.1). However, due to weathering and erosion such a complete sequence may not be present uniformly throughout the basin. The petrographic and chemical aspects of the major rock types are discussed below.

4. 2 CHARNOCKITE AND GNEISSES

The most wide spread geological formations of the study area are the Precambrian crystalline rocks comprising charnockites and the associated gneisses. The leading characterstics of the charnockites are the granulitic texture and the invariable presence of rhombic pyroxene amongst the constituents (Table 4.2).

Table 4.1. Generalised geological succession of the study area (modified after Paulose and Narayanaswami, 1968 and Soman, 1997).

<table>
<tr><th>Age</th><th></th><th>Formation</th><th colspan="2">Lithology</th></tr>
<tr><td rowspan="2">Quaternary</td><td>Recent</td><td>Alluvium</td><td colspan="2">Sands, clay.</td></tr>
<tr><td>Sub-Recent</td><td>Laterite</td><td colspan="2">Laterite derived from the Tertiary sediments and the Precambrian crystallines.</td></tr>
<tr><td rowspan="3">Tertiary</td><td>Upper Miocene</td><td>Warkali beds</td><td colspan="2">Fine to medium grained sand, variegated clay and lignite.</td></tr>
<tr><td>Lower Miocene</td><td>Quilon beds</td><td colspan="2">Limestone, calcareous clay and marl.</td></tr>
<tr><td>Eocene to Oligocene</td><td>Vaikom beds</td><td colspan="2">Gravel, coarse to fine sand, carbonaceous clay and lignite.</td></tr>
<tr><td rowspan="2" colspan="2">Precambrian</td><td>Migmatite group</td><td>Hornblende-biotite gneiss, biotite gneiss etc.</td><td rowspan="2">Intruded by felsic and mafic intrusive of age varying from Proterozoic to Tertiary</td></tr>
<tr><td>Charnockite group</td><td>Charnockites.</td></tr>
</table>

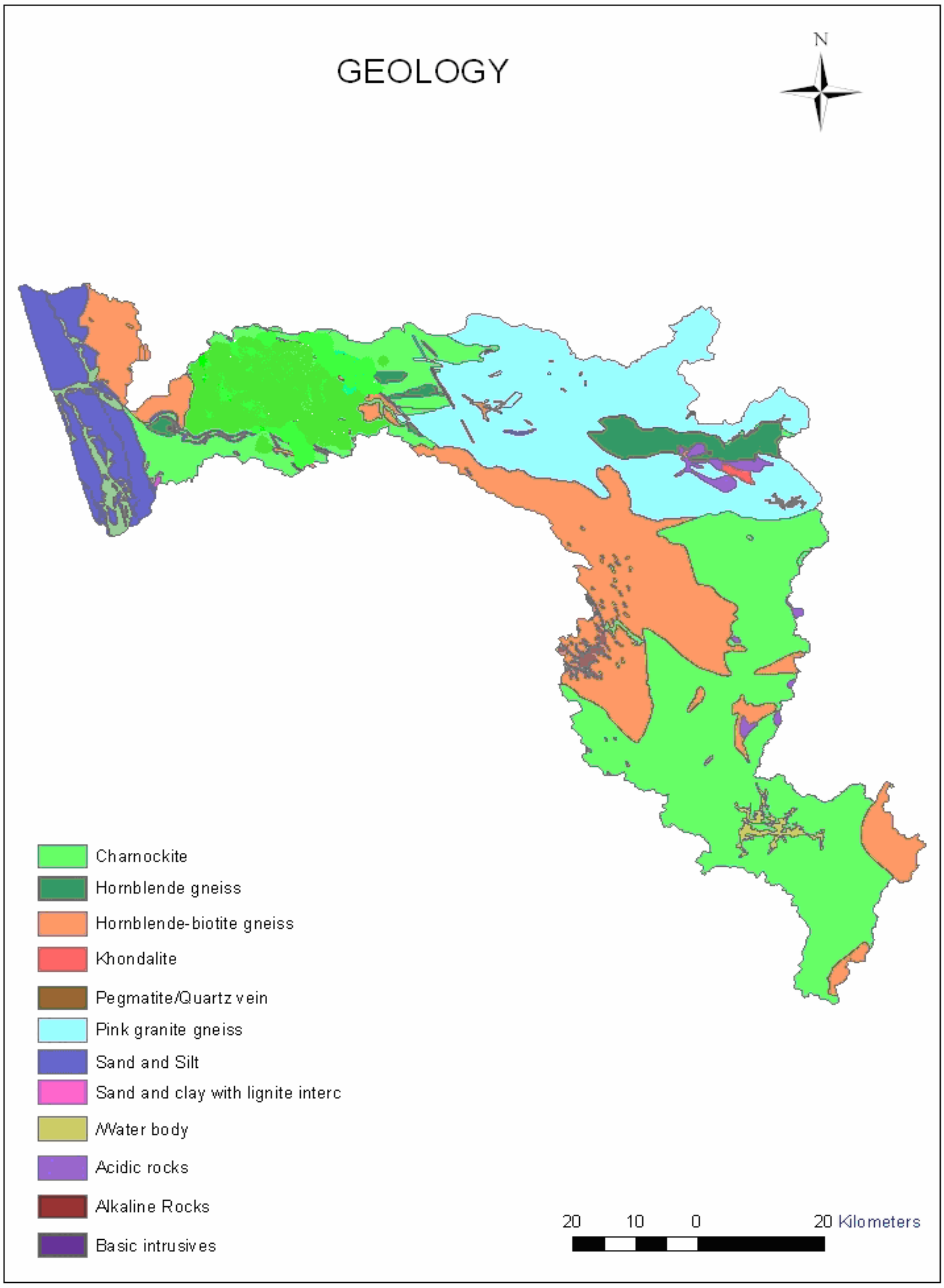

Fig. 4.1 Geology of the study area (GSI,1995).

These rocks occupy the highlands and midlands of the area and are well exposed in the central, eastern and south-eastern parts of the basin. In Periyar valley region, pyroxenites and alaskites constitute the charnockite group (Nair and Selvan, 1976). Textural, mineralogical and geochemical variations are observed in charnockites from different localities. Charnockites in this area are both massive and foliated, where the charnockite is foliated showing strike in NNE – SSW to N – S direction with gentle dip towards west. In the highland region, alteration of charnockites along the shear zone/faults or in contact with the neosome emplacement gave rise to the hornblende/biotite gneisses (Soman, 1997). The charnockites in many places are intruded by granites, dolerites and pegmatites. Minor rock units associated with the charnockites include calc-granulite, pyroxene granulites, khondalite and amphibolites. A variety of gneisses occur within the granulites terrain of the study area mostly associated with lineaments/faults, zones of migmatisation and granite emplacement. The second major rock type encountered in the area is the hornblende-biotite gneiss. It is mesocratic and medium grained. It occurs mainly in the high range regions of the study area. A major stretch of hornblende-biotite gnesiss (migmatite) is observed in the Munnar-Periyar region. This gneisses occur within the charnockite as enclaves and patches of metasediments, and are associated with granitic intrusions. The gneisses consist of quartz, plagioclase, K-feldspar, hornblende and biotite as major minerals. Mineralogical and chemical composition indicate that these are more granitic than the typical hornblende-biotite gneiss (Table 4.3).

Table 4.2. Chemical composition of Charnockites from Kerala (Wt.%). (Soman, 2002)

Oxide	Felsic charnockite from Cardamom hills(Average of 6 analyses)	Intermediate charnockite, Cardamom hills (Average of 5 analyses)	Intermediate to felsic Charnockite, North Kerala, (Average of 14 analyses)	Incipient Charnockite, Ponmudi
SiO_2	68.8	58.7	61.22	65.07
TiO_2	0.79	1.32	0.79	0.85
Al_2O_3	14.7	15.8	16.4	14.83
FeO	4.4	7.98	6.83	6.3
MnO	0.07	0.13	0.09	0.06
MgO	1.0	3.72	2.73	1.18
CaO	2.52	5.7	6.07	2.07
N_2O	3.15	3.79	3.76	2.46
K_2O	5.04	1.91	1.02	5.42
P_2O_5	0.23	0.59	0.19	0.2

These rocks follow the regional trend of foliation. In the northeastern part of the area, granite gneiss is the major rock type encountered. It is seen exposed in Adimali and Devikulam blocks. These rocks are well jointed. Hornblende-biotite gneiss, biotite gneiss and garnet-silliminate gneiss are spatially associated with charnockites at many places. They are the resultant of the regional migmatisation of the older rocks (Soman, 2002). At a few places, the migmatisation is complete and the paleosome and neosome are well developed.

Table 4.3 Chemical composition of Gneisses (Soman, 2002)

Oxide	Khondalite			Ga-Bi gneiss & Hornblende gneiss	
	South Kerala (Average of 13 analyses)	Palghat gap area (Average of 9 analyses)	Walkers analyses on Eastern Ghats Khondalite)	Ga-Bi gneiss, South Kerala (Average of 11 analyses)	Hornblende-biotite gneisses, North Kerala (Average of 7 analyses)
SiO_2	67.6	62.67	74.17	68.7	67.81
TiO_2	0.57	1.2	-	0.85	0.37
$Al2O_3$	16.8	14.42	17.16	14.3	16.6
FeO	5.34	8.84	7.82	5.62	3.38
MnO	0.06	0.07	-	0.08	0.04
MgO	1.59	2.67	0.83	1.02	1.6
CaO	1.31	2.59	0.81	2.37	3.55
Na_2O	2.58	1.47	0.49	2.44	4.37
K_2O	3.91	3.72	0.11	4.52	1.1
P_2O_5	0.09	0.27	-	0.2	0.16
Total	99.85	97.92	101.39	100.1	98.98

The rocks have a general trend of foliation of NW-SE to NNE to SSW. Intersection of the Salem, Madurai and Kerala aulacogenes give rise to the high altitude charnockitic massif of the Anamalai-Palani-Cardamom hills (Katz, 1978) where the Munnar Plateau is located. The underlying rocks in the western slopes include charnockite and charnockitic gneiss. Granitic gneiss, granite domes and patches of metasediments dominate the plateau proper. The crystalline rocks are extensively weathered and are overlain by the laterites.

4. 3. INTRUSIVE ROCKS

Basic, ultrabasic, acidic and alkaline intrusive are present in the study area. They are coarse grained and leucocratic. Basic intrusives are (mostly the dolerites of Deccan Traps age) seen at the middle part of the basin. In the Munnar area, two periods of granite emplacement have been noticed (Nair and Anil Kumar, 1989). Thinly foliated, pink, medium–grained gneissic granite containing biotite, magnetite and hornblende as mafic phases represent the first period of granite emplacement (Nair and Anil Kumar, 1989). This occurs as overturned, doubly plunging cross-folded brachy structure. The second period of granite emplacement is represented by the massive medium to coarse-grained granite, emplaced pre to syn-kinematic with the broad open WNW-ESE to EW trending folds. Cross cutting linear bodies of medium-grained, pink to grey granite along fractures trending NE, possibly represent the third phase of emplacement. Folded calc-granulite bands are seen in the area. The host migmatitic gneisses are of pink and grey varieties. The pink variety is rich in Potash feldspar while the grey variety is rich in biotite. The granite is composed of K-feldspar (mostly microcline), plagioclase (albite-oligoclase) and quartz. Biotite, sphene, apatite and zircon are the accessory minerals. Magnetite is the opaque mineral. Nair et al. (1983b) have reported syenite-carbonate veins in the area. A close look at the geology of the area (Nair and Anil Kumar,1989) in the background of the regional tectonic setting described by Katz (1978) suggested that Munnar – Periyar lake area is the SW extension of the Madurai aulacogene. The carbonate bands encountered in the area will be part of the migmatised metasedimentary sequence only. Dating of zircon, possibly from the massive medium to coarse grained granite (belonging to the second period) yielded age of 740± 30 Ma. (Soman, 1977).

Pegmatites intruding the meta-sedimentary sequence are also noted in the area. The pegmatite bodies occur along fractures and have sharp contacts with the country rocks. Mafic dyke intrusions contemporaneous with the Deccan Basalt magmatism, occur within charnockites and gneisses and cut all penetrative structures and they differ form one another in trend, mineralogy, composition and age therefore do not relate to a single swarm (Radhakrishna et al., 1990). The major strike directions of the dykes include NE-SW, NW-SE, NNW-SSE and ENE-WSW.

4. 4. TERTIARY FORMATIONS

Recent studies for the exploration of groundwater in the coastal plains of Kerala have revealed that the best development of Cenozoic sediments is in between Kollam and Kodumgallur (Nair et al., 2006; Bose and Kartha, 1977; Najeeb, 1999). The Tertiary formations occur all along the coastal belt underlying the alluvium. The Tertiary formations, however, are not exposed on the land surface in the area. These are formations underlained by the crystalline and overlain by the unconsolidated recent sediments. From the lithology of the tube well drilled by the Central Ground Water Board, a classification of the Tertiary sediments into three district formations as Vaikom, Quilon and Warkalli sequences of beds has been made.

The rocks of the Vaikom formation comprise gravel, coarse to very coarse sand with greyish clay and carbonaceous clay and seams of lignite. This has a thickness of 100 m and overlies the weathered crystalline rocks (Raghava Rao, 1976). The Quilon formation consists of fossiliferous shell limestone alternating with thick beds of sandy clays, calcareous clays and sandstone. The Quilon formation is conformably overlain by rocks of Warkalli formation comprising clays with lignite bed, sand and sandy clays and sandstone. This formation is nearly horizontal and has since been traced almost in the entire coastal stretch. From the field observations it is observed that the thickness of the sedimentary formations above the basement crystalline rocks ranges from 103.5 m at the northern part (Pallippuram) and 174 m at the southern part (Malippuram) of the coastal plains. (Table 4.6 & 4.7).

4.5 QUATERNARY FORMATIONS

Quaternary formation are found at the entire stretch of the coastal belt of the lowland area. This includes peat beds of both marine and fluvial environments, sand bars and sandy flats alternating with lagoonal clays and shell deposits. The Quaternary formations are separated from the underlying Tertiary rocks by ferruginous clay layer. The black clays with brackish water molluscan shells are comparable to those living in the present day lagoons of the area. This indicates that a major part of the Quaternary sediments were deposited in lagoonal-brackish water environments, got filled up and uplifted later (Soman, 1997).

4. 6 LATERITE

The residual laterite formation of the Pleistocene age occurs as a cover over the crystalline rocks and the solid materials. They occur all along the midland region and are insitu formed due to the weathering of either crystalline or sedimentary rocks. They are porous, reddish brown to buff colored and are generally soft when quarried and harden on exposure. At many places the process of laterisation is not complete and the foliation and joints of the parent rock is well preserved.

The thickness of laterite varies from place to place and reaches a maximum of 20 m along the midland region whereas in the eastern part they are either absent or observed a thin mantle over the country rock. The Munnar Plateau is the highest elevated surface in Kerala Region, and has remnant laterite cappings. In the western coastal part, laterite is considered to be the marker horizon to differentiate between the Tertiary and the Recent alluvial formations. The thickness of laterrite under the alluvium varies from 3 to 10 m and overlain the Tertiary formations. However at places, it is found that the laterites have been eroded before the deposition of the Recent alluvium.

4. 7 RECENT FORMATIONS

The unconsolidated alluvial formations occupy on the coastal plains on the western part of the area. It is of recent origin. It includes the sediments of back water and lagoonal deposits of black clay, fine to medium grained poorly sorted quartzite sand, silty sands of the plains and grey to dark grey beach sands. This alluvium occurs in the strip parallel to the coast with depth ranging from 10 to 15 m. Flood plain deposits along the river banks and the valley fill deposits also constitute the Recent formations. Thickness of alluvial sediments ranges from 20 to 56 m.

4. 8 LITHOLOGS

The typical lithologs representing the different physiographic units of the basin are shown in Tables 4.4- 4.7.

4.9 STRUCTURE

Tectonic activity plays an important part in developing drainage pattern and controlling river behaviour (Vaidyanathan, 1971; Radhakrishna, 1992; Sinha-Roy, 2001). Drury and Holt (1980) recognized different stages of

Table 4.4. Average Lithology of the Midland region of the study area

*Lithology of the Borewell drilled at Nedumbassery.	
Depth (m)	*Lithology*
0 to 3	Top soil
3 to 10	Laterite
10 to 12	Lithomargic clay
12 to 14	Weathered crystalline
14 to 54	Charnockite

*Source – Kerala State Groundwater department

Table 4.5 Average lithology of the Highland region of the study area.

*Lithology of the Borewell drilled at Udumbanchola	
Depth (m)	*Lithology*
0	Top soil
0	Laterite
0	Lithomargic clay
0 to 3	Weathered crystalline
3 to 110	Charnockite

*Source – Kerala State Groundwater department

Table 4. 6 Lithology of the Tube well drilled in the Lowland region of the study area

*Lithology of the Borewell drilled at Pallippuram	
Depth (m)	*Lithology*
0 to 82	Sandy clay
82 to 86	Clayey sand
86 to 103.5	Sandy clay
Below 103.5	Basement crystalline rock

*Source – CGWB

Table 4. 7 Lithology of the Tube well drilled in the Lowland region of the study area

*Lithology of the Borewell drilled at Malippuram	
Depth (m)	*Lithology*
0 to 146	Sandy clay
146 to 167	Clayey sand
167 to 174	Sandy clay
Below 174	Basement crystalline rock

*Source – CGWB

tectonic evolution for Indian craton through analysis of lineament pattern with the help of Landsat imagery. Lineaments trending NNE-SSW to NE-SW are identified as faults which have disturbed the dolerite dykes in south India (Grady, 1971). In the Kerala region, (Varadarajan and Balakrishnan, 1980; Nair, 1990) grouped the lineaments into five sets such as (1) WNW-ESE, (2) NW-SE, (3) NNW-SSE, (4) NNE-SSW and (5) ENE-WSW. The lineament pattern in the Cardamom hills is dominated by NW-SE trends. This coincides with the general trend of the Precambrian structures in the area (K. Guru Rajesh,G.S. Vara Prasad and T.R.K. Chetty, 2007). The Periyar follows the same fault line for more than 20 km distance in the mountainous tract. The lineaments along the NW-SE direction and the other along the ENE-WSW direction indicate predominant strike- slip movement (Bhatttacharya and Dattatrayam, 2002). The northwestern part of the Idukki reservoir region is dominated with the NW-SE lineaments while the southern part is dominated with NE-SW lineaments. The Muvattupuzha – Thekkady fracture zone is is a WNW-ESE lineament. The NW-SE lineaments, often hosting dykes of dolerite/gabbro composition have a definite signature in the geological setting of the region. The available age data (61±9 Ma) on these dykes from South Kerala suggests that they are genetically related to the Deccan Trap volcanic activity (Radhakrishna et.al, 1990). Offset of NW-SE lianements by the WNW-ESE lineaments (Proterozoic age) would show that the former are older than WNW-ESE lineaments, although dyke intrusions indicate evidences of activity around 65 Ma, corresponding to Deccan trap volcanism.

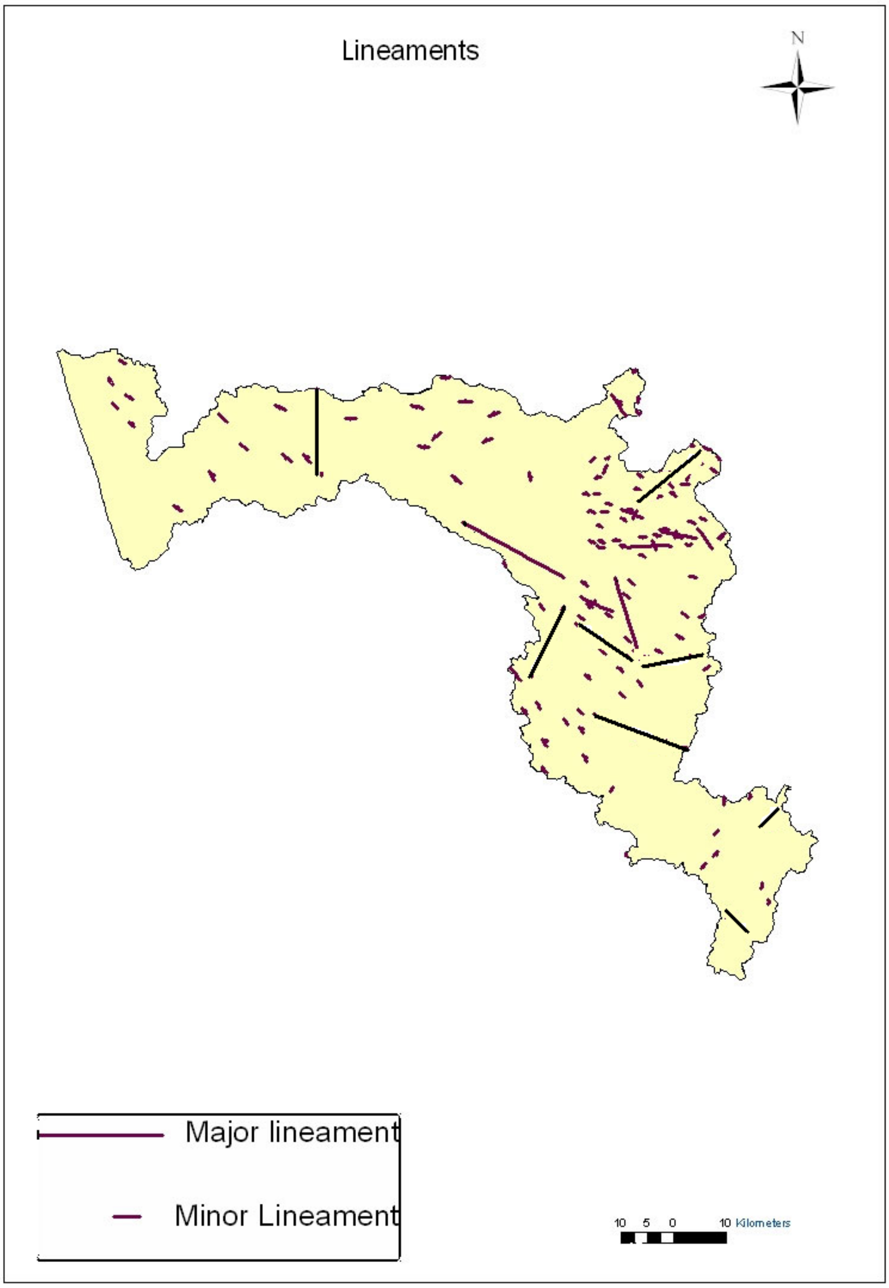

Fig.4.2. Lineaments of the Periyar River Basin

A variety of minor structures like folds, faults joints etc are encountered in the crystalline rocks of the area.

The dykes occur within charnockites and gneisses and cut all penetrative structures and they differ from one another in trend, mineralogy, composition and age and therefore do not relate to a single swarm (Radhakrishna et al. 1990). The intrusive of the area include basic dykes of gabbro and dolerite, pink granite and pegmatite veins. A dominant dyke is trending NNW-SSE extending from south to north in Koovappady and Angamaly blocks. The dyke is about 300 m wide and almost continuous. There are small other dolerite dykes trending NW-SE cutting across the main dyke in Kothamangalam, Koovapady and Angamaly blocks. These dykes appear to have been emplaced along the major lineaments. The Munnar plateau is characterized by U-shaped valleys and broad ridges/ circular hillocks are characteristics of the plateau. The southern limit of the plateau shows sudden decline in elevation and coincide with the lineament of the Bodinayakkunnur pass (Soman, 2002). Quartz veins are ubiquitous in the area, occouring within the gneisses and they cut across the foliation. Narayanaswami (1976) identified two major synclines in (i) the Palghat Gap area between Nilgiris and Anamalai - Palani ranges and (ii) in the Munnar - Thodupuzha-Muvattupuzha region extending into Kambam - Pariakulam valley of Tamilnadu between Palani and Varshanad ranges; two major anticlines along the Kottayam-Pirmed-Kakkiar hill ranges. The intrusive of the area include basic dykes of gabbro and dolerite, pink granite, quartz and pegmatite veins.

4. 10. DISCUSSION

The geology of the study area has a direct influence on the hydrogeological and hydrochemical aspects of the area. The mode of occurrence of groundwater is as varied as the rock types in which they occur. A close correlation of the geology of the study area with the hydrogeological and hydrochemical data of the basin revealed that the geology of the area has high influence of the groundwater potential of the area. The charnockite which is the dominant geological formation of the study area is a good aquifer for the development of groundwater. From the geophysical investigations conducted as part of the present study and the lithologs of the borewells drilled at various locations in the study area by the State Groundwater Department, it is observed that the charnockite of the midland region where the charnockite is capped with thick soil cover is high yielding for bore wells, as there is high recharge due to precipitation from the overlying soil layer. In the highland region, where generally the intensity of erosion is high, the solil cover is missing at several places and the charnockites are seen exposed on the surface. At such regions, the surface and subsurface ruoff is high and the rate of infiltration is also very low. Hence, it is observed that the bore wells drilled in such regions were dry as the groundwater potential in these regions is very low. Charnockites are moderately feasible for groundwater development where there is a thin capping of soil and also where the surface and sub-surface runoff is low. It is also observed that the migmatites of the study are less fractured and are devoid of any interconnected fractures and hence these regions are generally poor in groundwater potential. The correlation of the lithological aspects with groundwater yield of the basin is discussed elsewhere (Chapter VII). Similarly, the electrical conductivity variations in relation to rock/soil type are discussed in Chapter V.

Like soils, the confining rock formation has a direct influence on the groundwater quality of the study area. The chemical composition of the groundwater which moves from the recharge area to the discharge area reflects changes by various geochemical processes (Cetindag et al., 2004). The control of geology on the chemistry of groundwater of the basin is discussed in the section on hydrochemistry (Chapter VI).

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Chapter V

Geophysical Investigation

5.1 INTRODUCTION

Water plays a vital role in the development of any activity in the Periyar River Basin area. Thus, the availability of surface and ground water governs the process of planning and development. The surface water resource of the area is inadequate to fulfill the water demand. Productivity through groundwater is quite high as compared to surface water, but groundwater resources have not yet been properly developed through exploration. Water quality and fresh water availability to a large extent, determine the quality of our lives. Groundwater exploration in hard rocks is faced with several difficulties on account of wide and erratic variation of vital parameters which characterize the groundwater regime of the area. Spatial variations of these parameters are attributed, among other causes, to tectonic activities and degree of weathering of near-surface rocks (Benson et al, 1997). These processes induce directly or indirectly, secondary porosity in the rocks to a variable extent. As a result, the groundwater potential also varies significantly from place to place even in the same geological formation. From the hydrogeological data combined with geophysical, hydrometeorological and pumping tests, it is possible to develop and manage the groundwater resources of the basin (Raghunath, 1987). The key to success to any geophysical survey is the calibration of the geophysical data with the hydrogeological and geological ground truth information (Lashkaripour, et al, 2005). The analysis and interpretation of existing topographic maps, geological maps, aerial photographs, satellite imageries and other pertinent records are to be done as a part of the hydrogeological studies supplemented by field investigations. In groundwater studies, the resistivity method can furnish valuable information on the subsurface geology, which might be unattainable by other geophysical methods (Sharma and Baranwal, 2005). Geoelectrical methods have been used for a variety of purposes including demarcation of geological contacts (Ballukraya et al. 2001) and also for groundwater exploration and evaluation (Flathe, 1955; Zohdy, 1969; Fitterman and Stewart, 1986; McNeill, 1990; Karanth, 1987; Janardhana Raju et al., 1996). Geo-electrical methods are used extensively in groundwater mapping for investigation of the vulnerability of aquifers and shallow aquifers themselves. The geoelectrical method is capable of mapping both low and high resistive formations and therefore a valuable tool for vulnerability studies (Chistensen & Sorensen 1998;, Sorensen et al., 2005). From various electrical methods, the direct-current (DC) resistivity method for conducting a vertical electrical sounding (i.e. Schlumberger sounding) is extensively used for groundwater studies due to the simplicity of the technique, easy interpretation and rugged nature of the associated instrumentation. The technique is widely used in soft and hard rock areas (Urish and Frohlich, 1990; Ebraheem et al., 1997). However, groundwater investigations in hard rock area are often more difficult, as the well sites must be located with great care. Bore wells, tube wells and open dug wells constructed without proper hydrogeological and geophysical studies often fail to yield groundwater. The joints, fractures and weathering facilitate groundwater accumulation and movement (Narayanpeethkar et al. 2006). Groundwater yield depends on the size of these fractures and their interconnectivity (Chandra et al., 2004).

5.2 RESISTIVITY OF GEOLOGICAL FORMATIONS

In resistivity prospecting, earth is assumed to have a number of homogenous layers of differing resistivity bound by sharp vertical and horizontal contacts. The resistivity of water bearing rocks primarily depends on the porosity and permeability, the chemical composition and temperature. The presence of water and its chemical character are the main factors that control the flow of the electric current because most rocks are highly resistant to electrical flow. The porous geological formations saturated with groundwater of high ionic strength are charaterised by very low resistivity (Gilkeson and Wright, 1983). Thus resistivity decreases as porosity, hydraulic conductivity, water content and water salinity increase. Clay and Shale have low resistivities than that of saturated sand and gravel. In weathered rocks, the electrical resistivity usually varies with depth (Mallick and Roy, 1968; Koefoed, 1979).

Resistivity prospecting aims at determining the resistivity of the formations which in turn can be used to determine the subsurface structures of large groundwater basins, horizontal and vertical distribution of the aquifer, salt-fresh water boundaries, presence of buried channels, etc. The resistivity variations in the subsurface can be studied from surface observations. Mooney (1980) has given representative resistivity values for different kinds of earth materials. Gaur and Bhimasankaram (1977), Pandey and Murali (1984) and Telford et al.(1990) have also given comprehensive list of resisitivity values of various rock types, minerals and soils. The electrical resisitivity 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 5.1).

Table 5.1 Range of resistivity values (ohm-m) of common rocks/material (Singhal and Gupta, 1999).

Rocks/materials	Almost dry	Saturated with water
Quartzite	4.4×10^3 - 2×10^8	50 - 500
Granite	10^3 - 10^8	50 – 300
Limestone	600 - 10^7	50 – 1000
Basalt	4×10^4 – 1.3×10^8	10 – 50
Gneiss	6.8×10^4 – 3×10^8	50 – 350
Sand	150 – 2×10^3	10 - 100

In electrical resistivity method, current is passed into the earth using two current electrodes, from an AC or DC source, and the resulting potential distribution is measured using two more electrodes called potential electrodes (Fig. 5.1). If the current is passed into the isotropic and homogenous medium, then the resistivity obtained will be the 'true resistivity'. However, in nature, the earth is never homogenous and hence the resistivity obtained is called as 'apparent resistivity'. The apparent resistivity is related to the geometry of the electrode configuration and parameters of the geoelectric section. The measured values of apparent resistivity at a point must not be directly associated with the electric resistivity of the ground immediately below the point. Curves and mathematical relations are available to compute geoelectric parameters from apparent resistivity readings obtained using different electrode settings. In vertical electrical sounding (VES), a series of measurements of resistivity are made by increasing the electrode spacing in successive steps about a fixed point. It has been stated in many references on geophysical prospecting that the depth of probing depends on how far apart two current electrodes are placed. Furthermore, when sounding with the Schlumberger array and when the distance between the current electrodes are increased, the distance between the current and potential electrodes at the centre of the array is also increased. It is this latter increase that actually matters. In electrical sounding with the Schlumberger array, the respective electrode spacing as AB/2 is increased at successive intervals and the value of the appropriate apparent resistivity is plotted as a function of the electrode spacing on logarithmic co-ordinate paper. The curve is called an electrical sounding curve.

In principle, the current electrodes and the potential electrodes may be placed anywhere on the surface and the resistivity may be calculated using the formula:

Pa = K. dv/I, where,

Pa	=	Apparent Resistivity
dv	=	Potential Difference
I	=	Current passed into the earth
K	=	Configuration constant

5.3. METHODS OF RESISTIVITY SURVEYS

5.3.1 Profiling:

The resistivity profiling is a technique to locate lateral variations in resistivity at a constant depth. Here the electrode configuration remains the same for the entire area and it is moved as a whole along a traverse, generally normal to the strike of the rock formations. This resistivity profiling is used as a semi-reconnaissance tool in the search of vertical structures with large resistivity contrasts such as faults, geological contacts, dykes, shear zones and veins. Electrode separation for profiling is chosen after conducting a number of vertical electrical soundings in an area. Based on these soundings, an optimum spacing is chosen for the required depth of investigation. Interpretation of resistivity profiling data is usually qualitative in nature. If we run a number of profiles in an area, we can even expect to find somewhat similar results and by joining these anomalies it is possible to support or other wise the lineaments shown by the remote sensing method.

5.3.2 Vertical Electrical Sounding (VES)

The vertical electrical sounding is a technique to study the variations of resistivity with depth below a given point on the earth's surface. This method is extensively used for the quantitative estimation of the geoelectric parameters. Thus the apparent resistivity obtained for progressively increasing current electrode separation would reflect on the vertical distribution of the resistivity in a geological section. Current electrode separation is increased from smallest possible value to the maximum separation needed to reach a required depth of investigation. A VES is typically carried out in Schlumberger array, where the potential electrodes are placed in a fixed position with a short separation and the current electrodes are placed symmetrically on the outer sides of the potential electrodes (Fig. 5.1). After each resistivity measurement, the current electrodes are moved further away from the centre of the array. In this way the current is stepwise made to flow through deeper and deeper parts of the ground. For large distances between the current electrodes, the distance of the potential electrodes is increased to ensure that the measured voltage is above the noise level and the detection level.

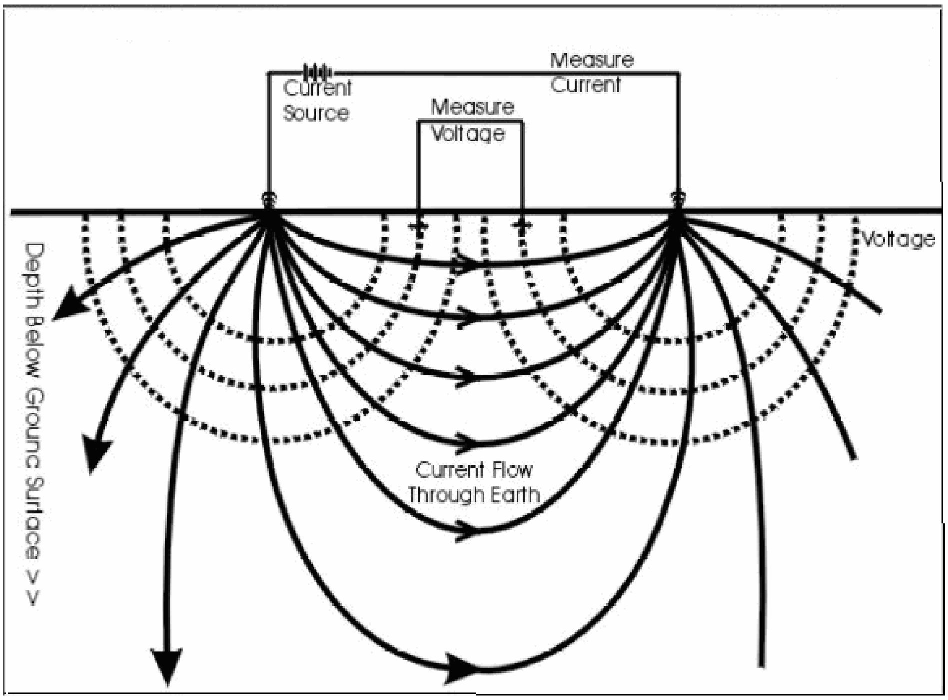


Fig. 5.1. Schlumberger electrode arrangement.

in the instrument. In crystalline terrains, the maximum depth of penetration needed is to reach the compact rock (bed rock), usually having infinite resistivity. Infinitely, resistive basement is reflected in the sounding curves as an asymptote at the extreme right hand part, making an angle of 45° with the x–axis on the double log sheet. Survey will be stopped as soon as this asymptotic part of the curve is obtained.

The present investigation attempted to assess the ground water potential of Periyar River Basin and to demarcate suitable locations for groundwater exploration, suggest suitable methods of tapping ground water without any adverse effects and also to suggest precautionary measures to prevent salt water intrusion.

As part of the groundwater studies of the area, detailed geophysical investigation has been carried out in the Periyar River Basin using the Schlumberger arrray at the selected locations (Table5.2 and Fig. 5.2).. Current electrode spacing (AB/2) was gradually increased up to 200 m for delineation of deeper structures. Electrodes were spread in the direction parallel to strike direction. Over layered earth structures (1-D situation), variation in apparent resistivity with current electrode separations is quite smooth (Koefoed, 1979). Further, this variation is also smooth when the direction of spread is parallel to the strike and erratic when the direction of spread is perpendicular to the strike for 2-D situation (Keller and Frischknecht, 1966). In the present study, a rather smooth variation in apparent resistivity is observed up to large electrode separations in the strike direction. Therefore, we assume that in such situation 1-D interpretation will yield significant subsurface features for the recommendation of appropriate locations for groundwater development.

5.3.3 Season of field work

The best and less noisy data are collected if a good contact to the ground is present. A good ground contact results in a relative low contact resistance between the electrodes and the ground, which ensure that relative high current can be supressed into the ground. Good contact between the electrodes and the ground is obtained, when the soil is moist and at least partly saturated by water. It can be difficult to obtain a good data quality or even to collect data, if the soil at ground surface is completely dry. In an area with dry soil, the data quality can be enhanced, if the soil around the electrodes is watered by salty water. In the present study, the vertical electrical soundings were carried out during November- December 2005 and January 2006.

5.4 DATA ACQUISITION AND PROCESSING

For an overall assessment of groundwater of the study area, initially, the geological, geomorphologic and geohydrological studies were carried out on a regional scale for the entire basin and based on this 105 locations (Table 5.2), distributed approximately in a grid pattern were selected for detailed resistivity soundings. VES were carried out in these locations using Schlumberger configuration with an electrode separation of 100 m – 200 m.

The value of the appropriate apparent resistivity is plotted as a function of the electrode spacing on logarithmic co-ordinate paper. The curve is called an electrical sounding curve. The purpose of interpretation of geoelectric sections namely the resistivity and thickness of the formations which are subsequently correlated with the geology as well as hydrogeology of the area.

5.5 VES DATA INTERPRETATION

Vertical electrical soundings were carried out in the study area using Schlumberger electrode arrangement at selected locations with objective of analyzing geophysical parameters quantitatively and qualitatively.

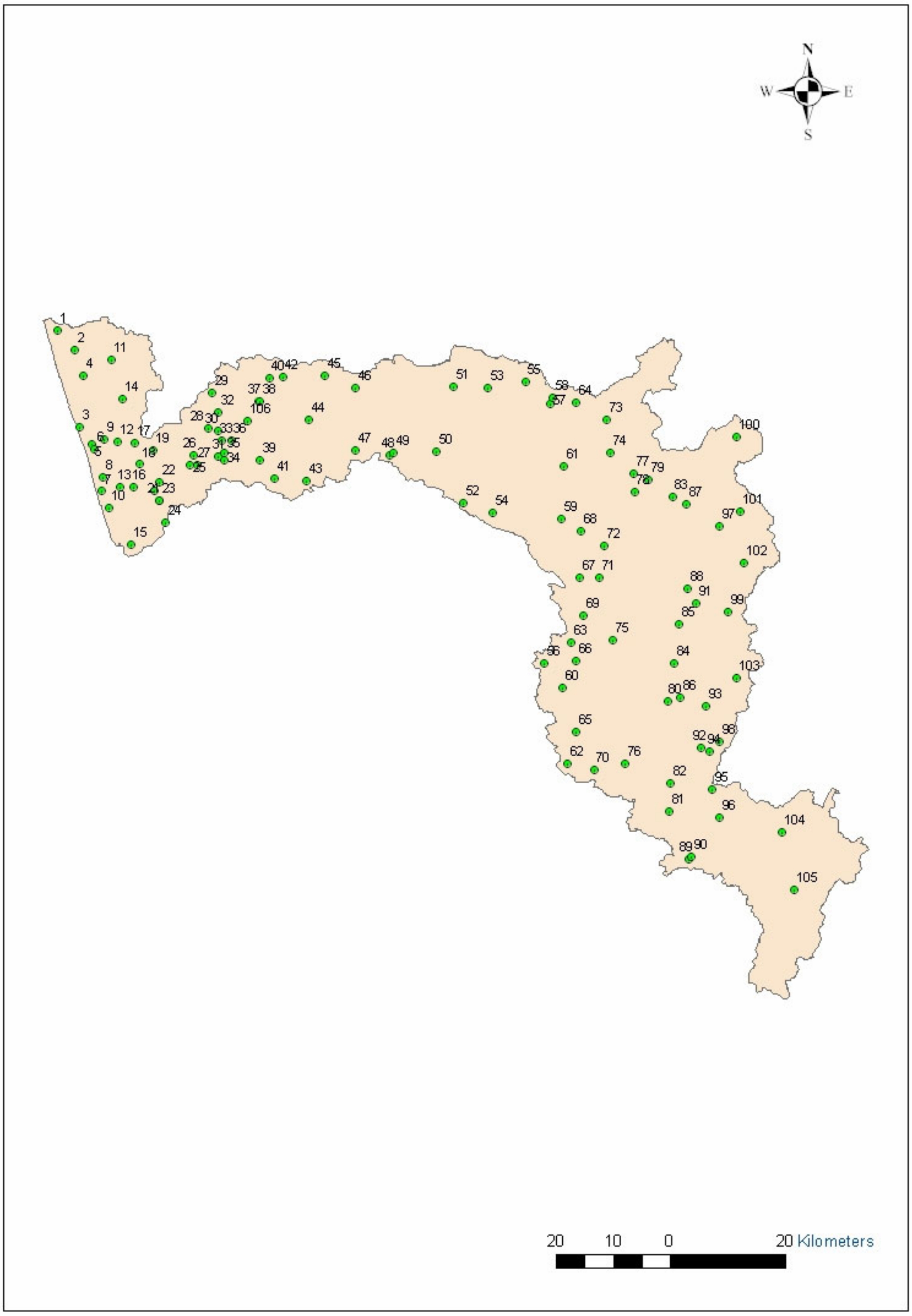


Fig. 5.2 VES locations of the study area.

Table 5.2 Analysed Vertical electrical sounding (VES) data of the Periyar River Basin (h1 to h5 are layer thicknesses and ρ1 toρ6 are apparent resistivities.

VES NO	Location	Lat	Long	h1(m)	h2(m)	h3(m)	h4(m)	h5(m)	ρ1	ρ2	ρ3	ρ4	ρ5	ρ6	Curve Type
1	Matilakom	76.14	10.32	1.50	0.90	13.20	9.50	0.00	234	45	7	2	1	0	Q
2	Pappinivattom	76.165	10.293	1.10	0.66	0.54	2.90	6.20	262	46	22	8	4	3	Q
3	Munambam	76.172	10.172	1.80	2.20	18.80	22.10	0.00	45	24	8	2	1	0	Q
4	Eriyad	76.18	10.25	1.60	1.20	13.50	10.30	0.00	195	39	12	8	4	0	Q
5	Cherai	76.192	10.144	2.20	3.10	21.60	24.20	0.00	85	25	9	6	3	0	Q
6	Pallipuram	76.195	10.137	1.70	4.80	17.50	24.00	0.00	65	28	7	6	3	0	Q
7	Nayarambalam	76.207	10.072	2.10	3.20	19.80	24.20	0.00	52	34	9	2	2	0	Q
8	Edavanakad	76.208	10.092	1.80	2.40	22.50	25.60	0.00	96	31	6	4	2	0	Q
9	Paravur	76.211	10.152	1.20	3.60	6.90	24.00	0.00	68	36	19	11	3	0	Q
10	Njarakkal	76.218	10.045	1.90	2.70	20.40	23.60	0.00	59	32	8	3	2	0	Q
11	Vellangallur	76.22	10.28	1.90	3.40	18.20	11.50	34.50	620	1355	275	450	624	870	AH
12	Ezhikkakara	76.231	10.148	1.80	5.40	22.40	16.60	0.00	65	14	2	1	1	0	Q
13	Kongarpally	76.236	10.077	2.40	4.30	19.20	19.40	0.00	138	75	32	21	8	0	Q
14	Poyya	76.239	10.216	1.80	3.60	16.20	10.20	31.60	532	1324	221	421	288	568	AH
15	Vypin	76.25	9.99	1.70	2.60	21.50	25.30	0.00	72	33	13	5	1	0	Q
16	Varapuzha	76.256	10.077	1.70	0.85	13.50	17.00	0.00	120	35	6	21	8	0	Q
17	Mannam	76.258	10.146	3.20	5.80	6.80	34.00	0.00	650	425	325	185	45	0	Q
18	Alangad	76.266	10.114	2.40	5.80	2.10	33.20	0.00	1370	975	425	226	625	0	K
19	Chengamanad	76.287	10.136	1.50	7.50	2.40	26.40	0.00	2110	4350	552	242	780	0	AH
20	N.Kalamassery	76.290	10.072	2.30	6.80	3.50	35.50	0.00	876	1154	642	225	354	0	KH
21	Kalamassery	76.297	10.056	1.50	4.80	3.20	7.20	18.00	505	1235	224	875	14	86	KQ
22	Elur_north	76.297	10.086	1.10	2.20	3.10	22.40	0.00	192	66	10	8	15	0	Q
23	Pathalam	76.297	10.086	2.50	10.00	19.50	30.00	15.00	740	570	340	220	185	435	H
24	Edappally	76.307	10.022	1.50	1.35	0.50	28.40	0.00	245	145	105	45	7	0	Q
25	Aluva	76.346	10.112	1.80	6.10	9.60	23.50	0.00	620	1110	1450	265	675	0	KH
26	Desom	76.352	10.127	1.40	2.80	6.90	15.20	62.10	1225	675	298	145	495	890	H
27	Alwaye	76.356	10.112	1.85	2.85	13.44	47.60	65.79	1113	1652	562	175	295	450	AH

28	Nedumbassery	76.374	10.170	1.30	2.30	5.44	5.00	0.00	843	252	87	434	654	0	HK
29	Karukutty	76.381	10.225	1.50	3.10	7.20	16.20	81.00	1210	722	275	144	225	725	H
30	Kaladi	76.389	10.167	2.40	4.20	2.10	21.40	32.40	1154	865	325	225	653	910	H
31	Chowara	76.389	10.126	1.50	0.45	3.91	30.20	0.00	1810	1082	152	288	292	0	HA
32	Chowara	76.389	10.126	1.60	6.40	21.30	0.00	0.00	382	152	342	1110	0	0	HA
33	Angamaly	76.389	10.195	1.40	0.70	15.60	36.00	0.00	1030	3475	375	150	285	0	H
34	Sreemoolanagaram	76.395	10.150	1.50	9.60	11.20	21.20	54,2	1450	954	325	165	725	1050	H
35	Aluva_East	76.399	10.119	2.10	1.20	57.60	60.60	0.00	702	1050	210	442	650	0	AH
36	Vazhakkulam	76.400	10.131	1.90	9.60	10.50	48.00	0.00	802	696	272	1225	544	0	HA
37	Kanjur	76.410	10.150	2.10	6.80	1.50	14.60	45.30	976	1454	675	275	554	990	KH
38	Manjapra	76.453	10.213	1.60	6.34	2.10	5.50	33.00	170	340	105	423	54	238	AH
39	Manjapara	76.455	10.212	1.80	8.60	23.70	0.00	0.00	832	1050	543	365	679	0	K
40	Vallom	76.456	10.120	3.20	6.90	4.70	42.20	0.00	689	998	430	175	375	0	KH
41	Sulli	76.471	10.249	2.10	7.20	12.40	19.60	0.00	880	975	1354	245	775	0	KH
42	Edakuna	76.491	10.251	1.90	5.20	13.20	0.00	0.00	660	886	1230	1395	0	0	A
43	Odakkali	76.529	10.087	1.95	2.96	19.20	10.30	0.00	453	674	164	155	165	0	AH
44	Malayattur	76.533	10.183	1.90	1.52	18.30	0.00	0.00	537	925	168	720	0	0	AH
45	Illithodu	76.557	10.253	1.90	1.90	55.80	59.60	0.00	2100	210	1400	1800	1910	0	A
46	Panamkuzhi	76.605	10.233	2.30	4.80	12.30	15.80	0.00	1654	1155	875	454	1	0	H
47	Pindimana	76.660	10.128	1.50	0.45	3.20	20.30	18.20	510	1253	1860	625	1820	1980	A
48	Thattekad	76.666	10.132	1.30	1.69	3.20	6.80	26.00	402	805	688	174	420	985	AH
49	Thattekad	76.666	10.132	3.10	12.40	63.50	0.00	0.00	2600	1300	350	1050	0	0	H
50	Adigalthoti	76.761	10.235	1.20	5.20	18.60	22.60	0.00	1950	1290	375	390	885	0	H
51	Neriyamangalam	76.775	10.052	1.40	3.08	0.92	26.00	49.00	368	148	450	625	238	475	H
52	Minikutti	76.815	10.234	1.80	5.50	7.00	16.80	0.00	910	270	825	1230	1620	0	HK
53	Chempankuzhi	76.821	10.036	2.50	5.25	22.20	16.20	0.00	1015	3195	1320	3150	1996	0	AH
54	Puthukudy	76.873	10.243	1.10	4.80	21.30	0.00	0.00	715	954	1324	1545	0	0	A
55	Kulamavu	76.903	9.799	2.40	16.80	30.40	0.00	0.00	920	230	875	416	0	0	HA
56	Puttikudi	76.912	10.209	1.70	4.30	15.50	24.60	0.00	1600	1325	325	1010	1075	0	H
57	Sembukulam	76.916	10.218	1.50	6.75	7.80	10.00	0.00	1020	525	1245	925	1245	0	QK
58	Machipilavu	76.929	10.027	1.40	3.50	10.20	6.80	0.00	1495	1875	1510	1920	2250	0	KQ

59	Vellakkanam	76.932	9.761	2.50	5.20	19.40	0.00	0.00	1053	1654	1675	1865	0	0	A
60	Anakkulam	76.934	10.111	1.50	5.80	32.20	0.00	0.00	512	995	4480	2240	0	0	KH
61	Nallathani	76.940	9.642	2.80	6.72	28.00	0.00	0.00	432	1200	2000	2160	0	0	HA
62	Mattuthavalam	76.945	9.833	1.90	0.57	3.75	40.20	0.00	1310	3250	342	1575	605	0	AH
63	Nemakkad	76.953	10.210	1.50	2.25	68.00	0.00	0.00	560	1120	480	1890	0	0	AH
64	Nadukani	76.953	9.692	1.30	0.78	29.70	0.00	0.00	1400	2100	680	1400	0	0	KH
65	Chelachuvadu	76.958	9.934	2.30	4.50	12.60	0.00	0.00	565	925	1425	1654	0	0	A
66	Adimali	76.961	10.008	1.90	10.20	36.00	48.00	0.00	710	1750	910	665	450	0	AH
67	Vazhathope	76.964	9.874	1.50	12.00	57.00	0.00	0.00	2200	660	260	600	0	0	H
68	Idukki	76.978	9.842	1.60	7.20	4.00	26.00	0.00	410	160	213	665	1090	0	HA
69	Elappara	76.981	9.631	1.20	7.20	16.00	0.00	0.00	700	280	750	300	0	0	HA
70	Velluthuval	76.990	9.934	1.90	3.80	20.20	14.10	0.00	1315	986	336	275	1225	0	K
71	Tankamani	76.998	69.984	3.50	12.60	40.80	0.00	0.00	852	683	302	1425	0	0	HA
72	Parappayarkudi	77.001	10.183	2.20	4.50	22.20	0.00	0.00	865	986	1543	1865	0	0	A
73	Kandalur	77.007	10.131	1.60	5.20	17.20	0.00	0.00	615	910	1325	1850	0	0	A
74	Kanniyar	77.011	9.836	1.65	1.70	11.20	21.20	13.20	996	605	990	268	902	1348	HA
75	Narakkanam	77.030	9.642	1.85	6.30	39.40	0.00	0.00	2010	1520	713	1047	0	0	H
76	Rajamala	77.043	10.099	1.50	3.10	7.60	24.20	36.10	1005	202	1050	906	1815	2010	HA
77	Kunjithanni	77.046	10.069	1.40	1.68	8.50	22.30	0.00	610	890	1104	1632	1695	0	A
78	Oonnukal	77.065	9.634	2.00	1.80	12.00	54.00	0.00	1400	1120	4200	1680	885	0	H
79	Munnar	77.067	10.088	2.10	10.20	6.30	28.50	0.00	1815	896	3496	424	482	0	HA
80	Ayyappancoil	77.097	9.740	2.20	1.40	30.60	0.00	0.00	2505	986	235	463	0	0	H
81	Vandiperiyar	77.100	9.567	1.70	2.50	5.95	6.20	31.80	520	416	395	2010	1875	1050	HA
82	Devikulam	77.106	10.061	1.50	1.05	4.86	26.60	14.20	710	1390	182	625	980	1345	AH
83	Irattayar	77.107	9.800	1.50	2.25	62.40	66.15	0.00	602	2100	440	1750	2100	0	AH
84	Nirmalacity	77.115	9.862	2.20	14.30	37.80	54.30	0.00	920	460	162	525	976	0	H
85	Kattappana	77.117	9.745	2.25	14.65	42.50	0.00	0.00	1110	335	896	675	0	0	HA
86	Mulavara	77.126	10.051	1.40	5.10	21.70	0.00	0.00	920	1025	1430	1765	0	0	A
87	Rajakumari	77.129	9.917	2.80	6.30	9.20	13.50	0.00	1850	1460	950	375	650	0	H
88	Vallakadavu	77.131	9.491	2.90	7.25	25.00	35.15	0.00	820	656	750	225	855	0	H
89	Mount Plateau	77.135	9.494	1.00	5.50	10.20	21.30	0.00	735	1450	375	243	1240	0	KH
90	Pampupara	77.150	9.667	1.30	0.78	19.80	10.20	0.00	705	285	1215	605	592	0	HA

91	Pampupara	77.150	9.667	1.20	0.84	7.20	20.20	0.00	380	1431	1020	729	1550	0	AK
92	Vandanmedu	77.158	9.733	1.70	5.95	31.20	0.00	0.00	522	260	985	1125	0	0	H
93	Chakkupallam	77.158	9.733	1.10	3.25	9.15	11.25	0.00	915	643	310	712	986	0	HA
94	Puttadi	77.163	9.661	1.20	0.65	7.36	9.00	16.00	485	1210	280	825	208	753	KH
95	Kumily	77.167	9.600	2.80	8.96	40.80	0.00	0.00	700	420	960	1000	0	0	HA
96	Kuruppampady	77.171	9.711	2.40	9.50	14.40	27.32	0.00	540	108	280	1100	450	0	HK
97	Palada	77.179	9.556	1.50	2.70	13.00	0.00	0.00	1020	325	265	705	0	0	HA
98	Venad	77.179	10.016	1.60	6.80	35.20	0.00	0.00	2814	1405	452	2510	0	0	HA
99	Kochachara	77.179	9.676	2.60	2.52	13.20	13.30	0.00	2200	3300	1080	650	1320	0	AH
100	Ramakkalmedu	77.192	9.881	1.40	5.60	4.90	12.00	12.50	880	528	1160	1700	2240	3360	HA
101	S.Parvathipuram	77.205	10.157	2.10	13.50	32.50	10.50	0.00	1685	1015	555	2125	2650	0	H
102	Santhampara	77.211	10.038	1.40	2.10	9.30	24.20	10.95	1310	2620	773	2050	482	1260	KH
103	Udumbanchola	77.217	9.958	1.40	2.80	18.20	13.20	0.00	890	240	1300	4200	4950	0	QK
104	Anakkakara	77.270	9.761	1.80	7.10	19.40	0.00	0.00	490	765	830	986	0	0	A
105	Mullakkudy	77.277	9.534	1.20	10.50	12.60	28.30	0.00	510	1650	280	195	750	0	KH
106	Thannikkudy	77.297	9.442	1.60	6.20	14.60	0.00	0.00	555	745	995	1240	0	0	A

5.5.1 Qualitative Interpretation

Interpretation of electrical sounding curves is done by various methods. They are classified as analytical methods, semi empirical and empherical method. Analytical methods are more informative and complete compared to other methods. Several published theoretical curves are available for matching the curves, which include Campagine Generale de Geophysique (CGG-1963), Orellana and Mooney (1966), VonNostrand (1966) and VanDam and Meulenkamp (1969). In qualitative interpretation the potential zones are found out by studying the nature of the field curve. Sometimes it is useful to make a rapid qualitative study of the field curves before a detailed quantitative interpretation. The interpretation of VES data is done by analyzing 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 the area. The qualitative analysis gives the number of layers and the order of resistivity.

5.5.2 Types of Curves

The two geo-electrical parameters used in this computation are resistivity (ohm-m) 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 ($\rho 1<\rho 2$) is characterized by either topsoil or weathered layer followed by hard compact resistive basement rock. In descending type curve (ρ $1>\rho 2$), a compact layer is overlain by a thick clay layer or saline aquifer and is called conductive basement.

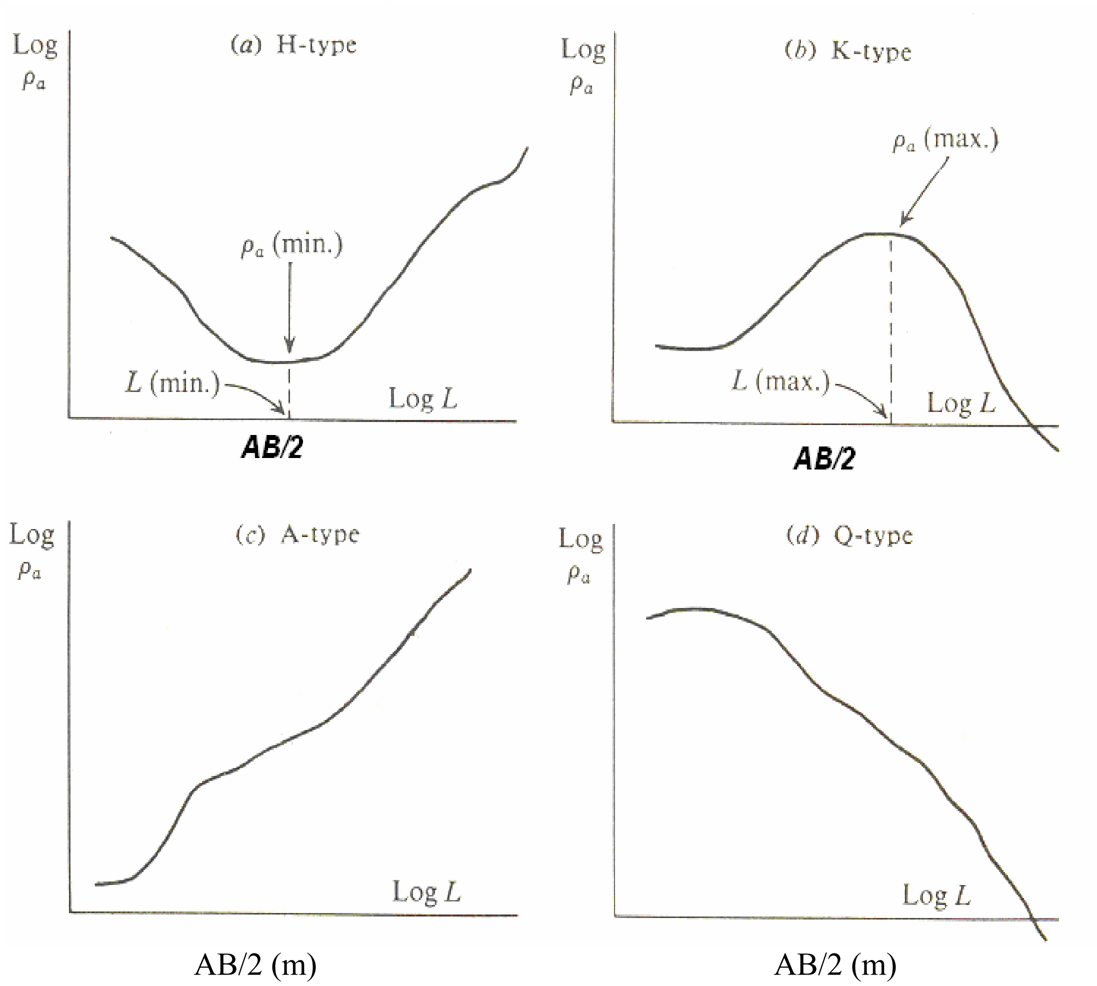


Fig. 5.3 Common types of sounding curves (apparent resistivity ρ plots against half electrode-spacing AB/2) in three layered formations.

In a three layered geological formation, four types of sounding curves are possible. (Fig. 5.3). If $\rho1$, $\rho2$ and $\rho3$ are resistivity of the 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 thin conductive topsoil and therefore the resistivity of the layers continuously increases 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 water predominates. ‘H’ type curves are generally obtained in hard rock terrains consisting of dry top soil (first layer) of high resistivity followed by either water saturated or weathered layer of low resistivity.

5.5.3 Curve Matching Technique

The master curves are prepared with dimensionless coordinates. These theoretical curves are constructed for an assumed geo-electric section. These theoretical curves are calculated and drawn on the assumption that each of the layer has uniform resistivity and that the interfaces between the layers form horizontal planes with sharp contacts. Set of master curves for a two-layer and three layered earth are available.

The field data should be plotted in the form of apparent resistivity versus half the distance of the current electrodes on the log-log paper and the same should be superposed on the master curves and matched. The field curve is generally drawn on a transparent sheet. To match the field curve, it is necessary to slide the master curve around the field curve until the latter coincides more or less with one of the master curves. While matching, the respective co-ordinate axes should be strictly parallel. If the field curves match perfectly with any of the master curves, then the field parameters are same as those of the theoretical curve. Sometimes it may be necessary to interpolate between two of the theoretical curves to obtain the geoelectric parameters of the field curve.

During the field survey, the apparent resistivities obtained for different electrode spacings are recorded. These apparent resistivities are plotted against current electrode spacing on as double log graph sheets having 62.5 modulus to get the field curves. The field curves are interpreted by curve matching techniques as described above.

The resistivity of the first layer ($\rho 1$) of this basin ranges from 45 ohm-m at Munambam to as high as 2814 ohm-m at Venad and the thickness varies from 1m to 3.5m. The thickness and apparent resistivity contour maps (Fig. 5.4 a & b) shows that thickness of the first layer varies based on the topography and soil types. The unconsolidated loose soils are more susceptible to erosion. In majority of the stations in the highland and midland regions, the topmost layer is hard soil as capping and in the coastal plains it is unconsolidated sandy alluvium where the chemical quality is poor. The resistivity of the second layer ($\rho 2$) ranges from 14 ohm-m at Ezhikkakara to 4350 ohm-m at Chengamanad.

(Fig.5.5 a and b) and generally consists of hard laterite in the midland and parts of the highland regions and weathered hard rocks as lenses in the upland regions and sandy soil in the coastal plains.

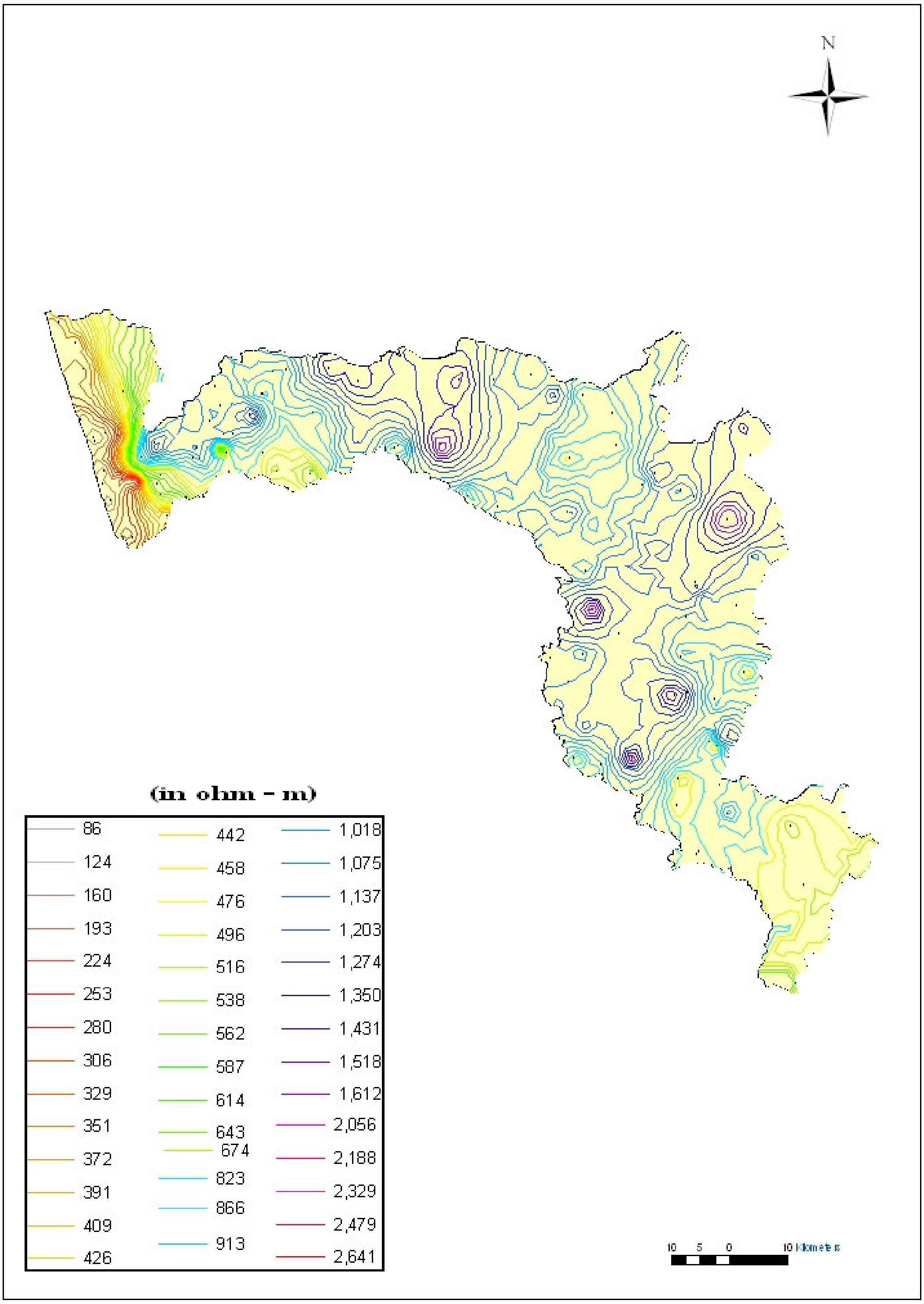


Fig. 5.4a. Apparent Resistivity (ohm-m) contour map of the First layer of the study area

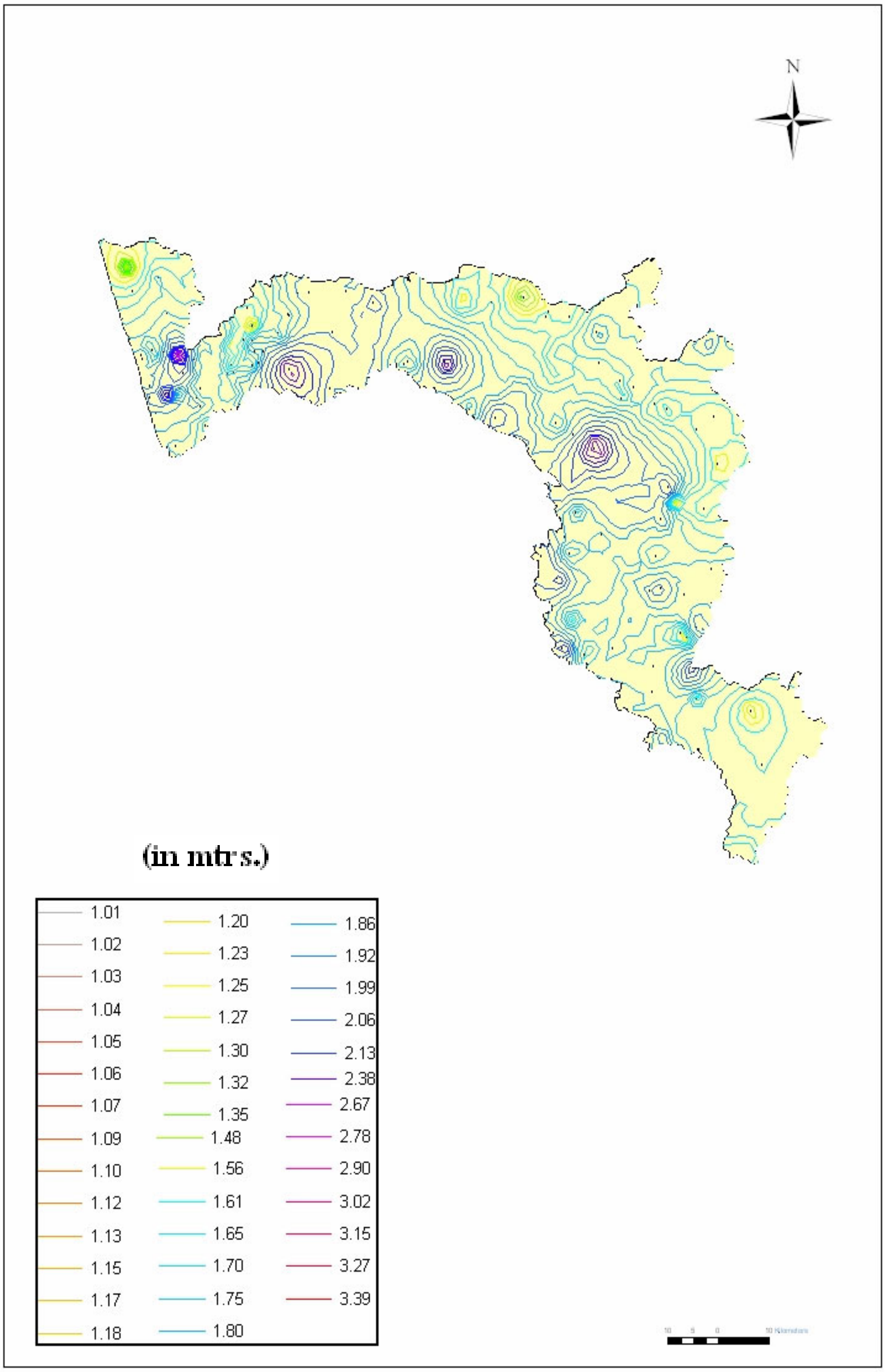


Fig. 5. 4b Thickness Contour (m) map of the First layer of the study area.

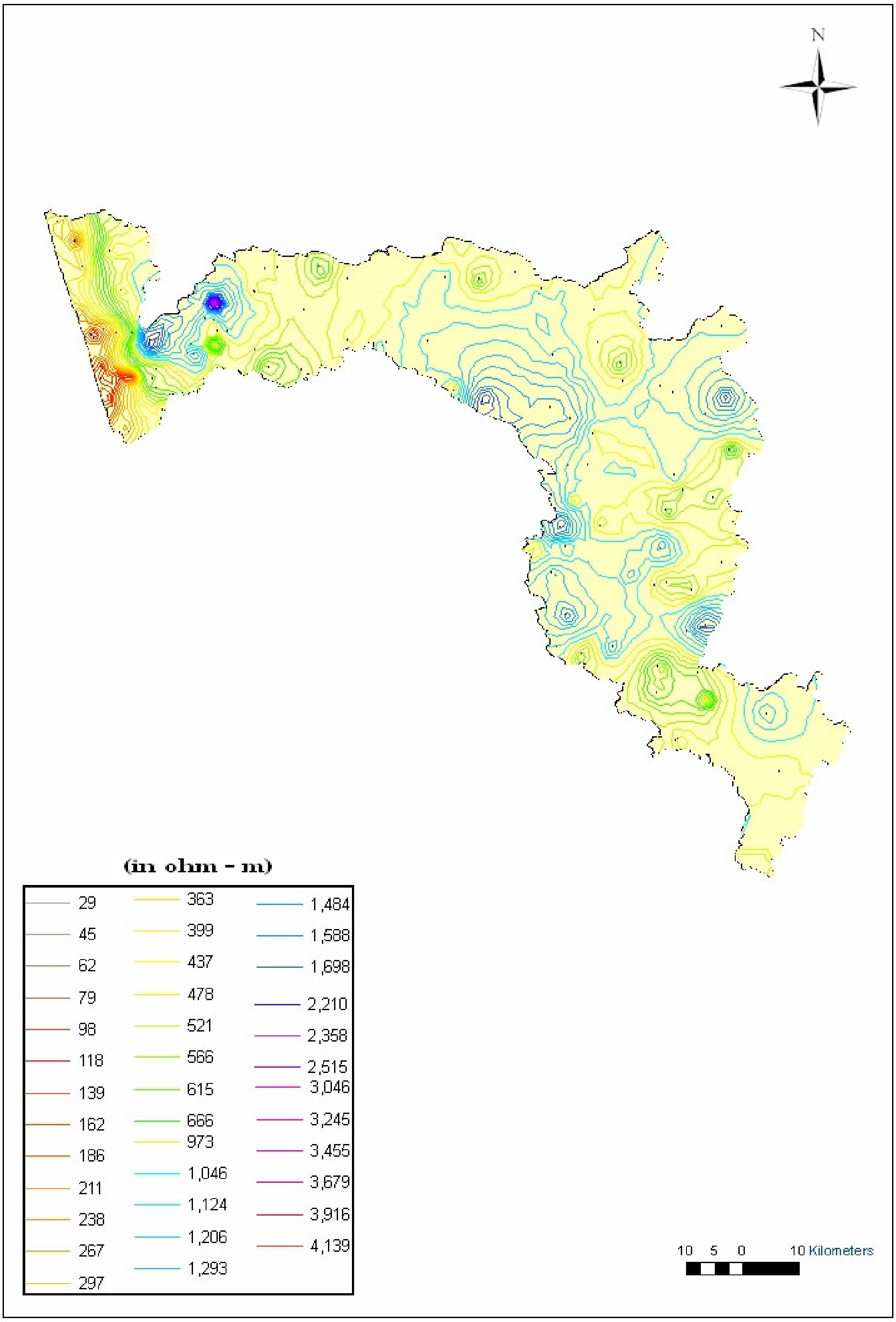


Fig. 5. 5a. Apparent Resistivity (ohm-m) contour map of the Second layer of the study area.

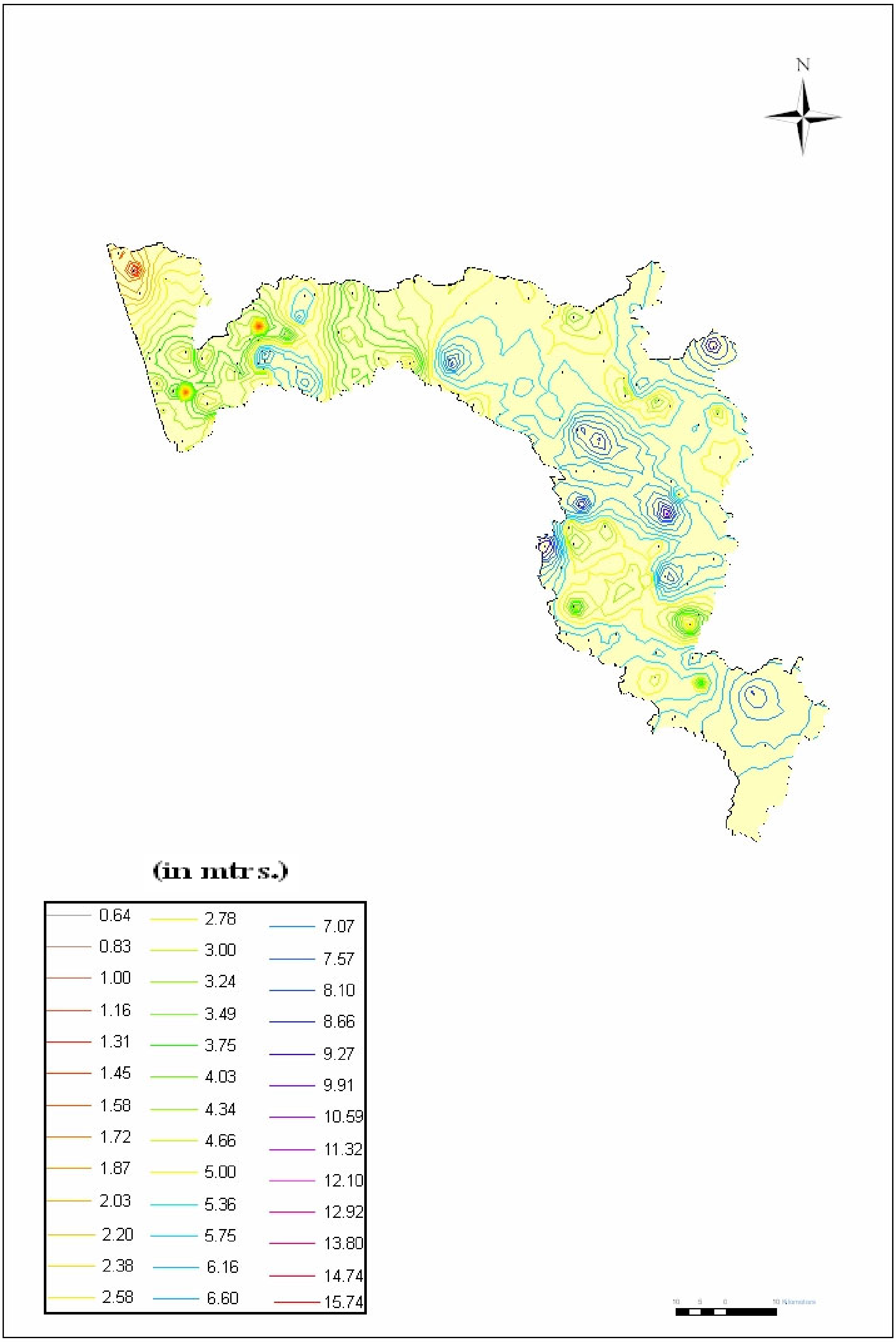


Fig. 5.5 b Thickness Contour (m) map of the Second layer of the study area.

From the contour map of the second layer, it is observed that the thickness of this layer varies from 0.45m to 16.8m. The resistivity valus less than 500 ohm-m are considered as phreatic aquifer zone as the area is mainly lateritic in nature (Ramanujachary and Balakrishnan, 1985). The high resistivity of the second layer at places like Chegamanad, Oonnukal, Pindimana and Angamaly comparatively high (>1500 ohm-m) are due to the presence of hard laterite in the area. Here the laterite is underlain by lithomargic clay.

Also, the resistivity of the second layer in high range places like Munnar, Nallathani, Mattuthavalam, Nadukani, and Vellakkanam are also high due the presence of highly weathered crystalline rocks, where the laterite layer is missing. In the coastal area, the second layer, namely the clayey sand is the dominant aquifer, in the midland land region and parts of the lowlands at Poyya, Chengamanad, Pathalam, and Kalamassery and in the midland region; the laterite is the dominant phreatic aquifer. In the highland regions, where the laterite is missing, weathered crystalline is the dominant phreatic aquifer at places like Nirmala city, Idukki, Elappara, Vandiperiyar, Kattappana, Pampupara, Udumbanchola, Palada, Vandanmedu etc. Claye sand with varying composition is continued in the coastal planes and considerable thickness of lithomargic clay is found at places like Chengamanad, Poyya and Kalamassery of the lowland region and the central part of Aluva and Kunnathunad taluks and this also acts as good phreatic aquifer of the area. In the highland region fractured crystalline

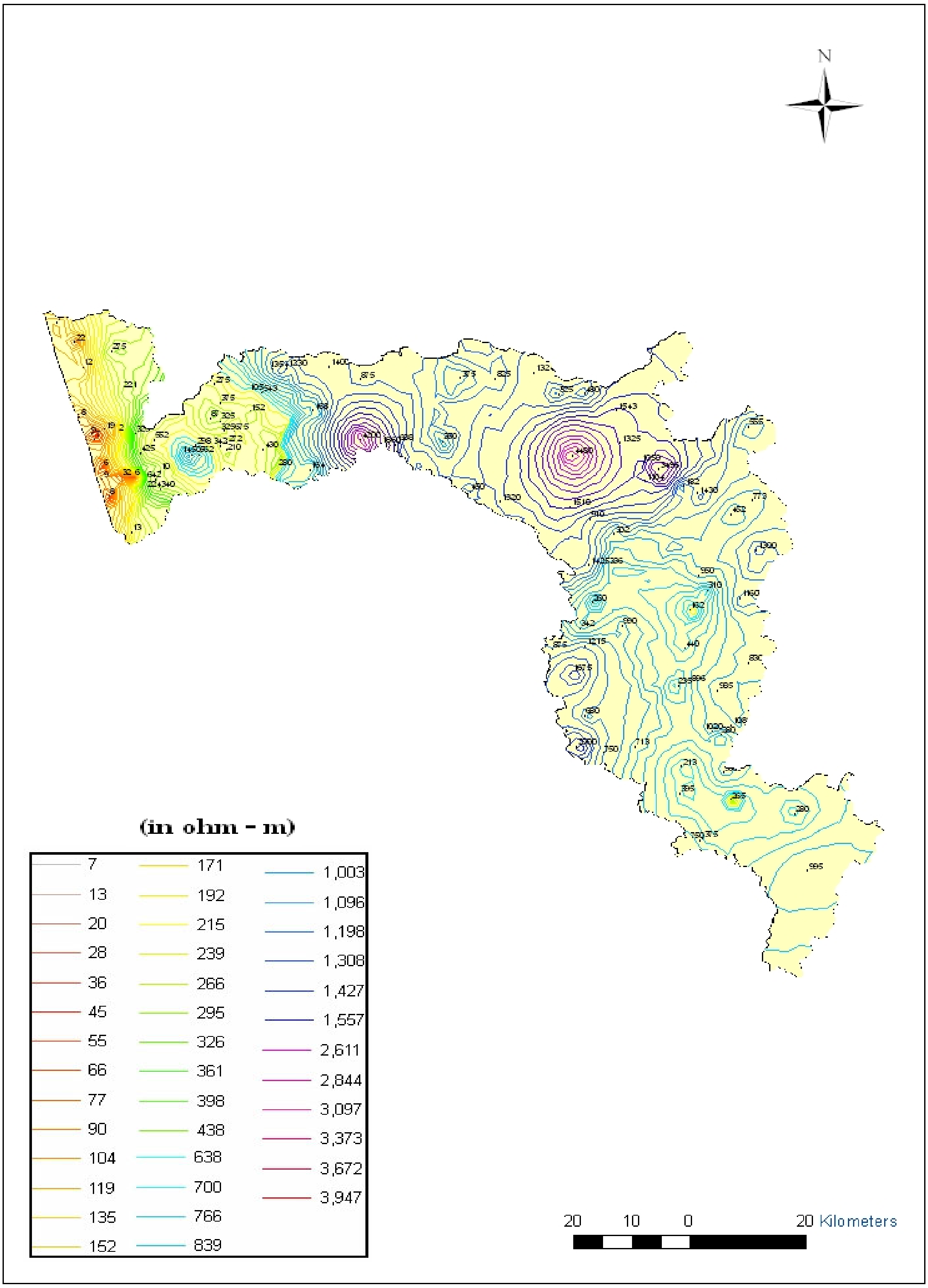


Fig.5.6a. Apparent Resistivity (ohm-m) contour map of the Third layer of the study area.

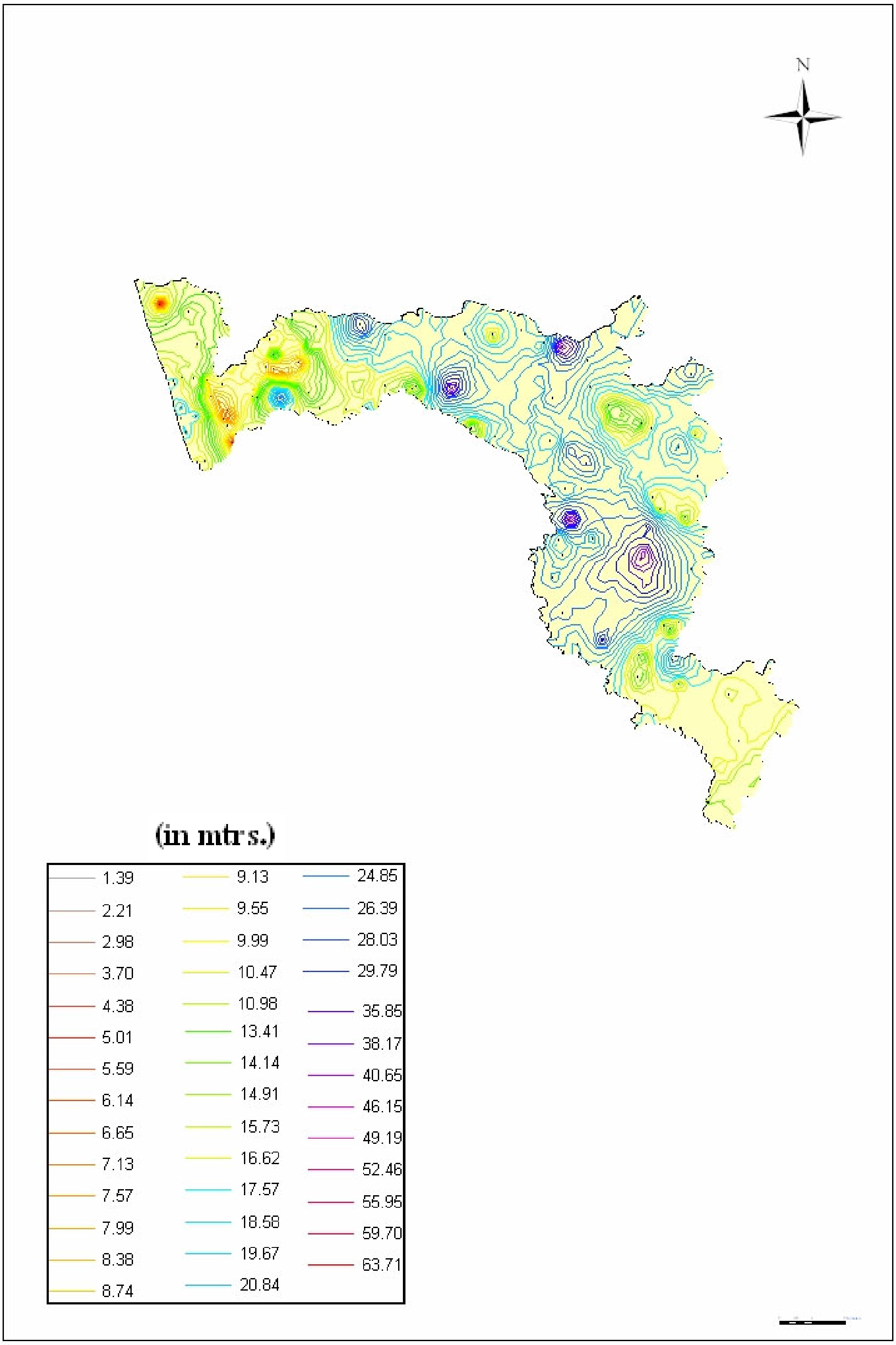


Fig. 5. 6b Thickness Contour (m) map of the Third layer of the study area.

rocks is the dominant third layer and acts as a good aquifer. Resistivity of the fourth layer varies from 1 ohm-m at Narakkal and Ezhikkakara to 4200 ohm-m at Udumbanchola and the thickness varies from 2.9 m to 66.15 m.

The clayey sand is the fourth layer aquifer in the coastal planes and the crystalline formations are encountered as the fourth layer in all other parts of the study area. The fourth layer is deeper and acts as good aquifer in places like Neriyamangalam, Puttadi, Kulamavu, Elappara, Vellathuval, Kanniyar, Rajamala etc; of the highland region. The fifth layer acts as a good aquifer in the midland region, except Illithodu, Malayattoor, Thattekkad and Edakuna area, where the aquifers are poor yielding. The fifth layer is present only at places like Neriyamangalam, Kanniyar, Rajamalam Vandiperiyar, Devikulam, Puttadi, Ramakkalmedu and Santhampara, but with high resistance values exhibiting the massive nature of the subsurface layer.

The resistivity of the fifth layer varies from 1 ohm-m at Vypin, Narakkal, Mathilakom and Ezhikkakara to 4950 ohm-m near Ramakkalmedu with depths varying from 6.2m to 81m. Presence of a few deep layers with resistivity ranges from 3 ohm-m to 3360 ohm-m, in depths ranging from 6.2m to 81m was also analysed. Very high subsurface resisitivity of various layers s (> 1000 ohm-m) observed in locations in the highland and midland regions of the basin. This is an indication of the massive and unfractured nature of the subsurface formations. The resistivity of the subsurface layers is high where the surface and the subsurface runoff are also high and the infiltration is very low.

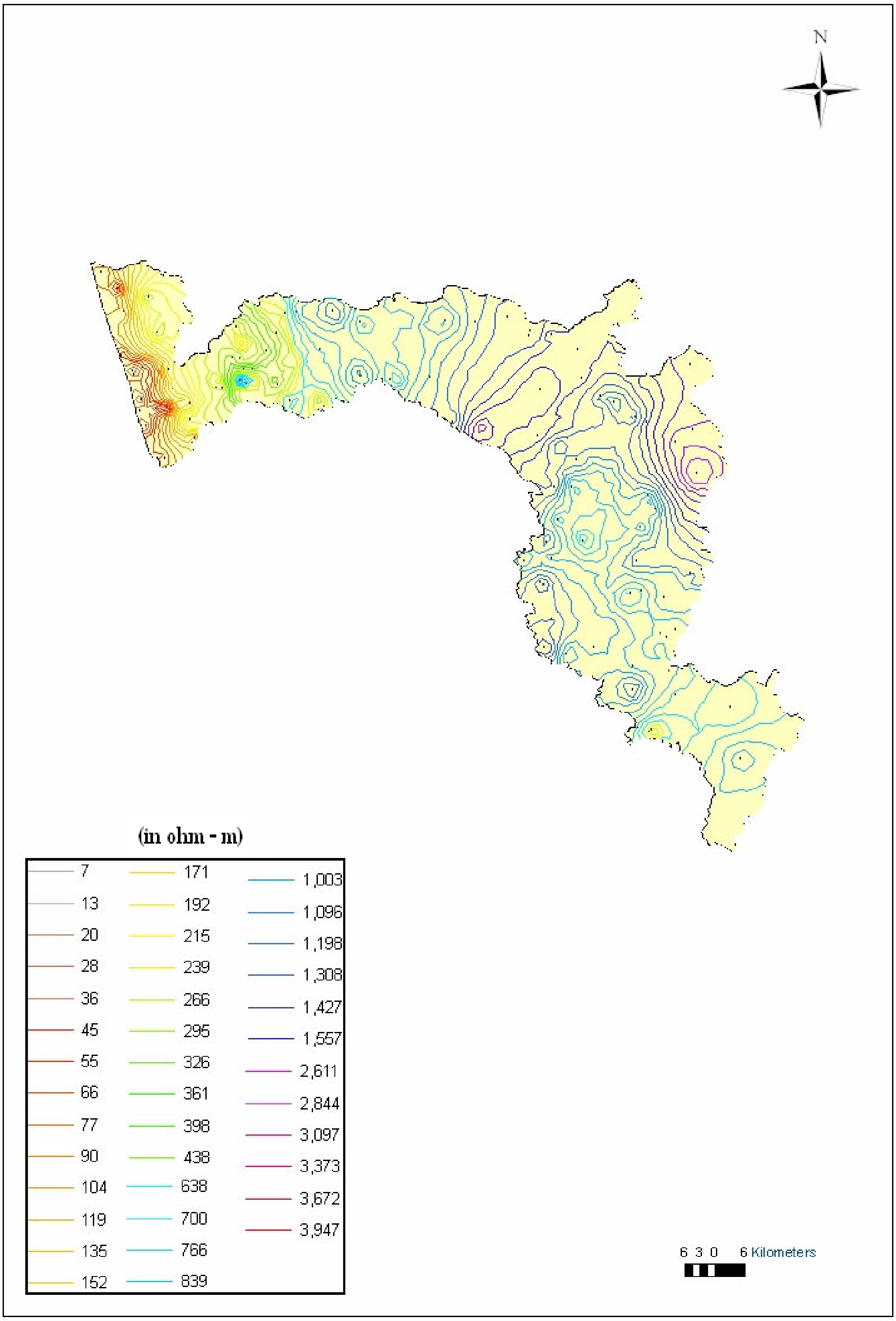


Fig. 5.7a Apparent Resistivity contour (ohm-m) map of the Fourth layer of the study area

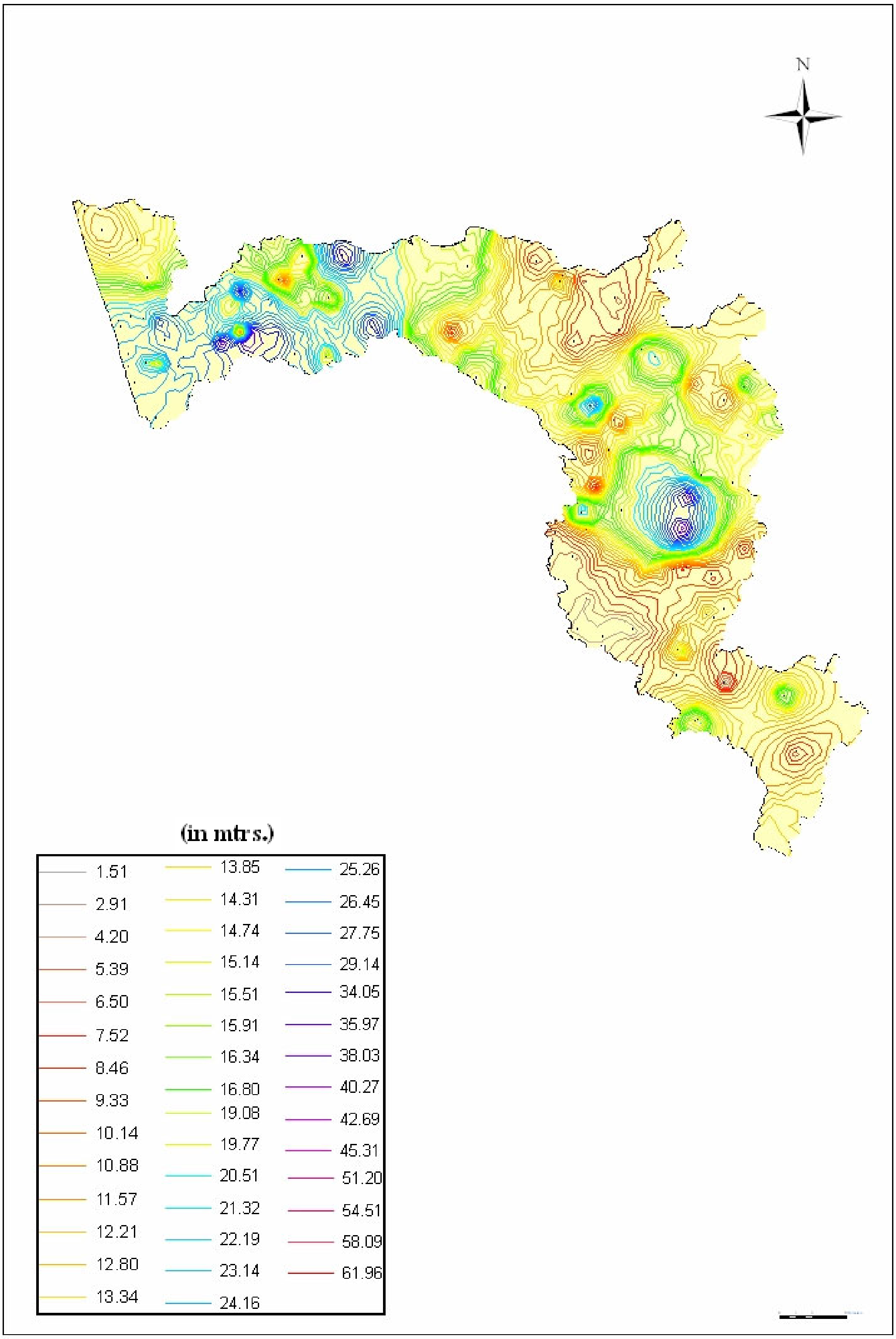
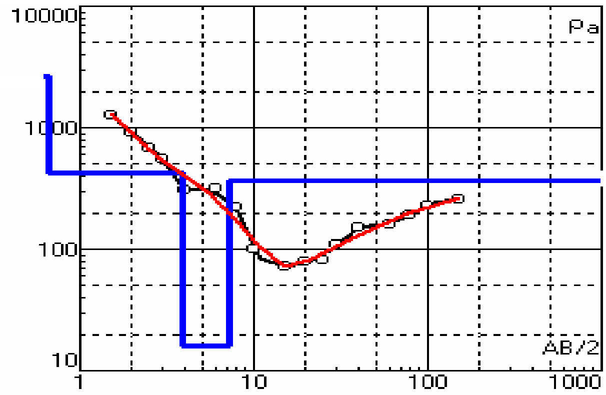


Fig. 5. 7b Thickness Contour (m) map of the Fourth layer of the study area.

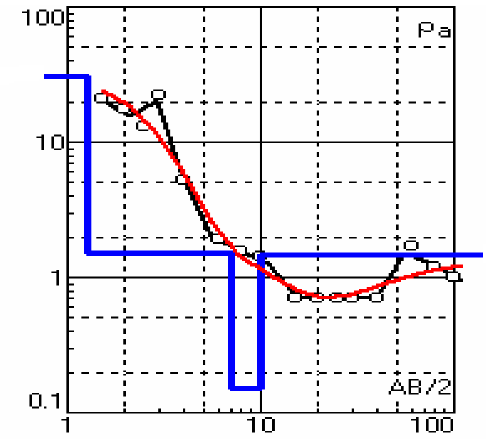
5.6 COMPUTER INTERPRETATION TECHNIQUE

Computer as means for the interpretation of VES data helps in determining accurately the geoelectrical parameters of the various layers. In horizontally stratified subsurface the changes in resistivity is transitional with increasing depth. In such a case we can assume each bed to be consisting of various thin beds and the resistivity linearly increasing of various thin beds and the resistivity linearly increasing with depth. The transition layers can be of importance in finding depths to bed rock, fresh-saline water interface, depths to aquifers, etc., . Interpretation of VES data by curve matching technique can lead to many errors, both in delineating the bed boundaries as well as in estimating the resistivity of the different beds. The usage of computers in interpreting VES data minimizes the error in interpretation. In the computer interpretation technique, the numerical solution of apparent resistivity as a function of the parameters of the geoelectric section and the electrode separation are obtained. The IPI2win2 software was used for this purpose. The field data is compared with the data derived from a layered model. If the two data sets do not agree, then the parameters of the model are adjusted until the data agree. Now the model parameters represent that of the field parameters. A comparative study has been made between the manual and the computer generated VES curves interpretation curves and seen that both are matching each other. (Fig. 5.8 a to c).



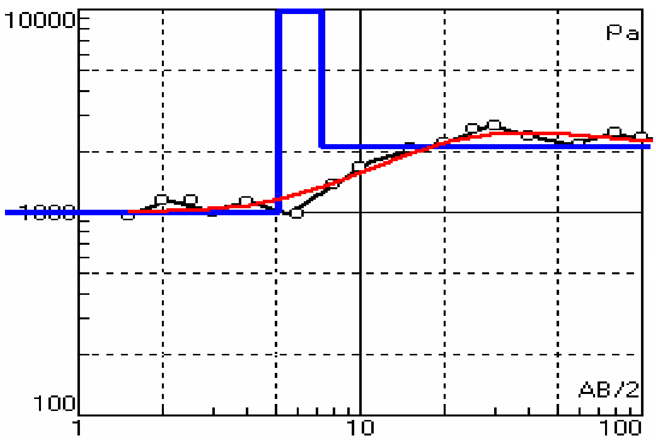
N	1	2	3	4
ρ	2627	427	15.9	365
h	0.665	3.26	3.3	

(a) Nedumbassery.



N	1	2	3	4
ρ	30.7	1.49	0.152	1.46
h	1.27	5.75	3.04	

(b) Edavanakkad

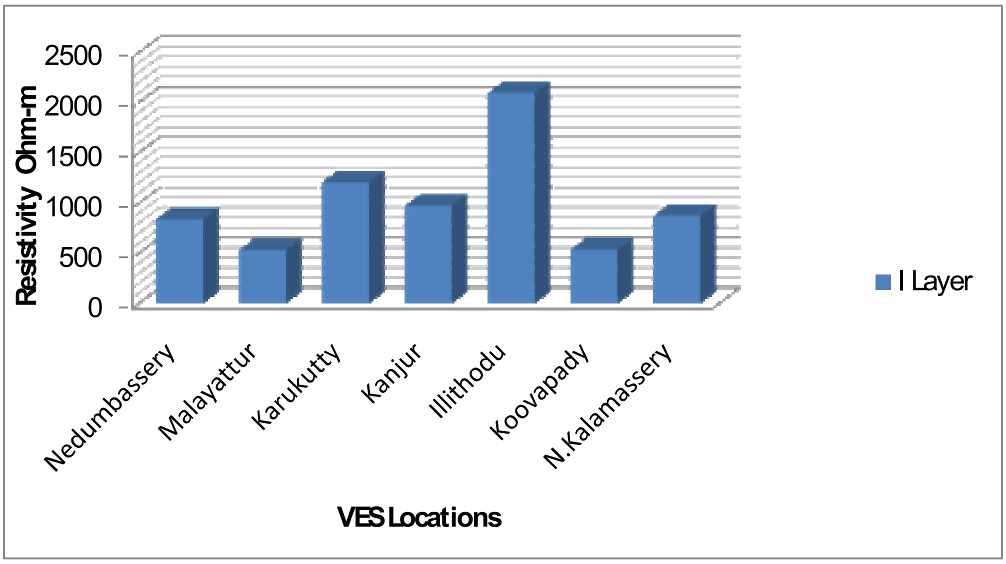


N	1	2	3
ρ	1001	14500	2098
h	5.17	2.14	

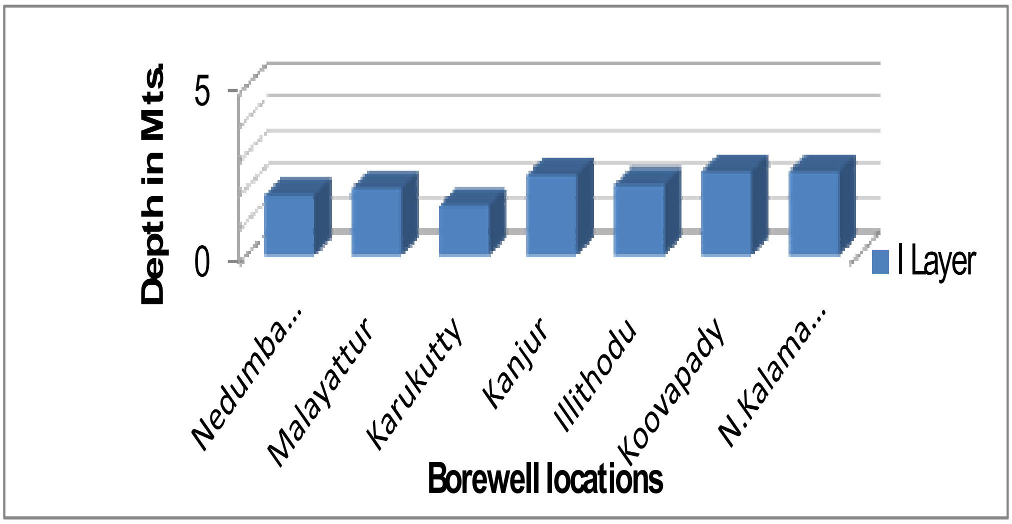
Fig. 5.8 a to c. Comparison of the manual and computer generated VES curve interpretations. q- is the resistivity and h- is the layer thickness.

5.7 CORRELATION OF THE RESISTIVITY RESULTS WITH BOREWELL LITHOLOGY

Lithologic information obtained from the borewell log of the area can be used to correlate the lithology with the resistivity of the different layers.

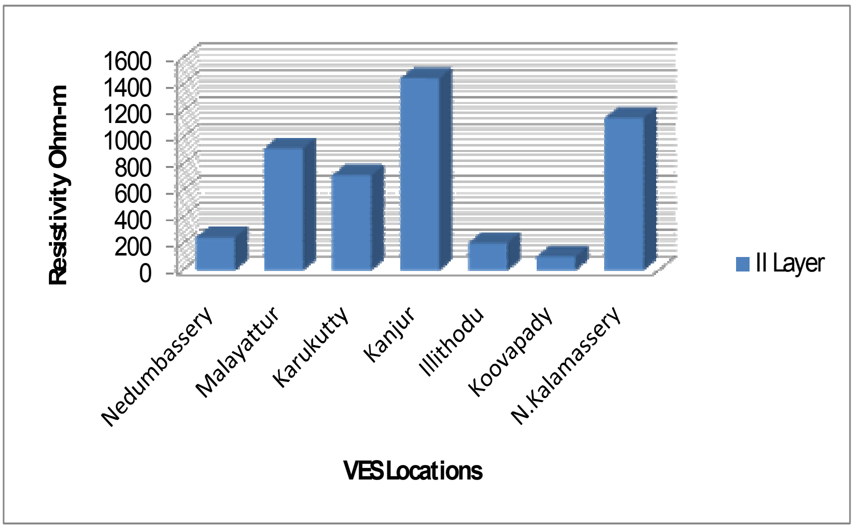


(a)

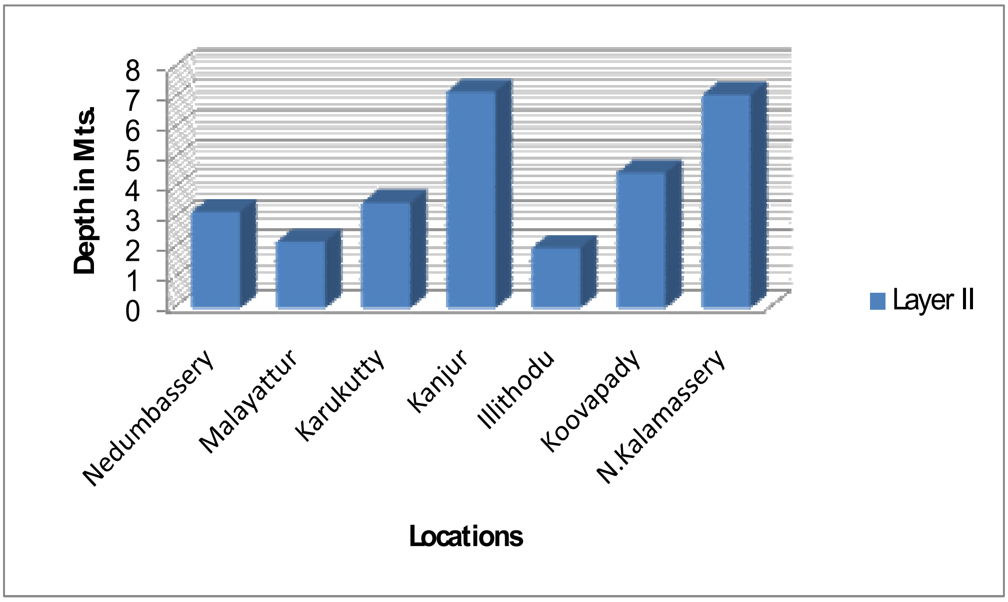


(b)

Fig. 5 .9 a & b. Comparision of (a) resistivity with the (b) borewell lithology of the first layer.

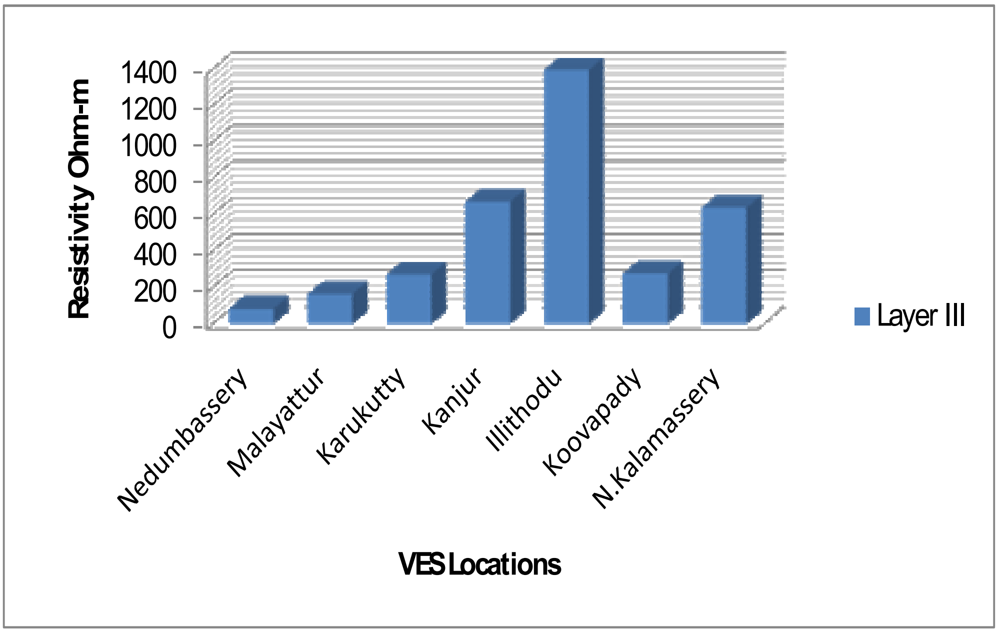


(a)

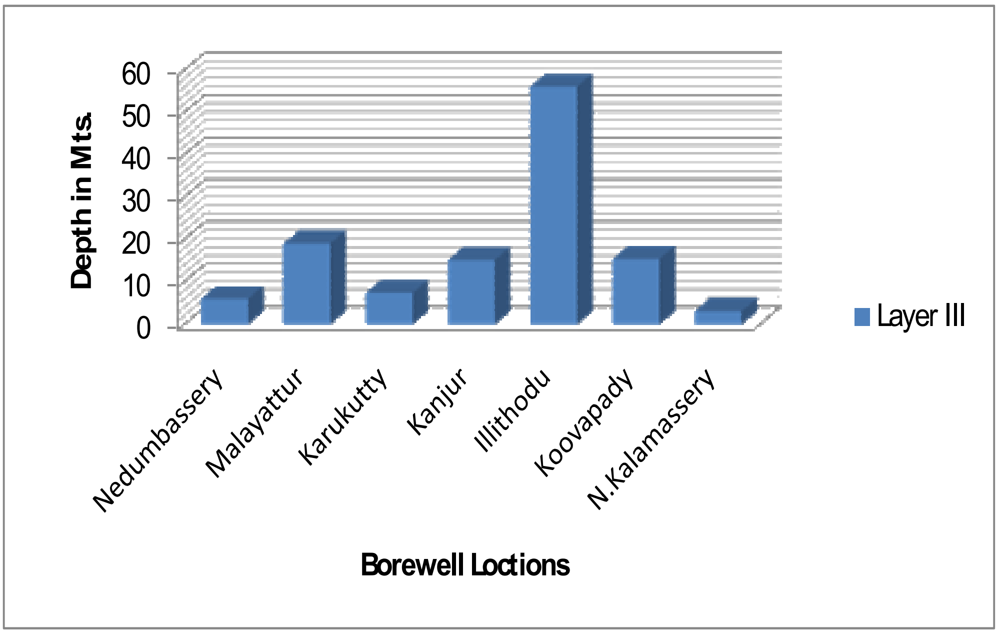


(b)

Fig. 5.10 a & b. Comparison of (a) resistivity with the (b) borewell lithology of the second layer.

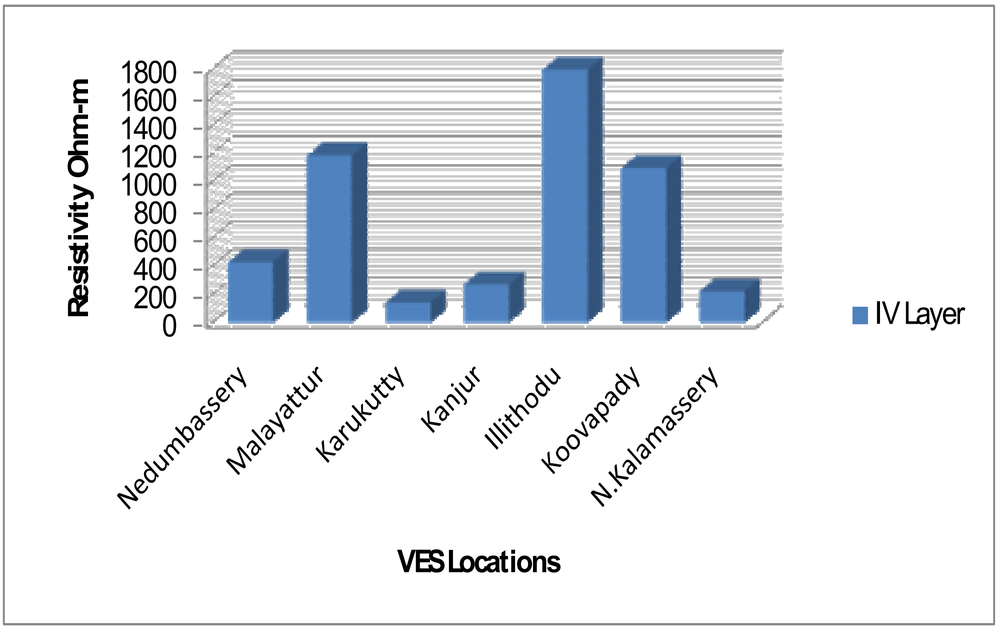


(a)

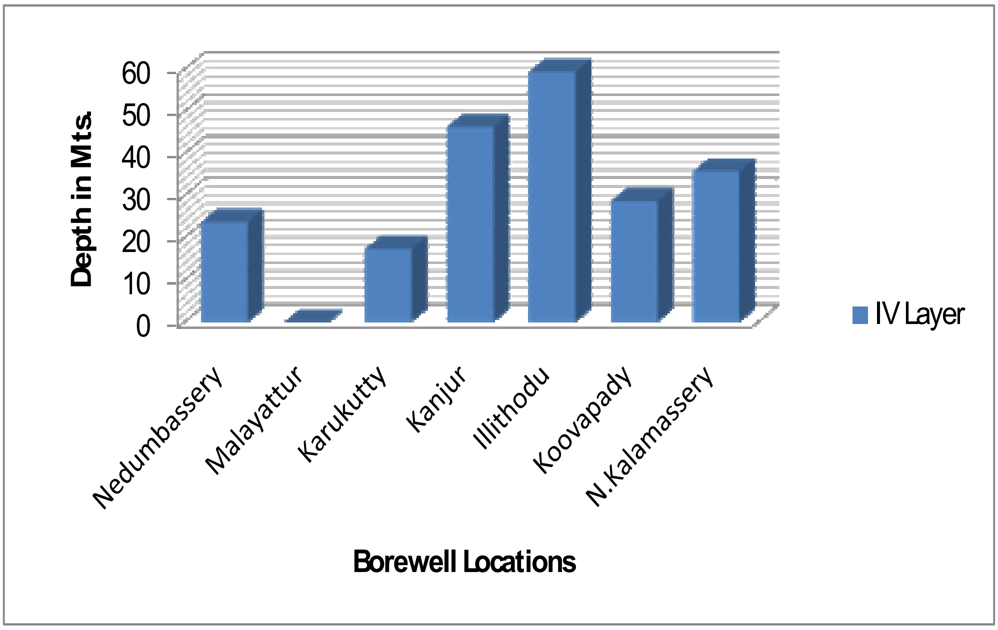


(b)

Fig. 5,11 a & b Comparison of (a) resistivity with the (b) borewell lithology of the third layer.



(a)



*Source: Kerala State Groundwater Department.

(b)

Fig. 5.12 a & b. Comparison of (a) resistivity with the (b) borewell lithology of the fourth layer.

The Kerala State Groundwater Department drilled some borewells adjacent to some of the VES locations and the lithology of the selected 7 borewells were collected and analysed. All these borewells are located in the midland region of the basin. The details of the analysed layer resistivity and actual layer thickness in each location are given in Fig. 5. 9a to Fig.5.12b. In general, the electrical resistivity field data shows a satisfactory match with a 3 – 4 layer earth section. For example, the electrical sounding lithology of the borewell drilled at Nedumbassery shows matching with a three layer earth section with a thin conducting top layer (1.8 m) underlying a layer of laterite (3.2 m). The laterite is underlain by the lithomargic clay (6.2 m). The laterite and the lithomargic clays are the dominant phreatic aquifer of the area. This is a good yielding well with a discharge of 5000 lph. This is underlain by the fractured layer of charnockite (24 m). The basement rock is massive below 25 m. No further fractured layers are encountered even though the total depth of the borewell drilled was 75 m. Likewise the lithology of all the other 6 bore wells are matching with the resistivity sounding data (Fig. 5.12 a & b). A correlation between the lithology and resistivity is outlined in Table 5.3.

5.8 COASTAL AQUIFERS

The coastal zone in the Periyar River Basin is one of the most densely populated areas in the country. The natural balance between the fresh water and the salt water in this area is disturbed by groundwater withdrawals and other human activities that lower the groundwater level,

Table 5.3. Comparison of the yield of the borewell with the geology of the study area

No	Location	Taluk	Total depth drilled m.	Thickness in mts.				Rock type	Yield in lph.
				soil	Laterite	Litho-margic clay	Weathered rock		
1	Kanjukuzhy	Udumbanchola	100.00	1.00	2.00	0.00	4.00	Charnockite	750.00
2	Udumbanchola	Udumbanchola	110.00	0.00	0.00	0.00	3.00	Migmatite	Dry
3	Karikkode Jn	Udumbanchola	50.00	0.50	2.00	0.00	18.00	Charnockite	5000.00
4	Adimali	Devikolam	130.00	0.50	2.00	3.00	13.50	Charnockite	1000.00
5	Chithirapuram	Devikolam	45.00	0.00	0.00	0.00	12.30	Migmatite	Dry
6	Munnar	Devikolam	45.00	1.00	2.00	2.00	5.00	Migmatite	1000.00
7	Nedumkandom	Udumbanchola	30.00	1.00	0.00	0.00	8.50	Charnockite	1500.00
8	Kanjoor	Aluva	100.00	2.00	8.00	4.00	1.00	Charnockite	1500.00
9	Mambra	Aluva	66.00	1.00	4.00	0.00	1.00	Charnockite	8000.00
10	Kuruppampady	Kunnathunad	80.00	1.00	6.00	1.00	1.00	Gabbro	750.00
11	Mookkannur	Aluva	77.00	3.00	10.00	0.00	3.00	Charnockite	4000.00
12	Manjapra	Aluva	70.00	1.00	9.00	0.50	2.50	Charnockite	3000.00
13	Nedumbassery	Aluva	54.00	3.00	10.00	2.00	2.00	Charnockite	10000.00
14	Koovappady	Kunnathunad	80.00	0.00	0.00	0.00	3.50	Charnockite	5000.00
15	Odakkali	Kothamangalam	85.00	1.00	0.00	0.00	2.00	Charnockite	250.00

(Source - State Groundwater Department)

reduce freshwater flow to coastal waters and ultimately cause saline water intrusion. The deterioration of water quality in the coastal zones of the area is due to saltwater infiltration into the freshwater aquifer and has become a major concern. With the aim of providing valuable information on the hydrogeologic system of the aquifers, the subsurface lithology and delineating the groundwater salinity, electrical resistivity soundings were carried out with electrode spacing varying between 1 and 200 m. The DC resistivity surveys revealed significant variations in subsurface resistivity. Also, the electrical resistivity curves showed a dominant trend of decreasing resistivity with depth (thus increasing salinity). In general, the presence of four distinct resistivity zones were delineated viz. (i) The un-consolidated clayey sand having resistivity values ranging between 72 Ωm - 262 Ωm with a layer thickness ranging from 1.2 m – 3.2 m representing the first layer. This is the only fresh water aquifer of the area. (ii) The sandy clay having resistivity values ranging from 14 Ωm - 75 Ωm with a layer thickness varying from 0.66 m – 5.4 m. This is a transitional or mixing zone as the resistivity decreases with depth. (iii) The resistivity of the third layer varies from 24 Ωm to 75 Ωm with a layer thickness varying from 2 Ωm - 105 Ωm with a layer thickness of 2.9 m to 34 m. (iv) The layer four (zone D) is characterized with a resistivity from 2 Ωm - 45 Ωm with a layer thickness of 2.9 m – 34 m.

The subsurface formations with resistivities values generally below 4 Ωm reflecting an aquifer possibly containing brine. The rock matrix, salinity and water saturation are the major factors controlling the resistivity of the formation. Moreover, the inter phase of the freshwater - saline water qualities have been investigated and it is seen that the saline water intrusion into the aquifers can be accurately mapped using surface DC resistivity method. The iso-apparent resistivity map shows that contour patterns are almost parallel to the coast (north-south trend), with the increasing values towards east. The apparent resistivity along the eastern side is comparatively high when compared with the western margin of the area. It is also observed that the resistivity values decrease with increase in depth of investigation. The very low resistivity is an indication that the aquifers is of poor chemical quality. Based on the above observations, the fresh-water saline-water interface is demarcated (Fig. 5.13).

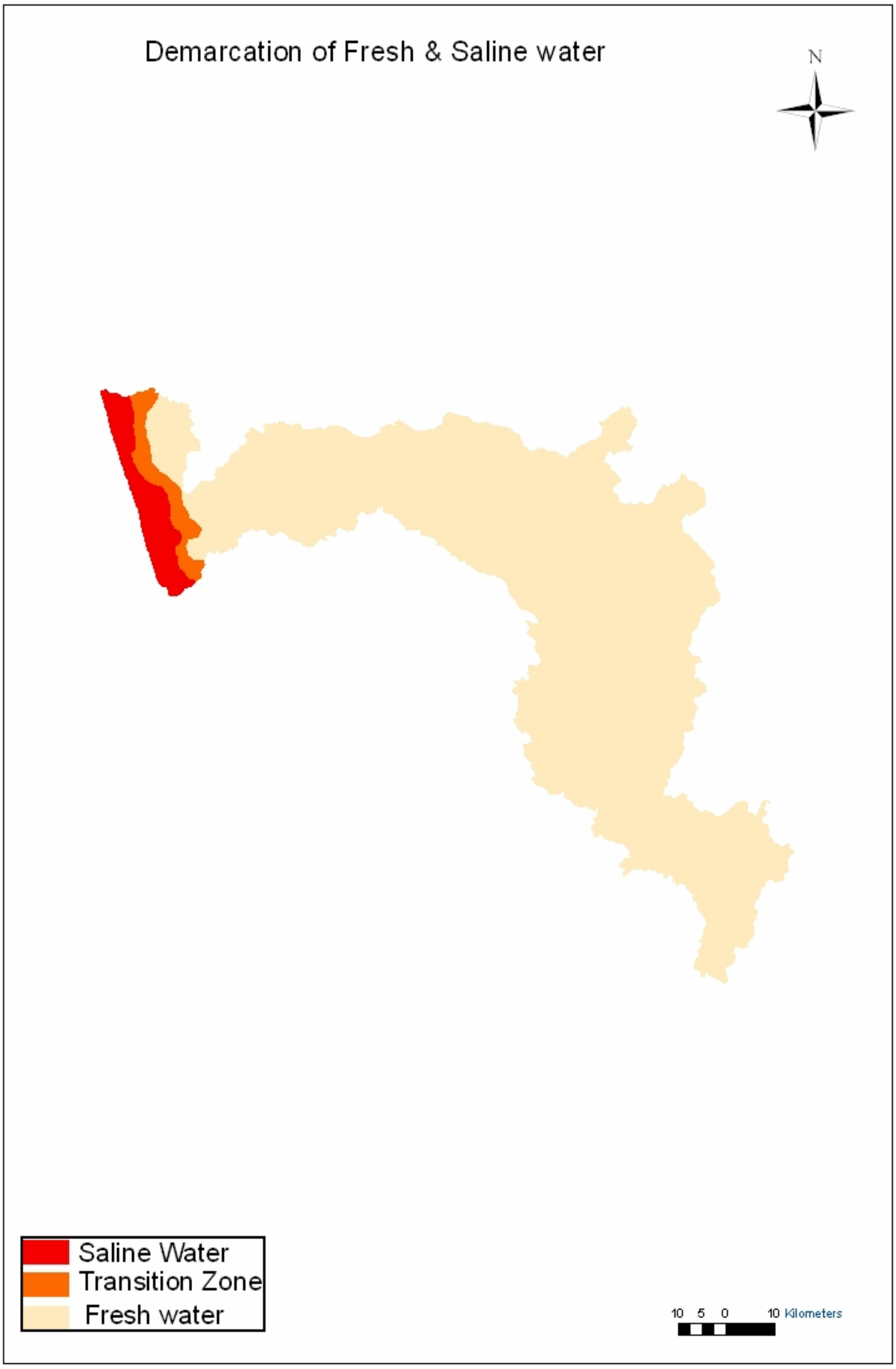


Fig. 5.13. Fresh water – Saline water interface of the study area.

5.9. DISCUSSION

The study reveals that the surface electrical soundings are very effective to study the groundwater potential of the area. The present study deals with the investigation to assess the aquifer conditions and to obtain adequate knowledge of the groundwater resource to protect groundwater supplies as a unique source of water for the study area and also the extent of salt water intrusion and to suggest precautionary measures to prevent salt water intrusion. Water resources of the area are threatened by increasing population trend with the resultant increase in water demand and the stresses of water use for various activities.

In the present study electrical resistivity surveys were carried out for evaluating the hydrogeological conditions of subsurface sequences of the area. The vertical electrical soundings by Schlumberger array were conducted in the study area. The vertical electrical soundings were carried out in the selected 105 locations, distributed approximately in a grid pattern to study the subsurface hydrogeological conditions of Periyar River Basin with current electrode spacing ranging from 100 m to 400 m. The apparent resistivities thus obtained for different electrode spacing were recorded (Table 5.2). These apparent resistivities are plotted against current electrode spacing in double log graph sheets having 62.5 modulus to get the field curves. The field curves are interpreted from curve matching technique. From the interpretation of the resistivity curves, the different layer resistivities and corresponding thickness and depth of the different subsurface layers were identified and dimension of the aquifer and type of bed rock were also indicated. The average resistivity of the first layer in the highland region is 1011.98 ohm-m, in the midland region, 1015.36 0hm-m and in the lowland region is 155.47 ohm-m. The average resistivity of the second layer in the highland region is 1048.17 ohm-m, midland region is 1120.09 ohm-m and in the lowland region is 66.65 ohm-m. The average resistivity of the third layer in the highland region is 976.84 ohm-m, midland is 532.37 ohm-m and in the low land is 35.26 ohm-m. The average resistivity of the fourth layer in the highland region is 1220 ohm-m, in the midland region is 474.94 ohm-m and in the lowland region is 19.89 ohm-m. The average resistivity of the fifth layer in the highland region is 1285.67 ohm-m, in the midland region is 551.71 ohm-m and in the lowland region is 6.47 ohm-m (Table 5.4). There is a gradual decrease in resistivity from the highlands to the lowlands. The lowest resisitvity in the western part of the lowland region is due to brackish water and other pollutants.

The boundary of the aquifers have been identified as zones with high, moderate and poor yield potential were estimated for future development of groundwater of the basin. Based on the analysis and interpretation of the VES data it is inferred that groundwater occours under phreatic conditions in the laterite, lithomargic clay, unconsolidated coastal

Table 5.4 *Summary of the Resistivity (ρ) - Thickness (h) based layering of the study area.

Physiography		h1	ρ1	h2	ρ2	h3	ρ3	h4	ρ4	h5	ρ5
Coastal Planes	Average	1.78	155.47	2.78	66.65	14.22	35.26	20.79	19.89	6.20	6.47
	Maximum	3.20	650.00	5.80	425.00	22.50	325.00	34.00	185.00	6.20	45.00
	Minimum	1.10	45.00	0.66	14.00	0.50	2.00	2.90	1.00	6.20	1.00
	Lithology	Sandy clay	Sandy clay	Clayey sand		Clayey sand		Clayey sand		Clayey sand	
Lowlands	Average	2.07	773.83	5.73	1102.17	10.45	354.50	21.27	402.83	24.78	348.33
	Maximum	2.5	1370	10.00	1355.00	19.50	642.00	35.50	875.00	34.50	625.00
	Minimum	1.5	505	3.40	570.00	2.10	221.00	7.20	220.00	15.00	14.00
	Lithology	Top soil		Laterite		Lithomarge		Weathered rock		Crystalline	
Midlands	Average	1.88	1015.36	4.73	1120.09	14.83	532.39	24.86	474.94	38.57	551.77
	Maximum	3.20	2600.00	12.40	4350.00	63.50	1860.00	60.60	1800.00	81.00	1910.00
	Minimum	1.20	170.00	0.45	152.00	1.50	87.00	5.00	144.00	15.00	1.25
	Lithology	Top soil		Laterite		Lithomarge		Weathered rock		Crystalline	
Highlands	Average	1.81	1011.98	5.60	1047.18	20.72	976.84	23.68	1220.00	22.97	1285.67
	Maximum	3.50	2814.00	16.80	3300.00	68.00	4480.00	66.15	4200.00	49.00	4950.00
	Minimum	1.00	368.00	0.57	108.00	0.92	162.00	6.20	195.00	10.95	208.00
	Lithology	Top soil		Weathered rock		Crystaline		Crystaline		Crystalline	

sediments, weathered crystallines and under semi-confined conditions in the fractured crystalline rocks in the area. The movement of groundwater in the area is mainly controlled by joints and other planes of structural weakness, openings in rocks, interconnection of fractures and their extent.

From the analysis and Interpretation of the VES data it is inferred that the distribution of the various subsurface layers are not uniform within the basin. Based on the interpretation of the geoelectrical data it is inferred that sandy soil is the dominant phreatic aquifer of the coastal plains, laterite and lithomargic clay are the dominant phreatic aquifers of other lowland and the midland regions. In the highland region weathered crystalline rocks are the prominent phreatic aquifers. Tapping of the phreatic aquifers is technically feasible in these regions. But in regions where the soil, laterite and weathered rock thickness is negligible or absent, such areas are technically not feasible for development of groundwater through open dug wells.

The top layer in the coastal plains is the clayey sand which is a good aquifer of the area, but in the midland region and the eastern part of the lowland region, the second layer namely the laterite and the third layer, lithomargic clays are the good aquifers. In area where the subsurface runoff is very high and infiltration is low, there is meagre chance for groundwater recharge and such regions are classified as poor yielding in groundwater resource. From the analysis of the VES data it is inferred that the clayey sand is a good aquifer in the coastal planes, laterite and lithomargic clay are the good aquifers in the midland region and the weathered hard rock is the dominant phreatic aquifer of the highland regions. The size and location of the fractures, interconnection of the fractures, and the amount of the material that may be clogging the fractures and recharging sources determine how much water one can get out of the hard rock. The volume of water stored in fractured hard rocks is less compared to the conventional aquifer. When fractures become narrower at depth, this amount further decreases. The total amount of water storage in the fractures of the hard rock area is small; hence, groundwater levels and the well's yield can decline dramatically during the summers. Therefore, the location of potential fracture zones in hard rock area is extremely important to yield large amounts of groundwater.

The spectrum of resistivity values of different rock types and soils show that the coastal clay and sand trapped with salt water show resistivity less than 20 ohm-m, highly fractured crystalline rocks in general, show resistivity range between 100 and 250 ohm-m, moderately fractured crystalline formations show the resistivity between 250 and 500 ohm-m and the massive crystalline formations exhibit the resistivity of more than 500 ohm-m.

The resistivity data add valuable information about the presence of the conducting subsurface fracture and groundwater movement of the area. Analysis of the data reveals that shallow aquifers are dominant in the lowland and midland region and some lenses in the highland regions. Based on the geophysical survey, the fresh-water saline-water interface of the coastal aquifers has been demarcated around 10 km eastwards of the coast.

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Chapter VI

Groundwater Chemistry

6.1 INTRODUCTION

Groundwater plays a significant role in augmenting water supply to meet the ever increasing demand for various purposes. Water in the natural environment contains many dissolved substances and non-dissolved particulate matter. Generally high concentrations of dissolved constituents are found in groundwater than surface water because of its greater exposure to soluble minerals of the geological formations (Todd, 1980). Dissolved salts and minerals are necessary components of good quality water, as they help to maintain the health and vitality of the organisms that rely on this ecosystem service (Stark et al., 2001). The quality of surface and groundwater are functions of various factors (Allen and Chapman, 2001) such as the chemistry of the rainfall and other atmospheric inputs, weathering of minerals in soils and rocks, inputs derived diffuse agriculture sources (fertilizers or enhanced mineralization), man-made inputs from point sources such as individual factories or more generally from the urban area, and finally the amount of rainfall and evaporation.

In the Periyar River Basin area, groundwater is the major source of drinking water. Most of the people have their own dug wells to meet their water requirements. Besides, public water distribution systems also partly meet the water requirements of the area. So far no detailed investigation of the Periyar River Basin as a whole in terms of the quality of the groundwater has been carried out except the studies concentrated in around the river mouth from Aluva to Eloor (CGWB, 1989; NEERI, 1992; Gopalan, 1992; CPCB, 2000)). Hence a detailed study on the physical, chemical and bacteriological qualities of the groundwater of the study area has been taken up to evaluate its suitability for various purposes.

6.2. GROUNDWATER QUALITY OF THE STUDY AREA

Hydrochemical investigation was carried out to under stand the nature of the aquifers and their mode of occurrence as part of the present study. Pre-monsoon and Post-monsoon water samples were collected from the 72 pre-fixed open dug wells (Fig. 6.1) of the study area and were analyzed for various parameters using the standard analytical methods and the results are given in Table 6.1a and b. Water quality is determined by comparing the physical, chemical and bacteriological characteristics of the water samples with the standard water quality guidelines or standards. Drinking water quality guidelines and standards are designed to enable the provision of clean and safe water for human consumption, thereby protecting human health. These are usually based on scientifically assessed acceptable levels of toxicity to either humans or aquatic organisms.

Table 6.1a. Chemical parameters of the Groundwater of the Periyar River Basin (Pre-monsoon period)

Well No.	Location	District	Date of sampling	Na	CO3	Alk	SO4	Fe	TH	EC	pH	TDS	HCO3	NO3	Ca	Mg	K	Cl
OW01	Pappinivattom	Thrissur	03/03/2004	16.50	0.00	40.00	11.90	0.39	85.00	220.00	8.20	132.00	47.04	2.80	25.00	4.90	1.50	23.00
OW01	Pappinivattom	Thrissur	06/03/2005	15.30	2.28	41.20	10.10	1.30	84.00	220.00	8.30	132.00	56.40	2.84	28.00	2.40	3.00	21.00
OW01	Pappinivattom	Thrissur	07/03/2006	14.80	0.00	39.00	10.60	1.40	69.00	190.00	8.20	114.00	48.20	2.72	29.00	3.50	2.80	21.20
OW02	Lokamalleswara	Thrissur	13/03/2004	39.40	6.00	110.00	8.30	0.10	118.00	635.00	8.70	381.00	132.00	4.70	29.60	10.80	5.20	57.00
OW02	Lokamalleswara	Thrissur	15/03/2005	19.50	3.60	80.00	6.06	0.17	95.00	320.00	8.50	192.00	143.20	4.72	34.00	5.70	4.80	28.00
OW02	Lokamalleswara	Thrissur	15/03/2006	30.00	9.30	127.10	7.00	0.16	112.00	630.00	8.80	378.00	172.70	4.62	36.20	17.30	4.50	49.00
OW03	Poyya	Thrissur	27/03/2004	6.40	0.00	10.80	2.30	0.28	21.00	65.00	7.10	39.00	10.80	2.32	9.00	2.00	1.30	10.00
OW03	Poyya	Thrissur	11/03/2005	6.10	0.00	13.60	1.90	0.25	20.00	70.00	7.20	42.00	16.50	2.82	6.10	2.20	1.50	10.00
OW03	Poyya	Thrissur	16/03/2006	6.90	0.00	5.00	1.80	0.20	22.00	70.00	7.10	42.00	16.10	2.34	8.90	2.40	2.00	11.00
OW04	North Parur	Ernakulam	15/03/2004	22.20	4.70	96.00	22.59	2.80	92.10	350.00	8.50	210.00	102.80	1.90	29.90	2.40	8.20	31.40
OW04	North Parur	Ernakulam	17/03/2005	16.60	9.60	92.00	22.37	2.25	115.00	320.00	8.40	192.00	92.70	1.18	42.00	5.10	7.20	27.80
OW04	North Parur	Ernakulam	04/03/2006	15.00	4.80	90.00	19.81	3.74	85.90	250.00	8.40	150.00	97.80	3.30	32.10	3.60	6.20	19.40
OW05	Munambam	Ernakulam	02/03/2004	39.00	30.00	51.00	15.00	3.45	189.00	312.00	8.90	199.00	138.00	4.80	60.00	4.90	6.80	73.00
OW05	Munambam	Ernakulam	04/03/2005	47.00	12.00	52.00	26.00	4.00	175.00	546.00	8.90	328.00	159.00	5.40	64.00	6.00	6.50	75.00
OW05	Munambam	Ernakulam	09/03/2006	26.70	6.00	45.00	9.40	3.20	168.00	480.00	8.84	288.00	81.00	4.60	54.00	3.49	8.20	49.50
OW06	Pallipuram	Ernakulam	23/03/2004	21.90	15.80	188.20	14.44	2.60	198.00	530.00	8.68	318.00	205.70	1.30	68.00	10.90	8.30	28.30
OW06	Pallipuram	Ernakulam	04/03/2005	21.00	21.60	266.00	16.31	2.80	298.00	590.00	8.90	385.00	221.00	2.40	75.30	16.00	8.40	29.20
OW06	Pallipuram	Ernakulam	22/03/2006	24.20	27.90	267.90	15.50	2.70	293.00	580.00	8.90	348.00	202.00	2.48	76.90	16.10	9.10	45.00
OW07	Ezhikara	Ernakulam	05/03/2004	23.00	4.65	105.00	24.20	2.44	116.00	360.00	8.70	216.00	120.70	2.32	36.40	3.20	7.80	34.20
OW07	Ezhikara	Ernakulam	22/03/2005	20.00	9.30	102.00	21.30	2.50	111.00	345.00	8.60	207.00	118.30	2.48	35.00	2.50	8.70	30.00
OW07	Ezhikara	Ernakulam	05/03/2006	22.20	4.70	98.00	22.59	2.10	103.00	350.00	8.49	210.00	102.80	2.50	32.00	3.30	8.20	31.40
OW08	Edavanakad	Ernakulam	05/03/2004	124.80	61.40	254.60	41.60	2.60	345.00	1040.00	9.10	624.00	223.10	3.90	92.00	19.20	16.40	180.30
OW08	Edavanakad	Ernakulam	03/03/2005	207.00	18.80	298.80	58.39	3.52	394.00	2100.00	9.20	1260.00	255.40	3.57	116.00	26.10	23.20	345.90
OW08	Edavanakad	Ernakulam	02/03/2006	136.30	26.40	234.00	44.12	2.44	367.00	1180.00	8.90	708.00	231.80	4.26	95.20	29.20	16.00	185.10
OW09	Varapuzha	Ernakulam	06/03/2004	75.50	32.50	152.00	27.50	2.09	148.00	710.00	8.90	426.00	175.30	13.53	99.00	14.80	16.00	115.90
OW09	Varapuzha	Ernakulam	12/03/2005	160.00	31.20	196.00	48.20	2.95	235.00	1290.00	8.60	774.00	224.80	36.40	96.00	22.00	24.40	277.30
OW09	Varapuzha	Ernakulam	03/03/2006	147.00	4.80	230.00	42.14	2.07	225.00	1000.00	8.72	600.00	197.60	18.40	90.40	14.80	22.50	202.70
OW10	Njarakkal	Ernakulam	05/03/2004	19.00	6.98	194.00	13.60	2.80	182.00	410.00	8.70	246.00	222.40	2.50	52.50	15.30	4.30	28.80
OW10	Njarakkal	Ernakulam	07/03/2005	18.00	24.00	230.00	10.47	2.77	227.30	450.00	8.42	270.00	231.80	2.00	56.50	27.10	3.90	27.00
OW10	Njarakkal	Ernakulam	04/03/2006	17.00	9.60	110.00	15.40	2.70	151.00	310.00	8.42	186.00	214.00	2.40	48.60	11.40	5.20	24.40

OW11	Malipuram	Ernakulam	20/03/2004	29.00	27.90	197.90	11.50	2.41	233.00	580.00	8.90	348.00	184.60	5.90	86.90	16.10	8.10	45.00
OW11	Malipuram	Ernakulam	05/03/2005	28.80	20.90	213.40	41.80	1.80	222.00	550.00	8.80	330.00	217.70	5.30	88.60	18.50	8.80	42.00
OW11	Malipuram	Ernakulam	02/03/2006	27.80	24.00	180.00	38.00	2.02	227.00	500.00	8.80	300.00	170.80	4.80	78.90	7.20	7.20	40.00
OW12	Edappally	Ernakulam	16/03/2004	27.40	21.28	156.20	18.30	0.50	201.00	490.00	8.60	294.00	126.88	2.78	71.00	4.80	8.20	39.50
OW12	Edappally	Ernakulam	15/03/2005	32.50	27.90	230.90	24.50	0.62	232.00	660.00	8.90	396.00	224.80	2.90	71.70	14.00	11.20	48.00
OW12	Edappally	Ernakulam	22/03/2006	24.50	37.20	196.50	20.60	0.57	188.00	530.00	8.90	318.00	169.60	1.88	68.90	9.90	6.10	35.00
OW13	Elur North	Ernakulam	03/03/2004	501.00	60.00	310.00	16.40	2.09	445.00	3250.00	8.90	1950.00	256.20	5.20	113.50	63.80	37.20	680.00
OW13	Elur North	Ernakulam	10/03/2005	630.00	54.00	365.40	23.30	2.50	524.00	5050.00	9.10	3030.00	335.90	4.80	132.40	106.60	40.00	1111.00
OW13	Elur North	Ernakulam	20/03/2006	932.00	30.20	272.80	23.40	3.00	596.00	5550.00	8.90	3330.00	342.40	5.34	128.50	115.80	65.00	1523.00
OW14	Pathalam	Ernakulam	01/03/2004	22.00	1.20	4.10	23.00	1.00	90.00	284.00	8.30	170.00	64.00	3.10	28.00	7.60	3.10	34.00
OW14	Pathalam	Ernakulam	15/03/2005	31.70	2.10	4.50	25.00	1.30	186.00	690.00	8.50	414.00	20.00	3.80	28.00	7.73	9.50	42.30
OW14	Pathalam	Ernakulam	19/03/2006	23.00	2.30	4.70	24.00	1.20	98.00	321.00	8.40	192.00	76.00	3.70	30.00	6.40	3.80	37.00
OW15	Paravur	Ernakulam	05/03/2004	18.00	24.00	224.20	19.10	1.17	280.00	490.00	8.80	294.00	224.80	2.60	78.50	8.10	8.19	27.50
OW15	Paravur	Ernakulam	03/03/2005	16.00	36.00	212.00	18.90	1.20	234.00	510.00	8.70	306.00	182.40	4.30	82.00	6.30	8.80	24.10
OW15	Paravur	Ernakulam	17/03/2006	14.60	16.80	182.00	15.80	1.50	186.90	420.00	8.90	252.00	187.90	2.10	66.70	4.90	8.60	21.50
OW17	Chalakka	Ernakulam	10/03/2004	37.00	0.00	112.00	28.00	0.70	94.00	407.00	8.30	282.00	127.00	3.70	21.50	12.00	4.90	55.00
OW17	Chalakka	Ernakulam	10/03/2005	36.00	7.20	115.00	29.60	0.65	104.00	413.00	8.69	247.00	100.00	2.10	23.00	14.00	5.10	55.00
OW17	Chalakka	Ernakulam	21/03/2006	37.00	34.00	112.00	29.00	0.85	124.00	465.00	8.60	279.00	139.00	2.50	28.00	13.00	4.50	54.00
OW18	Chengamanad	Ernakulam	10/03/2004	24.00	8.00	3.60	2.00	0.50	43.00	220.00	8.00	132.00	14.00	24.00	7.90	5.40	4.50	37.00
OW18	Chengamanad	Ernakulam	15/03/2005	14.00	0.00	3.80	2.10	0.55	42.00	195.00	8.20	117.00	34.00	23.00	6.60	5.00	4.80	21.00
OW18	Chengamanad	Ernakulam	15/03/2006	20.00	0.00	3.40	1.90	0.65	48.00	205.00	8.10	123.00	12.00	37.00	8.80	6.60	4.70	31.00
OW19	Alwaye	Ernakulam	12/03/2004	5.50	0.00	87.80	6.00	0.72	98.00	220.00	8.40	132.00	68.32	2.96	93.00	1.20	3.60	10.30
OW19	Alwaye	Ernakulam	10/03/2005	5.30	10.80	124.20	6.10	0.10	121.00	270.00	8.60	162.00	129.50	0.66	48.50	0.00	3.80	7.00
OW19	Alwaye	Ernakulam	07/03/2006	5.40	8.00	102.10	6.80	0.26	135.00	220.00	8.40	132.00	108.30	0.34	45.60	5.10	3.36	7.40
OW20	Karukutty	Ernakulam	03/03/2004	10.00	4.65	106.70	3.40	0.62	86.00	230.00	8.50	138.00	120.70	2.10	36.30	4.90	2.50	16.60
OW20	Karukutty	Ernakulam	05/03/2005	13.30	6.60	115.20	3.20	0.50	92.00	260.00	8.60	156.00	122.90	2.98	40.70	2.60	2.10	19.00
OW20	Karukutty	Ernakulam	05/03/2006	12.50	4.60	88.20	4.00	0.65	82.00	150.00	8.50	90.00	61.50	2.60	26.20	3.50	1.90	19.00
OW21	Aluva East	Ernakulam	03/03/2004	19.00	4.80	66.00	11.90	1.21	109.00	250.00	8.43	150.00	70.80	3.84	22.80	11.00	3.60	27.30
OW21	Aluva East	Ernakulam	14/03/2005	23.10	10.48	76.80	12.30	1.00	114.00	320.00	8.50	192.00	78.32	4.80	53.00	12.20	4.30	31.20
OW21	Aluva East	Ernakulam	16/03/2006	14.50	7.10	74.50	13.33	1.10	100.00	260.00	8.32	156.00	76.50	3.59	20.00	9.20	4.60	21.60
OW22	10th Mile	Idukki	14/03/2004	11.40	0.00	57.70	2.40	0.80	55.80	159.00	8.10	95.40	60.48	2.57	12.00	6.20	2.70	15.70
OW22	10th Mile	Idukki	15/03/2005	11.45	0.00	36.00	2.79	1.10	30.00	98.00	8.20	58.80	43.90	2.30	11.00	2.40	2.33	16.90
OW22	10th Mile	Idukki	04/03/2006	9.60	0.00	30.72	1.10	0.83	48.00	130.00	8.10	78.00	30.72	2.50	13.00	0.00	2.20	2.70
OW23	Chowara	Ernakulam	15/03/2004	19.60	0.00	9.50	3.90	0.36	37.00	190.00	7.30	114.00	21.30	8.82	16.10	3.70	2.00	29.00
OW23	Chowara	Ernakulam	06/03/2005	16.00	0.00	13.60	2.50	0.27	42.00	183.00	7.50	109.80	16.50	8.60	13.10	3.70	2.20	24.80
OW23	Chowara	Ernakulam	16/03/2006	22.20	0.00	12.00	3.80	0.40	39.00	210.00	8.00	120.00	37.10	8.90	17.60	3.40	2.60	29.00

OW24	Vazhakkulam	Ernakulam	04/03/2004	4.40	0.00	10.20	3.70	0.35	26.00	70.00	7.40	42.00	15.20	2.10	8.00	2.00	1.70	8.20
OW24	Vazhakkulam	Ernakulam	03/03/2005	9.30	0.00	10.00	3.40	0.30	25.00	75.00	7.50	45.00	12.20	2.64	5.90	2.40	2.00	17.00
OW24	Vazhakkulam	Ernakulam	14/03/2006	8.20	0.00	11.10	3.25	0.25	31.00	72.00	7.70	43.00	15.00	3.40	6.30	2.50	2.05	15.78
OW25	Nedumbassery	Ernakulam	05/03/2004	9.60	0.00	29.40	2.51	1.80	34.80	133.00	7.79	79.80	35.90	3.48	10.00	2.40	1.80	13.20
OW25	Nedumbassery	Ernakulam	05/03/2005	7.50	0.00	34.90	2.12	1.28	32.00	131.00	7.90	78.60	42.60	3.40	8.10	4.90	1.30	14.40
OW25	Nedumbassery	Ernakulam	02/03/2006	9.30	0.00	28.00	2.57	1.77	25.30	107.00	7.36	64.20	34.20	3.10	7.00	3.70	1.37	13.60
OW26	Kaladi	Ernakulam	05/03/2004	19.50	0.00	54.60	21.30	0.80	71.00	230.00	8.20	138.00	41.50	4.90	20.10	6.20	3.20	28.00
OW26	Kaladi	Ernakulam	10/03/2005	22.00	0.00	48.00	19.00	0.70	75.00	330.00	8.10	198.00	38.00	4.30	22.00	6.90	3.50	34.70
OW26	Kaladi	Ernakulam	04/03/2006	19.20	0.00	52.00	22.70	0.80	75.00	245.00	8.20	147.00	42.60	3.68	16.10	5.50	2.50	27.30
OW27	Angamali	Ernakulam	25/03/2004	9.20	0.00	13.70	5.22	0.10	49.90	102.00	7.90	61.20	16.70	10.40	10.50	2.40	1.70	16.70
OW27	Angamali	Ernakulam	13/03/2005	11.60	0.00	16.00	3.14	0.25	40.40	140.00	8.20	84.00	19.50	12.10	10.10	3.70	2.30	18.40
OW27	Angamali	Ernakulam	15/03/2006	14.80	0.00	29.10	2.90	0.15	52.00	140.00	7.90	106.00	35.20	11.10	10.20	3.70	2.60	21.00
OW29	Vapalassery	Ernakulam	05/03/2004	10.10	0.00	18.00	3.75	0.85	43.00	194.00	7.90	116.40	37.80	5.42	12.10	3.70	2.80	16.90
OW29	Vapalassery	Ernakulam	02/03/2005	4.00	0.00	14.00	5.14	0.90	40.40	140.00	8.21	84.00	19.50	4.10	12.10	3.70	2.30	18.40
OW29	Vapalassery	Ernakulam	05/03/2006	8.20	0.00	13.70	5.22	0.75	32.50	102.00	7.90	61.20	16.70	3.40	11.00	2.50	1.70	13.70
OW30	Manjapara	Ernakulam	05/03/2004	7.30	0.00	17.50	5.10	0.30	25.00	115.00	7.70	68.00	21.30	2.92	4.50	2.50	3.70	11.00
OW30	Manjapara	Ernakulam	03/03/2005	8.00	0.00	18.00	4.00	0.43	25.30	110.00	7.50	66.00	22.00	2.50	4.00	2.90	3.30	13.60
OW30	Manjapara	Ernakulam	04/03/2006	9.80	0.00	16.00	5.63	0.35	27.00	123.00	8.20	74.00	23.50	2.19	4.20	2.10	3.10	17.00
OW31	Attara	Ernakulam	03/03/2004	15.00	0.00	16.00	4.43	1.29	60.60	197.00	7.60	118.20	19.50	21.70	14.10	6.20	4.00	27.20
OW31	Attara	Ernakulam	13/03/2005	15.80	0.00	11.80	6.20	0.34	53.70	185.00	7.30	126.00	15.70	26.73	13.90	3.60	4.90	29.30
OW31	Attara	Ernakulam	01/03/2006	16.00	0.00	14.00	3.00	1.20	50.00	171.00	7.20	102.60	4.80	27.50	14.00	4.10	5.20	30.30
OW32	Sulli	Ernakulam	10/03/2004	9.80	0.00	33.00	6.00	0.27	20.00	144.00	7.30	86.40	33.00	12.40	10.00	2.43	3.40	13.80
OW32	Sulli	Ernakulam	04/03/2005	9.40	0.00	21.50	4.00	0.09	25.00	138.00	7.60	82.80	28.30	13.92	11.10	2.50	3.70	14.00
OW32	Sulli	Ernakulam	20/03/2006	12.50	0.00	21.30	4.30	0.38	40.00	135.00	7.60	81.00	29.00	14.50	10.20	3.90	4.50	17.00
OW33	Manjapra	Ernakulam	05/03/2004	8.60	0.00	11.80	7.07	0.35	34.80	137.00	7.40	82.20	14.30	3.12	4.60	3.60	4.80	14.10
OW33	Manjapra	Ernakulam	28/03/2005	6.30	0.00	17.50	6.00	0.08	25.00	141.00	7.70	84.60	21.30	1.92	3.90	3.50	3.70	11.50
OW33	Manjapra	Ernakulam	02/03/2006	8.30	0.00	18.00	7.00	0.43	25.30	132.00	7.50	79.20	22.00	2.50	4.50	4.90	3.30	14.60
OW34	Planatation	Ernakulam	01/03/2004	18.10	0.00	44.40	18.40	1.20	92.00	350.00	7.50	210.00	54.20	7.00	26.90	12.90	2.10	32.30
OW34	Planatation	Ernakulam	13/03/2005	13.70	0.00	36.40	18.61	0.90	85.00	310.00	8.10	186.00	55.90	5.55	20.00	11.20	3.20	23.30
OW34	Planatation	Ernakulam	04/03/2006	22.00	0.00	34.00	25.97	0.70	65.00	330.00	7.90	198.00	41.50	4.30	22.00	8.90	2.80	34.70
OW36	Vallom	Ernakulam	14/03/2004	13.50	0.00	21.20	3.10	1.60	25.00	122.00	7.50	73.50	24.00	1.32	8.10	3.20	3.80	22.50
OW36	Vallom	Ernakulam	14/03/2005	13.60	0.00	25.00	4.80	1.90	32.00	221.00	7.80	133.00	31.50	2.90	18.00	5.10	3.80	21.80
OW36	Vallom	Ernakulam	15/03/2006	13.20	0.00	21.00	4.40	1.40	30.60	117.00	7.90	70.00	26.20	5.75	12.50	2.50	4.25	20.50
OW37	Vengoor	Ernakulam	16/03/2004	7.60	0.00	41.20	8.48	0.67	54.70	155.00	8.00	93.00	50.20	0.80	10.00	7.30	8.30	11.80
OW37	Vengoor	Ernakulam	05/03/2005	5.40	0.00	50.00	7.08	1.00	55.60	125.00	8.20	75.00	61.00	1.10	12.00	7.40	8.00	9.20
OW37	Vengoor	Ernakulam	20/03/2006	8.00	2.32	62.00	6.97	0.90	96.00	170.00	8.40	102.00	64.00	1.24	14.30	6.20	9.90	15.40

OW38	Malayattur	Ernakulam	20/03/2004	5.30	0.00	10.24	1.50	0.90	28.00	50.00	7.50	30.00	12.24	4.20	4.00	2.80	1.90	8.30
OW38	Malayattur	Ernakulam	16/03/2005	4.70	0.00	8.00	2.00	0.75	26.00	57.00	7.60	34.20	9.80	5.50	3.90	2.50	1.60	6.70
OW38	Malayattur	Ernakulam	04/03/2006	5.30	0.00	18.00	1.43	1.37	25.30	52.00	7.30	40.80	18.00	6.50	4.00	3.70	2.00	9.60
OW39	Panamkuzhi	Ernakulam	10/03/2004	5.50	0.00	15.00	3.10	0.55	30.00	76.00	7.60	48.00	13.30	2.30	12.30	4.20	0.90	10.50
OW39	Panamkuzhi	Ernakulam	04/03/2005	5.20	0.00	7.80	4.76	0.76	14.90	71.00	7.40	42.60	19.60	2.20	11.00	1.20	4.00	9.80
OW39	Panamkuzhi	Ernakulam	10/03/2006	5.40	0.00	10.00	2.43	0.85	10.10	67.00	7.30	40.20	16.20	2.50	12.00	1.20	1.41	9.70
OW40	Kuruppampady	Ernakulam	18/03/2004	7.10	0.00	14.00	5.14	1.86	30.30	89.00	7.20	53.40	17.10	6.10	6.00	3.20	2.70	12.60
OW40	Kuruppampady	Ernakulam	04/03/2005	9.10	0.00	12.00	4.38	1.59	48.00	108.00	7.60	64.80	24.60	6.84	9.20	5.20	2.90	15.40
OW40	Kuruppampady	Ernakulam	03/03/2006	7.80	0.00	12.00	4.70	1.77	45.00	87.00	7.50	52.20	20.40	7.10	7.20	4.70	2.90	15.00
OW41	Kottapadi	Ernakulam	02/03/2004	8.20	0.00	56.00	10.00	0.60	56.00	150.00	8.20	90.00	56.00	0.90	16.00	6.43	4.40	14.50
OW41	Kottapadi	Ernakulam	20/03/2005	8.30	4.80	35.80	10.60	0.65	63.00	130.00	8.50	78.00	65.60	2.74	18.00	7.90	3.80	12.00
OW41	Kottapadi	Ernakulam	11/03/2006	8.40	4.60	65.00	10.70	0.52	67.00	131.00	8.40	78.60	67.90	0.82	16.20	6.20	3.50	15.00
OW42	Keezhmadu	Ernakulam	27/03/2004	9.00	6.90	89.20	14.00	2.80	76.00	190.00	8.60	114.00	98.60	0.14	30.40	6.20	3.20	16.00
OW42	Keezhmadu	Ernakulam	07/03/2005	9.80	12.00	110.00	14.50	2.90	177.00	160.00	8.53	96.00	109.80	2.22	38.90	8.70	3.40	13.70
OW42	Keezhmadu	Ernakulam	07/03/2006	8.10	4.80	102.00	6.71	2.48	100.00	220.00	8.30	132.00	114.70	2.80	36.00	7.40	1.79	14.70
OW43	Thattekad	Ernakulam	12/03/2004	9.30	0.00	28.00	4.10	0.80	25.00	83.00	8.00	49.80	51.50	2.40	8.20	3.60	1.75	17.50
OW43	Thattekad	Ernakulam	20/03/2005	7.20	0.00	37.00	4.80	1.20	32.00	81.00	7.90	48.00	52.50	2.20	9.50	4.00	1.80	11.60
OW43	Thattekad	Ernakulam	12/03/2006	8.90	0.00	33.00	4.90	0.70	27.00	126.00	8.20	76.20	56.40	2.60	10.90	3.60	1.30	16.80
OW44	Kuttamangalam	Ernakulam	29/03/2004	13.50	6.90	71.00	11.00	1.45	82.00	430.00	8.60	258.00	85.00	6.92	36.50	7.70	1.80	23.00
OW44	Kuttamangalam	Ernakulam	03/03/2005	14.00	7.20	56.00	11.70	1.30	73.00	410.00	8.70	246.00	95.20	8.60	32.00	7.50	2.20	21.70
OW44	Kuttamangalam	Ernakulam	02/03/2006	11.20	0.00	28.00	6.39	1.46	61.00	340.00	8.05	204.00	34.20	5.80	28.10	5.40	2.50	16.50
OW45	Pindimana	Ernakulam	29/03/2004	7.50	0.00	28.00	3.20	0.40	45.00	110.00	7.70	66.00	44.20	1.32	14.10	2.50	3.50	10.00
OW45	Pindimana	Ernakulam	03/03/2005	6.30	4.80	48.00	4.63	0.31	49.00	115.00	8.30	97.20	51.00	1.32	13.00	5.40	3.00	9.60
OW45	Pindimana	Ernakulam	02/03/2006	6.80	0.00	34.00	5.83	1.64	40.40	92.00	7.96	55.20	41.50	0.80	11.00	4.90	2.77	9.70
OW46	Keerampara	Ernakulam	20/03/2004	6.20	0.00	52.20	5.00	1.24	67.00	124.00	7.90	74.40	53.00	1.40	11.00	7.20	1.20	11.20
OW46	Keerampara	Ernakulam	12/03/2005	6.20	0.00	40.00	5.08	1.30	62.00	127.00	8.10	76.20	57.40	0.61	10.90	6.10	1.30	11.31
OW46	Keerampara	Ernakulam	07/03/2006	6.20	0.00	32.00	5.00	0.91	45.00	83.00	7.90	49.80	45.00	2.30	9.00	5.50	0.90	9.80
OW47	Neriyamangalam	Ernakulam	24/03/2004	8.60	3.00	21.30	4.00	0.30	41.00	130.00	7.70	78.00	51.20	3.10	8.60	5.10	3.20	12.20
OW47	Neriyamangalam	Ernakulam	29/03/2005	7.80	0.00	18.50	2.90	0.41	35.00	122.00	7.20	73.00	51.90	2.74	9.00	4.50	2.40	12.00
OW47	Neriyamangalam	Ernakulam	03/03/2006	8.90	2.20	20.20	0.00	0.42	33.00	128.00	7.90	77.00	43.70	3.00	8.10	4.90	2.20	12.70
OW48	Marayoor	Idukki	15/03/2004	10.40	0.00	34.00	3.60	0.31	46.50	80.00	7.90	52.00	41.50	4.30	11.20	4.50	2.80	15.40
OW48	Marayoor	Idukki	14/03/2005	9.20	0.00	41.60	4.20	0.30	49.00	90.00	8.00	64.00	41.60	4.80	12.00	4.90	1.90	14.50
OW48	Marayoor	Idukki	02/03/2006	9.60	0.00	35.00	3.90	0.29	45.00	100.00	8.10	60.00	42.70	5.10	11.20	4.08	2.10	15.80
OW50	Adimali	Idukki	03/03/2004	9.60	8.50	23.00	5.40	0.78	31.00	151.00	7.60	91.00	21.40	3.44	10.00	4.87	3.90	15.70
OW50	Adimali	Idukki	02/03/2005	10.20	0.00	21.00	6.00	0.80	28.80	143.00	7.50	86.00	19.50	2.90	8.80	5.45	4.30	19.60
OW50	Adimali	Idukki	16/03/2006	9.80	0.00	18.00	5.80	0.90	26.00	132.00	7.50	79.00	17.29	3.20	8.00	4.48	4.00	16.55

OW51	Vellathooval	Idukki	15/03/2006	12.00	3.80	19.50	0.50	1.80	28.00	145.00	7.50	87.00	17.40	31.00	8.00	2.95	4.50	20.00
OW55	Munnar	Idukki	12/03/2004	5.80	0.00	21.80	1.95	0.90	25.80	94.00	7.40	56.00	22.00	9.80	8.60	2.80	2.20	8.50
OW55	Munnar	Idukki	21/03/2005	5.40	0.00	22.00	2.00	0.86	25.60	102.00	7.60	61.00	25.00	10.40	9.00	2.40	2.60	10.00
OW55	Munnar	Idukki	13/03/2006	5.00	0.00	20.00	2.10	1.00	24.00	72.00	7.70	43.00	24.40	9.20	8.90	2.30	1.95	7.90
OW56	Mattupetty	Idukki	14/03/2006	5.40	0.00	21.00	0.00	0.50	20.00	89.00	7.60	53.00	15.00	12.00	4.00	2.40	2.60	10.00
OW57	Devikulam	Idukki	15/03/2004	10.70	0.00	35.28	1.80	0.90	30.00	110.00	8.00	66.00	25.00	4.00	10.20	2.23	2.45	17.50
OW57	Devikulam	Idukki	05/03/2005	10.50	8.20	38.00	1.95	1.20	34.00	115.00	8.40	69.00	24.00	3.80	11.50	2.53	2.50	15.40
OW57	Devikulam	Idukki	15/03/2005	9.10	0.00	36.00	2.10	1.00	23.30	80.00	7.80	48.00	25.00	16.00	12.00	2.30	2.30	13.50
OW58	Poopara	Idukki	15/03/2004	13.20	9.60	30.00	4.50	0.30	29.00	136.00	8.50	81.60	15.00	18.00	22.00	7.30	4.60	21.00
OW58	Poopara	Idukki	14/03/2005	14.20	9.80	28.50	4.20	0.40	31.00	142.00	8.50	85.20	12.30	17.50	21.00	7.00	8.00	22.50
OW58	Poopara	Idukki	03/03/2006	12.90	0.00	29.00	4.20	0.38	35.00	145.00	8.20	87.00	14.00	18.00	34.00	11.00	6.50	20.50
OW59	Udumbanchola	Idukki	04/03/2004	12.50	0.00	37.00	1.10	1.10	48.00	138.00	8.10	82.80	40.72	13.50	9.00	3.10	1.20	16.70
OW59	Udumbanchola	Idukki	15/03/2005	12.70	0.00	38.00	1.40	0.90	51.00	148.00	8.20	88.80	39.10	13.40	10.40	3.00	1.80	17.00
OW59	Udumbanchola	Idukki	10/03/2006	9.00	0.00	39.00	1.51	1.20	50.40	129.00	8.10	77.40	40.48	12.70	9.70	2.71	1.70	15.70
OW60	Upputhara	Idukki	10/03/2004	12.60	0.00	51.00	4.20	0.98	45.00	150.00	8.10	90.00	64.40	13.00	13.20	3.47	2.80	18.00
OW60	Upputhara	Idukki	03/03/2005	12.50	0.00	54.00	4.40	0.90	44.50	178.00	8.20	106.80	69.10	12.80	13.50	3.60	2.80	17.00
OW60	Upputhara	Idukki	20/03/2006	13.40	0.00	52.00	4.71	1.00	44.40	159.00	8.10	95.40	70.48	13.20	12.00	3.20	2.70	19.00
OW61	Nedumkandam	Idukki	04/03/2004	27.00	4.50	87.00	7.30	1.75	127.00	154.00	8.60	92.40	24.50	10.80	30.00	9.04	6.40	39.60
OW61	Nedumkandam	Idukki	03/03/2005	25.70	3.80	84.00	6.80	1.90	126.00	142.00	8.70	85.20	22.40	11.52	29.10	11.00	6.50	43.00
OW61	Nedumkandam	Idukki	19/03/2006	27.60	4.78	89.64	5.40	1.80	116.84	165.00	8.40	99.00	25.50	12.39	28.40	11.16	6.20	40.85
OW62	Vazhathope	Idukki	04/03/2004	9.10	0.00	15.90	8.60	1.18	37.00	128.00	7.80	74.00	23.50	3.60	14.50	4.60	2.50	16.50
OW62	Vazhathope	Idukki	04/03/2005	9.40	0.00	15.30	8.70	1.10	33.00	130.00	7.70	78.00	24.60	3.70	14.00	4.20	2.57	14.30
OW62	Vazhathope	Idukki	15/03/2006	9.80	0.00	14.60	7.80	1.40	32.50	124.00	7.90	73.00	24.00	3.50	13.00	4.30	2.60	17.00
OW63	Idikki	Idukki	14/03/2004	12.00	0.00	21.30	4.10	1.20	43.00	128.00	7.50	72.00	12.50	9.50	12.60	3.80	3.80	18.60
OW63	Idikki	Idukki	14/03/2005	12.50	0.00	22.50	4.50	1.30	39.00	125.00	7.50	74.00	11.50	10.80	13.00	3.90	4.20	16.50
OW63	Idikki	Idukki	14/03/2006	11.50	0.00	21.00	4.20	1.00	42.00	142.00	7.40	85.00	14.50	10.40	12.10	3.70	4.10	18.50
OW64	Irattayar	Idukki	03/03/2006	22.00	0.00	28.40	3.80	0.50	94.00	140.00	6.11	84.00	13.50	14.00	13.00	6.00	3.60	33.00
OW65	Chithirapuram	Idukki	04/03/2004	27.00	4.50	87.00	7.30	1.75	127.00	154.00	8.60	92.40	24.50	10.80	30.00	9.04	6.40	39.60
OW65	Chithirapuram	Idukki	03/03/2005	25.70	3.80	84.00	6.80	1.90	126.00	142.00	8.70	85.20	22.40	11.52	29.10	11.00	6.50	43.00
OW65	Chithirapuram	Idukki	19/03/2006	27.60	4.78	89.64	5.40	1.80	116.84	165.00	8.40	99.00	25.50	12.39	28.40	11.16	6.20	40.85
OW68	Kattapana	Idukki	04/03/2004	20.40	0.00	46.00	4.50	0.30	50.00	160.00	8.20	96.00	13.00	5.90	26.50	16.00	3.50	29.00
OW68	Kattapana	Idukki	12/03/2005	24.20	0.00	52.00	5.50	0.40	65.00	165.00	8.10	98.00	12.00	6.20	27.00	17.00	4.10	33.50
OW68	Kattapana	Idukki	03/03/2006	22.80	0.00	41.00	5.40	0.30	60.00	154.00	8.00	91.00	6.10	7.50	24.50	16.00	4.00	31.50
OW69	Ayyappancoil	Idukki	05/03/2004	14.50	0.00	35.60	3.60	1.53	46.00	106.00	7.80	64.00	25.60	8.56	19.00	4.55	2.70	21.10
OW69	Ayyappancoil	Idukki	10/03/2005	15.30	0.00	39.40	3.90	1.40	40.00	100.00	8.01	60.00	24.50	8.49	18.50	4.62	2.90	22.10
OW69	Ayyappancoil	Idukki	05/03/2006	12.20	0.00	40.70	4.10	1.54	43.00	108.00	8.20	65.00	27.40	8.20	16.50	4.70	3.20	16.00

OW70	Chakkupallam	Idukki	07/03/2004	23.40	0.00	69.90	8.10	0.80	60.00	145.00	8.20	87.00	19.00	9.10	23.40	5.30	4.10	33.30
OW70	Chakkupallam	Idukki	05/03/2005	23.00	3.40	78.00	7.90	0.70	62.00	155.00	8.40	93.00	21.00	8.50	26.10	5.70	3.90	32.00
OW70	Chakkupallam	Idukki	17/03/2006	22.70	0.00	58.00	8.37	0.64	61.00	145.00	8.10	87.00	22.00	8.69	22.40	5.20	4.30	32.90
OW71	Mariyapuram	Idukki	04/03/2004	20.40	0.00	46.00	4.50	0.30	50.00	160.00	8.20	96.00	13.00	5.90	26.50	16.00	3.50	29.00
OW71	Mariyapuram	Idukki	12/03/2005	24.20	0.00	52.00	5.50	0.40	65.00	165.00	8.10	98.00	12.00	6.20	27.00	17.00	4.10	33.50
OW71	Mariyapuram	Idukki	03/03/2006	22.80	0.00	41.00	5.40	0.30	60.00	154.00	8.00	91.00	6.10	7.50	24.50	16.00	4.00	31.50
OW72	Vandanmedu	Idukki	21/03/2004	15.50	0.00	20.80	3.50	1.30	56.00	165.00	7.70	99.00	26.80	7.50	17.20	2.80	6.80	22.00
OW72	Vandanmedu	Idukki	10/03/2005	16.50	0.00	33.50	3.20	1.00	30.20	132.00	7.60	79.00	22.00	6.50	17.20	2.80	4.00	23.60
OW72	Vandanmedu	Idukki	12/03/2006	15.80	0.00	21.20	3.50	0.80	56.00	128.00	7.60	77.00	26.80	4.90	16.80	2.50	6.80	21.50
OW74	Pampupara	Idukki	13/03/2006	13.00	9.60	19.00	1.50	0.90	38.00	154.00	8.40	92.00	21.00	16.00	8.40	3.90	3.40	19.00
OW75	Elapara	Idukki	31/03/2004	9.20	0.00	17.40	4.10	0.61	54.00	180.00	8.19	98.00	27.04	2.65	23.00	2.41	5.20	14.00
OW75	Elapara	Idukki	12/03/2005	11.30	0.00	19.40	3.60	0.50	51.00	165.00	8.10	99.00	23.60	2.56	26.10	2.47	5.00	16.00
OW75	Elapara	Idukki	17/03/2006	9.20	0.00	20.48	3.40	0.43	53.00	160.00	8.10	96.00	20.48	2.06	23.00	2.40	5.60	13.00
OW76	Chapathu	Idukki	07/03/2004	13.60	0.00	16.40	3.58	0.35	40.00	154.00	7.80	92.00	17.50	2.10	13.00	2.36	4.20	19.50
OW76	Chapathu	Idukki	12/03/2005	12.30	0.00	19.40	3.60	0.40	41.00	140.00	8.10	72.00	23.60	1.56	13.80	2.47	4.30	16.00
OW76	Chapathu	Idukki	17/03/2006	10.10	0.00	13.94	3.78	0.30	43.00	162.00	7.70	90.20	17.01	4.44	12.00	2.48	4.20	15.65
OW77	Kulamavu	Idukki	06/03/2004	24.50	5.20	32.00	5.20	0.33	45.00	142.00	8.80	85.20	24.50	3.50	26.00	6.20	3.60	35.00
OW77	Kulamavu	Idukki	05/03/2005	25.40	4.80	35.00	4.80	0.39	47.00	155.00	8.50	93.00	27.50	4.20	25.20	5.80	3.30	37.00
OW77	Kulamavu	Idukki	04/03/2006	23.50	4.90	34.00	5.60	0.40	46.00	149.00	8.60	89.40	25.80	4.50	37.90	5.50	3.70	34.00
OW78	Vandiperiyar	Idukki	10/03/2004	22.00	0.00	27.50	9.00	0.30	38.00	168.00	7.90	88.00	28.00	2.90	26.00	4.20	4.50	32.00
OW78	Vandiperiyar	Idukki	03/03/2005	23.00	0.00	26.80	8.00	0.30	36.00	170.00	7.60	91.00	29.00	3.80	24.00	3.80	4.20	33.00
OW78	Vandiperiyar	Idukki	05/03/2006	23.00	0.00	28.30	7.50	0.28	39.00	165.00	7.40	89.00	25.00	3.20	24.00	3.20	4.60	33.00
OW79	Kumily	Idukki	06/03/2004	24.50	5.20	32.00	5.20	0.33	45.00	142.00	8.80	85.20	28.00	3.50	26.00	6.20	3.60	35.00
OW79	Kumily	Idukki	05/03/2005	25.40	4.80	35.00	4.80	0.39	47.00	155.00	8.50	93.00	31.00	4.20	25.20	5.80	3.30	37.00
OW79	Kumily	Idukki	04/03/2006	23.50	4.90	34.00	5.60	0.40	46.00	149.00	8.60	89.40	27.00	4.50	24.50	5.50	3.70	34.00

Table - 6.1b Groundwater analysis data of Periyar river basin (Post - monsoon)

Well No.	Location	Date of Sampling	Ca	Mg	Na	K	Fe	HCO3	CO3	SO4	Cl	NO3	F	TDS	TH	EC	pH
			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	µS/cm	
OW01	Pappinivattom	04/10/2006	18.00	1.00	7.60	0.80	0.20	33.00	0.00	4.80	12.00	1.30	0.08	84.00	49.10	140.00	8.10
OW01	Pappinivattom	13/10/2004	15.70	1.50	5.80	0.80	0.70	36.60	0.00	3.10	10.00	1.20	0.07	90.00	45.40	150.00	7.80
OW01	Pappinivattom	16/10/2005	14.20	1.20	5.30	1.70	1.00	34.00	0.00	3.80	10.00	1.76	0.04	72.00	40.42	120.00	8.00
OW02	Lokamalleswaram	18/10/2004	29.60	10.80	39.40	21.70	0.10	132.00	6.00	8.30	57.00	4.70	0.60	381.00	118.26	635.00	8.70
OW02	Lokamalleswaram	18/10/2005	17.50	4.20	10.30	15.30	0.06	70.30	2.20	2.80	17.00	3.80	0.30	150.00	60.96	250.00	8.40
OW02	Lokamalleswaram	06/10/2006	16.00	8.50	24.90	15.50	0.06	78.80	7.00	3.40	39.00	3.00	0.20	234.00	74.84	390.00	8.30
OW03	Poyya	18/10/2004	5.20	1.20	3.90	1.70	0.11	7.90	0.00	1.40	7.00	2.10	0.02	36.00	17.92	60.00	6.80
OW03	Poyya	25/10/2005	7.50	1.90	3.20	1.10	0.15	6.60	0.00	1.60	6.10	1.78	0.01	33.00	26.54	55.00	7.00
OW03	Poyya	05/10/2006	4.00	1.40	3.70	1.10	0.20	6.90	0.00	1.50	7.00	2.06	0.09	36.00	15.74	60.00	6.80
OW04	North_parur	15/10/2006	28.00	1.20	6.00	5.70	1.25	83.00	0.00	7.50	10.60	1.20	0.09	117.60	74.92	196.00	8.10
OW04	North_parur	20/10/2005	28.00	2.40	9.20	5.20	1.50	83.20	0.00	5.76	14.80	0.78	0.05	120.00	79.84	200.00	8.20
OW04	North_parur	10/10/2004	24.00	1.30	11.00	6.00	1.10	70.70	2.70	8.20	20.00	0.90	0.07	132.00	65.33	220.00	8.30
OW05	Munambam	10/10/2005	32.00	2.40	15.30	7.20	1.45	80.00	2.40	9.30	28.90	3.60	0.20	210.60	89.84	351.00	8.70
OW05	Munambam	12/10/2006	25.50	1.90	13.00	2.50	1.00	59.00	18.00	5.50	24.00	2.80	0.25	186.00	71.54	310.00	8.40
OW05	Munambam	07/10/2004	29.00	2.00	17.00	5.10	1.80	72.00	0.00	6.40	28.00	3.20	0.26	198.00	80.70	330.00	8.20
OW06	Pallipuram	07/10/2006	60.70	7.90	14.60	7.30	1.50	140.00	16.80	11.08	23.50	0.80	0.35	252.00	184.13	420.00	8.40
OW06	Pallipuram	06/10/2005	65.50	12.60	17.00	8.19	1.45	165.00	18.00	12.10	27.50	0.70	0.21	294.00	215.39	490.00	8.50
OW06	Pallipuram	01/10/2004	65.50	12.50	15.50	7.30	1.33	151.00	25.90	13.50	20.00	4.82	0.30	306.00	214.98	510.00	8.40
OW07	Ezhikkakara	23/10/2006	21.00	2.40	10.20	5.20	1.10	93.20	0.00	10.76	17.80	1.70	0.50	135.00	62.34	225.00	8.19
OW07	Ezhikkakara	02/10/2005	24.00	1.80	11.00	6.00	1.09	70.70	0.00	11.00	20.00	1.60	0.61	138.00	67.38	230.00	8.10
OW07	Ezhikkakara	01/10/2004	21.90	2.10	13.70	6.40	1.24	87.80	0.00	12.00	19.00	1.85	0.52	144.00	63.36	240.00	8.20
OW08	Edavanakad	07/10/2006	80.80	23.40	110.00	7.30	1.21	175.70	38.40	25.95	189.20	2.60	0.60	528.00	297.90	880.00	8.50
OW08	Edavanakad	12/10/2005	72.00	24.40	65.70	7.20	1.10	167.80	0.00	23.95	116.40	2.17	0.40	468.00	280.00	780.00	8.60
OW08	Edavanakad	07/10/2004	63.00	13.90	59.00	8.31	1.68	216.70	29.30	22.50	92.20	2.70	0.50	384.00	214.47	640.00	8.70
OW09	Varapuzha	11/10/2006	80.00	12.90	19.50	5.70	1.00	157.60	19.20	36.34	31.20	3.10	0.16	294.00	252.87	490.00	8.30
OW09	Varapuzha	05/10/2005	76.00	19.00	60.60	15.80	1.75	177.40	21.10	34.36	115.70	4.16	0.28	552.00	267.87	920.00	8.40
OW09	Varapuzha	16/10/2004	87.00	12.00	25.30	9.70	1.24	137.12	68.32	21.90	33.70	2.74	0.26	288.00	266.68	480.00	8.40

OW10	Njarakkal	23/10/2006	34.00	4.90	8.70	2.40	0.60	176.90	14.20	8.69	13.70	1.12	0.54	210.00	105.08	350.00	8.10
OW10	Njarakkal	02/10/2005	37.70	8.80	11.10	2.91	0.80	138.10	5.30	11.50	17.00	1.20	0.52	174.00	130.32	290.00	8.30
OW10	Njarakkal	01/10/2004	34.00	3.60	10.00	3.20	0.68	139.00	0.00	11.80	15.30	1.30	0.40	72.00	99.75	120.00	7.90
OW11	Malipuram	15/10/2006	40.00	3.40	19.00	3.50	1.50	129.00	0.00	7.30	26.00	3.50	0.71	202.20	113.93	337.00	8.20
OW11	Malipuram	06/10/2005	49.50	12.60	17.00	4.19	1.17	224.80	24.00	22.10	27.50	3.80	0.68	294.00	175.39	490.00	8.70
OW11	Malipuram	01/10/2004	51.50	9.50	17.00	4.30	1.23	223.90	25.90	13.50	25.00	4.82	0.53	306.00	167.68	510.00	8.80
OW12	Edappally	20/10/2006	60.90	2.40	21.60	7.20	0.30	110.00	11.80	14.52	31.20	2.03	0.14	258.00	162.09	430.00	8.40
OW12	Edappally	16/10/2005	62.00	6.30	19.60	4.30	0.36	151.70	18.88	15.44	28.60	0.90	0.24	258.00	180.82	430.00	8.50
OW12	Edappally	07/10/2004	65.70	11.00	21.50	7.56	0.31	200.40	16.00	15.60	31.50	2.18	0.18	264.00	209.33	440.00	8.30
OW13	Elur_north	01/10/2006	69.70	65.70	372.00	30.50	1.20	268.10	34.60	10.40	664.60	2.10	0.92	1470.00	443.51	2450.00	8.80
OW13	Elur_north	20/10/2005	8.10	4.90	13.00	5.80	1.70	35.50	0.00	8.30	20.00	2.24	0.32	108.00	40.33	180.00	8.10
OW13	Elur_north	19/10/2004	104.00	60.70	400.50	35.50	1.42	194.56	92.16	11.60	700.20	4.60	0.80	1860.00	508.77	3100.00	8.30
OW14	Pathalam	07/10/2004	23.00	4.80	19.00	2.10	0.60	69.00	0.00	29.00	28.00	2.40	0.36	163.80	77.17	273.00	8.20
OW14	Pathalam	10/10/2006	24.00	5.30	18.00	1.70	0.50	76.00	0.00	21.60	30.00	2.10	0.33	169.80	81.72	283.00	8.00
OW14	Pathalam	14/10/2005	22.00	4.80	19.00	2.10	0.40	72.00	0.00	29.00	32.00	2.20	0.35	167.40	74.67	279.00	8.10
OW15	Paravur	06/10/2006	62.00	2.70	11.70	6.10	0.70	170.80	24.00	12.00	17.50	1.70	0.35	228.00	166.07	380.00	8.40
OW15	Paravur	20/10/2004	63.80	3.10	15.20	7.60	0.95	176.90	16.50	16.86	22.50	1.93	0.36	252.00	172.20	420.00	8.60
OW15	Paravur	12/10/2005	71.50	3.50	13.50	7.30	0.93	171.00	25.90	13.50	20.00	2.20	0.30	255.00	193.09	425.00	8.50
OW17	Chalakka	12/10/2006	21.00	9.00	24.00	4.00	0.40	73.00	0.00	25.00	37.00	2.00	0.30	219.60	89.39	366.00	8.20
OW17	Chalakka	01/10/2005	19.00	10.50	26.00	4.50	0.40	75.00	0.00	26.00	38.00	1.80	0.30	225.00	90.53	375.00	8.10
OW17	Chalakka	05/10/2004	17.50	9.50	25.00	3.50	0.45	95.00	0.00	24.50	38.00	2.80	0.20	220.80	82.68	368.00	8.00
OW18	Chengamanad	01/10/2006	7.20	2.90	13.00	3.90	0.35	9.80	0.00	1.00	19.00	29.00	0.05	97.80	29.89	163.00	7.20
OW18	Chengamanad	02/10/2005	5.60	2.40	12.60	3.60	0.45	20.00	0.00	1.20	18.00	19.00	0.10	96.60	23.84	161.00	7.60
OW18	Chengamanad	18/10/2004	5.60	3.90	18.00	3.50	0.35	9.80	0.00	1.60	24.00	15.00	0.05	84.00	29.98	140.00	7.20
OW19	Alwaye	20/10/2006	30.40	0.00	4.00	1.70	0.29	94.60	0.00	4.00	6.00	1.14	0.06	114.00	76.00	190.00	8.30
OW19	Alwaye	10/10/2004	84.00	1.50	4.50	3.40	0.69	51.20	10.20	4.70	8.20	4.94	0.01	114.00	216.15	190.00	8.20
OW19	Alwaye	04/10/2005	50.00	3.64	7.10	6.50	0.77	88.00	18.60	12.00	13.00	2.02	0.00	138.00	139.92	230.00	8.50
OW20	Karukutty	06/10/2006	21.10	2.50	6.20	2.26	0.12	70.40	2.70	2.25	10.60	1.60	0.05	94.80	63.00	158.00	8.30
OW20	Karukutty	17/10/2004	15.00	1.20	7.50	1.30	0.10	64.63	0.00	2.40	11.40	1.10	0.02	96.00	42.42	160.00	7.80
OW20	Karukutty	15/10/2005	17.00	2.70	6.60	0.70	0.20	56.10	0.00	3.30	9.40	1.80	0.03	66.00	53.57	110.00	8.10
OW21	Aluva_East	04/10/2006	17.90	6.10	12.80	3.10	0.50	64.60	0.00	8.00	19.10	1.93	0.20	120.00	69.75	200.00	8.22
OW21	Aluva_East	10/10/2004	16.00	6.10	12.00	2.80	0.45	69.60	0.00	7.80	19.10	2.70	0.23	126.00	65.00	210.00	7.73

OW21	Aluva_East	02/10/2005	36.10	8.00	17.00	3.04	0.40	72.30	5.30	7.10	22.20	3.52	0.20	180.00	123.04	300.00	8.40
OW23	Chowara	06/10/2006	10.30	2.60	11.00	1.80	0.13	10.80	0.00	1.12	16.90	6.00	0.10	105.60	36.41	176.00	7.00
OW23	Chowara	01/10/2005	13.00	2.40	16.20	1.70	0.12	4.88	0.00	2.80	25.20	7.16	0.10	96.00	42.34	160.00	7.10
OW23	Chowara	06/10/2004	13.00	2.40	17.60	1.00	0.13	34.00	0.00	2.70	25.00	6.70	0.09	96.00	42.34	160.00	7.20
OW24	Vazhakkulam	10/10/2006	4.10	2.50	6.40	1.30	0.19	10.00	0.00	2.00	11.50	2.48	0.07	39.00	20.50	65.00	7.10
OW24	Vazhakkulam	01/10/2005	3.90	1.60	8.10	2.30	0.20	8.80	0.00	2.20	15.00	2.52	0.08	39.00	16.31	65.00	7.00
OW24	Vazhakkulam	01/10/2004	5.00	1.20	5.70	1.80	0.10	9.76	0.00	2.60	10.30	3.21	0.07	36.00	17.42	60.00	7.30
OW25	Nedumbassery	13/10/2004	6.00	1.20	7.70	0.80	0.95	7.20	0.00	1.60	14.80	2.03	0.08	52.80	19.92	88.00	7.02
OW25	Nedumbassery	04/10/2006	5.00	2.40	7.40	0.60	0.60	7.30	0.00	1.82	11.50	2.90	0.10	46.20	22.34	77.00	6.78
OW25	Nedumbassery	01/10/2005	6.10	2.50	6.60	0.81	0.90	13.50	0.00	1.25	11.90	2.44	0.10	49.80	25.50	83.00	7.00
OW26	Kaladi	01/10/2004	11.90	2.90	12.10	17.00	0.30	39.20	0.00	11.40	20.30	3.00	0.07	114.00	41.64	190.00	7.90
OW26	Kaladi	12/10/2005	10.00	3.90	14.20	12.70	0.40	31.50	0.00	12.00	25.00	4.68	0.06	108.00	40.98	180.00	8.10
OW26	Kaladi	05/10/2006	6.10	4.40	10.40	10.00	0.32	36.60	0.00	11.98	16.50	3.80	0.08	102.00	33.28	170.00	7.90
OW27	Angamali	04/10/2006	8.00	1.25	9.70	1.30	0.09	9.80	0.00	3.46	16.40	7.50	0.05	67.80	25.12	113.00	7.30
OW27	Angamali	09/10/2005	8.00	2.40	7.30	1.50	0.04	7.20	0.00	4.86	13.70	5.36	0.06	54.00	29.84	90.00	7.20
OW27	Angamali	10/10/2004	7.80	3.60	11.00	2.20	0.05	24.20	0.00	2.80	20.00	5.98	0.05	108.00	34.25	180.00	7.70
OW29	Desom	01/10/2004	10.50	3.20	7.00	2.20	0.08	24.20	0.00	2.80	11.00	3.98	0.03	108.00	39.36	180.00	7.70
OW29	Desom	13/10/2006	8.00	2.40	7.30	1.00	0.20	7.20	0.00	4.86	13.70	2.36	0.03	54.00	29.84	90.00	7.70
OW29	Desom	01/10/2005	9.10	3.10	7.50	1.86	0.20	9.60	0.00	4.80	12.20	3.40	0.04	72.00	35.45	120.00	8.10
OW30	Manjapara	04/10/2006	2.00	2.40	6.60	2.90	0.10	19.50	0.00	3.60	10.20	1.28	0.08	55.20	14.84	92.00	7.30
OW30	Manjapara	15/10/2005	2.30	1.70	5.40	2.40	0.15	18.20	0.00	4.70	9.80	2.78	0.11	61.20	12.72	102.00	7.30
OW30	Manjapara	17/10/2004	2.40	1.50	6.60	2.22	0.20	19.00	0.00	3.90	11.90	1.84	0.07	63.00	12.15	105.00	7.40
OW31	Attara	02/10/2006	8.00	2.40	8.90	2.20	0.90	7.30	0.00	3.85	14.40	5.10	0.00	71.40	29.84	119.00	6.80
OW31	Attara	02/10/2005	10.00	3.70	11.80	1.90	0.86	12.00	0.00	5.00	19.60	5.13	0.00	84.00	40.16	140.00	7.00
OW31	Attara	12/10/2004	11.60	2.40	20.80	3.70	0.10	10.90	0.00	1.80	32.00	6.40	0.00	81.00	38.84	135.00	6.90
OW32	Sulli	01/10/2006	8.70	4.70	6.40	4.60	0.25	24.20	0.00	3.80	9.00	11.20	0.06	76.20	41.01	127.00	7.30
OW32	Sulli	05/10/2005	9.90	3.60	7.80	3.10	0.25	24.40	0.00	3.20	14.00	11.78	0.06	72.00	39.50	120.00	7.40
OW32	Sulli	02/10/2004	8.20	3.60	7.60	4.20	0.18	21.00	0.00	3.50	13.50	10.80	0.04	79.20	35.25	132.00	6.90
OW33	Plantation Jn	01/10/2004	3.30	2.50	6.40	4.22	0.46	19.00	0.00	4.50	10.90	1.84	0.04	55.80	18.50	93.00	7.20
OW33	Plantation Jn	13/10/2005	3.00	2.70	5.90	4.40	0.30	19.20	0.00	5.50	9.80	2.78	0.18	58.80	18.57	98.00	7.35
OW33	Plantation Jn	04/10/2006	2.00	2.40	6.60	3.90	0.05	19.50	0.00	4.81	11.30	1.40	0.38	63.00	14.84	105.00	7.29
OW34	Kalady	07/10/2005	11.10	8.10	11.30	11.70	0.60	45.30	2.45	6.20	21.50	4.00	0.01	107.40	60.95	179.00	7.60

OW34	Kalady	05/10/2004	16.00	8.40	12.20	13.10	0.55	50.30	0.00	15.30	22.20	4.80	0.15	86.70	74.43	144.50	7.80
OW34	Kalady	02/10/2006	6.20	7.35	10.30	10.00	0.30	36.00	0.00	11.80	16.40	3.70	0.02	101.70	45.62	169.50	7.55
OW36	Vallom	13/10/2006	4.10	1.50	9.10	3.20	0.15	14.50	0.00	3.20	17.20	4.00	0.00	61.80	16.40	103.00	7.20
OW36	Vallom	10/10/2004	4.30	2.20	10.60	3.10	0.90	16.20	0.00	2.56	19.50	2.80	0.10	72.60	19.77	121.00	7.20
OW36	Vallom	14/10/2005	5.90	3.40	9.60	2.50	0.40	13.40	0.00	4.20	16.30	1.74	0.10	61.80	28.68	103.00	7.30
OW37	Vengoor	11/10/2006	10.00	1.20	3.00	3.60	0.65	43.90	0.00	7.20	5.20	0.40	0.00	55.80	29.92	93.00	8.00
OW37	Vengoor	11/10/2005	8.00	2.40	3.80	3.20	0.52	31.10	0.00	6.83	7.20	0.50	0.00	47.40	29.84	79.00	7.70
OW37	Vengoor	12/10/2004	8.30	2.30	3.30	2.80	0.50	29.60	0.00	7.10	5.30	0.70	0.00	42.60	30.18	71.00	7.80
OW38	Malayattur	10/10/2006	2.50	1.20	5.20	1.34	0.41	12.20	0.00	0.69	8.70	0.40	0.20	22.20	11.17	37.00	7.10
OW38	Malayattur	04/10/2005	2.80	1.20	5.00	1.00	0.15	13.20	0.00	1.32	8.80	0.82	0.30	25.20	11.92	42.00	7.20
OW38	Malayattur	12/10/2004	3.00	1.45	6.00	1.50	0.25	11.88	0.00	1.00	10.10	0.46	0.57	21.00	13.44	35.00	7.30
OW39	Panamkuzhi	03/10/2006	4.00	1.20	4.10	0.89	0.45	14.60	0.00	3.90	7.60	1.50	0.08	33.00	14.92	55.00	7.00
OW39	Panamkuzhi	12/10/2005	6.00	4.70	5.80	1.00	0.35	14.20	0.00	2.30	8.50	1.60	0.03	38.40	34.26	64.00	7.40
OW39	Panamkuzhi	17/10/2004	7.60	2.40	5.50	1.10	0.39	9.76	0.00	3.50	9.30	1.40	0.06	36.00	28.84	60.00	6.90
OW40	Kuruppampady	11/10/2006	4.00	1.20	6.80	1.80	0.61	9.80	0.00	1.92	11.60	3.20	0.10	42.00	14.92	70.00	6.80
OW40	Kuruppampady	19/10/2005	6.20	2.40	5.60	1.50	0.50	9.50	0.00	3.28	9.80	2.89	0.18	45.00	25.34	75.00	7.10
OW40	Kuruppampady	10/10/2004	6.20	3.10	6.00	1.73	0.60	16.30	0.00	2.10	10.80	2.80	0.11	48.00	28.20	80.00	7.00
OW41	Kottapadi	09/10/2004	11.00	2.40	6.90	6.20	0.32	49.00	0.00	8.50	10.90	2,6	0.10	72.00	37.34	120.00	7.60
OW41	Kottapadi	07/10/2006	9.70	4.70	6.50	7.30	0.42	39.50	0.00	8.70	10.00	0.64	0.14	66.00	43.51	110.00	7.90
OW41	Kottapadi	11/10/2005	10.00	2.40	5.00	5.30	0.25	24.40	0.00	9.20	9.40	0.62	0.35	63.00	34.84	105.00	7.70
OW42	Choornikara	13/10/2005	8.00	6.30	5.30	2.90	1.50	65.00	4.70	5.43	8.80	0.60	0.32	138.00	45.82	230.00	8.43
OW42	Choornikara	02/10/2006	6.10	5.60	4.30	1.26	1.42	58.60	0.00	5.78	5.80	2.10	0.26	66.00	38.20	110.00	8.24
OW42	Choornikara	01/10/2004	7.60	5.10	5.40	2.36	1.26	64.00	8.00	6.80	7.40	2.00	0.19	132.00	39.90	220.00	8.40
OW43	Thattekad	12/10/2006	5.50	2.60	6.20	0.90	0.15	32.00	0.00	2.30	10.70	1.25	0.27	47.40	24.41	79.00	7.90
OW43	Thattekad	14/10/2005	5.30	3.00	6.70	0.72	0.10	42.50	0.00	3.80	11.50	1.20	0.25	63.60	25.55	106.00	7.70
OW43	Thattekad	14/10/2004	5.80	2.30	5.80	1.10	0.30	39.50	0.00	3.70	8.50	1.50	0.30	40.80	23.93	68.00	7.80
OW44	Kuttamangalam	23/10/2004	15.50	2.40	7.60	20.00	0.51	43.30	0.00	18.00	14.00	4.42	0.14	258.00	48.59	220.00	7.80
OW44	Kuttamangalam	21/10/2006	10.00	2.40	6.70	5.30	0.30	26.40	0.00	4.63	12.60	4.47	0.30	256.00	34.84	130.00	7.64
OW44	Kuttamangalam	07/10/2005	14.50	3.30	9.60	18.80	0.80	32.50	0.00	8.90	17.50	4.38	0.26	251.00	49.77	210.00	7.60
OW45	Pindimana	07/10/2004	12.40	1.30	5.60	2.85	0.19	21.70	0.00	7.91	9.50	2.12	0.11	55.80	36.33	93.00	7.60
OW45	Pindimana	21/10/2005	10.00	2.40	4.20	2.30	0.21	23.90	0.00	8.80	7.80	1.26	0.18	54.60	34.84	91.00	7.59
OW45	Pindimana	05/10/2006	8.00	2.40	4.40	2.60	0.11	24.40	0.00	8.78	7.70	1.90	0.10	47.40	29.84	79.00	7.50

OW46	Keerampara	10/4/2004	6.00	3.70	4.10	0.70	0.13	31.70	0.00	4.23	7.70	0.15	0.14	47.40	30.16	79.00	7.80
OW46	Keerampara	10/6/2005	8.00	4.90	5.30	0.80	0.30	31.10	0.00	4.47	9.80	0.25	0.09	60.00	40.08	100.00	7.70
OW46	Keerampara	10/10/2006	8.40	6.40	5.30	0.82	0.90	43.00	0.00	4.00	8.60	1.04	0.18	64.20	47.23	107.00	7.70
OW47	Neriyamangalam	23/10/2004	5.60	2.40	5.20	1.60	0.24	27.30	1.80	0.00	7.00	2.22	0.15	45.60	23.84	76.00	7.20
OW47	Neriyamangalam	02/10/2005	4.10	1.30	5.60	1.02	0.32	20.80	0.00	18.00	10.60	2.30	0.05	40.80	15.58	68.00	6.90
OW47	Neriyamangalam	21/10/2006	4.00	1.20	4.30	1.00	0.20	19.50	0.00	1.32	6.80	1.84	0.16	35.40	14.92	59.00	7.12
OW48	Marayoor	10/10/2004	7.80	2.41	5.20	0.80	0.15	29.40	0.00	2.40	7.30	1.45	0.25	42.00	29.38	70.00	7.80
OW48	Marayoor	16/10/2006	6.00	2.70	5.49	0.61	0.25	24.60	0.00	1.70	9.90	1.00	0.10	33.00	26.07	55.00	7.20
OW48	Marayoor	18/10/2005	7.06	2.46	6.20	0.90	0.17	26.00	0.00	2.20	10.60	2.10	0.20	39.60	27.73	66.00	7.70
OW50	Adimali	15/10/2004	7.40	3.68	3.80	2.40	0.16	17.64	0.00	3.50	7.00	1.64	0.01	66.00	33.58	110.00	7.30
OW51	Pallivasal	04/10/2005	6.40	2.40	10.00	4.20	1.20	14.90	2.50	0.00	17.00	28.00	0.05	82.80	25.84	138.00	6.76
OW52	Tukkupalam	15/10/2006	8.10	1.90	8.90	1.60	0.45	29.40	0.00	1.60	12.60	0.60	0.20	66.00	28.04	110.00	7.90
OW52	Tukkupalam	10/10/2005	6.00	1.60	9.00	1.70	0.35	35.20	0.00	1.60	15.40	0.40	0.08	54.00	21.56	90.00	7.80
OW52	Tukkupalam	02/10/2004	7.40	2.60	9.60	1.30	0.20	44.10	0.00	1.00	15.20	0.50	0.15	57.00	29.16	95.00	7.90
OW52	Adimali	11/10/2006	6.00	3.20	3.75	2.18	0.15	14.60	0.00	3.90	7.10	2.90	0.03	61.20	28.11	102.00	7.20
OW55	Adimali	14/10/2005	6.70	3.40	6.20	2.80	0.15	16.20	0.00	3.81	11.50	2.10	0.04	60.60	30.68	101.00	7.10
OW55	Munnar	16/10/2006	5.00	1.40	3.34	0.92	0.55	20.00	0.00	0.65	5.90	5.30	0.18	36.60	18.24	61.00	7.40
OW55	Munnar	05/10/2005	6.60	1.26	3.20	1.20	0.50	19.40	0.00	0.63	5.40	6.00	0.18	51.00	21.66	85.00	7.50
OW55	Munnar	21/10/2004	6.50	1.80	4.00	1.10	0.20	18.80	0.00	0.70	7.00	5.50	0.09	48.00	23.63	80.00	7.20
OW56	Mattupetty	04/10/2005	3.20	2.00	4.70	2.10	0.20	9.80	0.00	0.24	7.00	16.00	0.44	46.20	16.20	77.00	6.80
OW57	Devikulam	07/10/2006	4.00	1.20	5.20	1.90	0.50	12.20	0.00	0.79	10.00	1.80	0.10	22.80	14.92	38.00	7.50
OW58	Devikulam	16/10/2005	4.80	1.90	6.00	2.60	0.70	16.00	0.00	1.10	11.45	1.12	0.06	44.40	19.79	74.00	7.60
OW58	Poopara	23/10/2006	6.00	2.80	7.50	3.60	0.24	24.00	0.00	2.50	13.60	4.60	0.12	84.00	26.48	140.00	7.10
OW59	Devikulam	20/10/2004	6.50	1.90	7.80	2.50	0.65	18.00	0.00	0.95	14.00	1.40	0.08	39.00	24.04	65.00	7.60
OW59	Udumbanchola	15/10/2004	6.50	2.90	8.90	0.60	0.45	29.40	0.00	0.75	15.60	9.10	0.09	66.00	28.14	110.00	7.90
OW59	Udumbanchola	10/10/2006	7.00	2.40	7.45	0.80	0.41	33.90	0.00	0.79	13.90	8.60	0.08	58.80	27.34	98.00	7.80
OW59	Udumbanchola	01/10/2005	6.20	2.40	8.00	0.70	0.38	35.80	0.00	0.55	13.90	8.40	0.09	53.40	25.34	89.00	8.00
OW60	Santhampara	15/10/2004	8.00	2.90	9.90	1.60	0.69	49.40	0.00	1.30	15.60	9.10	0.08	66.00	31.89	110.00	7.90
OW60	Santhampara	02/10/2006	8.00	2.40	9.20	1.33	0.80	43.90	0.00	1.40	16.90	8.00	0.06	58.80	29.84	98.00	7.80
OW60	Santhampara	08/10/2005	7.20	2.79	9.00	1.70	0.75	55.80	0.00	1.50	15.90	8.70	0.08	53.40	29.43	89.00	7.90
OW61	Nedumkandam	24/10/2006	22.00	4.80	15.15	5.51	0.68	53.70	0.00	6.60	27.00	7.10	0.06	174.00	74.67	290.00	7.90
OW61	Nedumkandam	08/10/2005	23.70	3.90	16.40	3.10	0.70	164.80	0.00	5.41	25.60	6.48	0.05	168.00	75.23	280.00	8.10

OW61	Nedumkandam	20/10/2004	24.20	4.30	16.80	4.00	0.65	73.30	0.00	7.30	28.70	8.60	0.05	174.00	78.12	290.00	8.00
OW62	Vazhathope	03/10/2004	7.40	2.41	6.50	1.50	1.10	16.40	0.00	5.75	10.90	2.62	0.06	52.80	28.38	88.00	7.20
OW62	Vazhathope	24/10/2006	6.06	2.46	6.80	1.10	1.10	14.20	0.00	5.50	10.60	2.60	0.06	54.60	25.23	91.00	7.10
OW62	Vazhathope	08/10/2005	6.50	2.53	7.40	1.30	0.90	15.20	0.00	5.55	13.80	1.82	0.07	61.20	26.62	102.00	7.30
OW63	Idikki	02/10/2006	7.50	2.40	8.50	1.60	0.65	16.80	0.00	2.50	14.50	6.30	0.10	66.60	28.59	111.00	7.00
OW63	Idikki	07/10/2005	7.20	2.50	8.20	1.50	0.80	18.50	0.00	2.00	15.40	5.20	0.15	54.00	28.25	90.00	7.10
OW63	Idikki	14/10/2004	6.50	2.80	7.50	1.50	0.75	16.50	0.00	2.10	13.50	5.50	0.15	57.00	27.73	95.00	7.00
OW64	Irattayar	15/10/2006	6.00	2.60	8.00	1.40	0.20	7.30	0.00	2.00	13.00	13.00	0.20	87.00	25.66	145.00	8.20
OW65	Chithirapuram	24/10/2006	4.10	2.45	10.20	1.50	0.40	14.20	0.00	2.60	16.00	1.03	0.10	42.00	20.29	70.00	7.40
OW66	Nirmala_city	12/10/2006	4.90	2.70	6.80	1.70	0.25	22.00	0.00	2.40	9.50	3.90	0.10	50.40	23.32	84.00	7.40
OW68	Kattappana	28/10/2006	4.00	2.40	4.09	1.90	0.89	34.40	0.00	2.63	7.10	3.40	0.10	50.40	19.84	84.00	7.00
OW68	Kattappana	15/10/2005	4.10	2.06	3.10	1.40	0.90	36.30	0.00	2.38	5.40	3.24	0.11	48.00	18.69	80.00	7.20
OW68	Kattappana	04/10/2004	4.10	2.27	3.90	1.10	1.20	18.90	0.00	2.50	7.00	3.04	0.09	49.20	19.55	82.00	7.30
OW69	Ayyappancoil	05/10/2005	6.50	3.10	7.00	1.80	0.70	18.90	0.00	1.70	9.00	2.72	0.09	42.00	28.95	70.00	7.60
OW69	Ayyappancoil	05/10/2004	5.20	2.70	7.80	1.65	0.90	15.88	0.00	1.00	11.00	2.80	0.11	45.60	24.07	76.00	7.44
OW69	Ayyappancoil	09/10/2006	5.50	2.80	6.60	1.20	0.50	11.80	0.00	1.85	8.60	2.25	0.15	43.80	25.23	73.00	7.40
OW70	Chakkupallam	07/10/2004	17.50	3.10	13.50	2.90	0.36	45.00	0.00	6.80	20.60	3.21	0.02	108.00	56.45	180.00	7.90
OW70	Chakkupallam	15/10/2006	16.00	3.20	13.00	2.80	0.30	48.00	0.00	6.25	20.40	4.92	0.01	105.00	53.11	175.00	7.90
OW70	Chakkupallam	09/10/2005	17.10	3.40	15.00	3.10	0.25	49.70	0.00	5.83	22.10	4.84	0.02	99.00	56.68	165.00	7.80
OW71	Mariyapuram	10/10/2006	8.00	2.48	4.30	1.60	0.20	21.87	0.00	2.33	7.40	3.45	0.25	61.80	30.16	103.00	7.40
OW72	Vandanmedu	20/10/2006	4.50	2.10	4.20	1.50	0.60	19.00	0.00	2.20	7.80	3.50	0.15	51.00	19.86	85.00	7.10
OW72	Vandanmedu	09/10/2005	5.80	2.50	5.50	1.50	0.70	14.50	0.00	1.80	9.60	5.50	0.20	57.00	24.75	95.00	7.20
OW72	Vandanmedu	10/10/2004	7.70	2.50	6.10	1.87	0.80	23.50	0.00	2.25	11.60	6.50	0.25	72.00	29.50	120.00	7.00
OW73	Vellilamkandam	10/10/2006	4.00	2.50	4.80	1.20	0.40	14.58	0.00	1.95	7.00	1.32	0.05	34.20	20.25	57.00	7.40
OW74	Pampupara	09/10/2006	6.00	4.40	7.00	2.80	0.60	17.00	0.00	1.00	13.00	12.00	0.12	78.00	33.03	130.00	7.40
OW75	Elappara	13/10/2004	12.00	1.90	5.90	4.30	0.30	21.16	0.00	2.30	9.00	2.40	0.06	69.60	37.79	116.00	7.50
OW75	Elappara	07/10/2006	8.90	1.36	5.60	4.20	0.30	17.50	0.00	2.25	8.00	2.10	0.05	62.40	27.82	104.00	7.40
OW75	Elappara	15/10/2005	10.40	1.80	4.80	3.90	0.35	19.40	0.00	2.45	7.00	1.64	0.07	63.60	33.38	106.00	7.50
OW76	Chappathu	15/10/2005	10.40	1.85	7.00	1.20	0.20	14.40	0.00	1.75	10.50	0.64	0.09	63.60	33.58	106.00	7.50
OW76	Chappathu	18/10/2006	10.00	1.40	7.20	2.00	0.25	15.00	0.00	1.50	13.00	21.00	0.10	72.00	30.74	120.00	7.40
OW76	Chappathu	05/10/2004	9.00	1.50	8.20	2.00	0.28	13.80	1.68	2.10	13.00	16.00	0.10	66.60	28.65	111.00	7.30
OW77	Kulamavu	10/10/2006	19.50	3.10	23.60	3.60	0.25	18.00	0.00	3.60	37.00	23.00	0.03	93.60	61.45	156.00	7.20

OW78	Vandiperiyar	07/10/2005	18.40	2.80	24.80	3.80	0.32	19.00	0.00	3.20	38.00	21.00	0.19	97.20	57.48	162.00	6.90
OW78	Vandiperiyar	09/10/2004	18.20	3.40	22.50	3.20	0.20	18.00	0.00	3.80	37.00	22.50	0.09	91.20	59.43	152.00	7.10
OW79	Kumily	13/10/2004	20.00	3.60	9.20	2.20	0.27	23.40	0.00	3.10	13.70	8.50	0.10	81.00	64.75	135.00	7.98
OW79	Kumily	23/10/2006	24.30	2.50	14.00	2.20	0.15	21.00	0.00	3.10	21.00	8.00	0.09	87.00	71.00	145.00	8.00
OW79	Kumily	09/10/2005	16.10	2.70	12.50	1.80	0.25	22.00	0.00	2.90	18.30	8.60	0.13	82.80	51.32	138.00	7.90

In the study area, groundwater is mainly used for domestic, irrigation and industrial purposes. The quality criteria depend on the use of water for a particular purpose and water quality standards have to be maintained for different uses to avoid deleterious effects. Table 6.2 provides a summary of the WHO 1994 drinking water guidelines and the Bureau of Indian Standards (BIS, 1991) for drinking water quality. The World Health Organization (WHO, 1994) drinking water quality guidelines provide international norms on water quality and human health that are used as the basis for regulation and standard setting, in developing and developed countries world-wide. These guidelines are adopted by many countries as national guidelines to follow, even if they are not necessarily enforceable by law. There is a distinction between the two terms, guidelines and standards. In contrast, drinking water quality standards are primarily set by many nations and can be enforceable by law. Many countries set drinking water quality guidelines based on the WHO guidelines but may modify these based on what is achievable in their country. In India, based on the WHO guide lines, the drinking water quality standards have been introduced in 1983 (BIS -1983) and further modified the same in 1991 (IS:10500:1991). Drinking water quality standards as prescribed by the BIS (1991) and WHO (1993) are given in Table 6.2 below:

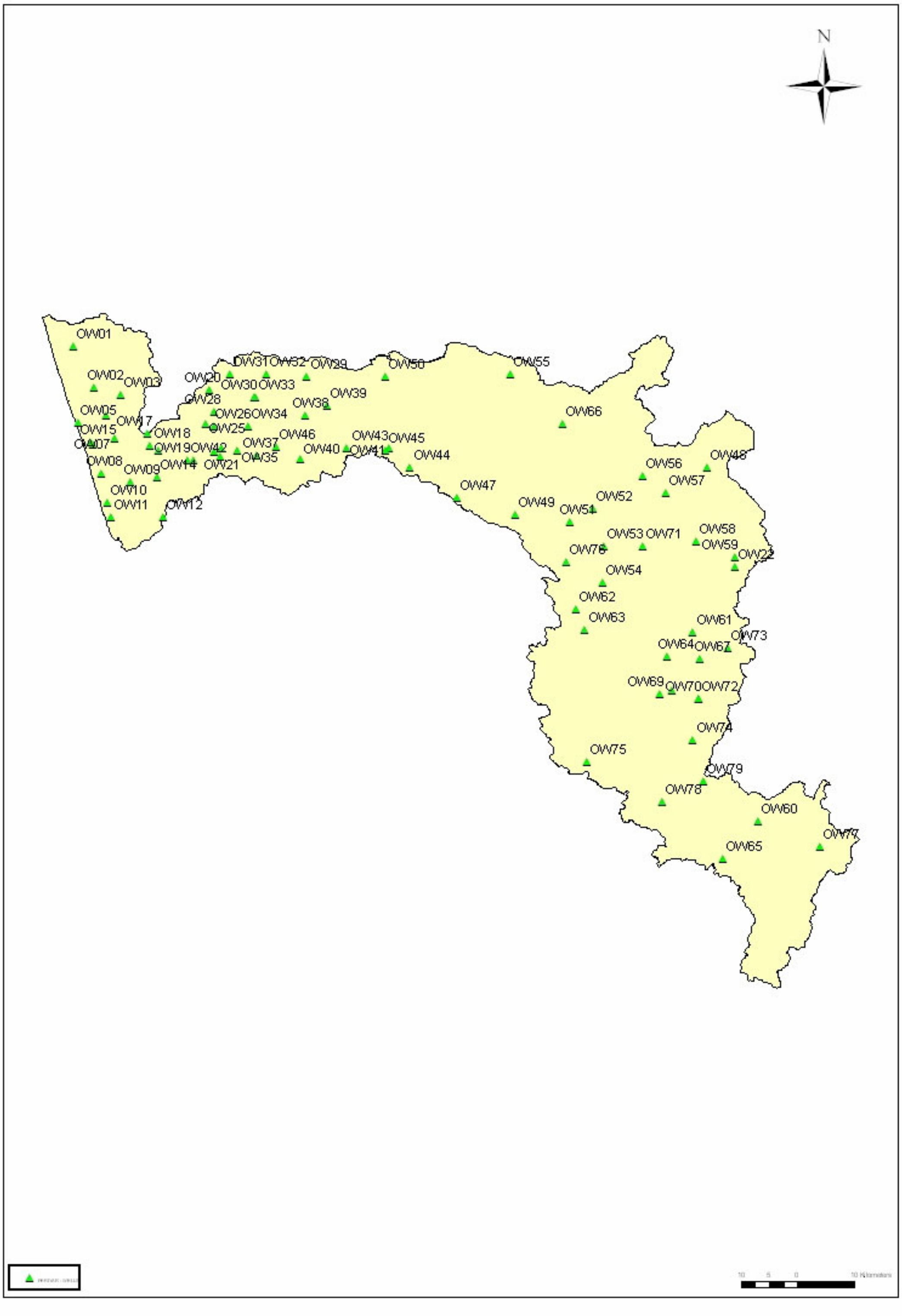


Fig. 6.1 Groundwater quality study locations of the Periyar River Basin

Table 6. 2 Indian Standards & WHO Guideline for Drinking Water.

Sl. No.	Parameter	BIS, Indian Standards (IS 10500:1991)		World Health Organization, 1993 (Guidelines) Maximum allowable concentration
		Desirable Limit	Permissible Limit	
1	Colour	5 Hazen Units	25 Hazen Units	15 True Colour Units
2	Turbidity	5.0 NTU	10 NTU	5.0 NTU
3	pH	6.5-8.5	No relaxation	6.5-8.5
4	Total Hardness (as $CaCO_3$)	300 mg/L	600 mg/L	500 mg/L
5	Chlorides (as Cl)	250 mg/L	1000 mg/L	250 mg/L
6	Residual Free Chlorine (When Protection against viral infection is required it should be *Min* 0.5 mg/L)	0.2 mg/L	-	-
7	Dissolved Solids	500 mg/L	2000 mg/L	1000 mg/L
8	Calcium (as Ca)	75 mg/L	200 mg/L	-
9	Sulphate (as SO42-)	200 mg/L	400 mg/L	400 mg/L
10	Nitrate (as NO3-)	45 mg/L	100 mg/L	10 mg/L
11	Fluoride (as F-)	1.0 mg/L	1.5 mg/L	1.5 mg/L
12	Phenolic Compounds (as C6H5OH)	0.001 mg/L	0.002 mg/L	-
13	Anionic Detergent (as MBAS)	0.2 mg/L	1.0 mg/L	-
14	Mineral Oil	0. 01 mg/L	0.03 mg/L	-
15	Alkalinity	200 mg/L	600 mg/L	-
16	Boron	1.0 mg/L	5.0 mg/L	-

Micro Pollutants (Heavy Metals & Pesticides)				
17	Zinc (as Zn)	5.0 mg/L	15 mg/L	5.0 mg/L
18	Iron (as Fe)	0.3 mg/L	1.0 mg/L	0.3 mg/L
19	Manganese (as Mn)	0.1 mg/L	0.3 mg/L	0.1 mg/L
20	Copper (as Cu)	0.05 mg/L	1.5 mg/L	1.0 mg/L
21	Arsenic (as As)	0.05 mg/L	No relaxation	0.05 mg/L
22	Cyanide (as CN)	0.05 mg/L	No relaxation	0.1 mg/L
23	Lead (as Pb)	0.05 mg/L	No relaxation	0.05 mg/L
24	Chromium (as Cr^{6+})	0.05 mg/L	No relaxation	0.05 mg/L
25	Aluminium (as Al)	0.03 mg/L	0.2 mg/L	0.2 mg/L
26	Cadmium (as Cd)	0.01 mg/L	No relaxation	0.005 mg/L
27	Selenium (as Se)	0.01 mg/L	No relaxation	0.01 mg/L
28	Mercury (as Hg)	0.001 mg/L	No relaxation	0.001 mg/L
29	**Total Pesticides**	Absent	0.001 mg/L	-
1	Sodium	-	-	200 mg/L
2	Aldrin & dieldrin	-	-	0.03 µg/L
3	DDT	-	-	1.0 µg/L
4	Lindane	-	-	3.0 µg/L
5	Methoxychlor	-	-	30.0 µg/L
6	Benzene	-	-	10.0 µg/L
7	Hexachlorobenzene	-	-	0.01 µg/L
8	Pentachlorophenol	-	-	10.0 µg/L

The hydrochemical investigation in the present study is restricted to the major ions concentrations, distributions, their relative abundance, bacteriological studies and the pattern of the variability in groundwater chemistry of the phreatic aquifers of the study area. Chemical parameters such as pH, EC, Alkalinity, Total Hardness, Calcium, Magnesium, Sodium, Potassium, Carbonate, Bicarbonate, Sulphate, Iron, Fluoride, and Chloride, (Table 6.1a &b, See Appendix I).

6.2.1 Physical parameters

6.2.1 (a) Colour

Drinking-water should ideally have no visible colour. Colour in drinking-water is usually due to the presence of coloured organic matter (primarily humic and fulvic acids) associated with the humus fraction of soil. Colour is also strongly influenced by the presence of iron and other metals, either as natural impurities or as corrosion products. It may also result from the contamination of the water source with industrial effluents and may be the first indication of a hazardous situation. The source of colour in drinking-water should be investigated, particularly if a substantial change has taken place. Most people can detect colours above 15 true colour units (TCU) in a glass of water. Levels of colour below 15 TCU are usually acceptable to consumers, but acceptability may vary. High colour could also indicate a high propensity to produce by-products from disinfection processes. No health-based guideline value is proposed for colour in drinking-water (WHO, 1993).

6.2.1 (b) Taste and odour

Taste and odour can originate from natural inorganic and organic chemical contaminants and biological sources or processes (e.g., aquatic micro-organisms), from contamination by synthetic chemicals, from corrosion or as a result of water treatment (e.g., chlorination). Taste and odour may also develop during storage and distribution due to microbial activity. These can be caused by the decaying of leaves, plants, organic matter, copper, iron, and manganese, which may be objectionable. Taste and odour in drinking-water may be indicative of some form of pollution or of a malfunction during water treatment or distribution. It may therefore be an indication of the presence of potentially harmful substances.

6.2.1 (c) Turbidity

Turbidity refers to water clarity. Turbidity in drinking water is caused by particulate matter that may be present from source water as a consequence of inadequate filtration or from suspension of sediments in the distribution system. It may also be due to the presence of inorganic particulate matter in groundwater. The appearance of water with a turbidity of less than 5 NTU is usually acceptable, although this may vary with local circumstances (WHO, 1993). Particulates can protect micro-organisms from the effects of disinfection and can stimulate bacterial growth. In all cases where water is disinfected, the turbidity must be low so that disinfection can be effective. No health-based guideline value for turbidity has been proposed by WHO, ideally median turbidity should be below 0.1 NTU for effective disinfection, and changes in turbidity are an important process control parameter. As per BIS, the desirable limit is 5 NTU and the maximum permissible limit is 10 NTU. Excessive amounts of turbidity also make water aesthetically objectionable. The turbidity of all the groundwater samples collected are between 0 and 1 and hence within the safe limit of the desirable limit of the BIS standards.

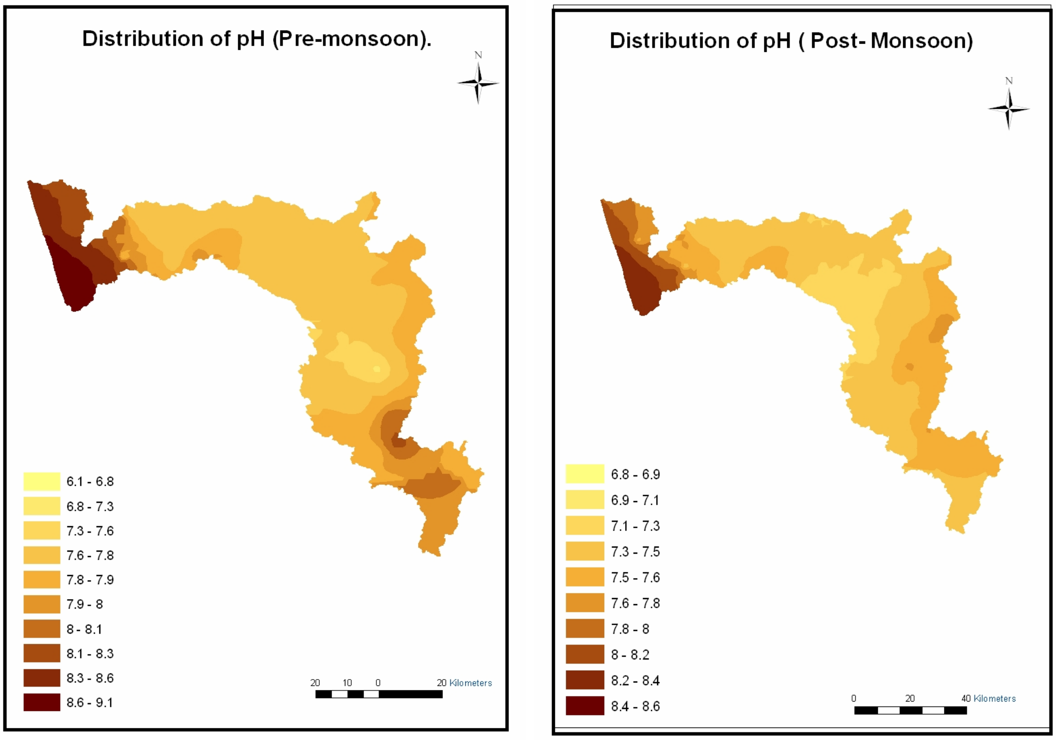
6.2.2 Chemical parameter

6.2.2 (a) pH

In water, a small number of water (H_2O) molecules dissociate and form hydrogen (H^+) and hydroxyl (OH^-) ions. If the relative proportion of the hydrogen ions is greater than the hydroxyl ions, then the water is defined as acidic. If the hydroxyl ions dominate, then the water is defined as alkaline. The relative proportion of hydrogen and hydroxyl ions are measured on a negative logarithmic scale from 1 (acidic) to 14 (alkaline): 7 being neutral. The range of desirable limit of pH of water prescribed for drinking purposes by BIS (1991) and WHO (1993) is 6.5 to 8.5, while that of EEC (Lloyd and Heathcote, 1985) is 6.5 to 9.0.

The pH is classified into 5 zones, viz (i) 0-5, (ii) 5-6. (iii) 6-7, (iv) 7-8 and (v) > 8. During the pre-monsoon season the study area show a minimum pH of 6.11, maximum of 9.2 and an average of 7.97 (Table 1a). The lowland region shows a minimum pH of 8.2, maximum of 9.2 at Edavanavakkad and an average of 8.69. The pH of groundwater of Eloor area and Vypin Island are slightly above the desirable limits. The midland region exhibits a minimum pH of 7.1, maximum of 8.7 and average of 7.92. The groundwater of this region is generally good for drinking purposes. The highlands show a minimum pH of 6.11 at Irattayar, maximum of 8.8 at Kumily and an average of.7.87. In the Pre-monsoon period the Groundwater of the highland region is generally good for drinking purposes except Kumily where the pH is slightly higher (8.7 - 9.1 during pre-monsoon) and at Irattayar where the pH is slightly lower (6.1 during pre-monsoon) than the desirable limits of 6.5-8.5(BIS, 1993).

The distribution of pH in groundwater of the study area during the post-monsoon season is given in Table 6.1b and also presented in thematic map (Fig. 6.2b). During the post-monsoon period, the minimum pH of the study area is 6.76, maximum is 8.8 and the average is 7.69. The lowland region shows the minimum pH of 7.8 at Pappinavattom, maximum of 8.8 at Malippuram and an average of 8.34. In the midland region the minimum pH is 6.78 at Nedumbassery, the maximum is 8.5 at Alwaye and the average is 7.53. In the highland region, the minimum pH is 6.76 at Adimali, maximum pH is 8.2 at Kumily and the average is 7.46. The pH values of the highland and midland region are safe for drinking purposes and in the lowland region, at Malippuram, Munambam, Edavanakkad of the Vypin area and the Eloor Industrial area are above the desired limit of drinking water standards. The probable reasons for the varying pH include soil chemistry and human input like that from the fertilizers.



(a) **(b)**

Fig. 6.2. Distribution of pH in the study area.
(a) Pre-monsoon (b) Post-monsoon.

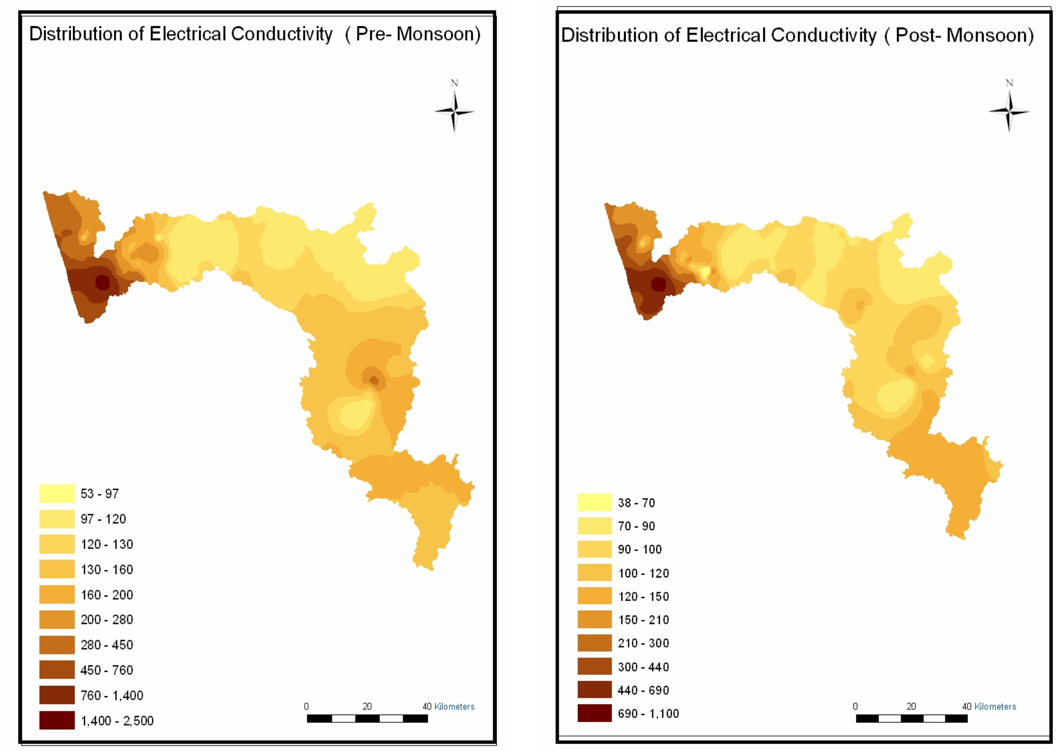
6.2.2 (b) Electrical Conductivity (EC)

Electrical conductivity is the measure of concentration of electrolyte in water in the form of ions (Karanth, 1987). It is measured in microsiemens/cm (μS/cm). Most of the inorganic salts, acids and bases when dissolved in water make it a good conductor, but organics do not. BIS does not prescribe any limit for this parameter. However, potable water normally register specific conductance from 50 to 500 μS/cm.

The distribution of EC values of the study area during the pre-monsoon period is presented in Table 6.1a. and in the thematic map (Fig.

6.3a). During the period the minimum EC of the study area was 50 μS/cm at Malayattur, maximum was 5550 μS/cm at Edavanakkad and the average was 349.49 μS/cm. In the highland region of the study area, the minimum EC was 63 μS/cm at Vellilamkandom, the maximum was 390 μS/cm at Vazhathoppe and the average was 149.45 μS/cm. In the midland region, the minimum EC was 50 μS/cm at Malayattur, the maximum was 465 μS/cm at Chalackal and the average was 163.67 μS/cm. In the lowland region, the minimum EC was 190 μS/cm at Pappinavattom, the maximum was 5550 μS/cm at Eloor-north and the average was 842.57 μS/cm. There is a sudden increase in EC in the lowland region of the basin. A sudden rise in conductivity in the water indicates addition of some pollutants to it (Trivedi and Goel, 1986). The area having the highest EC also has the highest pH.

The distribution of EC during the post-monsoon season is presented in Table 6.1b and also in the thematic map (Fig. 6.3b). During the period in the lowland region of the basin, the minimum EC was 120 μS/cm, maximum was 3100 μS/cm and the average was 494.86μS/cm. The maximum EC was observed at Eloor. In the midland region, the minimum of 35 μS/cm was observed in Malayattur and the maximum of 375 μS/cm at Chalackal. The average EC of the region was 130.44 μS/cm. The minimum EC was 38 μS/cm at Devikulam, maximum was 290 μS/cm at Santhampara and the average was 108.89 μS/cm. The EC in the highland and midland regions were within the permissible limit and in the Vypin Island and Eloor of the lowland region were above the safe limits.



(a) (b)

Fig. 6.3 Distribution of Electrical conductivity in the study area.
(a) Pre-monsoon (b) Post-monsoon

6.2.2 (c) Hardness as CaCO3

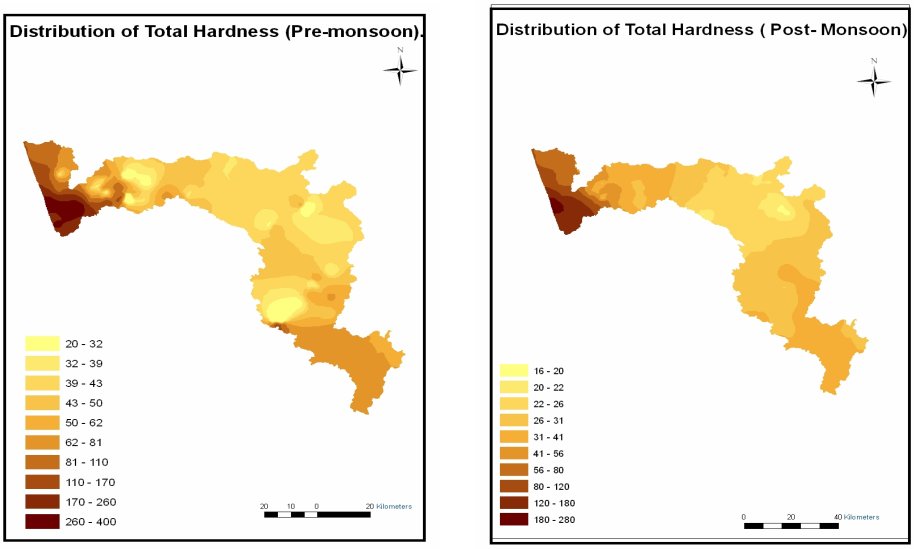
Probably the most common problem identified with ground water quality is that of hardness. Hardness is defined as water that is rich in calcium (Ca^{+2}) and/or magnesium (Mg^{+2}) (Taylor and Howard, 1994). Hard water generally causes the formation of soap curd in pipes, sinks, and bathtubs. Calcium may precipitate as calcium carbonate within the plumbing and clog pipes. Detergents and soaps do not readily dissolve in hard water, which limits the formation of lather and soap. Hardness of water-quality is an indication of the concentration of alkaline salts in water, mainly calcium and magnesium. If the water is “hard” then more soap, detergent or shampoo are necessary to raise lather. It also produces scale in hot water pipes, heaters, boilers and other units in which the temperature of water is increased materially. Carbonate hardness is caused by calcium and magnesium bicarbonate; non-carbonate hardness is caused by calcium sulfate, calcium chloride, magnesium sulfate, and magnesium chloride. The following scale may assist in appraising water hardness, measured by weight of dissolved salts (in milligrams per unit of water).

Table 6.3 Classification of the degree of hardness in water (Sawyer and McCarty, 1967)

Water class	*Range of Hardness (mg/L as CaCO3)*
Soft	0 - 75
Moderately Hard	75 - 150
Hard	150 - 300
Very Hard	>300

The spatial distribution of hardness of the study area during the pre-monsoon and the post-monsoon seasons are presented in Table 6.1a &b and thematic maps (Fig. 6.4a &b). The minimum total hardness of the groundwater of the study area during the pre-monsoon season is 19.1 mg/L the maximum is 795.84 mg/L and the average is 99.42 mg/L. The minimum total harness of the highland region of the area is 20 mg/L at Munnar, the maximum is 142 mg/L at Nedumkandom and the average is 44.53 mg/L. In the midland region of the study area, the minimum hardness is 10.1 mg/L., at Panamkuzhi, maximum is 182.5 mg/L., at Aluva-east and the average is 54.44 mg/L. In the lowland region the minimum hardness is 82.58 mg/L., at Pappinavattom, the maximum is 795.84 mg/L., at Eloor-north and the average is 207.7 mg/L.

During the post-monsoon season, the minimum hardness in the study is 11.17 mg/L, maximum is 508.77 mg/L and the average is 62.5 mg/L. The minimum hardness in the highland region of the study area is 14.92 mg/L at Neriyamangalam, maximum is 71 mg/L at Kumily and the average is 31.84 mg/L. The minimum hardness in the midland region is 12.72 mg/L at Manjapra and maximum is 123.04 mg/L at Aluva east and the average is 41.48 mg/L. The minimum hardness in the lowland region is 40.42 mg/L at Papinavattom, maximum is 508.7 mg/L at Eloor-north and the average is 155.48 mg/L.



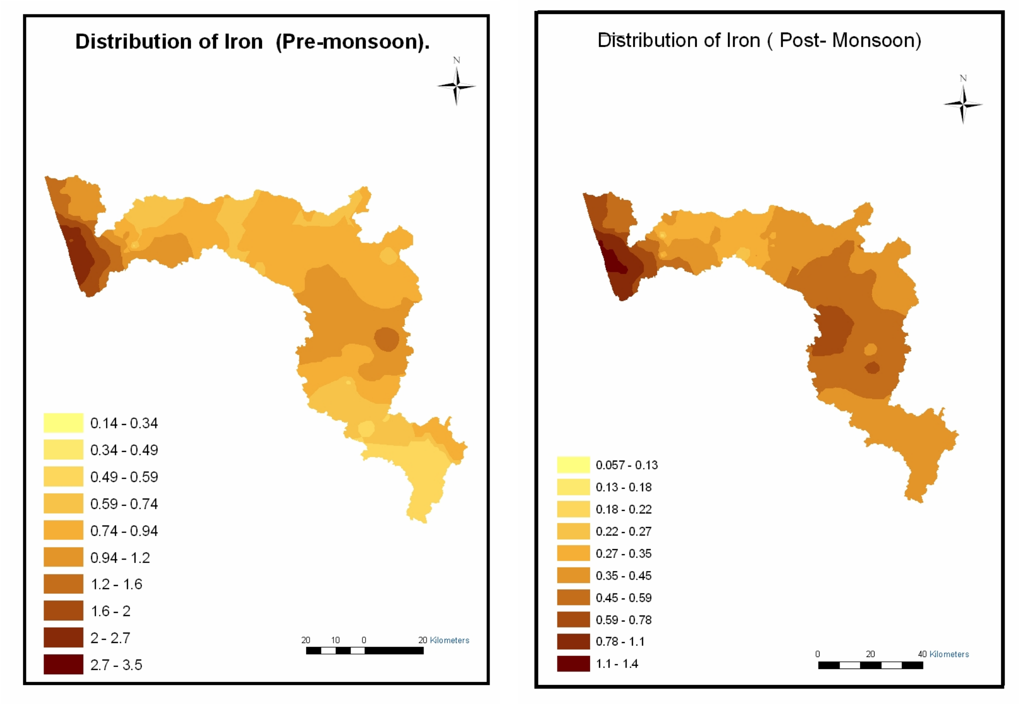
(a) (b)

Fig. 6.4 Distribution of Total hardness in the study area.
(a) Pre-monsoon (b) Post-monsoon

The quality of groundwater in the Vypin and Eloor area is hard to very hard, above the permissible range and in all other regions of the lowland region, the quality of groundwater is soft to moderately hard and is suitable for drinking purposes. This can be attributed to the proximity to the industrial belt.

6.2.2 (d) Total Iron

Excess Iron ($Fe^{+2,\ +3}$) in ground water provides the typical well water "rust" taste. Not only the unpleasant taste, iron can also stain plumbing fixtures, clothes, and dishes. Most ground water has at least trace amounts of iron because its presence in nature is so common. The Bureau of Indian Standards prescribes the limit of drinking water not to exceed 0.3 mg/L. Iron concentrations exceeding this level may cause the characteristic reddish staining. Iron is generally derived from minerals contained within the underlying bedrock. Acidic rainwater releases iron ions into solution. The concentration of iron in groundwater will be higher under more reducing conditions due to bacteriological action on organic matter which leads to the formation of various humic and fluvic compounds (Aplin and Zhao, 1989; White et al. 1991). Iron content in groundwater is mainly due to the dissolution of iron oxides (Singhal and Gupta, 1999). Under reducing conditions, the iron from the gneisses and iron oxides and hydroxides from laterites are leached into solutions in ferrous state.



(a) (b)

Fig. 6.5. Distribution of Iron in the study area.
(a) Pre-monsoon (b) Post-monsoon

Treatment for the reduction of iron can be done by several methods depending upon the concentration and the pH of the water. Initially, a water softener can be used to eliminate iron to tolerable levels. Secondly, potassium permanganate or "green sand" filters are highly successful. Aeration as well can aid in the precipitation of iron, thus removing it from the water.

Iron dissolved in groundwater is in the reduced Fe^{++} form. This form is soluble and normally does not cause any problems by itself. Fe^{++} is oxidised to Fe^{+++} on contact with oxygen in the air or by the action of iron related bacteria. Fe^{+++} forms insoluble hydroxides in water. These are rusty red and cause staining and blockage of screens, pumps, pipes, reticulation systems etc. If the iron hydroxide deposits are produced by iron bacteria then they are also sticky and the problems of stain and blockage are many times worse. The presence of iron bacteria may be indicated by rusty slime inside headwork's, reduced water flow form the bore and unpleasant odour from water pumped from the bore, slimy deposits blocking main and lateral lines, severe staining on pavements, walls foliage etc.

The distribution of iron in the study area, during the pre-monsoon and post-monsoon periods is presented in Table (6.1a & b) and in thematic maps (Fig. 6.5a &b). During the pre-monsoon period, the groundwater of the study area in general exhibits the minimum iron content of 0.05 mg/L maximum of 4 mg/L and the average is 1.14 mg/L. The highland region of the basin shows a minimum 0.03 mg/L at Nirmala city. maximum of 1.54 mg/L at Kattappana and an average of 0.15 mg/L. The midland region shows the minimum of 0.08 mg/L at Manjapra, maximum of 2.9 mg/L at Aluva and the average is 0.39 mg/L. The lowland region exhibits a minimum of 0.05 mg/L at Lokamalleswaram, the maximum of 4 mg/L at Munambam and the average is 0.98 mg/L.

During the post-monsoon period, the groundwater of the area has the minimum iron of 0.04 mg/L, maximum of 1.18 mg/L and the average is 0.58 mg/L. In the lowland region, the minimum is 0.06 mg/L at Lokamalleswaram, maximum is 1.8 mg/L at Munambam and average is 0.98 mg/L. In the midland region, the minimum is 0.04 mg/L at Angamaly, maximum is 1.5

mg/L at Aluva and the average is 0.4. In the highland region the minimum is 0.15 mg/L at Adimali, Kumili and Marayoor, maximum is 1.2 mg/L at Kattappana and the average is 0.55 mg/L.

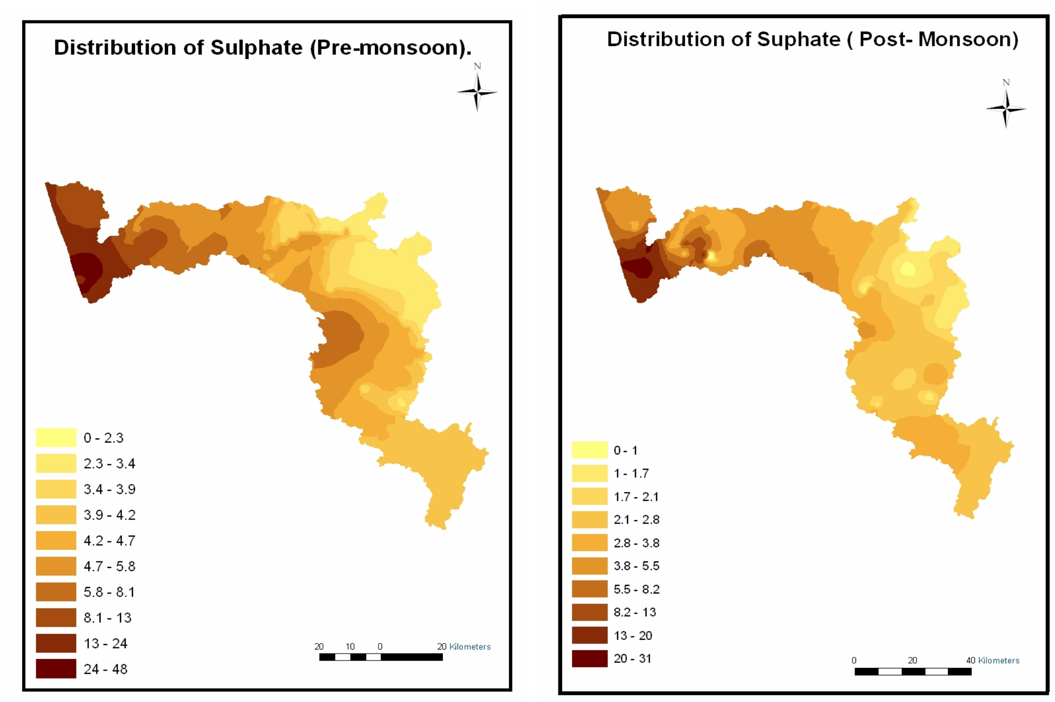
Total iron in the lowland exceeds the permissible limit in the Vypin island, Varapuzha and Eloor regions of the lowland region, in the midland it is within the permissible limit except at Aluva and in the Highland region at Pallivasal, Vazhathoppe and Kattappana exceeded the permissible limit during the Post-monsoon season.

6.2.2 (e) Fluoride

High concentrations of fluoride, often significantly above 1.5 mg/L, constitute a severe problem over large parts of India. Long-term use of groundwater for drinking has resulted in the onset of widespread fluorosis symptoms, from mild forms of dental fluorosis to crippling skeletal fluorosis. As per BIS the prescribed limit for fluoride is 0.6 to 1 mg/L. If the fluoride level in the water is beyond the limit, the water source should be either rejected or suitable treatment is to be done to bring down the fluoride level to the desired level.

The distribution of fluoride in the study area, during the pre-monsoon and the post-monsoon seasons are presented in Table (6.1a &b).The minimum concentration of fluoride in the groundwater of the area during the pre-monsoon period is 0.01 mg/L, maximum is 2.88 mg/L at Eloor-north, and the average is 0.38 mg/. In all the other area, the fluoride concentration is within the permissible limit. The minimum fluoride concentration in the study area during the post-monsoon period is 0.01 mg/L, maximum concentration is 0.92 mg/L at Eloor and the average concentration is 0.17 mg/L. The fluoride concentration of the study area during the post-monsoon period is within the permissible limit.

6.2.2 (f) Sulphate



(a) (b)

Fig. 6.6 Distribution of Sulphate in the study area
(a) Pre-monsoon (b) Post-monsoon

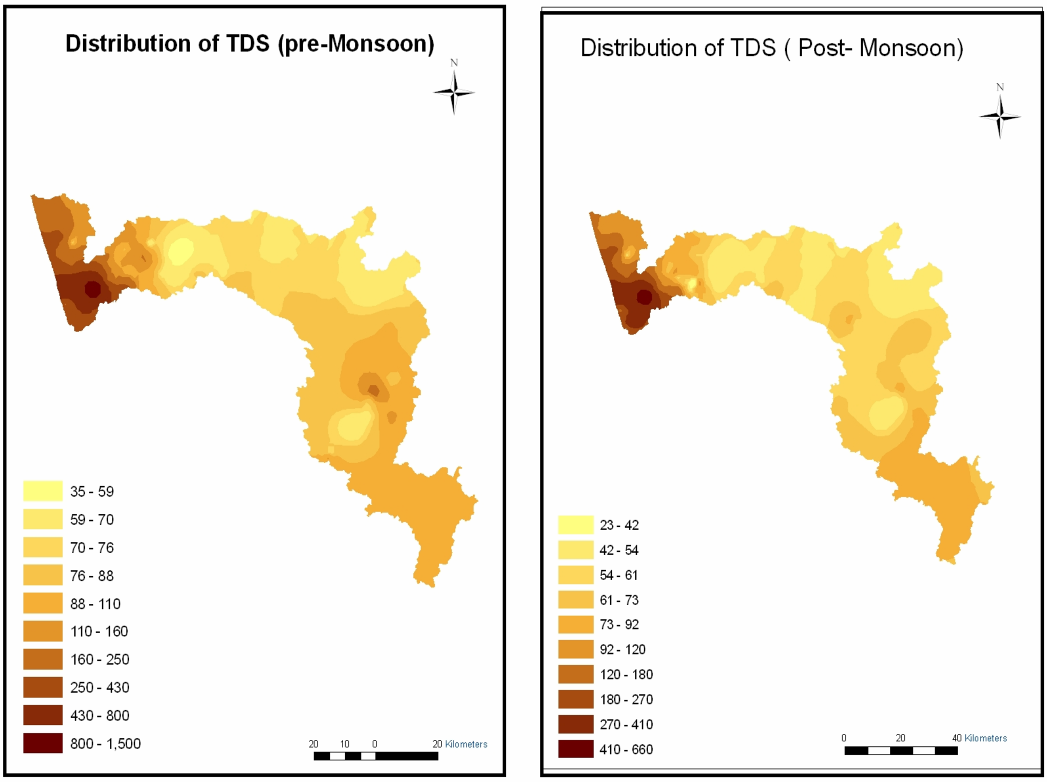
The pre-monsoon and post-monsoon distribution of sulphate in the study area is presented in Table 6.1a and b and thematic map Fig. 6.6a & b. The presence of sulphate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed users. Taste impairment varies with the nature of the associated cation. It is generally considered that taste impairment is minimal at levels below 250 mg/L (WHO 1993). The distribution of sulphate in the study area, during the pre-monsoon and the post-monsoon seasons are within the desirable of limit of drinking water standards.

6.2.2 (g) Total Dissolved Solids (TDS)

Total dissolved solids (TDS), is defined as the concentration of all dissolved minerals in the water. TDS is a direct measurement of the interaction between ground water and subsurface minerals. Drinking water quality is affected by the presence of soluble salts. TDS indicate the general nature of water quality. Hence the level of TDS is one of the characteristics which decide the quality of drinking water. Groundwater with TDS value of less than 300 mg/L is excellent for drinking purposes (WHO, 1993). High TDS, greater than 1000 mg/L, is commonly objectionable or offensive to taste. TDS levels over 2000 mg/L are generally considered as not suitable for drinking due to strongly offensive taste. The WHO guidelines (1993) and BIS standard (1991) prescribed the maximum permissible limit of TDS as 500 mg/L.

Table 6. 4. The potability of water in terms of TDS (WHO, 1993)

Water class	TDS mg/L
Excellent	< 300
Good	300 - 6000
Fair	6000 - 900
Poor	900 - 1200
Unacceptable	> 1200



(a) (b)

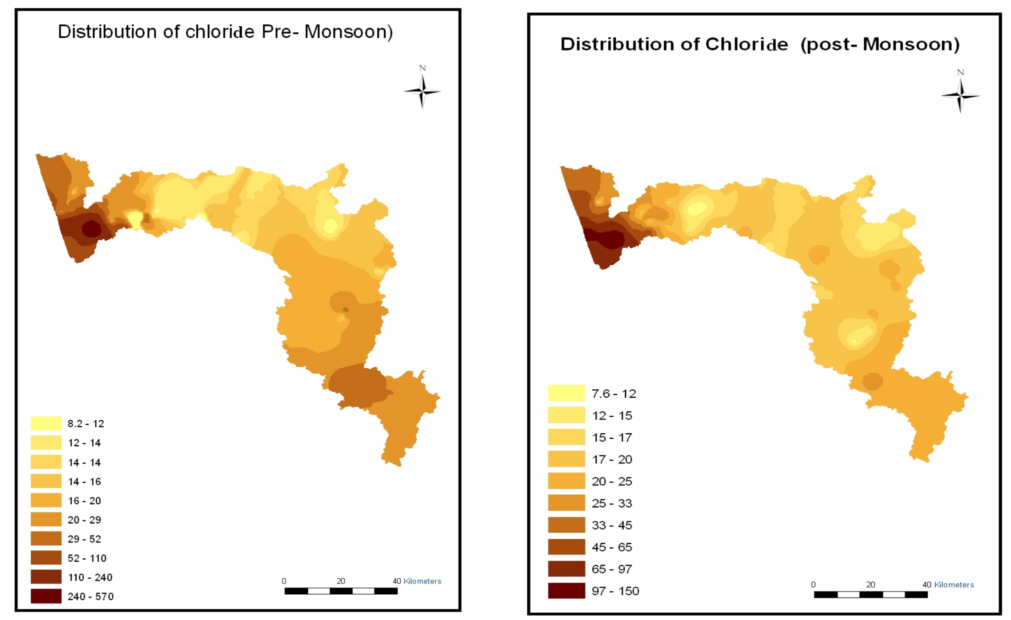
Fig. 6.7 Distribution of TDS in the study area
(a) Pre-monsoon (b) Post-monsoon

The distribution of TDS in the area, during the pre-monsoon and post-monsoon periods is presented in Table (6.1a & b) and also in thematic maps (Fig. 6.7a & b). In the area in general, the minimum TDS during the pre-monsoon period is 30 mg/L, maximum is 3030 mg/L and the average is 190.29 mg/L. The area having the highest TDS has the highest pH and EC also. During the period the minimum TDS in the lowland is 39 mg/L at Poyya, maximum is 3330 mg/L and the average TDS is 523.45 mg/L. In the midland region the minimum TDS is 30 mg/L at Malayattur, maximum is 258 mg/L at Kuttamangalam and average is 100.11 mg/L. In the highland region, the minimum TDS is 43.2 mg/L at Munnar maximum is 234 mg/L at Nedumkandom and the average is 142.5 mg/L. During the post-monsoon period, the minimum TDS of the study area is 21 mg/L maximum is 1860 mg/L and the average is 125.41 mg/L. In the lowland region, the minimum TDS is 72 mg/L at Pappinavattom, the maximum is 1860 mg/L at Eloor North and the average is 294.22 mg/L. In the midland region, the minimum TDS is 21 mg/L at Malayattur, the maximum is 221 mg/L at Chalackal and the average is 78.05 mg/L. In the highland region, the minimum TDS is 39 mg/L at Devikoulam, maximum is 174 mg/L at Nedumkandom and the average is 104.09 mg/L. The TDS in the study area is within the maximum permissible limit of the BIS except in Eloor area, where the limit exceeded the above limits. In general, the TDS limit of the groundwater of the midlands and highlands are within the permissible limit and in the lowland region it is above limits during the pre-monsoon period.

The hydrogeological properties of rocks will have a strong influence on the extent of water/rock reaction. Area with high groundwater- flow velocities usually has low dissolved solids due to 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 unconfined aquifers. In the study area the low TDS values can be attributed to high rainfall which causes dilution.

6.2.2 (h) Chloride

The distribution of chloride in the area, during the pre-monsoon and post-monsoon periods is presented in Table 6.1a & b and in thematic map (Fig. 6.8 a &b). The chloride during the pre-monsoon period shows the lowest concentration of 6.7 mg/L at Malayattur and the maximum concentration of 1523 mg/L in Eloor – north. The maximum concentration is found in the lowland region than in the highland and midland regions during the period. The minimum chloride concentration of 6.7 mg/L was found in the midland region next to the highland (8.5 mg/L) and lowland regions (21 mg/L). The average concentration of chloride in the study area during the pre-monsoon period was 45.95 mg/L. The average concentration in the lowland was 124.98 mg/L, in the midland was 18.28 mg/L and in the highland was 32.43 mg/L.



(a) (b)

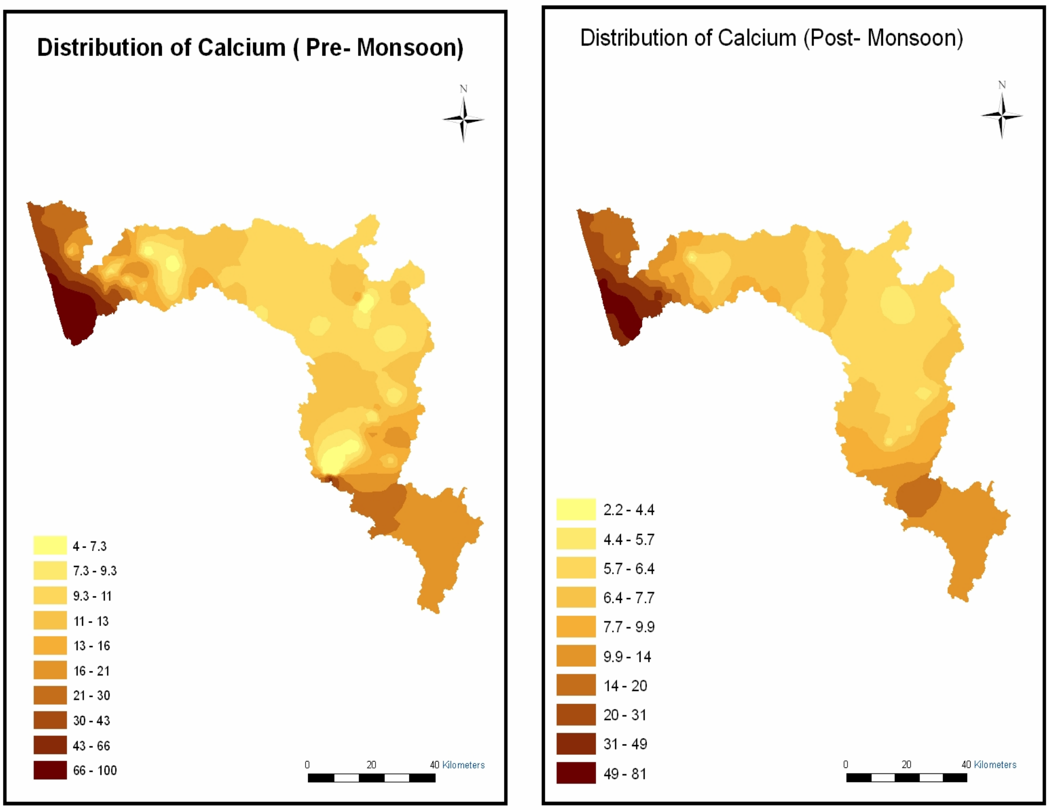
Fig. 6.8 Distribution of Chloride in the study area
(a) Pre-monsoon (b) Post-monsoon

During the post-monsoon period the maximum chloride concentration of 700.2 mg/L was found at Eloor-north, the minimum concentration of 5.2 mg/L was found at Vallom and the average concentration of the basin was 27.96 mg/L. The minimum concentration in the lowland is 10 mg/L, midland is 5.2 mg/L and the highland is 5.4 mg/L. The maximum concentration in the lowland is 700.2 mg/L, midland is 38 mg/L and in the highland is 118 mg/L. The average chlorine concentration in the lowland is 132.6 mg/L, midland is 13.86 mg/L and in the highland is 22.76 mg/L. The chloride content in the lowland region is found above the permissible limit in Vypin Island, Varapuzha and Eloor regions.

In general the chloride content in the groundwater of the basin is within the desirable limit during the pre-monsoon season except in the Vypin Island, Varapuzha and Eloor regions and during the post-monsoon season it is within the desirable except in the Eloor region.

6.2.2 (i) Calcium

The distribution of Ca^{++} in the area, during the pre-monsoon and post-monsoon periods is presented in Table (6.1a & b) and in thematic maps (Fig. 6.9a & b). The maximum concentration of calcium found during the pre-monsoon period was 132.4 mg/L in the Eloor-north region. The highest desirable limit is 75 mg/L and the maximum permissible limit (BIS, 1991) is 200 mg/L. The concentration of calcium is also above the highest desirable limit in Vypin island, Varapuzha and Eloor regions. All the other parts of the study area are within the highest desirable limits. The minimum concentration of calcium during the pre-monsoon period is 3.9 mg/L and the average is 27.15 mg/L. The highest concentration of Calcium found during the post-monsoon was104 mg/L at Eloor. It is above the highest desirable limit and within the limit and in all other area, it is above the highest desirable limit and within the maximum permissible limit. The minimum concentration is 2 mg/L and the average is 18.19 mg/L.



(a) **(b)**

Fig. 6.9 Distribution of Calcium in the study area
(a) Pre-monsoon (b) Post-monsoon

The distribution of other major cations and anions of the study area such as Na^+, K^+, Mg^{++}, $NO3^-$, $HCO3^-$ and $CO3^-$, during the pre-monsoon and post-monsoon periods is presented in Table 6.1a and b and in thematic maps (Fig. 6.10a to 6.16b). The concentration of Na^+ is above the maximum allowable concentration is the Eloor area. The concentration of alkali is above the desirable limit in the Edavanakkad area above the maximum permissible limit in Eloor region.

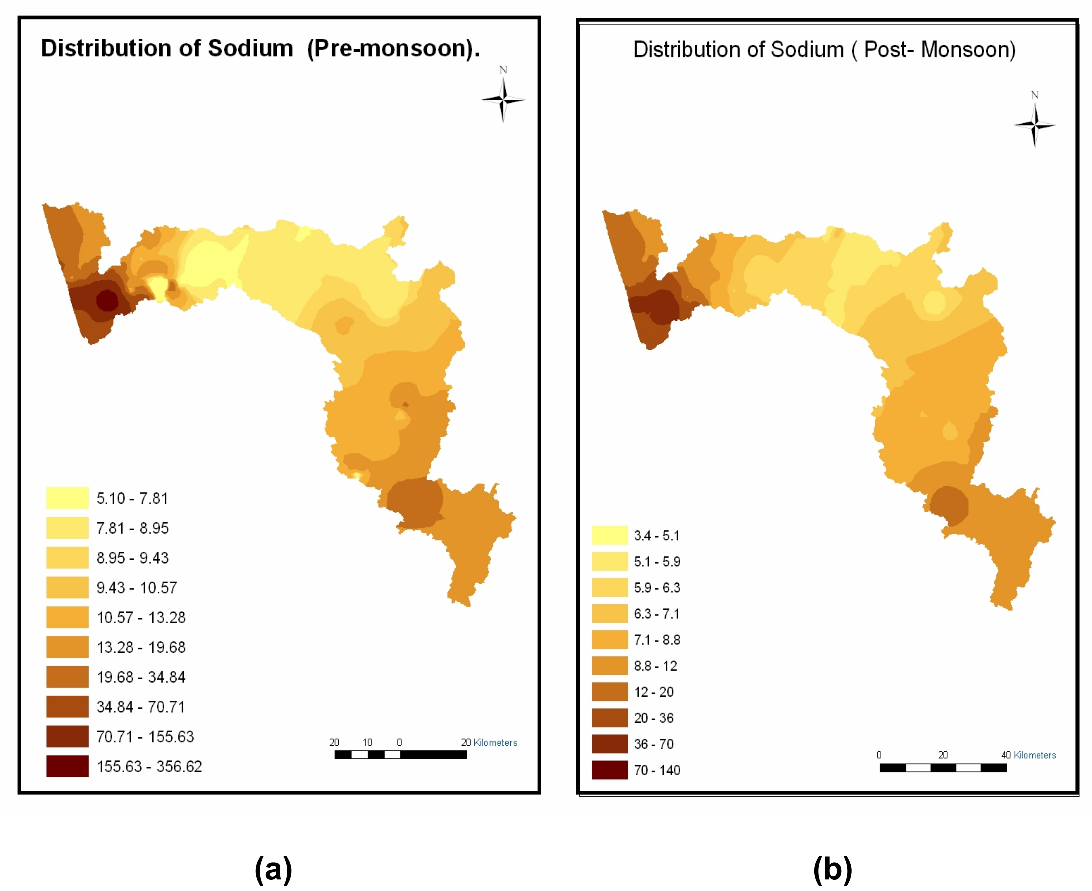
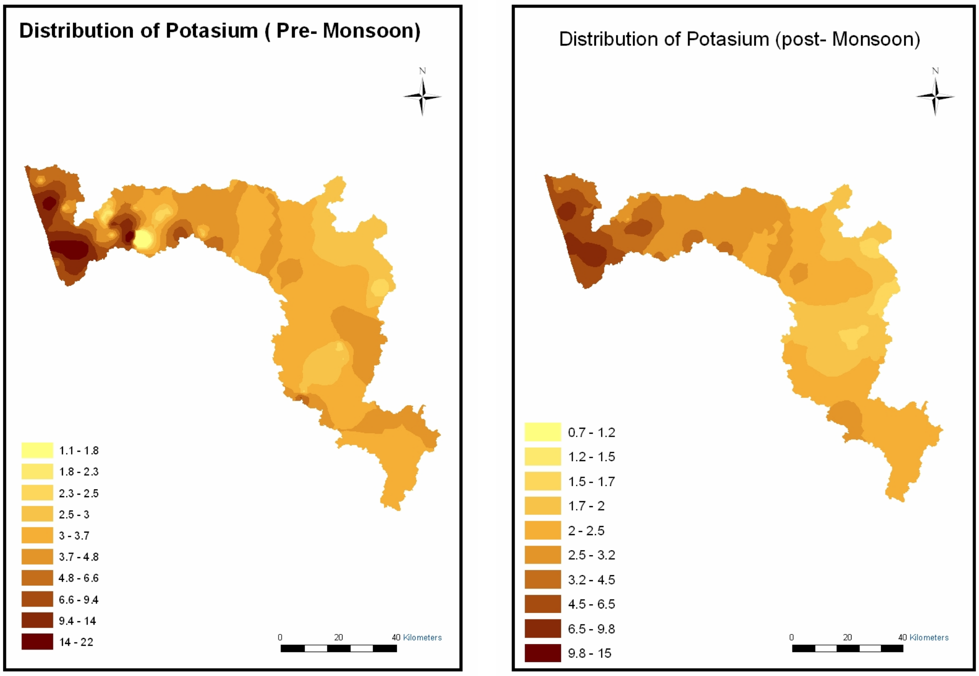


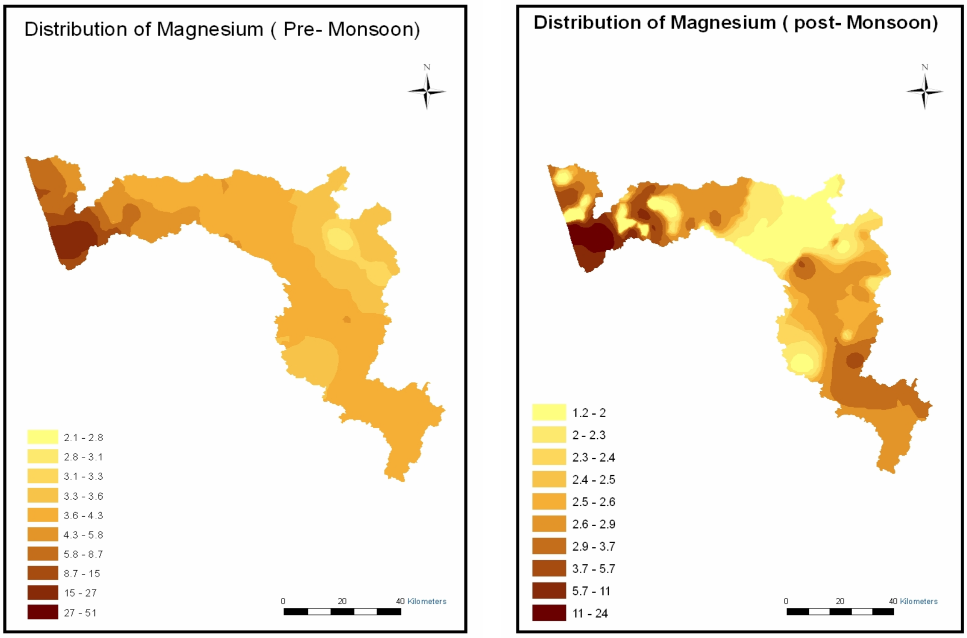
Fig. 6.10 Distribution of Sodium in the study area
(a) Pre-monsoon (b) Post-monsoon



(a) (b)

Fig. 6.11 Distribution of Potassium in the study area

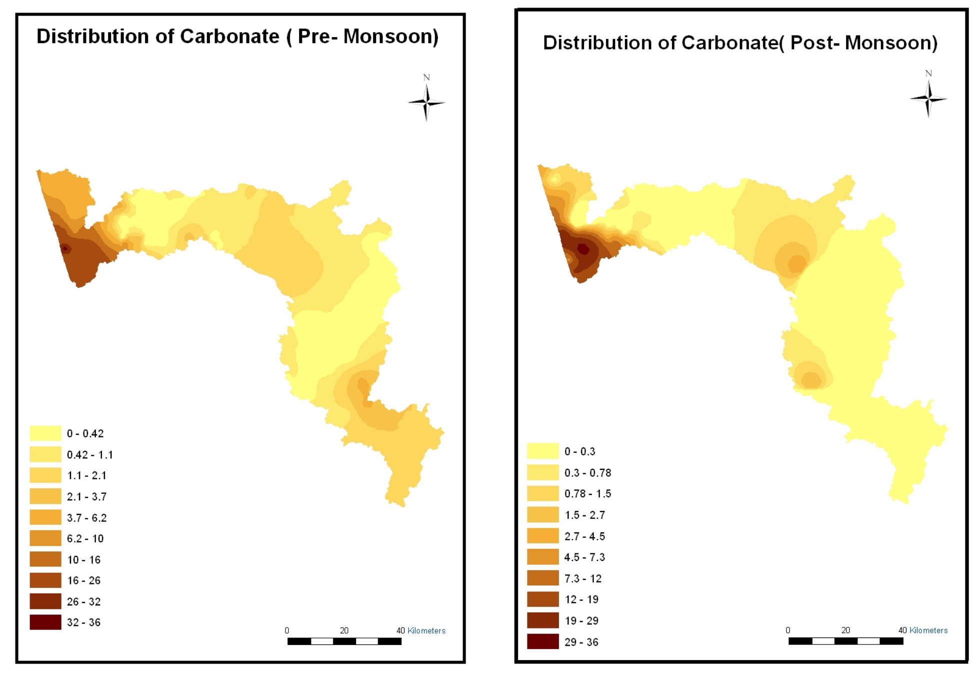
(a) Pre-monsoon (b) Post-monsoon



(a) (b)

Fig. 6. 12 Distribution of Magnesium in the study area

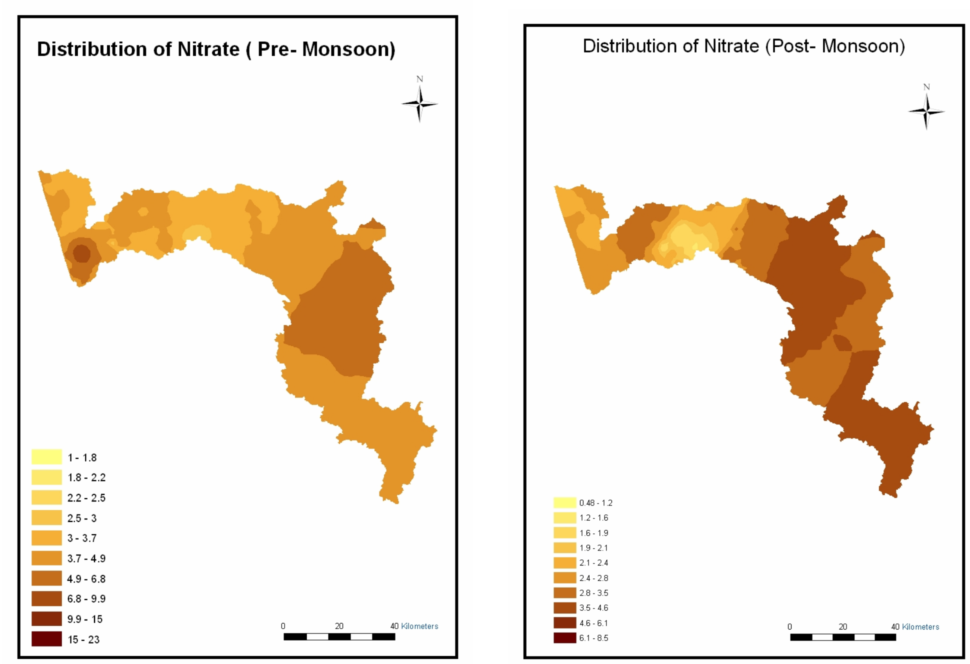
(a) Pre-monsoon (b) Post-monsoon



(a) (b)

Fig. 6.13 Distribution of Carbonate in the study area

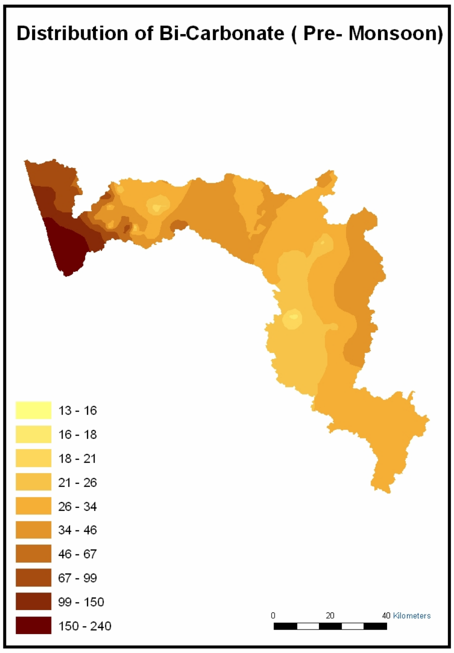
(a) Pre-monsoon (b) Post-monsoon

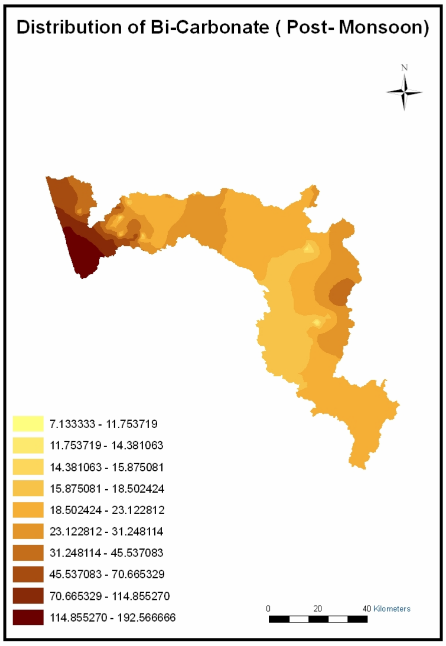


(a) (b)

Fig. 6.14 Distribution of Nitrate in the study area

(a) Pre-monsoon (b) Post-monsoon

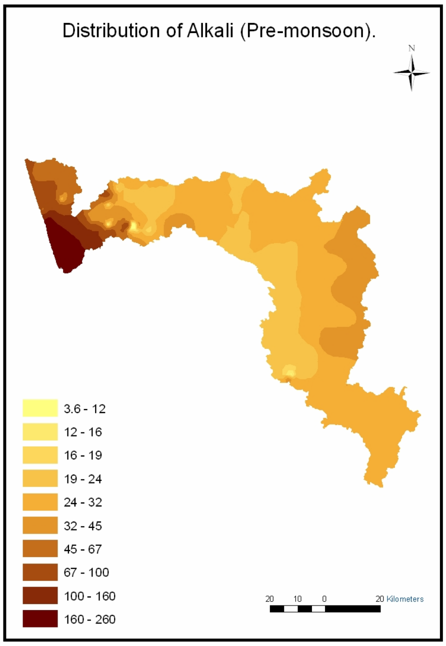


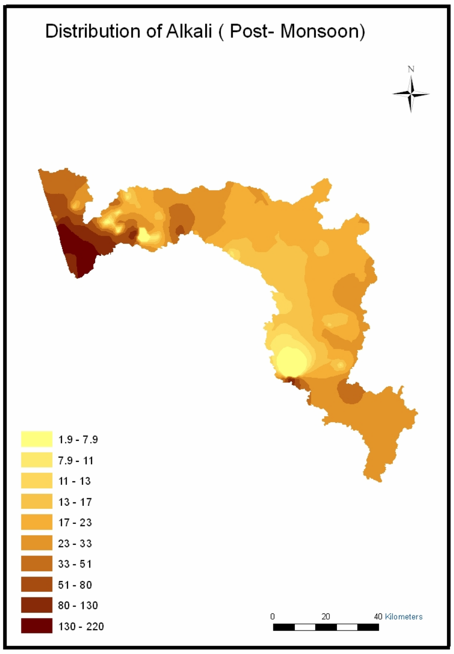


(a) (b)

Fig. 6.15 Distribution of Bi-carbonate in the study area

(a) Pre-monsoon (b) Post-monsoon





(a) (b)

Fig. 6.16 Distribution of Alkali in the study area

(a) Pre-monsoon (b) Post-monsoon

6.2.3 Bacteriological Analysis.

6.2.3 (a) Microbial pathogens and their control.

Along with the differences in mineral composition, water contains different levels of microorganisms. Bacteriological tests are available to determine whether water is bacteriologically safe for human consumption. The microbiological guidelines ensure that drinking water is free from micro-organisms which can cause disease. The provision of such a supply is of paramount importance to the health of a community. The most common and widespread health risk associated with drinking water is contamination, either directly or indirectly, by human or animal excreta, and with the micro-organisms contained in faeces. If the contamination is recent, some of the micro-organisms which cause these diseases may be present in the water. Drinking this water or using it in food preparation may cause new cases of infection. Those who drink groundwater that has not been disinfected are at increased risk of infection and diseases from pathogenic microorganisms (Macler and Merkle, 2000). Those at greatest risk of infection are infants and young children, people whose immune system is suppressed, the sick, and the elderly.

6.2.3 (b) Total Coliform bacteria

Total coliform bacteria are a group of bacteria found in high numbers in both human and animal intestinal wastes and are therefore found in water that has been contaminated with fecal material. Unfortunately, bacteria with the biochemical characteristics of total coliforms are also found in non-contaminated water. Thus, in the absence of fecal coliforms, the presence of total coliforms may indicate older fecal contamination or the presence of decaying organic matter. Although the total coliform bacteria group is a less reliable indicator of sewage contamination, because of its superior survival characteristics, it is preferred as an indicator of treatment adequacy in drinking water supply systems. Total coliforms are analyzed in the laboratory using the membrane filter test and are reported as colony forming units (CFU) per 100 millilitres (ml). As per WHO (1993), in disinfected drinking water, the maximum acceptable concentration is zero total coliforms per 100 ml in all samples.

Table 6. 5 Bacteriological analysis result of the study area

Well No.	LOCATION	DISTRICT	Period			
			Pre-monsoon		Post-monsoon	
			Total Colifo rms	Fecal Coliforms	Total Coliforms	Fecal Coliforms
			MPN	MPN	MPN	MPN
OW01	Pappinivattom	Thrissur	185	146	296	272
OW02	Lokamalleswaram	Thrissur	440	440	687	596
OW03	Poyya	Thrissur	0	0	65	45
OW04	North paravur	Ernakulam	325	325	445	445
OW05	Munambam	Ernakulam	1050	958	1075	1034
OW06	Pallipuram	Ernakulam	750	750	1025	976
OW07	Edavanakad	Ernakulam	850	850	1250	1250
OW08	Varapuzha	Ernakulam	1075	1025	1325	1325
OW09	Njarakkal	Ernakulam	510	510	826	778
OW10	Malipuram	Ernakulam	825	825	1540	1432
OW11	Edappally	Ernakulam	54	25	85	65
OW12	Eloor nort	Ernakulam	621	415	452	395
OW13	Kottapuram	Ernakulam	225	204	208	188
OW14	Chalakka	Ernakulam	185	157	210	205
OW15	Alwaye	Ernakulam	65	65	0	0

OW16	Karukutty	Ernakulam	0	0	0	0
OW17	Chowara	Ernakulam	0	0	25	25
OW18	Vazhakkulam	Ernakulam	0	0	0	0
OW19	Nedumbassery	Ernakulam	15	12	0	0
OW20	Kaladi	Ernakulam	1450	1345	910	825
OW21	Angamali	Ernakulam	1300	1300	1450	1450
OW22	Manjapara	Ernakulam	175	145	205	205
OW23	Kanjur	Ernakulam	25	18	32	30
OW24	Vallom	Ernakulam	0	0	0	0
OW25	Malayattur	Ernakulam	65	54	95	68
OW26	Panamkuzhy	Ernakulam	0	0	0	0
OW27	Kuruppampady	Ernakulam	0	0	54	54
OW28	Kottapadi	Ernakulam	0	0	18	18
OW29	Thattekad	Ernakulam	58	45	0	0
OW30	Kuttamangalam	Ernakulam	0	0	0	0
OW31	Pindimana	Ernakulam	125	105	15	15
OW32	Keerampara	Ernakulam	445	445	315	287
OW33	Neriyamangalam	Ernakulam	75	65	225	225
OW34	Marayoor	Idukki	65	65	85	85
OW35	Valara	Idukki	15	15	0	0
OW36	Adimali	Idukki	452	405	525	525
OW37	Kallar	Idukki	0	0	0	0
OW38	Vellatuval	Idukki	125	125	0	0
OW39	Munnar	Idukki	543	456	625	554
OW40	Devikulam	Idukki	123	95	154	126
OW41	Poopara	Idukki	0	0	0	0
OW42	Udumbanchola	Idukki	321	201	115	95
OW43	Vazhathope	Idukki	16	16	65	65
OW44	Idikki	Idukki	32	25	95	85
OW45	Irattayar	Idukki	0	0	0	0
OW46	Nedumkandam	Idukki	65	54	115	115
OW47	Pambadumpara	Idukki	0	0	0	0
OW48	Kattappana	Idukki	201	155	325	295
OW49	Ayyappancoil	Idukki	0	0	0	0
OW50	Chakkupallom	Idukki	0	0	0	0
OW51	Vandanmed	Idukki	65	55	0	0
OW52	Pampupara	Idukki	15	10	55	55
OW53	Elappara	Idukki	29	19	79	64
OW54	Vandiperiyar	Idukki	195	195	276	255
OW55	Kumily	Idukki	208	182	335	265

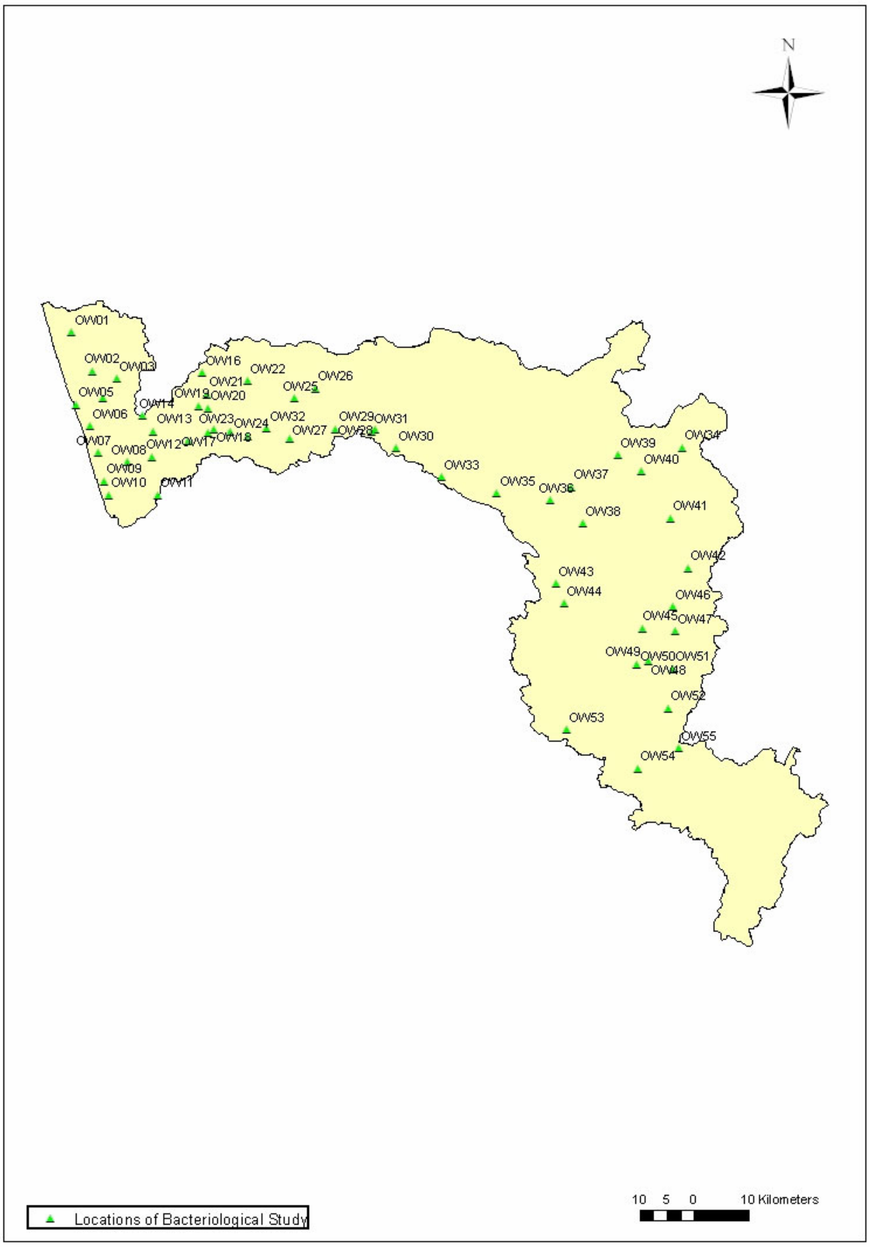


Fig. 6. 17 Bacteriological study locations.

6.2.3 (c) Fecal Coliforms

Fecal coliform bacteria are a subset of the total coliform bacterial group and are also are found in human and animal intestinal wastes. However, they are a more precise indicator of the presence of sewage contamination than total coliforms. The fecal coliform bacteria group includes the genera Escherichia and to a lesser extent, Klebsiella and Enterobacter. Fecal coliforms are analyzed in the laboratory using the membrane filter method and are reported as colony forming units (CFU) per 100 ml. The fecal coliform bacteria test measures the quantity of bacteria capable of producing gas from EC medium within 24 hours when incubated at 44.5°C. In disinfected drinking water, the maximum acceptable concentration of fecal coliforms is zero fecal coliforms per 100 ml (WHO, 1993).

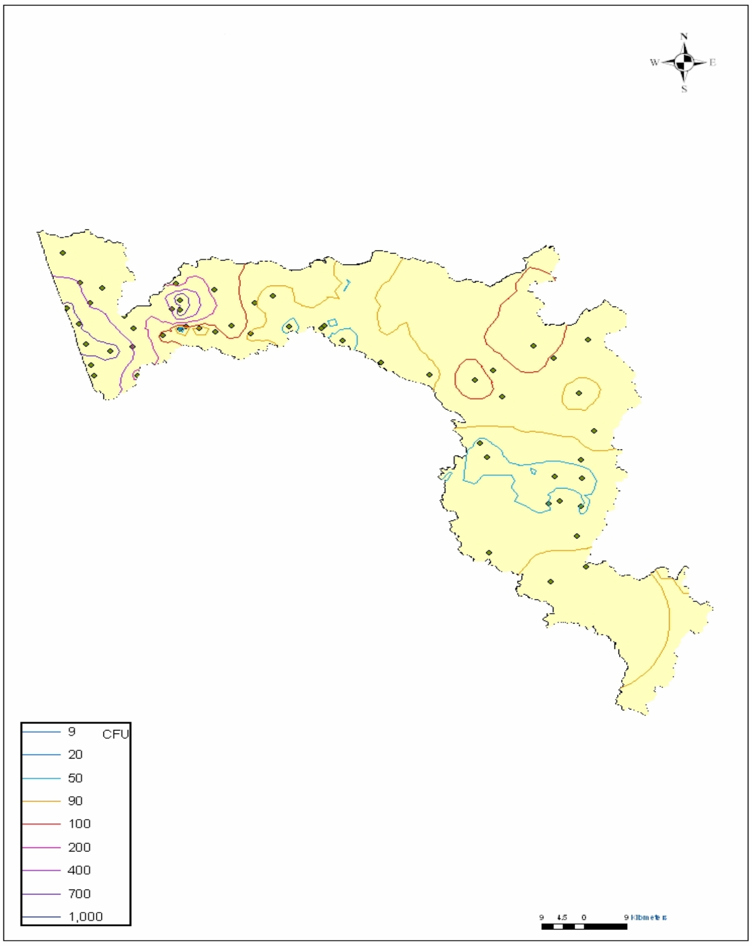


Fig. 6. 18 Distribution of fecal coliform bacteria in the study area during the pre-monsoon period.

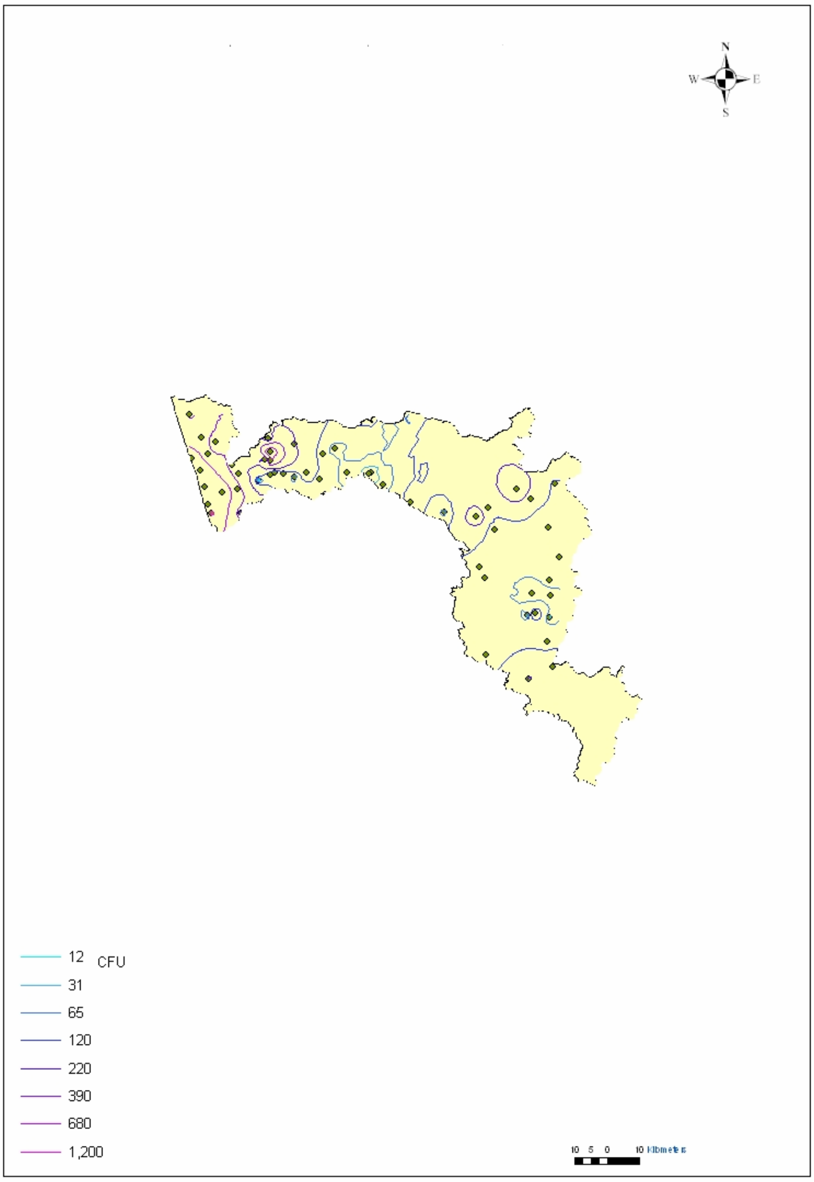


Fig. 6. 19 Distribution of fecal coliform bacteria in the study area during the post-monsoon season

As a part of the present water quality studies of the area, testing for two types of bacteria i.e., total coliform organisms and fecal coliform were carried out in the laboratory. To be considered safe, water suitable for drinking must be free of these organisms. As part of the present study pre-monsoon and post-monsoon water samples were collected from 52 open dug wells (Fig.6.17) of the study area scattered uniformly along the lowlands, midlands and highlands and the results are given in Table 6. These samples were analysed using the standard procedures. During the pre-monsoon season, the maximum total coliforms observed are 1450 CFU and the maximum fecal coliform is 1345 CFU at Kaladi. During the post-monsoon season, the maximum concentration of both the total coliform and fecal coliform bacteria was found at Angamaly. In both the cases the probable source is the unscientifically constructed septic tanks adjacent to these wells. From the analysis of the above data it is observed that in general, the threat of the growth of coliform bacteria is mainly dependent on the hydrogeological conditions of the area. The density of growth of bacteria is maximum where the aquifer is unconsolidated and the water table is at shallower depths. In the study area, the maximum influences of the microbial organisms are observed at the coastal plains where the water table is at shallower depths and the aquifer is mainly the unconsolidated sediments. The presence of these organisms is very low or absent where the water table is at deeper depths and also where the aquifers are mostly consolidated formations. It is also observed that the enrichment of the microbial organisms are maximum during the post-monsoon season as the water table is at shallower depths during the period and also due to this reason, the enrichment of the coliform bacteria is at the maximum level in the lowland region than to the midland and highland regions.

6.3 HILL – PIPER DIAGRAM

As water flows through an aquifer, it assumes a characteristic chemical composition as a result interaction with the lithologic frame work (Janardhana Raju, et al., 2009). One method of comparing the results of chemical composition of ground water is with a trilinear diagram (Fig. 6.17). This diagram consists of two lower triangles that show the percentage distribution on the milliequivalent basis of the major cation (Mg^{++}, Ca^{++}, and Na^{+} and K^{+}) and the major anions (Cl^{-}, $SO4^{2-}$and $CO3^{2-}$ and $HCO3^{-}$) and a diamond-shaped part above that summarizes the dominant cation and anions to indicate the final water type (Piper,1944).

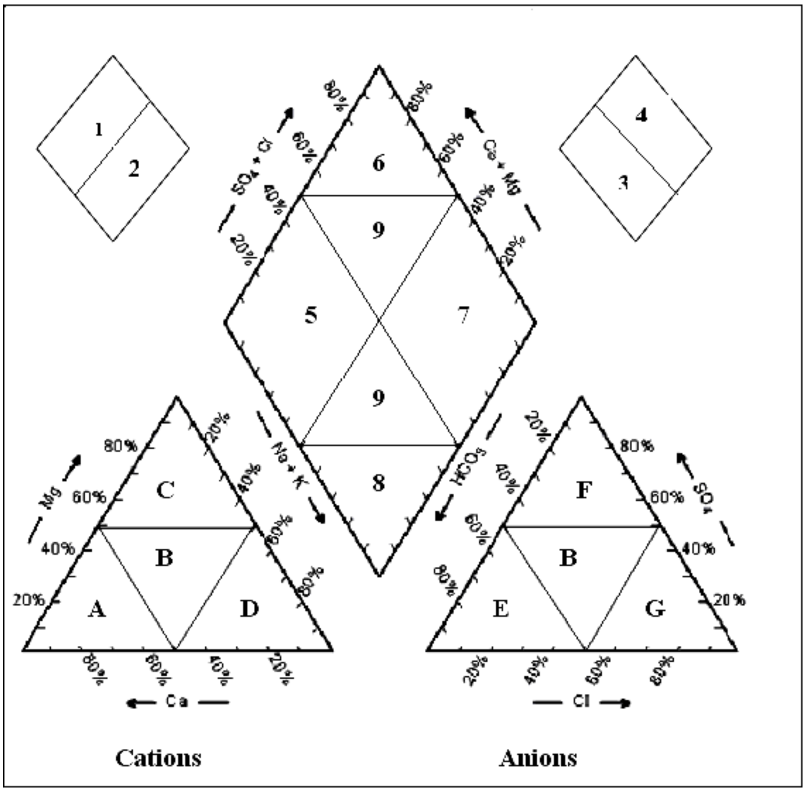


Fig. 6.20 Trilinear diagram showing the Hydrochemical facies of Groundwater (after Piper,1944).

This classification system shows the anion and cation facies in terms of major-ion percentages. The water types are designated according to the area in which they occur on the diagram segments (Fig. 6.17). The trilinear diagrams of Piper are very useful in bringing out chemical relationships among groundwater in more definite terms (Walton, 1970).

The data plot of the study area on the Piper's trilinear diagram in given in Fig, 6.18 & 19 respectively, correspond to the samples of the pre-monsoon and post-monsoon seasons respectively. The concentration of cation and anions are plotted as percentage in meq/l so that the total of cation and anions are made to 100 percent.

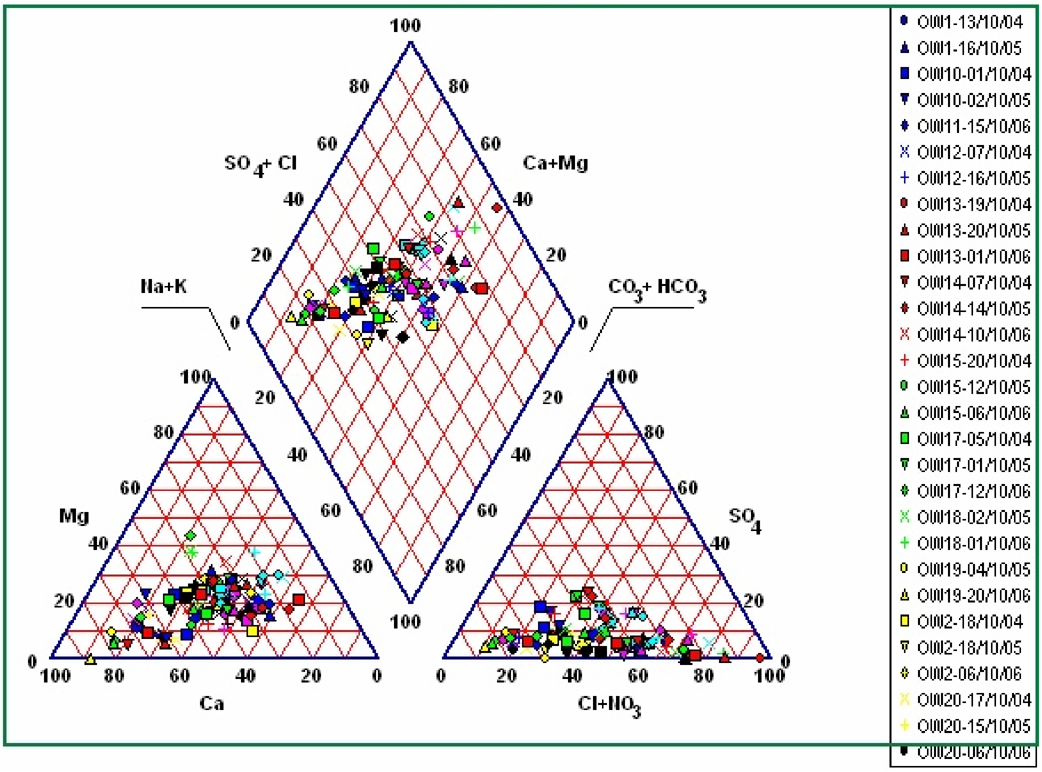


Fig. 6. 21 Piper diagram (Pre-monsoon)

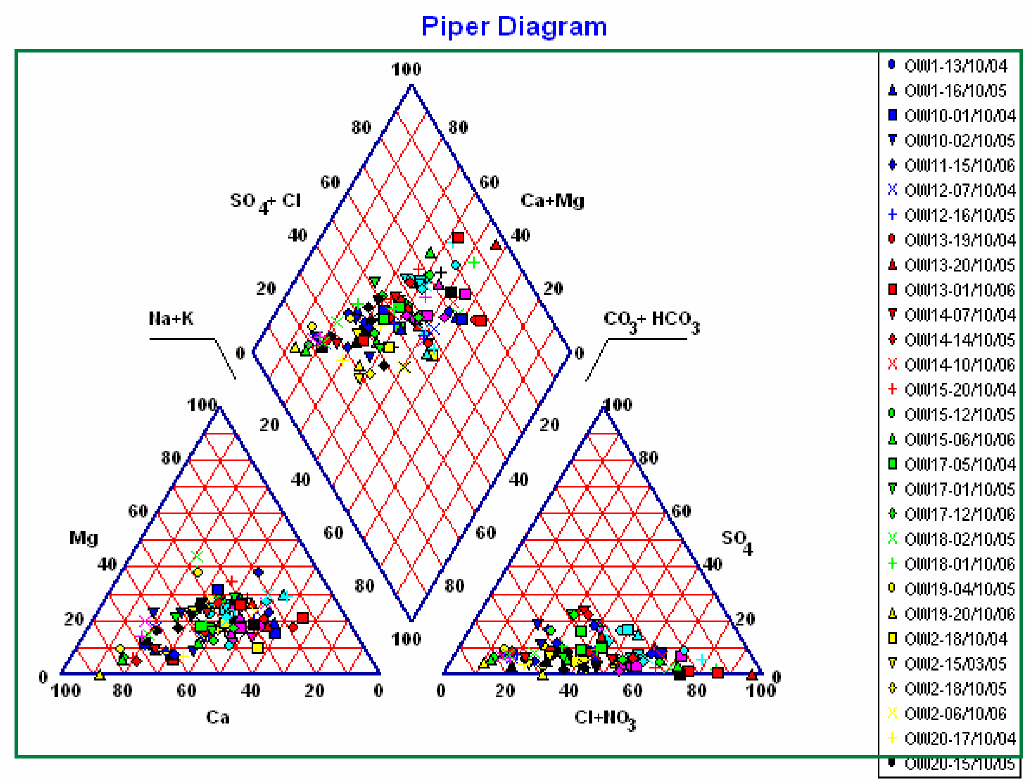
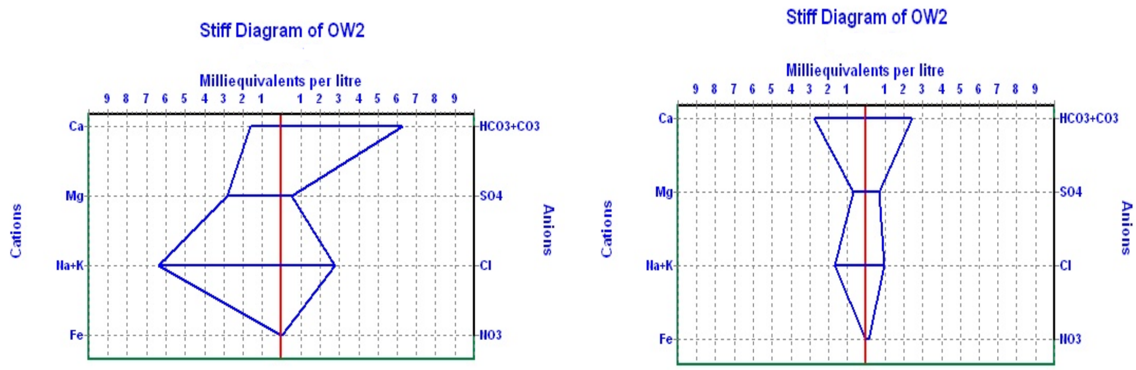


Fig. 6.22 Piper Diagram (Post-monsoon)

The diagram reveals the analogies, dissimilarities and different types of waters in the study area. The concept of hydrochemical facies was developed in order to understand and identify the water composition in different classes. Facies are recognizable parts of different characters belonging to the any genetically related system. Hydro-chemical facies are distinct zones that possess cation and anion concentration categories. 44 percent of the samples are falling under Ca-Na-HCO3-Cl type, 16 percent Ca-HCO3 type, 15 percent under Ca-Na-Cl type, 14 percent under Ca-HCO3-Cl type, 8 percent under Na-Cl type and 2 percent under Ca-Na-HCO3 type and 1 percent under Na-HCO3-Cl type. There is no significant change in the hydrochemical facies noticed during the pre-monsoon and post-monsoon periods.

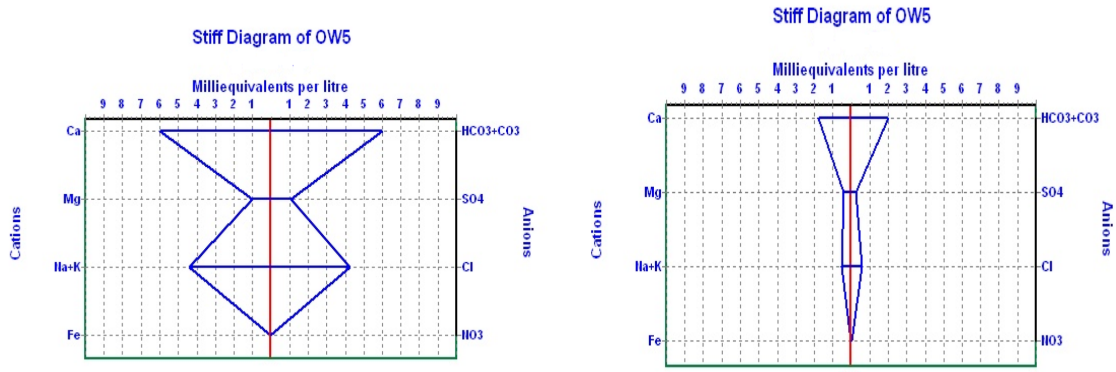
6.4 STIFF'S DIAGRAM

Stiff diagrams are a visual method to compare the relative proportion of ions in water (Stiff, 1951). Ion concentrations in milligrams per litre (mg/L) are converted into millequivalents per litre (meq/L). Cation are plotted on the left side of the diagram, with anions plotted on the right. The length of the diagram vertices is proportional to ionic content. Different ion concentrations can be plotted in Stiff's diagrams depending on aqueous geochemistry. All Stiff's diagrams will have sodium plus potassium, calcium and magnesium plotted on the left, with chloride, bi-carbonate plus carbonate and sulphates plotted on the right. When the nitrate (NO3) is to be plotted, then it will be plotted in the lower right area of the diagram. The points representing the values are connected to produce a distinctive shape or pattern. The patterns help to identify the water quality differences. The meq/l values of cation and anion are represented along the three horizontal axes at regular intervals as shown in Fig. 6. 20 a & b. The vertex points of the polygon are connected to produce a pattern whose shape is characteristics of a given type of water. The width of the pattern is an approximation of the total ionic strength (Hem, 1985). One feature is the tendency of a pattern to maintain its characteristic shape as the sample becomes diluted. It may be possible to trace the same type of groundwater contamination from a source by studying the patterns. The chemical composition of groundwater of a few typical open wells are plotted in the Stiff diagram as given in fig (6.23.1 to 5). The water quality of different wells can be compared using the diagram. For example OW8 is characterized with very high dissolved ions while OW37 is with very low ions. The pre-monsoon to post-monsoon variation in water quality is also depicted in these Stiff's diagrams.



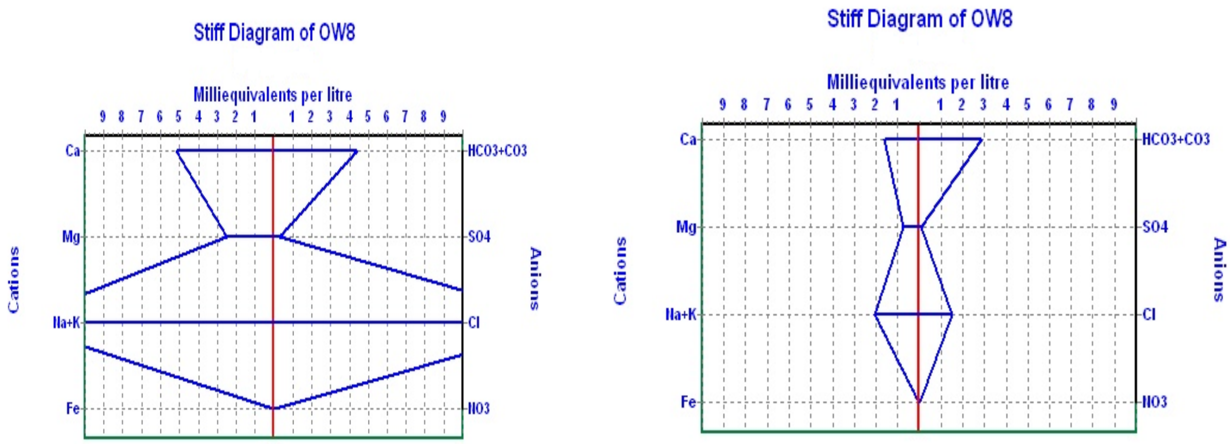
(a) **(b)**

Fig. 6.23.1 Stiff's diagrams of the pre-monsoon and post-monsoon water samples from Lokamalleswaram (OW-2)
(a) Pre-monsoon (b) Post-monsoon.



(a) **(b)**

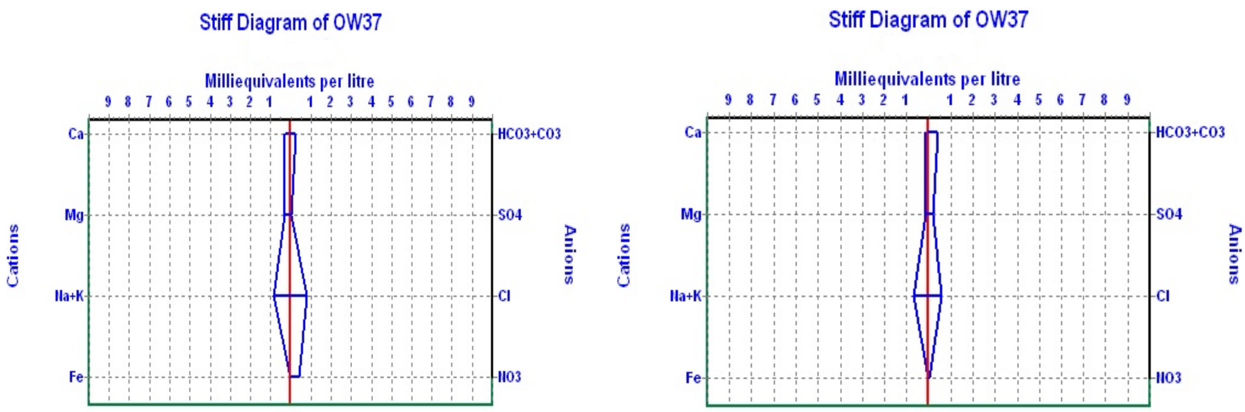
Fig. 6.23.2 Stiff's diagrams of the pre-monsoon and post-monsoon water samples from Munambam (OW -5)
(a) Pre-monsoon (b) Post-monsoon



(a) **(b)**

Fig. 6. 23.3 Stiff's diagrams of the pre-monsoon and post-monsoon water samples from Edavanakkad (OW-8)

(a) Pre-monsoon (b) Post-monsoon



(a) **(b)**

Fig. 6.23.4 Stiff's diagrams of the pre-monsoon and post-monsoon water samples from Vallom (OW – 3)

a) Pre-monsoon (b) Post-monsoon

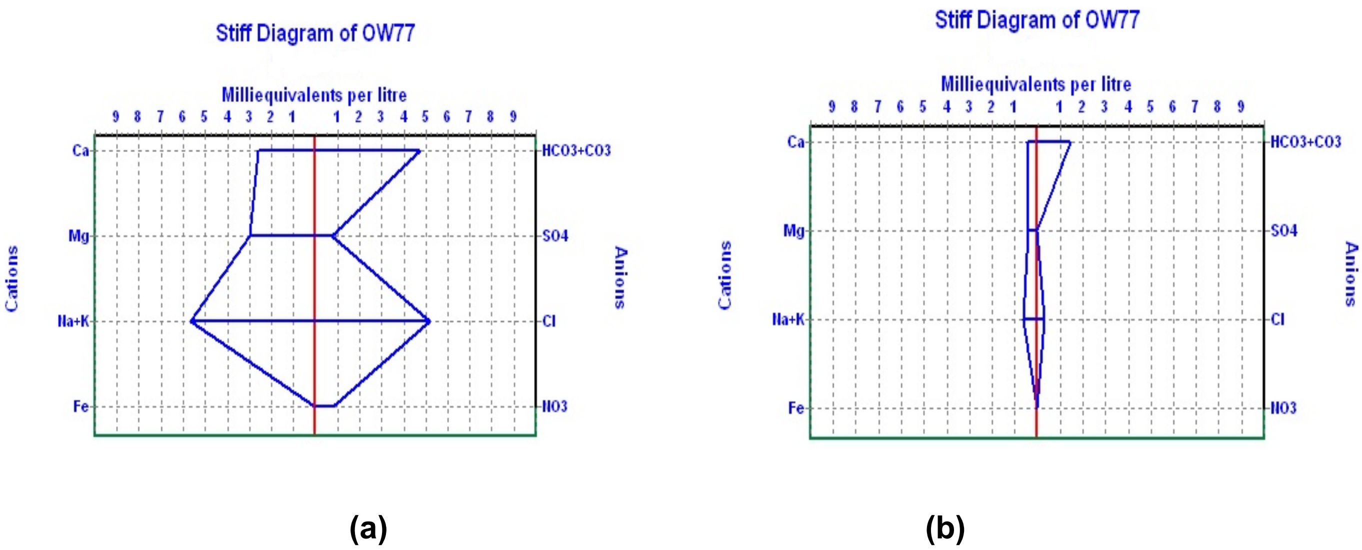


Fig. 6.23.5 Stiff's diagrams of the pre-monsoon and post-monsoon water samples from Kumili (OW – 77)

(a) Pre-monsoon (b) Post-monsoon

6.5 WATER QUALITY REQUIREMENTS FOR LIVESTOCK

Hem (1970) has suggested the upper limit for the concentration of TDS (mg/L) for the livestock. The upper limits for poultry, pigs, horses, cattle and sheep are 2860 mg/L, 5290 mg/L, 6435 mg/L, 7150 mg/L and 12900 mg/L respectively. As per this specification the groundwater of the midlands and highlands of the study area are suitable for animal consumption on all seasons, but the groundwater of the Eloor region of the lowlands is not suitable for poultry during the pre-monsoon period.

6.6 WATER QUALITY REQUIREMENTS FOR IRRIGATION

Agriculture is, by far, the largest water use at global level. Irrigation of agricultural lands accounted for 70% of the water used worldwide. In several developing countries, irrigation represents up to 95% of all water uses, and plays a major role in food the production and food security. Future agricultural development strategies depend on the possibility to maintain, improve and expand irrigated agriculture.

Irrigation water quality refers to the kind and amount of salt present in the water and their effects on crop growth and development. Salts are present in variable concentrations in all waters and the salt concentrations influence the osmotic pressure; the higher the concentration, the greater the osmotic pressure. Osmotic pressure in turn affects the ability of plants to absorb water through their roots. Plants can absorb water readily when osmotic pressure is low, but absorption becomes more difficult as the pressure increases. Even if the soil is thoroughly wet, plant roots have difficulty in absorbing water when the osmotic pressure is high. When the pressure is unusually high, it may even be impossible for plants to absorb sufficient water for normal plant growth. Under these conditions, plants may actually wilt when the roots are in water.

In the study area the main source of irrigation is groundwater. The surface water facility for irrigation is provided only in some parts of the midland region. Irrigation water quality is determined in several ways. The suitability of groundwater for irrigation is affected by the total content of soluble salts and relative proportion of Na, Ca, Mg etc. The EC and sodium concentrations are important in classifying irrigation water.

For the purpose of classification of irrigation water, Richards (1954) recognized four groups based on electrical conductivity.

Table 6. 6 Classification of Irrigation water (Richards, 1954)

Group	Electrical conductivity
Low	< 250 μs/cm
Medium	250 – 750 μs/cm
High	750 – 2250 μs/cm
Very high	2250 – 5000 μs/cm (salinity zone)

Based on the above classification, 93% the groundwater of the study area falls in the low to medium group and the rest under high to very high group on all seasons.

A high EC in water leads to formation of saline soil, high sodium content leads to the development of alkaline soil. Wilcox (1955) has classified the water for irrigation purpose based on the electrical conductivity (EC), TDS, Na percent and boron concentration (Table 6.6). Percent of sodium in water is a parameter computed to evaluate the suitability for irrigation (Wilcox, 1948). Excess sodium combining with carbonate will lead to the formation of alkaline soils while with chloride the saline soils are formed. Either of the soils will not support the growth of crops. As per the Indian standards, maximum of 60% sodium is permissible for irrigation water.

Table 6. 7 Classification of groundwater quality for irrigation (Wilcox, 1955)

Class of water	EC at 25°C (µS/cm)	TDS (mg/L)	Sodium %	Boron (mg/L)
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 average sodium concentration of the basin during the pre-monsoon period is 29, minimum is 4 and the maximum concentration is 932 (Table 6.1a and Fig. 6.10a). The average concentration of sodium during the post-monsoon period is 14.95, minimum is 3 mg/L and the maximum concentration is 400.5 mg/L (Table 6.1a and Fig. 6.1b). The distribution of sodium, EC and sodium are generally within the permissible range in the study area, except in the Vypin, Varapuzha and Eloor area, the groundwater is unsuitable for irrigation.

The U.S.Salinity Laboratory (1954), Department of Agriculture has constructed a diagram for rating irrigation waters with reference to SAR as an index of sodium hazard and EC as an index of salinity hazard. Sodium and salinity hazards are the two important parameters which can indicate the suitability of water for irrigation use. The quality classification of irrigation water is given in Table 6.7.

6.6.1 Salinity Hazard:

Low salinity water (C1) can be used for irrigating all types 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 for 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 the study area 49% of the samples fall in the C1 type, 41% C2 type, 9% C3 type and 1% in C4 type during the pre-monsoon season and 51% of the samples fall in C1 type, 43% C2 type, 3% C3 type and 3% C4 type during the post-monsoon season.

6.6.2 Sodium hazard:

Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of developing harmful levels of sodium. Medium-sodium water (S2) may cause an alkalinity problem in fine-textured soils under low-leaching conditions. It can be used on coarse textured soils with good permeability. High-sodium water (S3) may produce an alkalinity problem.

This water requires special soil management such as good drainage, heavy leaching, and possibly the use of chemical amendments such as gypsum. Very high sodium water (S4) is usually unsatisfactory for irrigation purposes. In the study area 98% of the samples fall in the S1 type, 1% in S2 type and 1% in S3 type during the pre-monsoon season and 97% samples fall in the S1 type and 3% S2 type in the post-monsoon season.

6.6.3 Sodium adsorption ratio (SAR):

Excess sodium in waters produces undesirable effects of changing soil properties and reducing soil permeability (Kelley, 1951). Hence the assessment of sodium concentration is made while considering the suitability for irrigation. A high salt content (high EC) in water leads to formation of saline soil, high sodium content leads to development of alkaline soil. Salinity hazard is a measure of electrical conductivity (EC), while sodium hazard is expressed in terms of Sodium Adsorption ratio (SAR), which is expressed as :

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

wherein all ions are expressed as milliequivalents per liter (meq/l). The potential for a sodium hazard increases in waters with higher SAR values. 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 based on the salinity hazard and S1, S2, S3 and S4 types based on the sodium hazard (Table 6.20a & b). The sixteen classes in the diagram indicate the extent that the waters can affect the soil in terms of salinity hazard. Crops should be selected on the basis of their salt tolerance and the salt content of the irrigation water and the soil.

The calculated values of SAR in the study area vary between 0.16 and 14.36 during the pre-monsoon period and between 0.13 and 7.72 during the post-monsoon period. The average SAR value in the pre-monsoon period is 1.07 and 0.81 in the post monsoon period. The plot on the data on the U.S. Salinity (Fig a and b) in which the EC is taken as Salinity hazard and SAR as Sodium (alkali) hazard, shows that 90% of the samples of the pre-monsoon season fall in the C1S1 and C2S1 field indicating low to medium salinity and low alkalinity, 8% of the samples fall in the C3S1 field indicating high salinity and low alkalinity, 1% fall in the C3S2 field indicating high salinity and medium alkalinity and 1% of the sample fall in the C4S3 field indicating very high salinity and high alkalinity. 94% of the samples of the post-monsoon season fall in the C1S1 and C2S1 field indicating low to medium salinity and low alkalinity. 3% of the samples fall in the C3S1 and 3% in the C4S2 field indicating high to very high salinity and low to medium alkalinity. Based on the U.S.S.L. classification, 90% of the groundwater of the area fall low to medium salinity and low alkalinity field and considered good for all irrigation purposes. 8% of the area falling in the high salinity and low alkalinity field, 1% in the high salinity and low alkali field and 1% of the area fall under very high salinity and high alkali. Hence the groundwater of this region is not suitable for irrigation under ordinary conditions. Selecting more tolerant crops is a practical solution to the toxicity problem.

6.7 CLASSIFICATION OF GROUNDWATER OF THE AREA BASED ON SALINITY

Many groundwater contain dissolved salts in such concentrations as to make them unusable for ordinary water supply purposes (Krigger, 1957). He has classified saline groundwater based on TDS (Table 6.8). Based on the above classification only 2% of the area, comprising the southern portion of Vypin Island and the Eloor area falls under the brackish water type and the groundwater of all other parts of the study area is fresh water type.

6.8 DISCUSSION

Water quality and utilization may be discussed from the perspective of physical, chemical and bacteriological parameters (Davis and De Wiest, 1966); the hydraulic regime and type of the flow system (Torth, 1984); and the hydrogeological properties of recharge and discharge areas (Cetindag and Unsal, 2004). The hydrochemical investigation in the present study is restricted to the major ions concentrations, distributions, their relative abundance, and the pattern of the variability in groundwater chemistry. On the basis of the groundwater chemistry an evaluation of groundwater for domestic and irrigation uses is established. The chemical composition of the groundwater which moves from the recharge area to the discharge area reflects changes by various geochemical processes (Bahattin Cetindag et al., 2004). The rapid industrial and urban growth along the banks and adjacent area of Periyar River had its origin in the early 1960s and since then it has been growing rapidly. These industries discharge their solid waste as well as effluents without any proper treatment into the river channel or on the low lying areas. The deterioration of quality of groundwater of Eloor and other parts of the lowland coastal region is due to the impact of these industrial effluent discharges and also due to the saline water incursion. In the highland region it is due to the excessive use of fertilizers and pesticides for agriculture. Shallow water table and depth and monsoon rainfall may influence the groundwater quality due to extensive agricultural practices as a non-point source (Sarkar and Hassan, 2006). A high TDS (levels above 1,000 mg/L) may cause corrosion of pipes and plumbing systems. To remove TDS to acceptable levels, a water softener with a reverse osmosis (R/O) system is usually effective.

Table 6.8. Classification of Saline Groundwater (Carroll, 1962).

Type of Groundwater	Total Dissolves Solids (mg/L).
Fresh water	0 – 1000.
Brackish water	1000 – 10000.
Saline water	10000 – 100000.
Brine	> 100000.

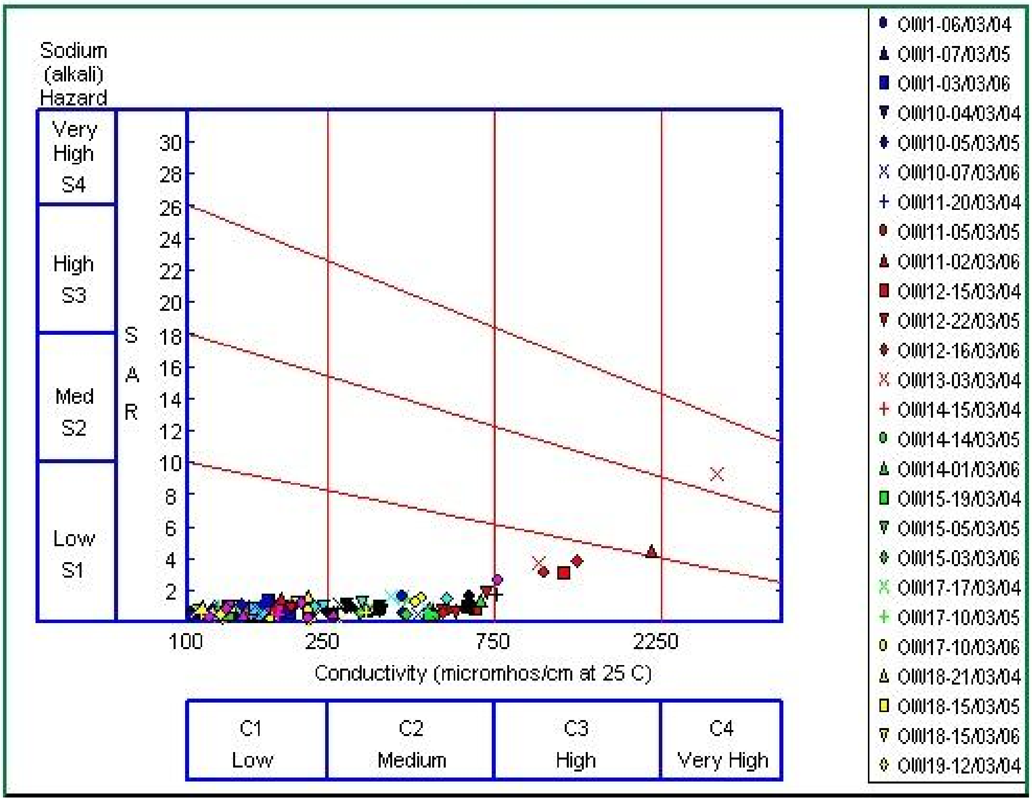


Fig. 6. 24 (a) Groundwater classification for irrigation, based on U.S.S.L. method (Pre-monsoon).

Discharge and leakages from open drains and septic tanks, unscientific construction of septic tanks, open defecation etc., are common problems in the study area and this condition paves the way for the production of bacterial colonies, which may contaminate the groundwater of the area. In pure water nitrate (NO_3) is seldom present. NO_3 occurs in groundwater, however, due to decaying of organic matter, fertilizers, poor sanitation, septic tank leakage, open sludge drains and unscientific disposal of Municipal wastes.

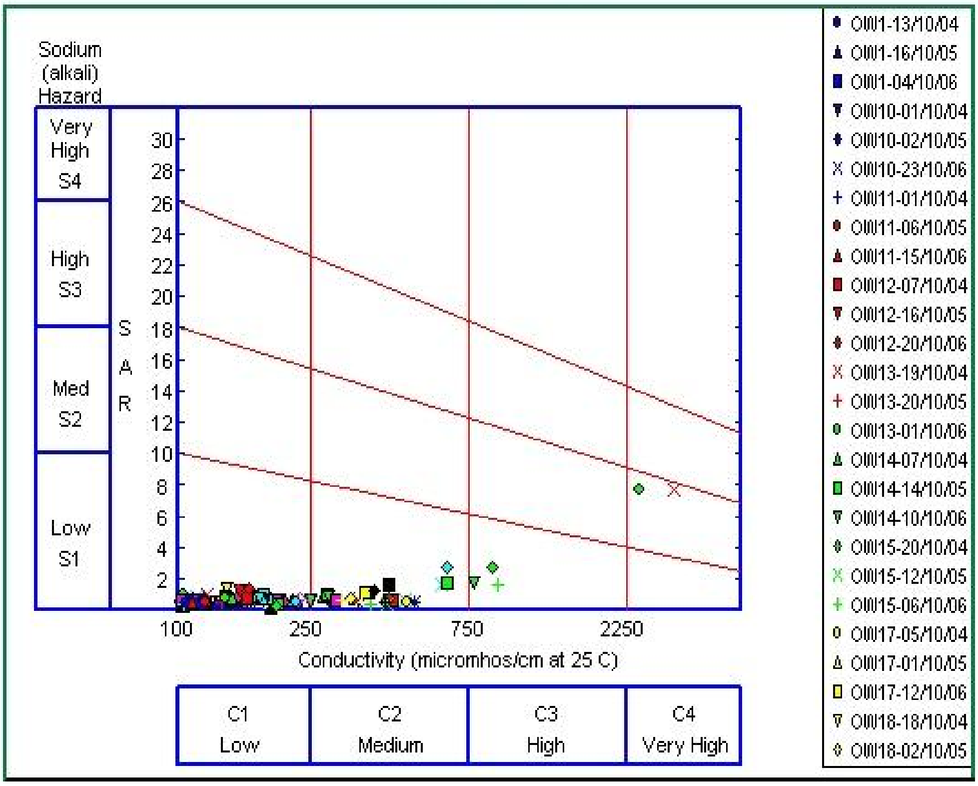


Fig. 6. 24 (b) Groundwater classification for irrigation, based on U.S.S.L. method (Post – monsoon).

The groundwater of the study area in general was alkaline in nature and higher EC values were noted during the pre-monsoon season. The HCO_3 in the study area was higher in pre-monsoon season due to weathering of rocks. Chloride was higher in indicating leaching from upper soil layers due to industrial and domestic activities and dry climates. Sulphate is higher in pre-monsoon season indicating breaking of organic substances from topsoil/water, leachable sulphate present in fertilizer and other human influences. Fluoride and NO_3 was higher in pre-monsoon indicating leaching of fluoride rich rocks and organic substances from weathered soil. The general dominance of anion was in the order of Cl > HCO_3 > SO_4 > NO_3. For cation Na was higher in pre-monsoon season indicating weathering from plagioclase bearing rocks. K was lesser in both the seasons indicating its lower availability in the rocks of the area. Ca and Mg were higher in pre-monsoon indicating the weathering from primary mineral sources. The general dominance of cation was in the order of Na > Ca > Mg > K. The results from the water analysis were used as a tool to identify the process and mechanisms affecting the chemistry of groundwater from the study area. Samples from both seasons fall in rock dominance zone suggesting precipitation induced chemical weathering along with dissolution of rock forming minerals.

The groundwater in the study area is a unique example for the impact of weathering, ion exchange and anthropogenic process controlling water chemistry. The chemical composition of groundwater of the study area is strongly influenced by rock- water interaction, dissolution and deposition of silicates group of minerals. Weathering of silicate minerals controls the major ion chemistry of calcium, magnesium, sodium and potassium. Chloride (Cl^{-}) was dominant due to the weathering and erosion of the crystalline rocks and also the anthropogenic impacts (human sources). The ion exchange and reverse ion exchange control the water chemistry of the study area. In general, water chemistry is guided by lithological influences on water chemistry by complex weathering process, ion exchange along with influence of Chloride ions from anthropogenic impact.

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Chapter VII
Quantitative Hydrogeology

7.1. INTRODUCTION

An aquifer can be compared to a bank account, and the groundwater occurring in an aquifer is analogues to the money in the account. Indiscriminate, unregulated and unscientific development of the ground water resources is the direct cause for the alarming decline in ground water level. The occurrence and distribution of groundwater are controlled by various geological and structural factors. The movement of groundwater is established by hydraulic properties (Todd. 1980). The evaluation of groundwater resource needs the study of occurrence, availability and behaviour of groundwater systems in that region. Geological formations are classified into four types based on their properties. They are (i) aquifer (ii) aquitard (iii) aquiclude and (iv) aquifuge. In crystalline rocks the near surface fractured rock forms extensive aquifers in many regions. The character of such aquifer results from the combined effects of fracture system, topography and weathering. In a massive crystalline complex, large areal extents of aquifers are not common. Topography commonly exerts a major influence through its effects on both weathering and the opening of joints, while weathering modifies both transmissive and storage characteristics of the rocks (Trainer, 1988).

The secondary features like lineament, fracture, fissure, shear zone, joints etc., are the principal hydraulic controls in hard rock terrain. Within the type of hydrogeological environment in hard rock terrain, overwhelming heterogeneity in the properties is noted. A parameter such as the hydraulic conductivity, which is determined by field methods, normally varies by several orders of magnitude within the same rock unit within a short distance (Gustafson and Krasny., 1994). Wells drilled on lineaments such as faults, major fractures and fractured dykes are good aquifers. For siting of a well, one needs to know the direction of groundwater flow and regional discharge zones. A detailed hydrogeological evaluation of formation involves the study of the hydrogeological behavior of the hard rock terrain. Groundwater in nature occurs in two different zones namely; the unsaturated zone and the saturated zone. The unsaturated zone occurs immediately below the land surface in most area and contains both water and air. In the unsaturated zone the flow occurs beneath the land surface and above the groundwater table. Groundwater table forms the boundary between the unsaturated subsurface flow and the saturated subsurface flow. In the unsaturated zone the preferred path of movement of moisture is vertical, by percolation, towards the saturated zone below. Water in the saturated zone is the only water under the subsurface that is available to supply wells and springs and is the water to which the name groundwater is correctly applied. Recharge of the saturated zone occurs by percolation of water from the land surface through the unsaturated zone. The water table is the level in the saturated zone at which the hydraulic pressure is equal to the atmospheric pressure and is represented by the water table. Below the water table the hydraulic pressure increases with depth.

7.2. AQUIFERS

7. 2. 1 Types of Aquifers of the study area.

Ground water occurs under unconfined; semi confined and confined conditions, in pores, rock fractures, cavities, and other openings in the geologic formations in the study area. The nature of the water-bearing openings within a specific geologic formation depends to a large extent on the mineral composition and structure of the formation and the geologic processes that initially formed and then further modified it. The most important water-bearing formations of the basin are unconsolidated sands and gravels, consolidated sands, laterites, weathered and the fractured crystalline rocks. Groundwater occurs under phreatic conditions in laterites, unconsolidated coastal sediments weathered and fractured crystalline rocks. It occurs under semi-confined to confined conditions in the deep seated fractured aquifer in the crystalline and Tertiary rocks.

7. 2. 2 Behavior of Groundwater in the study area

As part of the present study 5525 numbers of water level observations pertaining to 79 NHS of different stations distributed all over the basin being maintained by the Kerala State Ground Water Department (KSGWD) were collected for the period from 1985 to 2007 and this data is used for the present study. These data were analyzed and based on this, the water table fluctuation graphs, water table contour maps and hydrographs of the study area are prepared. The hydrographs of the selected network of stations show corresponding peaks and troughs with rainfall distribution. The best fit line for the hydrographs will bring out the trend of the water table with time. The peaks represent the low groundwater storage whereas the troughs correspond to the increase storage of groundwater. The overall trend of the water table during the period from 1985 to 2006 is given in Table. 7.1. The normal average water level of the study area is given in fig. 7.2, minimum and maximum average water levels in fig. 4.3a & b respectively. The maximum water level fluctuation in the lowland area is observed as 3.56m at Kottappuram and the minimum is 0.12 m at Varapuzha. The average water level of the low land region of the basin is 1.64m. In the midland region the maximum lowering of 9.4 m is observed in the well at Angamali, minimum is 0.27 m at Pindimana and the average is decline of the region is 4.84 m. In the highland region, the maximum lowering of 12.12 m is observed in the observation well at Kallar- Vattayar and the minimum fluctuation observed is

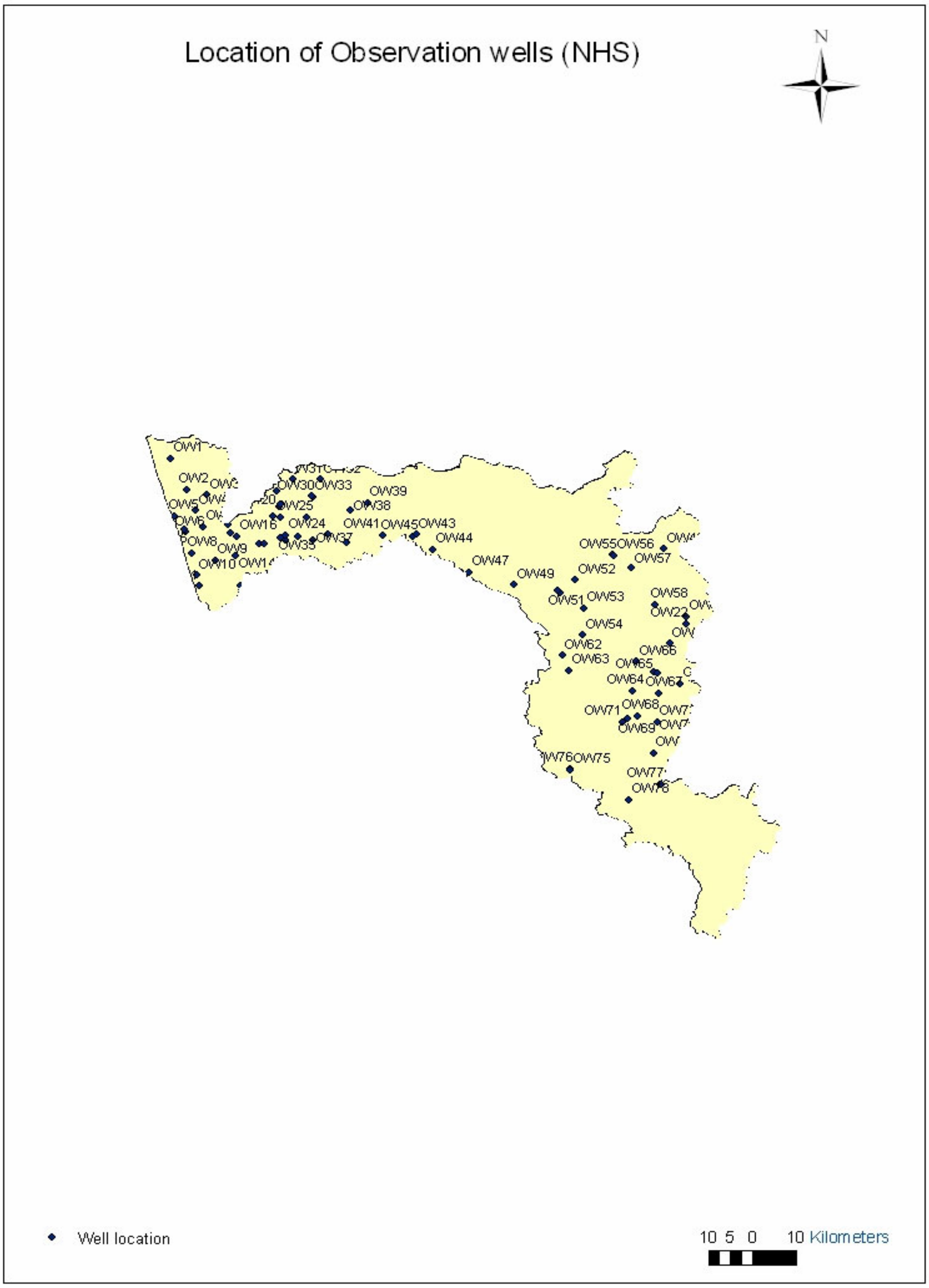


Fig. 7.1 Location of the National Hydrograph Stations (NHS) of the Periyar River Basin

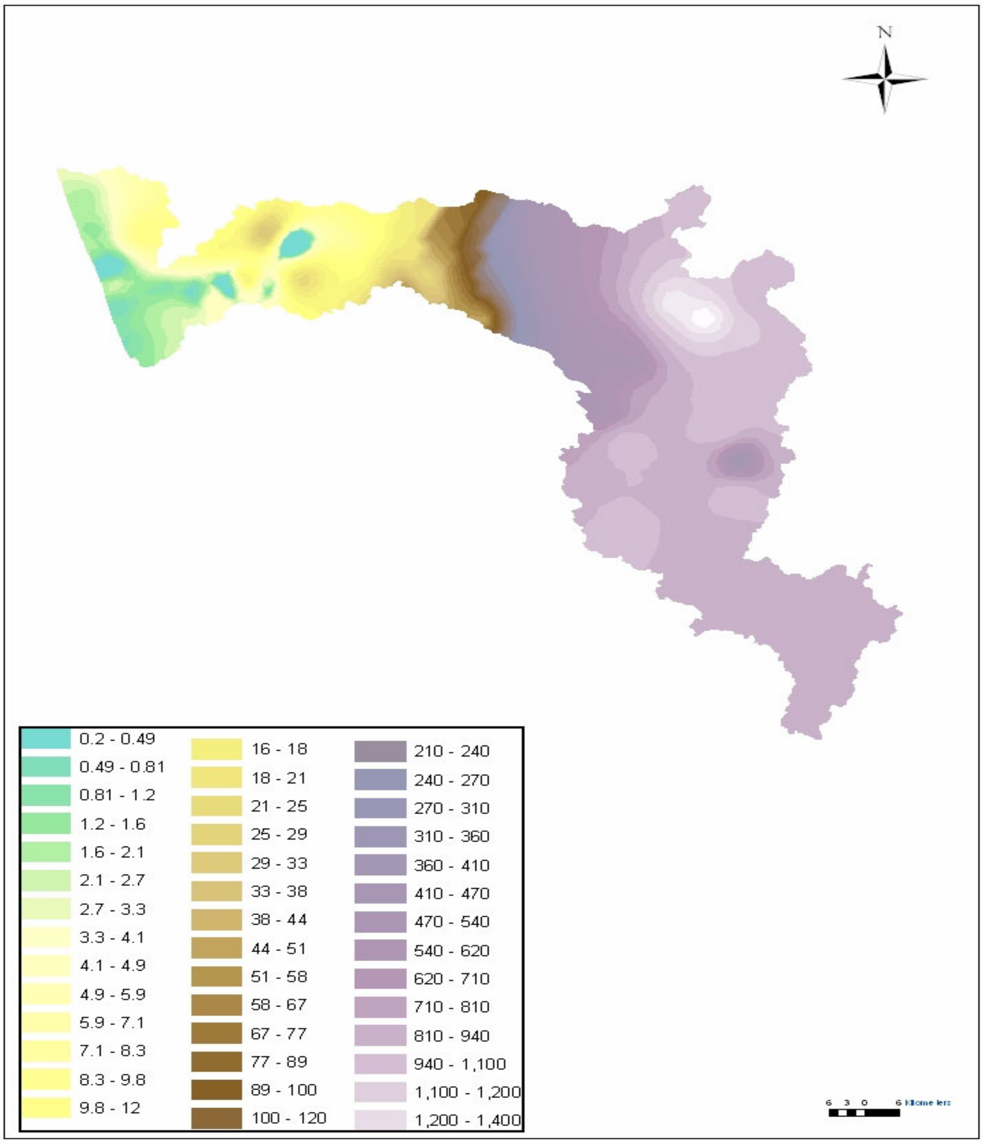
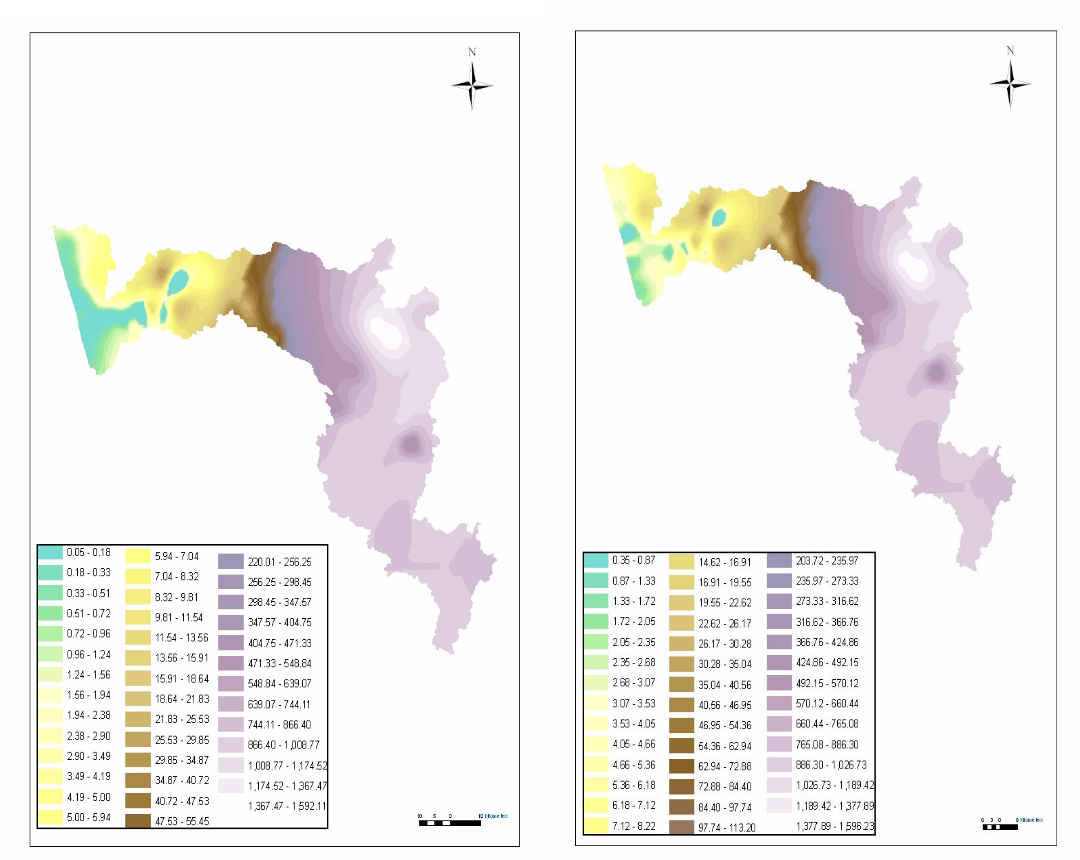


Fig. 7.2 Normal Groundwater level of the study area above MSL (from 1985 to 2006) in mtrs.

0.18 m at Elappara. The average water level fluctuation of the highland region is 4.11 m. Taking into consideration of the entire Periyar River Basin, the maximum fluctuation of 14.45 m has been observed at Poyya and the minimum and the minimum of 0.01 m at Munambam during the period.



(a) **(b)**

Fig. 7. 3(a) Minimum and (b) Maximum Groundwater level of the area above MSL (from 1985 to 2006) in mtrs.

From the analysis of the water level data, it is observed that 30 stations are showing declining trend and 39 stations are showing increasing trend and 10 stations are maintaining a steady level during the period. The increase in trend of water table is observed at Lokalamelleswaram, Pappinavattom, Munambam, Pallippuram, Njarakkal, Edavanakkad, Cherai, Kottappuram, Elur North and Edappally in the lowland region, Poyya, Aluva, Angamali, Attara, Chengamanad, Kuruppampady, Nedumbassery, Panamkuzhy, Kottappady, Pindimana, Kuttamangalam and Thattakkad in the midland region and Adimali, Kallar,-Vattayar, Vellathooval, Munnar, Devikolam, Marayoor, Chakkupallam, Idukki, Kattappana, Kumili, Udumbanchola, Vandamedu and Vandiperiyar in the highland region. The maximum trend of increase in water table is observed at Poyya, 0.187m/year. The average increase in trend at the above area is 0.02m/year. Declining trend in water table is observed in the observation wells at Varapuzha, Paravur, Malippuram in the lowland area, Chalackal, Vazhakkulam-north, Vallom, Chowara, Kanjur, Kalady, Karukutti, Malayattur, Manjapra and Keerampara in the midland region, Neriyamangalam, Pambadumpara, Udumbanchola, Valara and Elappara in the highland region. The average decline trend of the wells is 0.02 m/year (Table 7.1) and Fig 7.4.a & b. The water table contour map of the area reveals that the direction of groundwater flow reflects the surface topography.

7. 2. 3 Classification of groundwater level fluctuations

Davis and De Wiest (1966) classified groundwater level fluctuation in general into four basic types namely;

(i) Fluctuation owing to change in groundwater storage.

(ii) Fluctuation brought about by atmospheric pressure in contact with water surface in wells.

(iii) Fluctuation resulting due to deformation of aquifer and

(iv) Fluctuation owing to disturbances within the well. Minor fluctuations are attributed to chemical or thermal changes in and around the wells.

The magnitude of the water fluctuations depends on the usage, climate, drainage, topography and the geological conditions. Long term fluctuations in groundwater level studies will help us to understand the depletion and recharging conditions of an aquifer. The stress and strain in water level due to groundwater recharge, discharge and intensity of rainfall are reflected in water level fluctuations with time. The rate and magnitude of fluctuation during any period portrays the net effects of recharge or discharge during that period, in relation to inherent characteristics of the aquifer media (Rengarajan, 1996).

7. 2. 4 Analysis of Hydrographs of the study area

The well hydrograph is the graphical representation of the water table dynamics. The water levels fluctuate with annual recharge and discharge conditions. A high water table occurs during the wet season and low water table during dry seasons, indicating a gain or loss of water in the aquifer storage. Water table data is a direct indicator of the status of groundwater of the area. The hydrographs are showing declining trend where the groundwater exploitation is quite high and showing an increasing trend where the exploitation is low. Average water level is used as a tool that conveys the status of the groundwater of the area.

Table 7. 1 Long term groundwater level trend of the Observation wells of the Periyar River Basin (Period 1985 to 2006)

Well No.	Location	District	Taluk	Rise (Mtr./yr)	Fall (Mtr./yr)	Trend (Mtr/yr.)
OW01	Pappinivattom	Thrissur	Kodumgallur	0.018	0.000	0.018
OW02	Lokamalleswaram	Thrissur	Kodumgallur	0.024	0.000	0.024
OW03	Poyya	Thrissur	Kodumgallur	0.187	0.000	0.187
OW04	North Parur	Ernakulam	Paravur	0.009	0.000	0.009
OW05	Munambam	Ernakulam	Paravur	0.047	0.000	0.047
OW06	Pallipuram	Ernakulam	Kochi	0.013	0.000	0.013
OW07	Paravur Jn.	Ernakulam	Paravur	0.000	0.008	-0.008
OW08	Edavanakad	Ernakulam	Kochi	0.001	0.000	0.001
OW09	Varapuzha	Ernakulam	Paravur	0.000	0.026	-0.026
OW10	Njarakkal	Ernakulam	Kochi	0.007	0.000	0.007
OW11	Malipuram	Ernakulam	Kochi	0.000	0.013	-0.013
OW12	Edappally	Ernakulam	Kanayannur	0.009	0.000	0.009
OW14	Elur	Ernakulam	Paravur	0.014	0.000	0.014
OW15	Paravur	Ernakulam	Paravur	0.015	0.000	0.402
OW16	Kottapuram	Ernakulam	Paravur	0.013	0.000	0.013
OW17	Chalakkal	Ernakulam	Aluva	0.000	0.012	-0.012
OW18	Chengamanad	Ernakulam	Aluva	0.010	0.000	0.010
OW19	Alwaye town	Ernakulam	Aluva	0.000	0.010	-0.110
OW20	Karukutty	Ernakulam	Aluva	0.000	0.032	-0.032
OW21	Chalackal	Ernakulam	Aluva	0.012	0.000	0.012
OW23	Chowara	Ernakulam	Aluva	0.000	0.015	-0.115
OW24	Vazhakkulam	Ernakulam	Aluva	0.000	0.016	-0.016
OW25	Nedumbassery	Ernakulam	Aluva	0.026	0.000	0.026
OW26	Kaladi	Ernakulam	Aluva	0.048	0.000	0.048
OW28	Angamali	Ernakulam	Aluva	0.022	0.000	0.022
OW29	Ankamaly RH	Ernakulam	Aluva	0.009	0.000	0.009
OW30	Manjapara Town	Ernakulam	Aluva	0.000	0.011	-0.011
OW31	Attara	Ernakulam	Aluva	0.006	0.000	0.006
OW32	Sulli	Ernakulam	Aluva	0.000	0.025	-0.025
OW33	Manjapra In.	Ernakulam	Aluva	0.023	0.000	0.023
OW34	Kalady Jn.	Ernakulam	Aluva	0.000	0.027	-0.027
OW35	Kanjur	Ernakulam	Aluva	0.000	0.045	-0.045
OW37	Vallom	Ernakulam	Aluva	0.000	0.077	-0.077
OW38	Malayattur	Ernakulam	Kunnathunad	0.000	0.027	-0.027
OW39	Panamkuzhi	Ernakulam	Kunnathunad	0.012	0.000	0.012
OW40	Kuruppampady	Ernakulam	Kunnathunad	0.000	0.015	-0.015

OW41	Kottapadi	Ernakulam	Kothamangalam	0.008	0.000	0.008
OW42	Aluva	Ernakulam	Aluva	0.002	0.000	0.002
OW43	Thattekad	Ernakulam	Kothamangalam	0.074	0.000	0.074
OW44	Kuttamangalam	Ernakulam	Kothamangalam	0.002	0.000	0.002
OW45	Pindimana	Ernakulam	Kothamangalam	0.038	0.000	0.038
OW46	Keerampara	Ernakulam	Kothamangalam	0.000	0.050	-0.050
OW47	Neriyamangalam	Ernakulam	Kothamangalam	0.000	0.042	-0.042
OW48	Marayoor	Idukki	Devikolam	0.281	0.000	0.081
OW49	Valara	Idukki	Devikolam	0.000	0.041	-0.141
OW50	Adimali	Idukki	Devikolam	0.030	0.000	0.030
OW51	Adimali Jn.	Idukki	Devikolam	0.092	0.000	0.092
OW52	Kallar	Idukki	Devikolam	0.004	0.000	0.004
OW53	Vellatuval	Idukki	Devikolam	0.021	0.000	0.021
OW54	Churuli	Idukki	Devikolam	0.000	0.004	-0.004
OW55	Munnar	Idukki	Devikolam	0.020	0.000	0.020
OW56	Munnar town	Idukki	Devikolam	0.016	0.000	0.016
OW57	Devikulam	Idukki	Devikolam	0.004	0.000	0.004
OW58	Poopara	Idukki	Devikolam	0.000	0.047	-0.047
OW22	Santhampara	Idukki	Udumbanchola	0.000	0.027	-0.107
OW59	Udumbanchola town	Idukki	Udumbanchola	0.002	0.000	0.002
OW60	Udumbanchola GPO	Idukki	Udumbanchola	0.000	0.024	-0.024
OW61	Nedumkandam	Idukki	Udumbanchola	0.000	0.047	-0.047
OW62	Vazhathope	Idukki	Udumbanchola	0.020	0.000	0.020
OW63	Idikki	Idukki	Udumbanchola	0.034	0.000	0.034
OW64	Irattayar	Idukki	Udumbanchola	0.000	0.063	-0.063
OW65	Nedumkandam	Idukki	Udumbanchola	0.000	0.045	-0.045
OW66	Nirmala	Idukki	Udumbanchola	0.000	0.033	-0.033
OW67	Pambadumpara	Idukki	Devikolam	0.000	0.064	-0.064
OW68	Kattappana	Idukki	Udumbanchola	0.024	0.000	0.184
OW69	Ayyappancoil	Idukki	Udumbanchola	0.019	0.000	0.019
OW70	Chakkupallam	Idukki	Udumbanchola	0.036	0.000	0.036
OW71	Kattapana Jn.	Idukki	Udumbanchola	0.040	0.000	0.040
OW72	Vandanmedu	Idukki	Udumbanchola	0.021	0.000	0.021
OW73	Vellilamkandam	Idukki	Udumbanchola	0.000	0.061	-0.061
OW74	Pampupara	Idukki	Udumbanchola	0.004	0.000	0.004
OW75	Elappara	Idukki	Peerumade	0.023	0.000	0.023
OW76	Elapara town	Idukki	Peerumade	0.000	0.042	-0.042
OW77	Kumili Jn.	Idukki	Peerumade	0.000	0.080	-0.080
OW78	Vandiperiyar	Idukki	Peerumade	0.017	0.000	0.017
OW79	Kumily town	Idukki	Peerumade	0.041	0.000	0.041

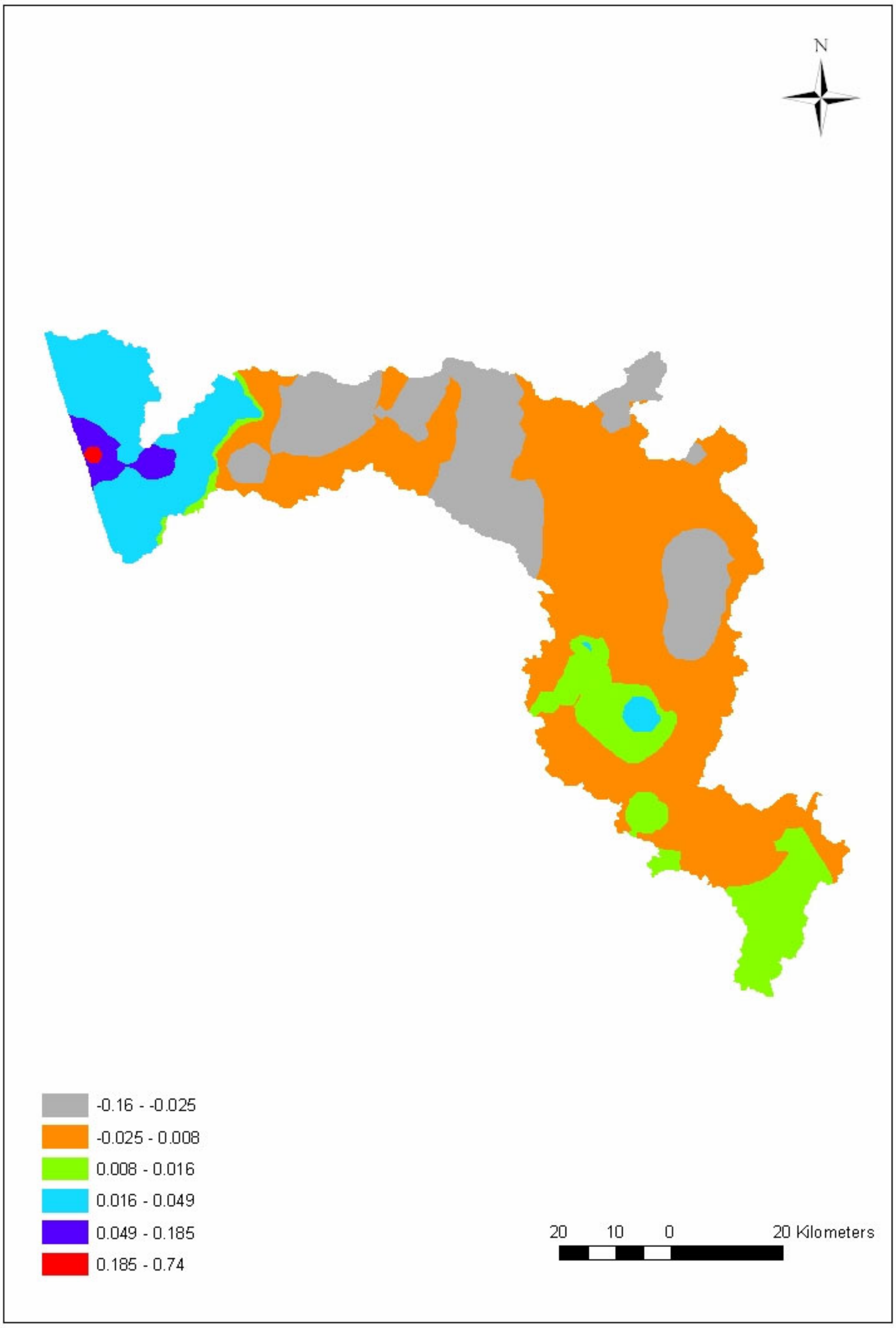


Fig.7.4 a. Long-term Pre-monsoon groundwater level trend of the Periyar River Basin, period 1985 to 2006)

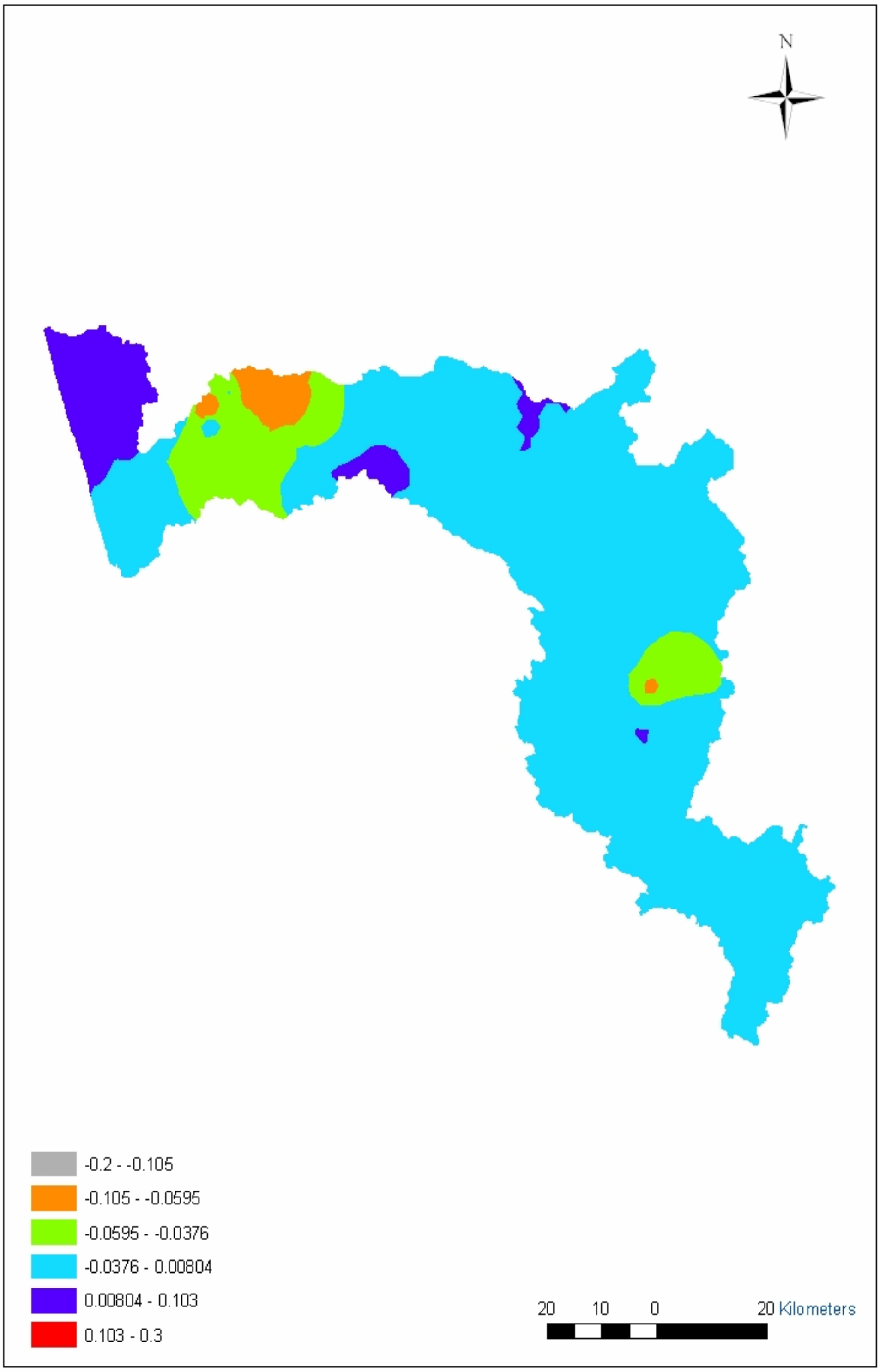


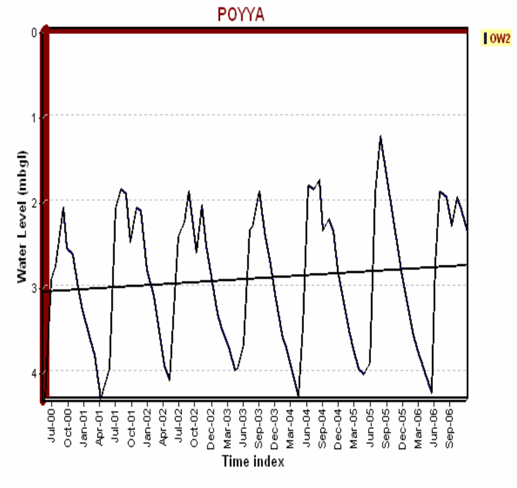
Fig. 7.4 b Long-term Post-monsoon groundwater level trend of the Periyar River Basin, Period 1985 to 2006.

Table 7.2 Average Groundwater level of the observation wells (NHS) of the Periyar River Basin (1985-2006)

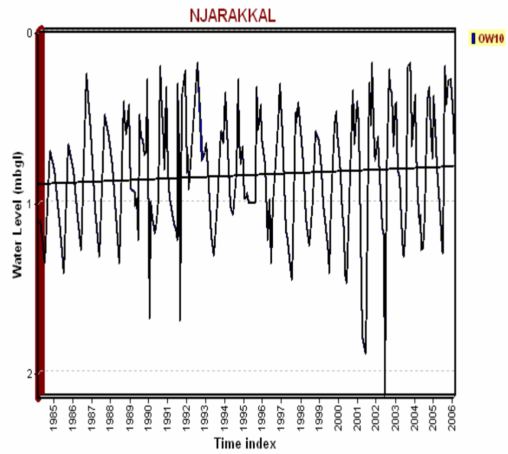
Well No	Location	Post monsoon water level (m)	Pre-monsoon water level (m)
OW01	Pappinivattom	1.59	4.64
OW02	Lokamalleswaram	1.75	4.32
OW03	Poyya	6.42	14.45
OW04	North parur	0.13	1.91
OW05	Munambam	0.01	1.92
OW06	Pallipuram	0.10	1.96
OW07	Paravur	1.02	2.79
OW08	Edavanakad	0.11	1.20
OW09	Varapuzha	0.12	3.15
OW10	Njarakkal	0.18	2.14
OW11	Malipuram	0.28	3.00
OW12	Edappally	0.20	2.23
OW14	Elur north	1.28	4.15
OW15	Paravur	1.50	5.41
OW16	Kottapuram	0.92	4.56
OW17	Chalakka	1.08	3.58
OW18	Chengamanad	6.00	11.63
OW19	Alwaye	5.04	12.66
OW20	Karukutty	3.72	9.05
OW21	Aluva East	5.68	7.37
OW22	Udumbanchola	1.51	6.60
OW23	Chowara	2.02	8.15
OW24	Vazhakkulam north	3.06	8.60
OW25	Nedumbassery	3.18	8.80
OW26	Kaladi	0.00	6.30
OW28	Angamali	1.61	9.40
OW29	Ankamaly	2.23	8.70
OW30	Manjapara	2.50	5.83
OW31	Attara	3.21	7.70
OW32	Sulli	0.20	5.58
OW33	Manjapra	1.34	4.46
OW34	Kalady	1.39	7.05
OW35	Kanjur	3.58	8.61
OW37	Vallom	3.42	7.74
OW38	Malayattur	3.15	8.30
OW39	Panamkuzhi	2.54	9.06
OW40	Kuruppampady	2.52	6.78
OW41	Kottapadi	1.40	3.94

OW42	Aluva	1.25	4.90
OW43	Thattekad	0.25	4.86
OW44	Kuttamangalam	1.52	4.12
OW45	Pindimana	0.17	8.10
OW46	Keerampara	1.89	6.04
OW47	Neriyamangalam	0.00	10.49
OW48	Marayoor	2.71	3.58
OW49	Valara	0.90	8.31
OW50	Adimali	1.90	4.15
OW51	Adimali	0.78	6.59
OW52	Kallar vattayar	5.30	12.12
OW53	Vellatuval	1.07	4.50
OW54	Churuli	0.06	3.43
OW55	Munnar	0.70	3.80
OW56	Munnar	0.67	4.05
OW57	Devikulam	2.40	6.52
OW58	Poopara	0.07	4.00
OW59	Udumbanchola	0.13	3.20
OW60	Udumbanchola	1.69	9.69
OW61	Nedumkandam	1.00	6.60
OW62	Vazhathope	7.38	11.75
OW63	Idikki	2.00	7.25
OW64	Irattayar	6.45	10.40
OW65	Nedumkandam	1.80	7.94
OW66	Nirmala city	0.56	3.29
OW67	Pambadumpara	1.15	5.13
OW68	Kattappana	5.87	10.00
OW69	Ayyappancoil	6.00	11.80
OW70	Chakkupallam	0.55	3.21
OW71	Kattapana	1.91	5.60
OW72	Vandanmedu	0.45	2.57
OW73	Vellilamkandam	3.42	8.46
OW74	Pampupara	0.17	2.21
OW75	Elappara	1.56	3.09
OW76	Elapara	0.18	2.92
OW77	Kumili	1.47	5.25
OW78	Vandiperiyar	5.79	9.33
OW79	Kumily	0.90	5.55

*Source - Kerala State Groundwater Department.

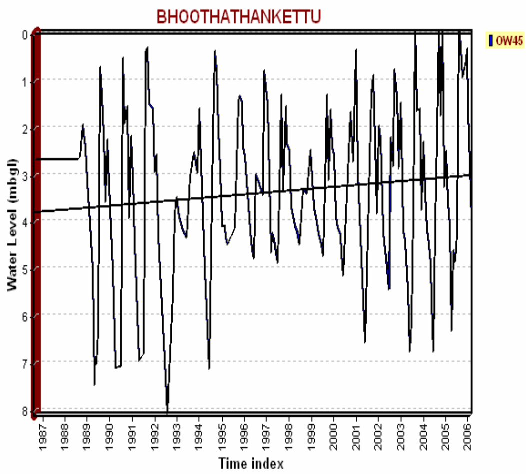


(a) Poyya

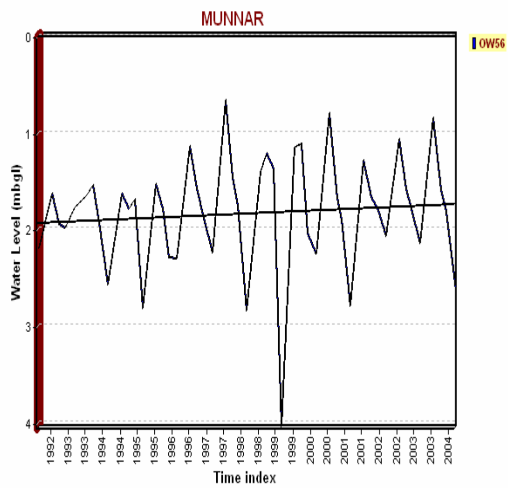


(b) Njarakkal

Fig. 7.5 (a) & (b). Hydrographs of NHS wells showing increasing groundwater level trend.

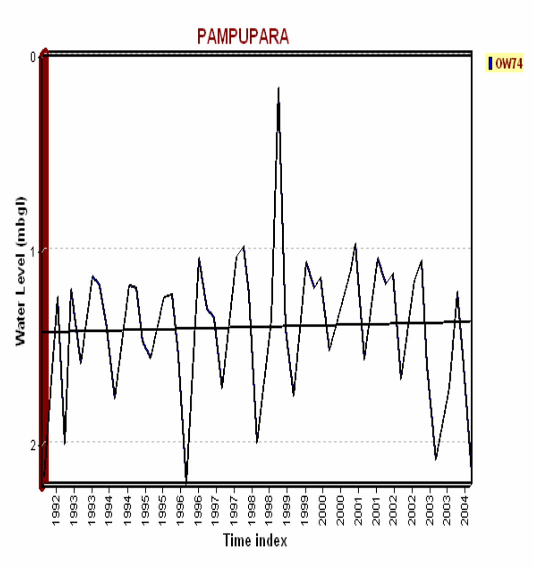


(c) Bhoothathankettu

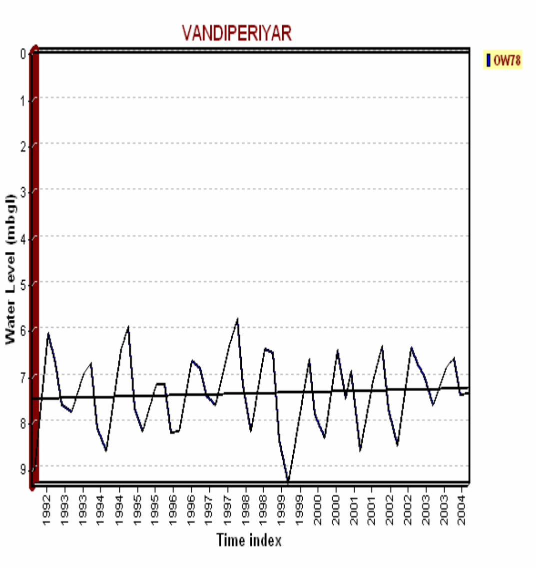


(d) Munnar

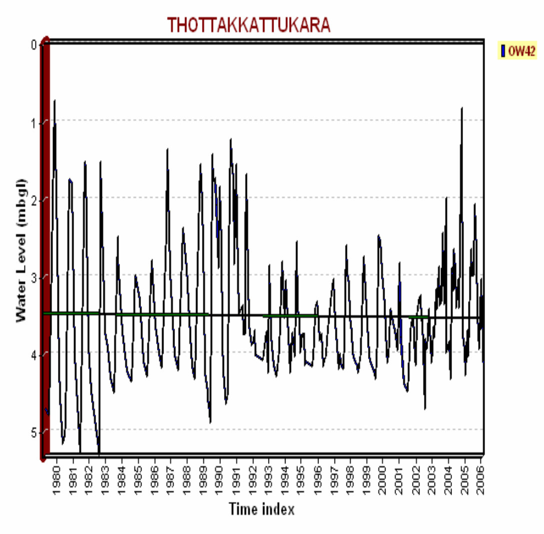
Fig.7 . 5 (e) & (f) Hydrographs showing increasing groundwater level trend.



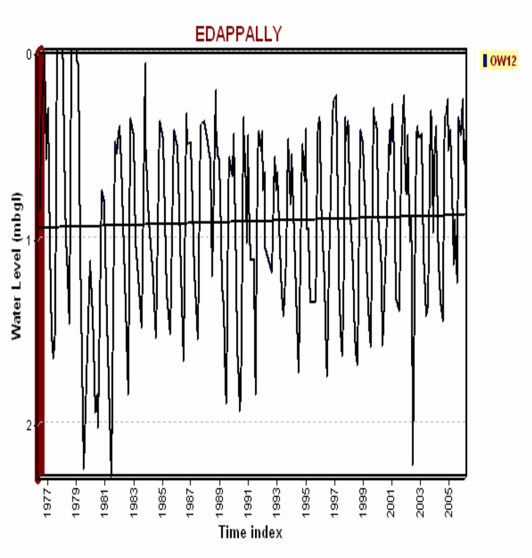
(e) Pampupara



(f) Vandiperiyar

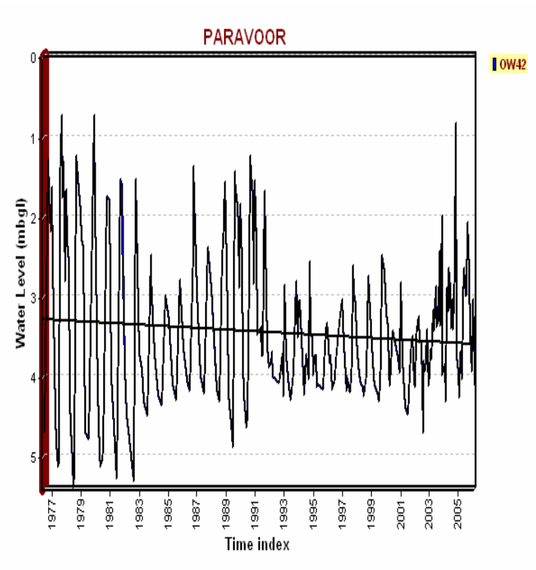


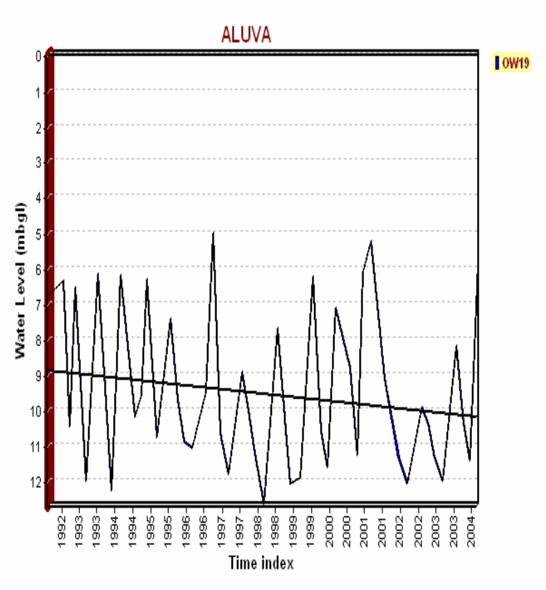
(g) Thottakkattukara



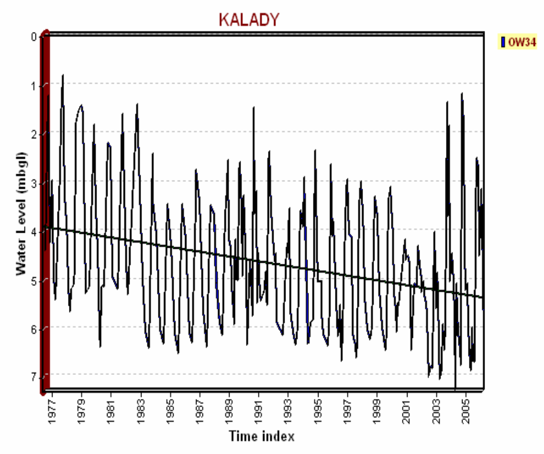
(h) Edappally

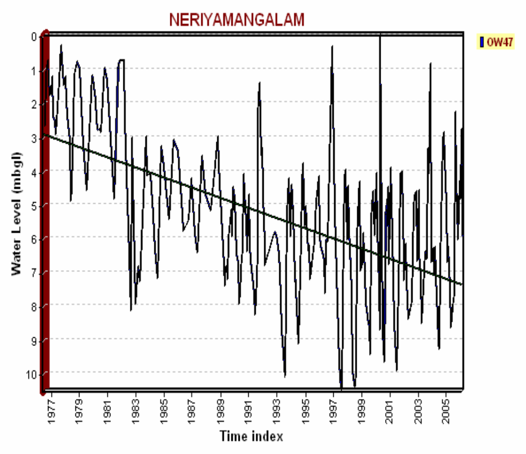
Fig. 7.5.(g) to (j) Hydrograph showing almost steady groundwater level trend



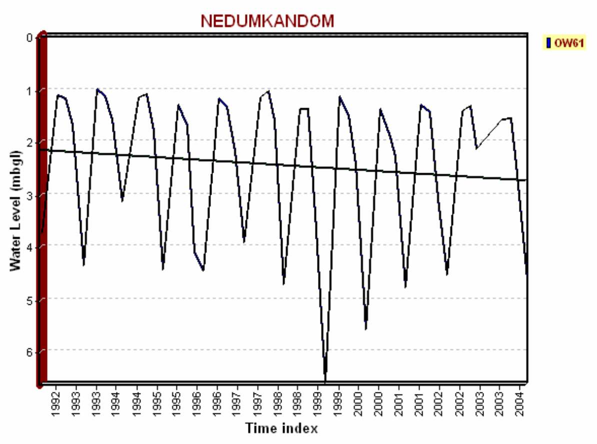


(i) Paravur **(j) Aluva**





(k) Kalady **(l) Neriyamangalam.**



(m) Nedumkandom

Fig. 7.5 (i) to (m). Hydrographs showing declining trend.

The long term hydrographs are constructed from the available observation well data and is presented below (Fig. 7.4a & b) and also in the individual well hydrographs (7. 5a to m). The continuous declining of water level trends, as evident from the hydrographs, reveals that the discharge is more than the recharge of groundwater.

The hydrographs were subjected to detailed analysis. The water level of the observation well at Paravur (Well No.7) was in the increasing upto 1999, steady during 2000 and 2001 and declining from 2002. (Fig.4.5 k). The water level of the observation well at Angamaly (Well No.29) was on the increasing trend upto 1995, steady during 1996 and 1997 and declining from 1998. The water level of the observation well at Suli (Well No.32) near Angamaly was also showing an increasing trend upto 2000, then steady during 2001 to 2003 and steadily decreasing from 2004. The observation well at Kalady (Well No. 34) was in the increasing trend upto 1995 then almost steady during 1996 and 1997 and steadily decreasing from 1998. The water level of the observation well at Malayattur (Well No. 38) was steadily increasing upto 1998, maintained steady level during 1999 and steadily decreasing from 2000. The observation well at Kuruppampady (Well No. 40) was steadily increasing upto 1998, maintained steady level during 1999 and steady trend from 2000. The observation well at Kavalangadu (Well No. 44) was in the increasing trend till 1996 and steadily decreasing from 1997. The observation well at Keerampara (Well No. 46) was showing an increasing trend upto 1999, and maintaining steady level during 2000 and 2001 and gradually decreasing from 2002. The observation well at Nedumkandom (Well No. 65) was mainitaining an increasing trend till 1999 and maintained steady level during 2000 and in the decreasing trend from 2000. The observation well at Nirmala City (Well No. 66) was maintaining an increasing trend upto 1997 and maintained a steady level during 1998 and in the decreasing trend from 1999.

From the above interpretations it is evident that the above wells were maintaining an increasing trend of the water table almost upto 1996. The intensity of indiscriminate sand mining from the Periyar River increased from 1997 and this is the reason for the abrupt reversal of the water level trend of the above locations. . The observation well at Neriyamangalam (Well No. 47) was in the increasing trend upto 1989 and then the trend was suddenly reversed in1990 and still continuing the decreasing trend. This was because of the interference due to the over pumping of groundwater from the 4 borewells drilled in the adjacent compound. These bore wells were drilled during 1988-89.

A close analysis of the well frequency for different ranges of depth to water table (DWT) from above hydrographs (Fig. 7.6) for 10 years from 1996 to 2005 show that 6.9% of the NHS exhibit 0-1mtrs. of water level fluctuation, 32.76% show the 1-3m fluctuation, 18.97% show variation between 5-8m and 12.07% show variation above 8m The maximum percentage of well frequency is in the range of 1-3m.

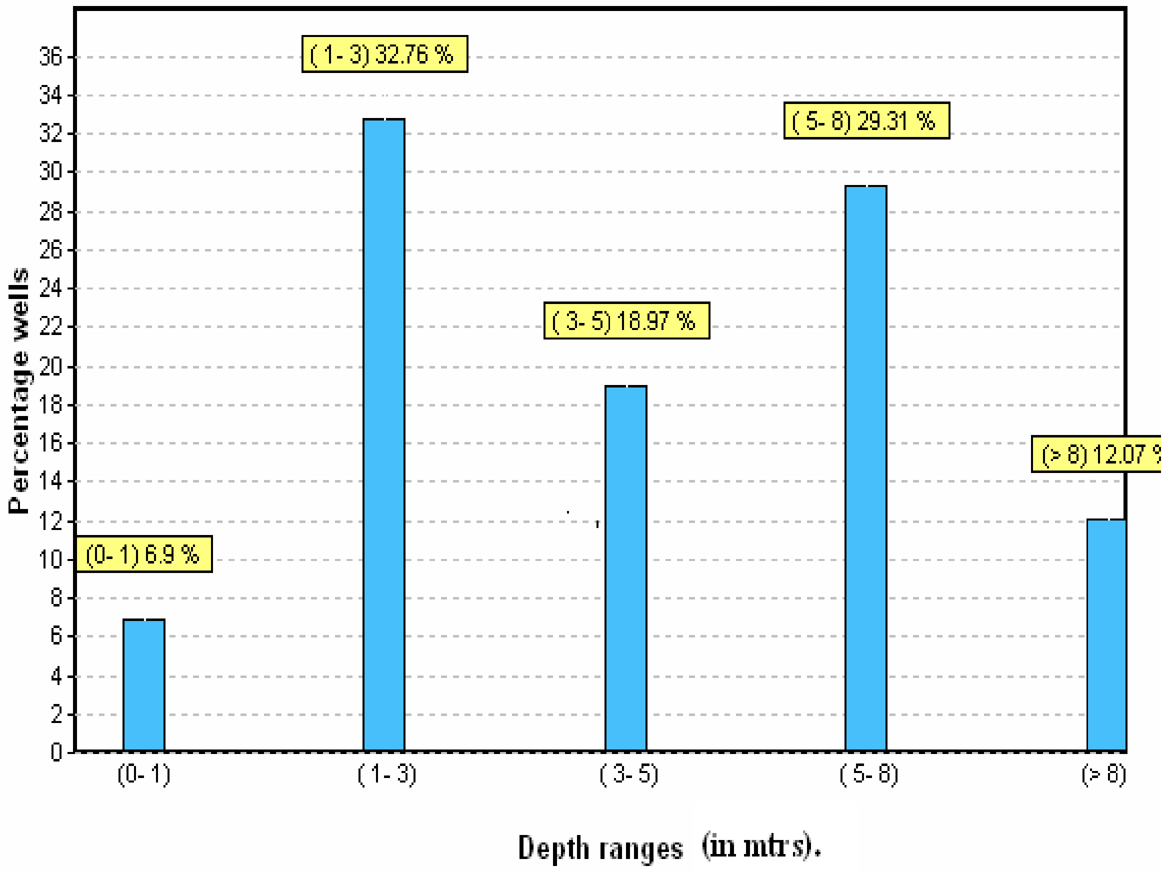


Fig. 7. 6 Hydrograph showing well frequency with respect to depth to water table

The analysis of the 10 years mean from 1995 to 2004 of the water level fluctuation was done and the same was plotted (Fig.7.6). The hydrograph shows that 33.33% of the NHS shows decrease in water level in the range of 0 to 1mtr., and 42.86% show increase in water level within the range of 0 to 1mt., 14.29% of the hydrographs show increase in water level in the range of 1 to 2 m, and 9.52% show increase in water table of more than 2 m.

From the analysis of the data it is inferred that the lowlands and midlands are highly feasible for the development of groundwater throuh dug wells and borewells. The highlands are moderately to poorly feasible for groundwater development through borewells and open dug wells. But the groundwater occurs under phreatic conditions along the valley fills of the highland region and this area is suitable for the development of groundwater through open dug wells.

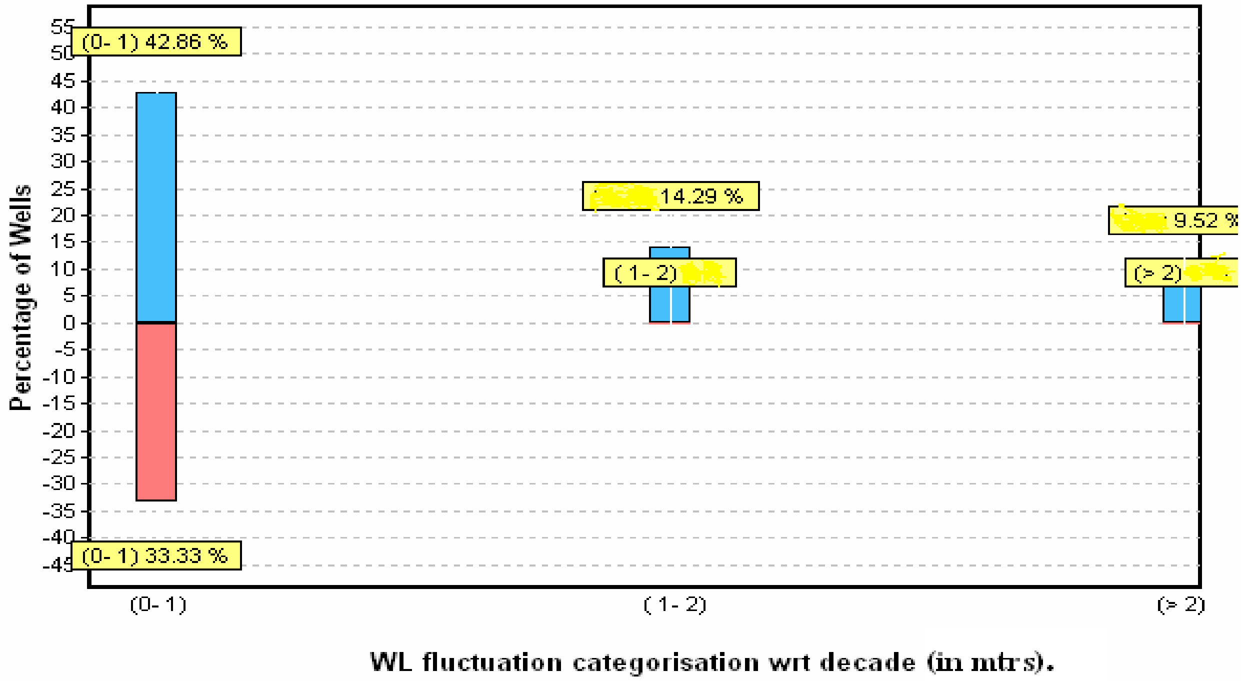
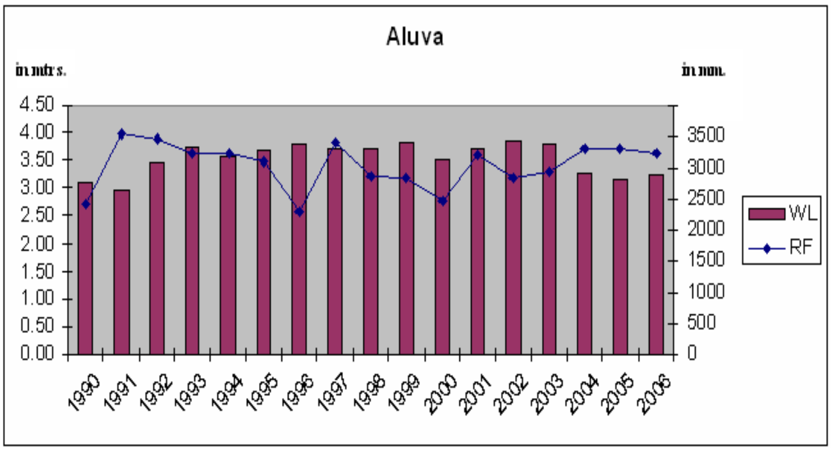


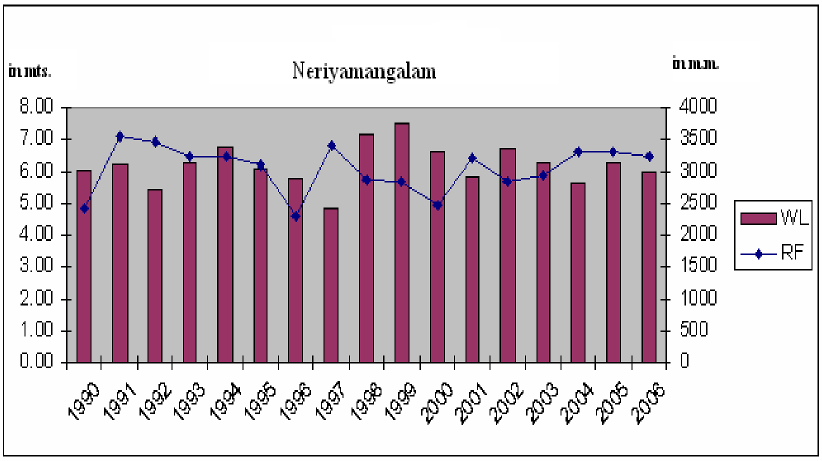
Fig. 7. 7 Categorization of water level fluctuations based on 10 years mean from 1995 to 2004.

7.2. 5 Comparison of groundwater table with rainfall

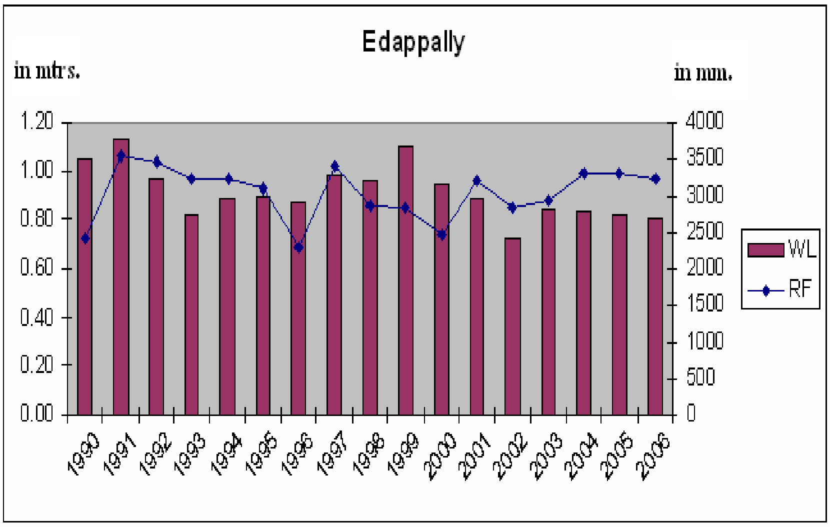
The groundwater level of some selected NHS of the study area for the period from 1990 to 2006 were compared with the corresponding rainfall. The fluctuation in groundwater level of these wells was almost concordant with the corresponding rainfall (Fig. 7.8(a) to (d).



(a) NHS at Aluva



(b) NHS at Neriyamangalam



(c) NHS at Edappally.
Fig. 7. 8 (a) to (c) Comparison of groundwater level with rainfall

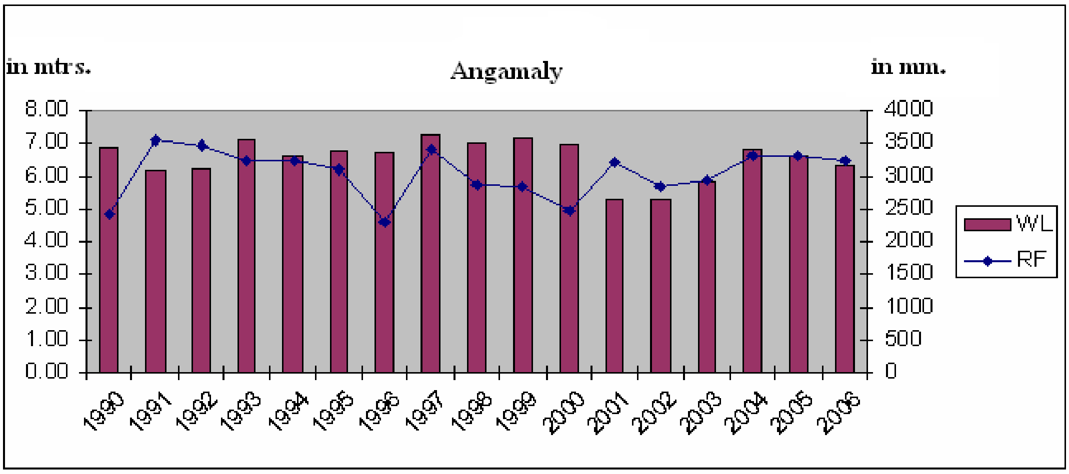
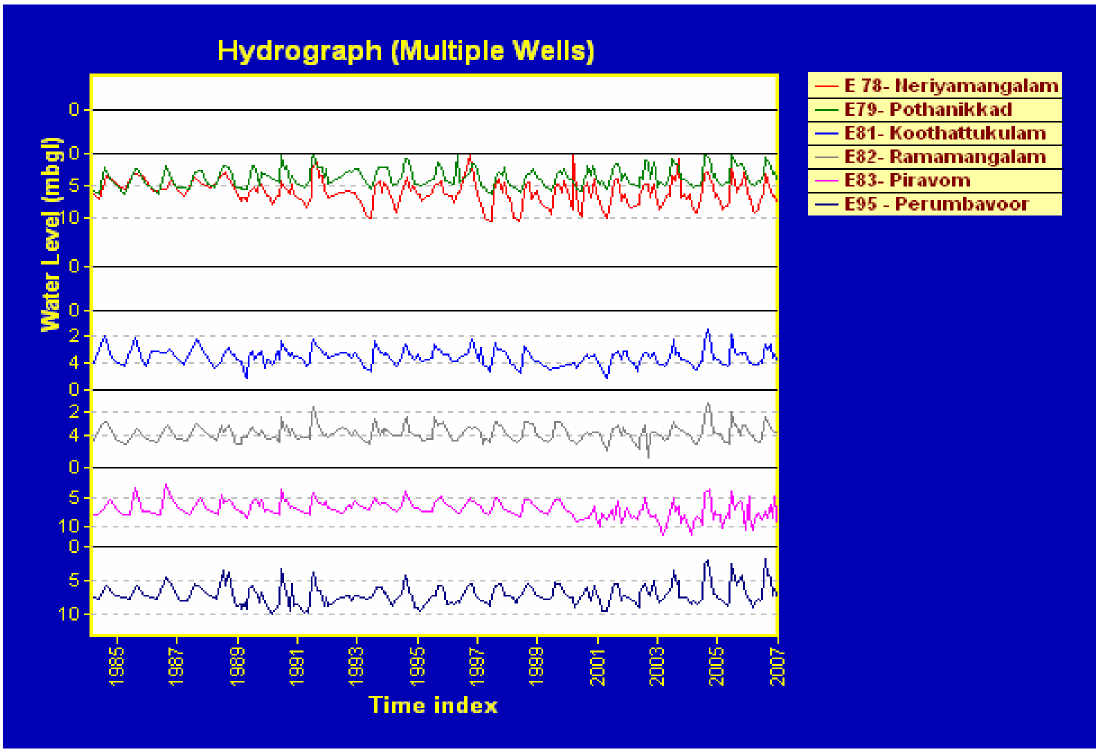


Fig. 7. 8 (d) Comparison of groundwater level with rainfall at Angamaly.

7.2.6 Comparison of the Periyar River Basin water table with the Muvattupuzha river basin

A random comparative study of the water table fluctuation of the Periyar River Basin with the adjacent Muvattupuzha river basin was carried out. The water table fluctuation data of Perumbavoor and Neriyamangalam NHS of the Periyar River Basin were compared with that of Pothanikkad, Koothattukulam, Ramamangalam and Piravom NHS of the Muvattupuzha river basin. On observation it is found that the trend of fluctuation of the basins is almost similar. The comparative fluctuations between the selected wells are shown in diagram (Fig. 7.9).



*Data source – State Groundwater Department

Fig. 7. 9 Correlation of water table of the Periyar River Basin (OW E-78 & E-95) with the Muvattupuzha River Basin (OW E-79 to E-83).

7 .2. 7 Grid deviation map

Groundwater system encompasses the channel of flow originating from a region of recharge where the meteoric water infiltrates into the ground and culminating in an area of discharge where it seeps out at the land surface, on the Indian Peninsular contest (Narasimhan, 1990). Groundwater flow path may penetrate down to a few metres below the land surface and the length of flow the path may penetrate down to a few metre below the land surface and the length of flow path from the recharge to discharge area may be the order of a few tens of metres to few hundreds of metres. The shallow system is sensitive to seasonal changes in precipitation and evapo-transpiration.

Grid deviation method applied in other quantitative studies appears to provide more convenient form of representation of hydrogeological variables (Saha and Chakravarthy, 1963). To evaluate the recharge-discharge zones, this method is widely adopted (Narasimha Prasad, 1984). It is objective, more informative and brings out more sharply the regional trend by eliminating the local interferences (Biswas and Chaterjee, 1967). The Grid deviation water table map of the study area is prepared (Fig. 7.10). The following steps were adopted in the preparation of the grid deviation water table map.

(1) Monthly water levels of 79 National Hydrographic Stations, for the period from 1985 to 2006 measured below ground level has been recalculated to water level altitude above MSL.

(2) An average elevation of water table for each observation well has been computed for the months from January to December.

(3) Annual average water level for each well has been computed. This is called the well average.

(4) Using the well average, a zonal average has been computed for each watershed and is called the grid average. The computed grid average of the basin is 390.57m above the MSL.

(5) The deviation of values between well averages and the grid average for all wells have been computed.

Table 7. 3 Groundwaer level fluctuation and Grid deviation computation for NHS of the Periyar River Basin.

Well No	Location	Altitude above MSL	Max. WL. above MSL	Min. WL above MSL	Normal WL above MSL	Grid Deviation
		M	M	M	M	M
OW01	Pappinivattom	4.90	3.440	0.26	1.85	-388.72
OW02	Lokamalleswaram	5.40	4.160	1.08	2.62	-387.95
OW03	Poyya	20.72	15.900	6.27	11.09	-379.48
OW04	North parur	3.11	2.980	1.20	2.09	-388.48
OW05	Munambam	1.97	1.960	0.05	1.01	-389.56
OW06	Pallipuram	2.10	2.070	0.14	1.10	-389.47
OW07	Paravur	3.15	2.130	0.36	1.25	-389.32
OW08	Edavanakad	1.30	1.190	0.10	0.64	-389.93
OW09	Varapuzha	3.36	3.240	0.21	1.72	-388.85
OW10	Njarakkal	2.25	2.120	0.11	1.11	-389.46
OW11	Malipuram	1.62	1.340	0.12	0.73	-389.84
OW12	Edappally	3.85	3.650	1.62	2.63	-387.94
OW14	Elur north	4.87	3.590	0.72	2.15	-388.42
OW15	Cherai	1.85	0.350	0.05	0.20	-390.37
OW16	Kottapuram	3.75	2.830	0.19	1.51	-389.06
OW17	Chalakka	7.25	6.170	3.67	4.92	-385.65
OW18	Chengamanad	9.20	3.200	0.57	1.89	-388.69
OW19	Alwaye	12.45	7.410	0.70	4.06	-386.51
OW20	Karukutty	19.20	15.480	10.15	12.81	-377.76
OW21	Aluva East	13.45	9.370	6.08	7.73	-382.84
OW23	Chowara	6.80	4.780	0.65	2.72	-387.85
OW24	N.Vazhakkulam	19.88	16.815	11.27	14.04	-376.53
OW25	Nedumbassery	14.32	12.220	5.52	8.87	-381.70
OW26	Kaladi	10.06	10.060	3.76	6.91	-383.66
OW28	Angamali	18.91	17.300	9.51	13.41	-377.16
OW29	Ankamaly	18.91	17.610	10.21	13.91	-376.66
OW30	Manjapara	16.50	14.000	10.67	12.34	-378.23
OW31	Attara	19.63	16.415	11.93	14.17	-376.40
OW32	Sulli	17.54	17.340	11.96	14.65	-375.92
OW33	Manjapra	18.84	17.940	14.38	16.16	-374.41
OW34	Kalady	9.58	9.230	2.30	5.76	-384.81
OW35	Kanjur	11.50	7.920	2.89	5.41	-385.16
OW37	Vallom	10.73	7.310	2.99	5.15	-385.42
OW38	Malayattur	15.82	12.670	7.52	10.09	-380.48
OW39	Panamkuzhi	13.65	11.114	4.59	7.85	-382.72
OW40	Kuruppampady	19.28	16.755	12.49	14.62	-375.95
OW41	Kottapadi	20.63	19.225	16.68	17.95	-372.62

OW42	Aluva	5.75	4.900	0.85	2.87	-387.70
OW43	Thattekad	34.22	33.970	29.36	31.66	-358.91
OW44	Kuttamangalam	35.75	34.450	31.50	32.98	-357.59
OW45	Pindimana	44.60	44.330	36.50	40.41	-350.16
OW46	Keerampara	27.26	25.370	21.22	23.30	-367.27
OW47	Neriyamangalam	55.90	55.900	45.41	50.66	-339.91
OW48	Marayoor	981.81	979.100	978.23	978.67	588.10
OW49	Valara	392.45	391.550	384.14	387.84	-2.73
OW50	Adimali	551.05	549.150	546.90	548.02	157.45
OW51	Adimali	551.05	550.270	544.46	547.36	156.79
OW52	Kallar-Vattayar	652.85	647.550	640.73	644.14	253.57
OW53	Vellatuval	536.74	535.670	532.24	533.95	143.38
OW54	Churuli	759.57	759.505	756.13	757.82	367.25
OW55	Munnar	1473.98	1473.280	1470.18	1471.73	1081.16
OW56	Munnar	1465.00	1464.330	1460.95	1462.64	1072.07
OW57	Devikulam	1598.63	1596.230	1592.11	1594.17	1203.60
OW58	Poopara	1015.85	1015.776	1011.85	1013.81	623.24
OW59	Udumbanchola	1086.12	1085.990	1082.92	1084.45	693.88
OW60	Udumbanchola	1086.12	1084.430	1076.43	1080.43	689.86
OW22	Udumbanchola	1086.12	1084.610	1079.52	1082.07	691.50
OW61	Nedumkandam	941.26	940.260	934.66	937.46	546.89
OW62	Vazhathope	577.69	570.310	565.94	568.12	177.55
OW63	Idikki	965.60	963.600	958.35	960.98	570.41
OW64	Irattayar	865.76	859.310	855.36	857.34	466.77
OW65	Nedumkandam	856.12	854.320	848.18	851.25	460.68
OW66	Nirmala city	876.86	876.300	873.57	874.94	484.37
OW67	Pambadumpara	344.65	343.500	339.52	341.51	-49.06
OW68	Kattappana	906.41	900.540	896.41	898.48	507.91
OW69	Ayyappancoil	872.62	866.620	860.82	863.72	473.15
OW70	Chakkupallam	1082.04	1081.490	1078.83	1080.16	689.59
OW71	Kattapana	877.27	875.360	871.67	873.52	482.95
OW72	Vandanmedu	1049.86	1049.410	1047.29	1048.35	657.78
OW73	Vellilamkandam	829.05	825.630	820.59	823.11	432.54
OW74	Pampupara	879.45	879.280	877.24	878.26	487.69
OW75	Elappara	1025.96	1024.400	1022.87	1023.64	633.07
OW76	Elapara	1025.96	1025.780	1023.04	1024.41	633.84
OW77	Kumili	875.40	873.930	870.15	872.04	481.47
OW78	Vandiperiyar	802.40	796.610	793.07	794.84	404.27
OW79	Kumily	888.97	888.070	883.42	885.74	495.17

(6) The deviation is used to prepare the thematic contour map called the grid deviation groundwater table map.

The grid deviation water level and well average of the area is presented in Table 7.3.

The grid deviation water table contour map of the study area is given in Figure 7.9. The positive zones in the area are recharge zones and negative zones are discharge zones. The positive and negative zones are demarcated by zero lines. It is found that the area under recharge is more than the discharge area. The major positive zone lies on the upstream area, mainly the Devikolam and Udumbanchola taluks of Idukki district and the major discharge zone lies in the downstream area central and western parts of the area, mainly the Kothamangalam, Kunnathunad, Aluva, Paravur and Kochi taluks of Ernakulam district. About 60 percent of the area is classified as the recharge area and that of 40 percent as the discharge area. Comparison of the normal water table contour map (Fig.7;2) with the grid deviation contour map (7.10) shows that, in general the groundwater flow direction coincides with the grid deviation map, suggesting that the topography play a significant role in the groundwater recharge and movement in the study area.

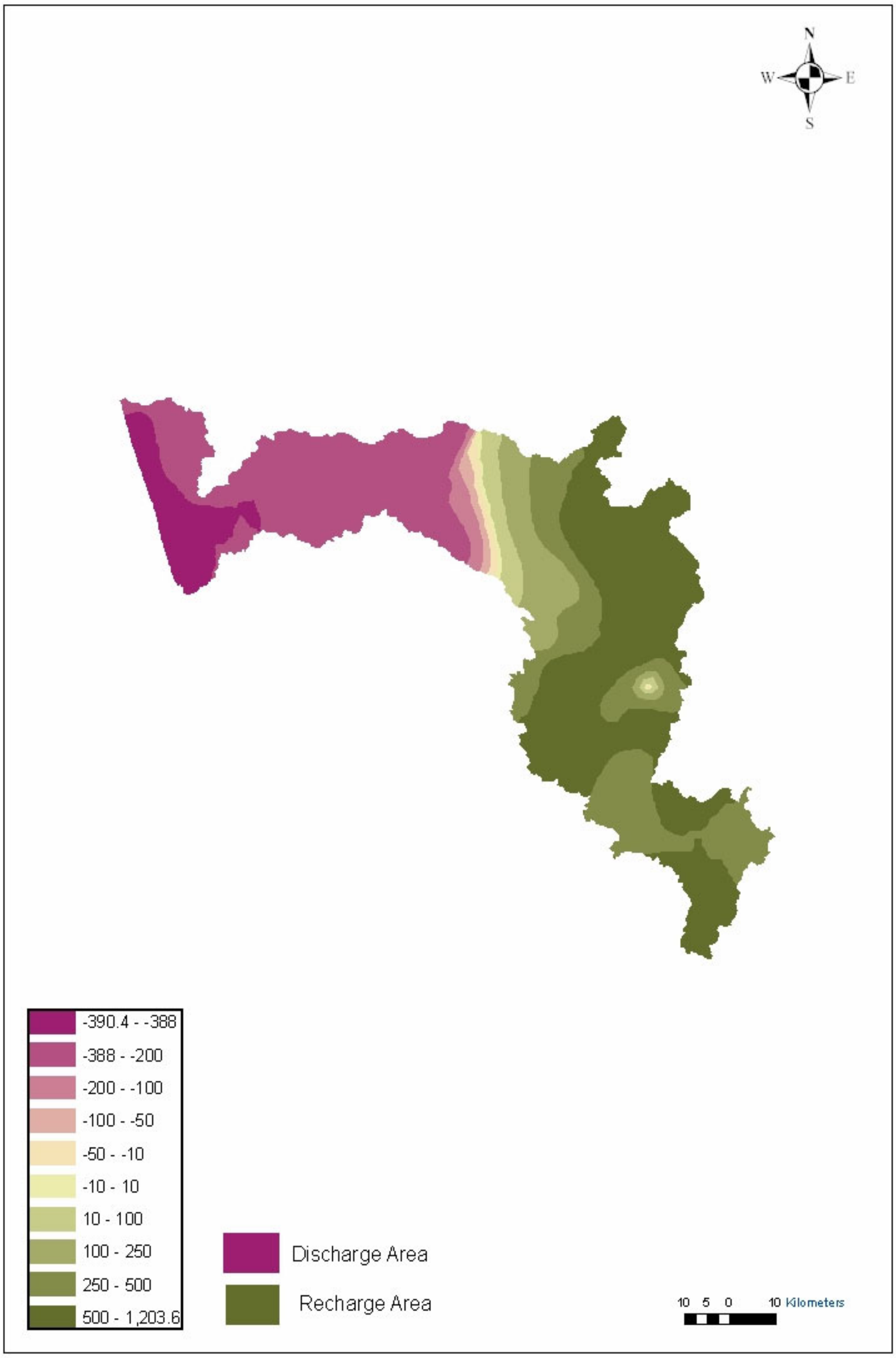


Fig. 7.10 Grid Deviation Groundwater table map of the Periyar River Basin showing the Recharge and Discharge area.

7.3. HYDRAULIC PROPERTIES OF AQUIFERS OF THE STUDY AREA

The occurrence and distribution of groundwater are controlled by various geological and structural factors. The movement of groundwater is established by hydraulic properties (Todd, 1980). Basic knowledge of groundwater hydraulics is needed for the judicious exploration of groundwater. The evaluation of groundwater resources requires a detailed study on the occurrence and behavior of groundwater and the various aquifer parameters such as transmissivity, storage coefficient, optimum yield, specific capacity etc. The present investigation is aimed to study these parameters and movement of groundwater of the basin.

7.3.1 Pumping test

Pumping test is commonly used to study the hydraulic characteristics of aquifers. Aquifer parameters can be evaluated using classical and digital models. Many of the available classical pumping test analysis are mostly graphical (Cooper and Jacob, 1946; Narasimhan, 1965; Papadopulos and Cooper, 1967; Raju and Raghava Rao, 1967; Adyalkar and Mani, 1972; Trilochan Das, 1972; Sammel, 1974, Neuman, 1975; Black and Kip, 1977, Ruston and Singh, 1983) which require data plotting and individual judgment during the curve fitting procedures. Alternatively, over the last three decades many computer methods have been proposed and successfully utilized for analyzing pumping test data (Saleem, 1970; Rayner, 1980; Mukhopadhy, 1985, Balasubramanian, 1986).

Pumping test is an important tool that provides information on the hydraulic properties of water-bearing layers and confining beds (Kruseman, G.P. and Rider, 1970). All this information is essential for efficient aquifer and well field management. In general, the objectives of a pumping test are:

- To obtain an understanding of the aquifer,
- To quantify the aquifer's hydraulic and physical properties and
- To determine the sustainable yield and efficiency of a well.

Kruseman and Ridder (1970) have given methods for analyzing pumping test data and evaluating aquifer parameters which are automated procedures to obtain the T and S of aquifers as given by Elvee (1980) and Kinzelbath (1989). In an unconfined aquifer, the drawdown is small when compared to the confined aquifer and the vertical component of flow can be negligible and Theis (1935) equation can be used to calculate the aquifer characterstics. As the drawdown is small compared to the saturated thickness, the Theis equation is applied for computation in the present study. Pumping tests were conducted in the selected 14 wells distributed uniformly in the area, to compute the hydraulic properties of the aquifers of the study area.

7.3.2 Specific yield (Sy): it is the water yielding capacity and is also termed as the effective porosity. It is expressed quantitatively as the percentage of the total volume of the rock occupied by the water which can be drained out by gravity. Specific yield increases with increase in grain size and sorting.

4.3.3 Specific retention: it is a measure of the volume of water which is retained by the aquifer material against gravity on account of cohesive and inter-granular forces. Specific retention increases with decrease in grain size and assortment.

4.3.4 Hydraulic conductivity (K) : It is also known as Permeability. It is a measure of the ease with which a fluid moves through a formation and is defined as the amount of flow per unit cross section area under the influence of a unit gradient. It has the dimensions of velocity and is usually expressed in m/day.

Transmissivity (T): Transmissivity or coefficient of transmissivity, is a hydraulic characteristic of the aquifer. It 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. It is therefore, a product of the average permeability and the saturated thickness of the aquifer, i.e.,

$T = Kb$,

Where: b = thickness of the aquifer [m]
K = hydraulic conductivity [m/d]
T = transmissivity [m^2/d].

Analysis of the data shows that the transmissivity is comparatively high in the midland regions of the basin and low in the lowland region and medium in the highland regions. The wells in the midland region are highly productive and most of the wells are located in the discharge zone based on grid deviation water table map. Groundwater potential zones have been delineated based on subsurface lithology, groundwater quality yield test in dug wells and also data related to thickness of aquifers.

7.3.5 Co-efficient of Storage or Storativity (S): It is defined as the volume of water that a vertical column of the aquifer of unit cross-sectional area releases from storage or taken into storage as the average head within this column declines or rises a unit distance. It is dimensionless. The storage co-efficient for a water table aquifer is given by:

Sw = Sy + bSs, where b is the height of the water table above the base of the free aquifer, and Sy is the specific yield of the aquifer. Usually Sy > bSs, thus Sw for all practical purposes be regarded as the Specific yield. The storage coefficient in unconfined aquifers, Sw, ranges from 0.05 to 0.30.

7.3.6 Specific Capacity: it a measure of both effectiveness of a well and also the aquifer characteristics (T and S). It is defined as the ratio of pumping rate and the draw down (Summers, 1972) and is usually expressed in liters per minute of drawdown for specific period of pumping. It is not constant and varies with a number of factors such as pumping time, pumping rate, well construction, boundary conditions with the aquifer and the influence by the nearby pumping wells. An overview of the equation used for estimation of specific capacity of wells proposed by many workers is compiled in Table 4.4. Slitcher (1905) gave the formula for computing the specific capacity as:

$$C = 2.303 \times (A/t) \times \log (S/S')$$

Where: C = Specific capacity of the well, in (lpm/mdd/m)

A = Area of cross section of the well, in sq.m.

T = Time since pumping stopped, in minutes

S = Drawdown in meters just before pumping stopped, in minutes.

S' = Residual drawdown in meters any time after pumping stopped, in minutes.

7.3.8 Evaluation of Aquifer Parameters

Pumping test has been carried out in the 14 open dug wells located uniformly in the highland, midland and lowland regions of the study area selected for this purpose. (Table 7.4). The drawdown and recovery data were recorded and analysed. The transmissivity is computed following Theis (1935) and Neumans (1965) methods. Processing of the pumping data has been carried out using the composite computer programme IPI2win and the results are given in Table (7.4).

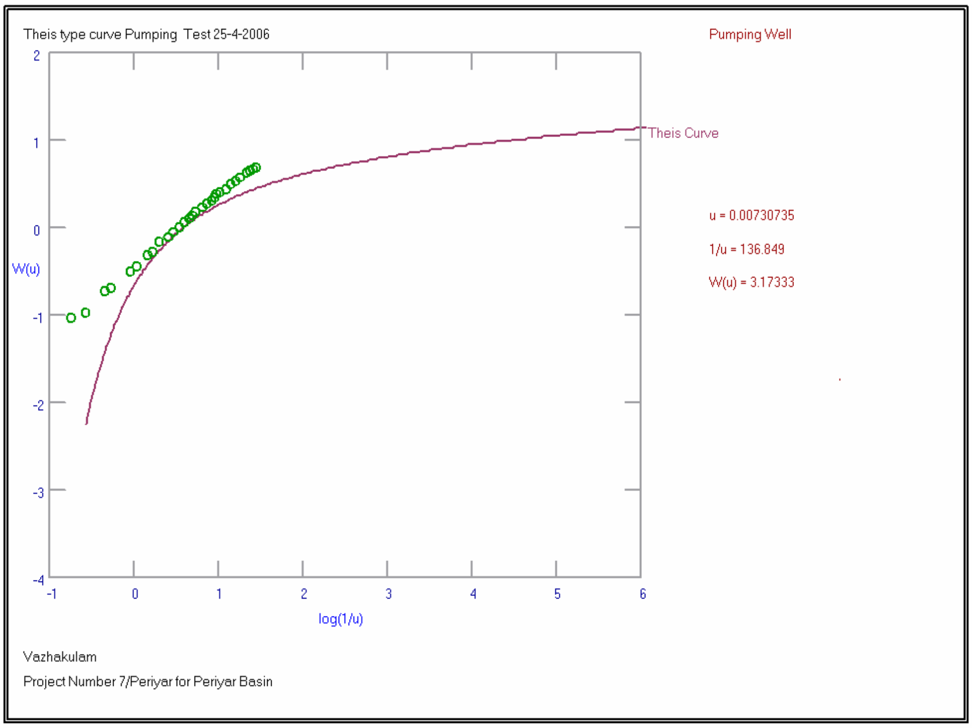


Fig. 7.11 Drawdown curve of well at Vazhakulam (Theis type)

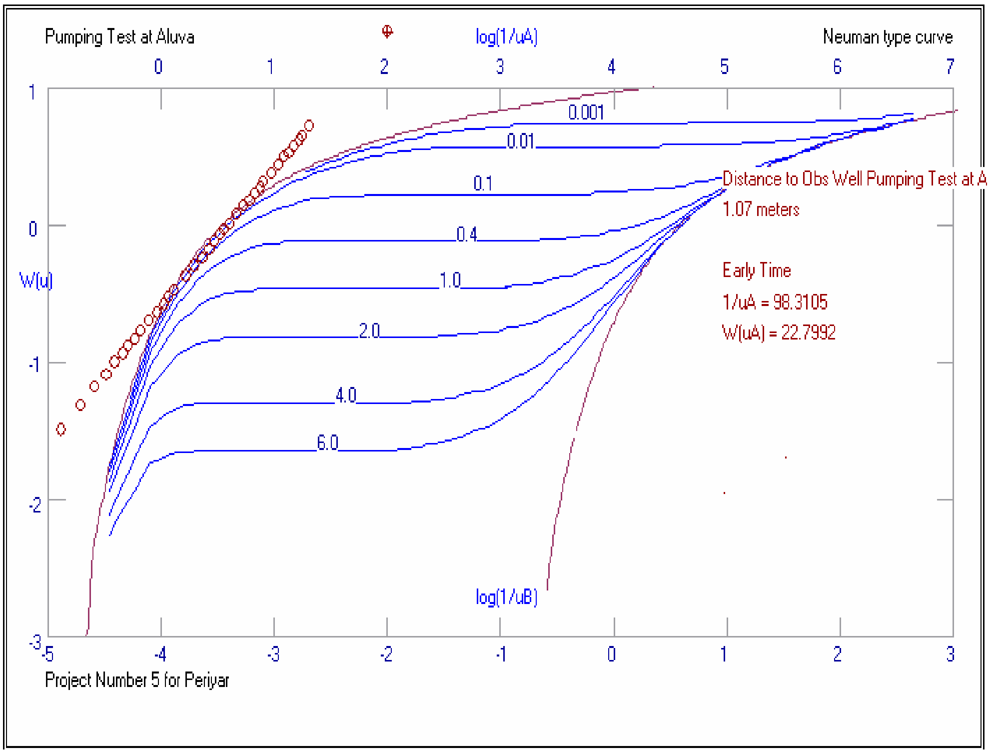


Fig. 7.12 Drawdown curve of well at Aluva (Neuman type)

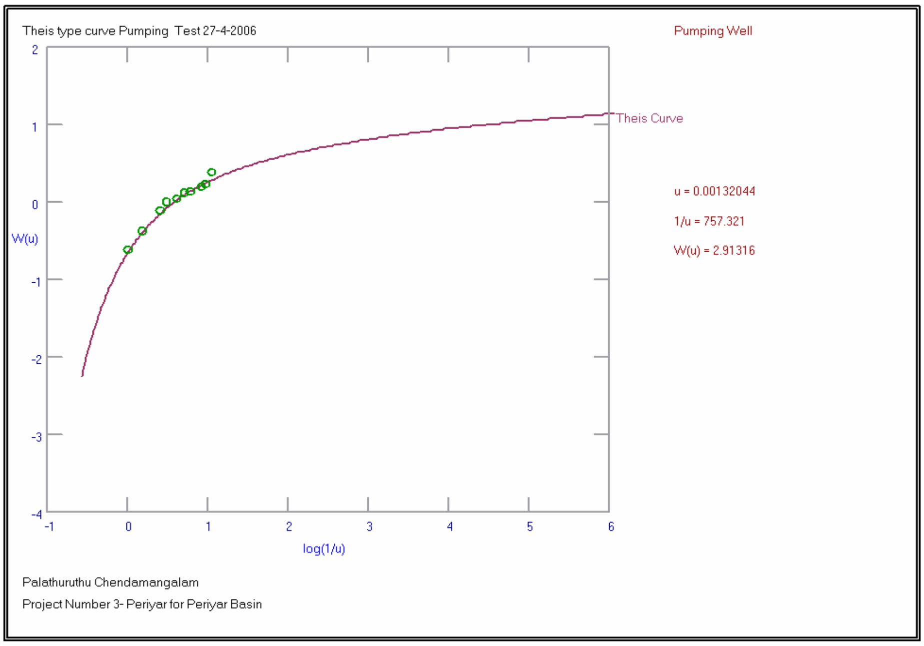


Fig. 7.13 Drawdown curve of well at Chendamangalam (Theis type)

The hydrogeological condition of the area has been evaluated based on the pumping test results. Analysis of the data shows that the transmissivity is comparatively high in the midland regions of the basin and low in the lowland region and medium in the highland regions (Fig. 7.11 to 7.13). Highly porous laterite is the dominant aquifer of the midland region. Clayey sand is the major aquifer of the lowland region and weathered crystalline is the major aquifer of the highland region. The wells in the midland region are highly productive and most of the wells are located in the discharge zone based on grid deviation water table map (Fig. 7.10). Also the major part of the midland region is recharged from the Periyar Valley Irrigation main canals and the sub canals. Due these reasons the transmissivity in the midland regions is comparatively higher than the highland and lowland aquifers.

Table 7. 4 Computation of Transmissivity and Optimum yield of dug wells of the Periyar River Basin

No.	Location	Transmissivity		Drawdown	Time (Days)	Radius(cm)	Theis Method		Neuman s Method	
		Neumans	Theis				Max.Sustained Yield	Optimum .Sustained Yield	Max.Sustained Yield	Optimum Sustained Yield
		m^2/ day	m^2/ day	m	Days	cm	m^3/day	m^3/day	m^3/day	m^3/day
1	Vellathooval	25.04	22.16	2.18	0.083	140	63.58	42.6	71.74	48.06
2	Chendamangalam	13.85	15.14	1.6	0.009	120	36.96	24.75	22.2	14.9
3	Kothamangalam	28.2	26	3.18	0.041	150	164.16	109.99	171.21	114.7
4	Vallam	220	231	1.2	0.173	150	441.34	295.7	424.04	284.08
5	Angamaly	70.2	73	1.3	0.208	160	181.12	121.35	175.5	117.6
6	Vazhakulam	102.39	98	1.49	0.208	150	152.91	102.45	159.98	215.81
7	Aluva	273	265	1.9	0.25	155	611.87	409.95	631.5	421.1
8	Chelachuvadu	20.1	18.3	2.1	0.173	165	66.28	44.41	71.9	48.19
9	Thakamani	30.15	26.2	3.6	0.18	140	154.35	103.41	135.78	90.9
10	Santhampara	12.5	10.9	3.2	0.22	145	87.97	58.94	98.4	65.9
11	Kattapana	13.8	14.08	2.1	0.145	150	71.115	47.64	68.7	46
12	Kumily	18.4	16.2	1.8	0.128	130	51.69	34.63	58.3	39.1
13	Chithirapuram	20.6	18.5	3.2	0.104	142	92.68	62.09	103.5	69.3
14	Kalady	185	179	2.1	0.25	160	486.85	326.19	505.6	338.7

The maximum transmissivity observed was 185 m^2 / day at Kalady and the minimum observed was 12.5 m^2 / day at Santhampara. The maximum optimum yield obtained in the study area is 338.7 at Kalady and the minium yield is 14.9 at Chendamangalam as deciphered in Table 7.3. The midland region of the study area is having higher yield than the highland and lowland regions as highly porous and permeable laterite is the dominant aquifer of the region. Hence the midland region is having higher yield than the lowland and highland regions.

The optimum sustained yield of each of the wells are computed separately as given in Table 7.4. Groundwater potential zones have been delineated based on subsurface lithology, groundwater quality yield test in dug wells and also data related to thickness of aquifers. These parameters were taken into consideration while preparing the groundwater resource map of the Periyar River Basin.

7.4. ESTIMATION OF GROUNDWATER RESOURCES OF THE STUDY AREA.

7. 4 .1 Norms for estimation of recharge

Detailed estimation of the groundwater resources of the Periyar basin is carried out adopting the Groundwater Estimation Methodology, 1997 (GEC-97). Groundwater Estimation Methodology (CGWB, 1997) has recommended norms for various parameters being used in groundwater recharge estimation. The norms may vary depending upon the aquifer formations and the agro-climatic conditions. The norms for specific yield and recharge from rainfall values are to be adopted from the guidelines of GEC ’97 methodology. In the Groundwater Estimation Methodology (GEC ’97) two approaches were recommended. (1) Water table fluctuation method and (2) Rainfall infiltration method.

The water table fluctuation method is adopted for the present estimation of the groundwater resource of the study area. The water level fluctuation method is based on the concept of storage changes due to difference between various input and output components. Input refers to recharge from rainfall and other sources, and subsurface inflow into the unit of assessment. Output refers to groundwater draft, evapo-transpiration, and base flow to streams and subsurface outflow from the study area. Since the data on inflow and outflow are not readily available, it is advantageous to adopt the unit for groundwater assessment as basin, as the inflow/outflow across these boundaries is taken as negligible. The area having slopes less than or equal to 20% has been demarcated and groundwater assessment is made only for such areas. The groundwater year is divided into monsoon (June to September) and non-monsoon (October to May) seasons, and groundwater assessment is made separately for these two seasons for the basin, and the annual quantity is obtained as the sum of the estimates for these two seasons. The available long term groundwater level for the period from 1985 to 2007 is used for computation of the resource.

7.4. 2 Estimation of groundwater recharge

The resource assessment during monsoon season is estimated as the sum of total of the change in storage and gross draft. The change in storage is computed by multiplying the water level fluctuation between pre and post monsoon periods with the area of assessment and specific yield of the formation. Monsoon recharge can be expressed as;

$R = (h \times Sy \times A) + D_G$

where h = rise in water level in the monsoon season, A = area for computation of recharge, Sy = specific yield of the formation, D_G = gross groundwater draft during monsoon.

The monsoon groundwater recharge has two components; rainfall recharge and recharge from other sources. It can be expressed as;

$R\ (normal) = R_{rt}\ (normal) + R_c+R_{sw}+R_t+R_{gw}+R_{wc}$ where;

R_{rt} is the normal monsoon rainfall recharge; R_c, R_{sw}, R_t, R_{gw} and R_{wc} are seepage recharge from canals, surface water irrigation, tanks and ponds, groundwater irrigation and water conservation structures respectively.

7.4.3 Total annual groundwater recharge.

Total annual groundwater recharge of the study area is computed as the sum of monsoon and non-monsoon recharges. An allowance is given for natural discharge in the non-monsoon season by deducting 5% of the total annual groundwater recharge as water level fluctuation method is employed to compute the rainfall recharge during the monsoon season.

Net Groundwater availability = Annual Groundwater recharge – natural discharge during non-monsoon season.

7.4.4 Estimation of Groundwater draft

The yearly groundwater draft of the study area is calculated for irrigation, domestic and industrial uses. The gross groundwater draft of the area includes the groundwater development from all groundwater extraction structures during monsoon as well as during non-monsoon period. (Table 7.2). The river basin falls into 20 blocks (partly or completely) within the administrative boundaries of Thrissur, Ernakulam and Idukki districts. The groundwater resource estimation of the basin was made based on the block as a unit. The estimated annual groundwater recharge is 652.72 MCM and the net annual groundwater availability is 602.19 MCM. Existing Gross annual groundwater draft for irrigation is 198.14 MCM and the existing Gross groundwater draft is 300.4 MCM. The net availability of groundwater for future development is 303.22 MCM.

Table 7. 5 Groundwater Resources of the Periyar River Basin.

Sl.No	Name of Block	Area	Total annual G.W. recharge	Net annual G.W. availability	Existing Gross G.W. draft for Irrigation	Existing gross G.W. draft for all uses	Net GW availability for future irrigation	Categorization for future GW development.
		Km^2	MCM	MCM	MCM	MCM	MCM	
1	2	3	4	5	6	7	8	9
1	Azhutha	875.00	54.00	48.56	4.46	8.94	38.47	Safe
2	Kattappana	373.00	14.87	14.13	7.04	13.53	0.00	Critical
3	Idukki	612.00	25.58	23.02	2.82	6.67	15.49	Safe
4	Nedumkandom	342.00	19.11	18.15	9.78	15.38	1.61	Safe
5	Adimali	510.00	56.08	50.47	8.91	13.60	35.99	Safe
6	Devikulam	434.00	18.91	17.94	2.18	5.21	12.10	Safe
7	Elamdesam	20.00	1.08	0.97	0.39	0.63	0.29	Safe
8	Angamaly	206.00	69.69	66.44	32.93	40.17	24.16	Safe
9	Koovapady	372.00	112.88	107.66	21.21	26.69	78.98	Safe
10	Parakkadavu	76.00	22.77	21.11	15.01	21.07	0.00	Critical
11	Alangad	65.00	23.96	21.62	7.34	15.78	24.16	Safe
12	Vazhakulam	114.00	53.20	47.93	18.82	27.42	18.55	Safe
13	Kothamangalam	792.00	57.73	51.96	17.32	24.43	25.48	Safe
14	Vypin	33.00	24.57	22.15	4.04	11.45	8.83	Safe
15	Paravur	77.00	16.47	14.62	7.96	13.43	0.00	Semi critical
16	Edappally	142.00	23.41	21.10	5.57	11.83	8.22	Safe
17	Kodumgallur	84.00	9.86	9.37	7.40	11.16	0.00	Over Exploited
18	Mathilakom	72.00	25.87	24.58	13.60	19.07	4.10	Safe
19	Vellangallur	35.00	13.68	12.31	5.06	6.56	5.34	Safe
20	Mala	30.00	9.00	8.10	6.30	7.38	0.45	Safe
	TOTAL		**652.72**	**602.19**	**198.14**	**300.40**	**302.22**	**SAFE**

7.4.5 Stage of groundwater development

The Stage of Groundwater development (%) = (Existing Gross groundwater Draft for all uses/ Net annual Groundwater Availability) x100.

The unit of assessment is categorized for groundwater development based on two criteria. They are;

(i) Stage of groundwater development and

(ii) Long term trend of pre and post-monsoon water level.

Table 7.6 Criteria for categorization of assessment units (GEC- 1997).

Sl.No	Stage of Groundwater Development	Significant long term decline		Categorizations
		Pre-monsoon	Post-monsoon	
1	< = 70%	No	No	Safe
		Yes/No	No/Yes	To be re-assessed.
		Yes	Yes	To be re-assessed.
2	> 70% and < = 90%	No	No	Safe
		Yes/No	No/Yes	Semi-Critical
		Yes	Yes	To be re-assessed.
3	> 90% and < = 100%	No	No	To be re-assessed
		Yes/No	No/Yes	Semi- Critical
		Yes	Yes	Critical
4	> 100%	No	No	To be re-assessed
		Yes/No	No/Yes	Over Exploited
		Yes	Yes	Over Exploited.

There are 4 categories based on the GEC-97 norms (Table7.1). They are (i) Safe, areas which have groundwater potential for development, (ii) Semi-Critical, areas where cautious groundwater development is recommended, (iii) Critical and (iv) Over exploited areas, where intensive monitoring and evaluation is essential and also future development is to be linked with water conservation measures and micro level studies. The present stage of development of groundwater of the study area is only 50%. Hence the Periyar River Basin is categorized for future groundwater development as “SAFE”.

7.4.6 Allocation of Groundwater resource for utilization

The net groundwater availability is to be apportioned between domestic, industrial and irrigation purposes. As per the National Water Policy, 2002, requirement of domestic water is to be given priority. The requirement for domestic and industrial water supply is to be shared based on population as projected to the year 2025. The water availability for irrigation use is obtained by deducting the allocation for domestic and industrial use from the net annual groundwater availability.

7.5 GROUNDWATER RESOURCE MAP OF THE PERIYAR RIVER BASIN.

Detailed groundwater investigation has been carriedout in the Periyar River Basin. The geomorphology, land use, soil types, different geological formations, their textures and structures, apparent resistivity of the different sub-surface layers, groundwater quality in different geological formations are taken into consideration for the delineation of the groundwater prospect map of the study area. To demarcate the different groundwater potential zones, all the above thematic layers are integrated according to their importance in GIS concept. The sequences followed here is in the order of (i) geomorphology, (ii) slope, (iii) altitude, (iv) geology, (v) structures, (vi) soil type (vii) landuse (viii) apparent resistivity of the sub-surface layers, (ix) aquifer parameters (x) groundwater quality etc. Based on these parameters, the groundwater resource map of the Periyar River Basin is prepared (Fig.7.14). The groundwater prospect zones are delineated into 5 zones based on the yield as (i) high yielding, (ii) moderately yielding (iii) low yielding (iv) poor yielding and (v) Poor chemical quality zones.

7.6 DISCUSSION

The available groundwater water level data collected for the period from 1985 to 2007 from 79 National Hydrograph Stations of the State Groundwater Department were collected and analyzed. Analysis shows that the groundwater trend is not uniform throughout the basin from 1985 to 2007. A close analysis of the pre-monsoon hydrographs show that 18.75% of the NHS exhibit 0-2 m. of water level fluctuation, 43.75% show the 2-5m fluctuation, 31.25% show variation between 5-10m and 6.25% show variation above 10 m The maximum percentage of well frequency is in the range of 2m to 5 m Analysis of the long term trend of the pre-monsoon water levels show

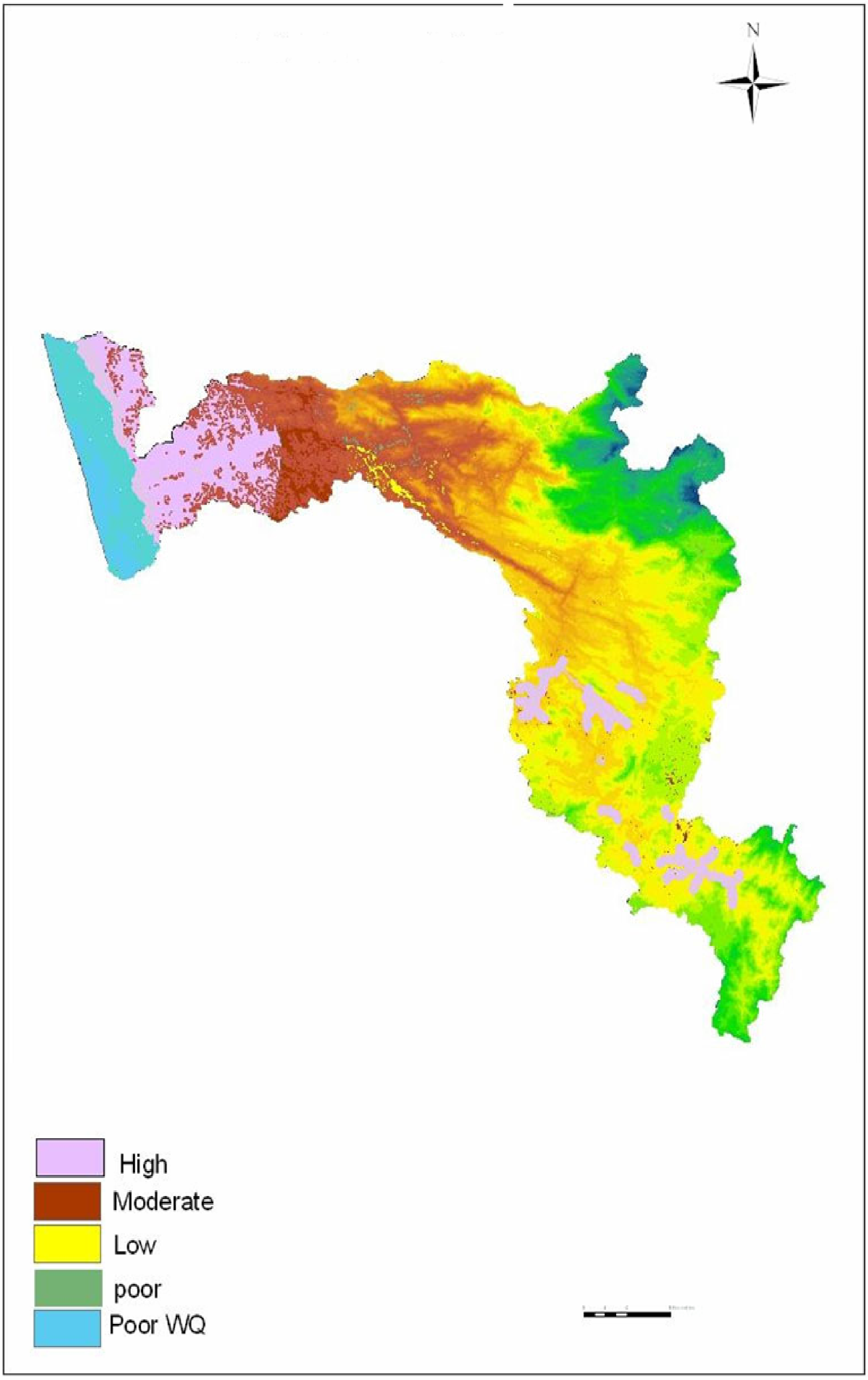


Fig. 7.14 Groundwater resource map of the Periyar River Basin (Four zones of varying yields and one zone of poor water quality).

that 44.7 percent of the wells are showing the increasing trend. The wells at Pappinavattom, Pallippuram, Kottappuram, Auva east, Edappally, Kottappady, Karukutty, Atttara, Chowara, Cherai, Elur, Manjapra, Chengamanad, Manjapra, Kallar, Vandammedu, Chakkupallam, Adimali, Vellathuval, Idukki and Kumili are showing an increase in water level during the period. The minimum increase is 0.002m/year, observed at Manjapra and the maximum is 0.075 m/year observed at Kottappuram. During the same period, water table of 48.7 percent of observation wells is showing the decreasing trend. The wells are located at Malipuram, Edavanakkad, Paravur, Narakkal, Varapuzha, Poyya, Lokamalleswaram, Kalady, Aluva, Chalackal, Kanjur, Angamaly, Vazhakulam, Kuruppampady, Malayattur, Keerampara, Kuttamangalam, Panamkuzhy, Ayyappancoil, Churuli, Devikulam, Elappara, Irattayar, Munnar, Nedumkandom, Nirmala city, Pampadumpara, Poopara, Udumbanchola, Valara, Vazhathoppe and Vellilamkandom. The minimum trend of decrease observed is 0.01m/year at Lokamalleswarm, Paravur and Nirmala city and the maximum trend of decrease is 0.085m/year at Panamkuzhy. 6.6 percent of the wells are maintaining a steady level. The wells at Edavanakkad and Pampupara are maintainng almost a steady level during the period.

During the post-monsoon period, 39.5 percent of the wells are showing increasing trend of water level. These include wells at Poyya, Pappinavattom, Lakamalleswaram, Vellilamkandom, Vellathuval, Vazhathope, Vandiperiyar, Valara, Udumbanchola, Poopara, Pambupara, Pambadumpara, Nirmala city, Nedumkandom, Munnar, Marayur, Kumily, Kaliyar, Irattayar, Idukki and Devikulam. 60.5 percent of the wells are showing the decreasing the period. this include wells at Njarakkal, Pallippuram, Paravur, Elur, Edappally, Aluva, Angamali, Altara, Chalackal, Chengamanad, Chowara, Edppally, Edavanakkad, Kalady, Karukutty, Keerampara, Kuruppampady, Malayattur, Manjapra, Nedumbassery, Neriyamangalam, Panamkuzhi, Pindimana, Thattekkad, Vallom, Adimali, Ayyappancoil, Churuli etc.

The long term trend analysis of the water level of the basin is made by taking the average of all the water levels of all the seasons together with the available data from 1985 to 2007. It is found that 38 percent of the wells are showing the declining trend, 10.5 percent of the wells show steady water table and 51.5 of the wells are showing increasing trend of water table. The groundwater depletion is mainly due to over exploitation of the resource. But in places like Aluva, Kalady, Malayattur etc., the depletion of water table may be due to the excessive sand mining from the Periyar River. The decrease in water level at places like Kanjur, Sreemoolanagaram etc., are due to the indiscriminate clay mining from the paddy fields of the area for manufacturing bricks. A close study of the depletion of water table in Neriyamangalam NHS revealed that the construction of a few deep bore wells around the existing observation well and the over abstraction of groundwater from these bore wells caused the lowering of water table in this area. Increase in water level trend is also noted in some places. This may be due to the less exploitation of groundwater. These areas were previously agricultural lands and huge quantity of water was used for irrigation. But now the cultivating lands are kept as barren land and water is not used for irrigation and thereby increased the groundwater level of the area. Immediate attention is essential to maintain the normal water level of the area by adopting suitable groundwater recharge structures and also judicious exploitation of the natural resources of the area without any adverse impact on the environment.

The grid deviation water table map of the study area is prepared and the positive zones in the area are delineated as recharge zones and negative zones are discharge zones. The positive and negative zones are demarcated by zero lines. It is found that the area under recharge is more than the discharge area. The major positive zone lies on the upstream area, mainly parts of Devikulam and Udumbanchola taluks of Idukki district and the major discharge zone lies in the downstream side, at the central and western parts of the area, mainly parts of Kothamangalam, Kunnathunad, Aluva, Paravur and Kochi taluks of Ernakulam district and Kodumgallur taluk of Thrissur district.

Detailed estimation of the groundwater resources of the Periyar basin is carried out adopting the Groundwater Estimation Methodology, 1997 (GEC-97). For more precision, the resource estimation of the basin was made based on each block as separate unit and the resource of the basin was estimated. The estimated annual groundwater recharge of the basin is 652.72 MCM and the net annual groundwater availability is 602.19 MCM.

Existing Gross annual groundwater draft for irrigation is 198.14 MCM and the existing Gross groundwater draft is 300.4 MCM. The net availability of groundwater for future development is 303.22 MCM. The present status of development of groundwater resource of the basin as per the GEC-97 criteria is only 50 percent. Hence the Periyar River Basin is categorized as “SAFE” for future development of groundwater.

Determination of potentiality and movement of groundwater is possible only if we know the characteristics of the aquifer of the area. Pumping tests are the best available methods to evaluate the aquifer parameters. Pumping tests have been carried out at 15 pre-determined open dug wells of the basin and the results obtained were analyzed. Clayey sand is the dominant aquifer of the coastal plains, lithomargic clay and laterites are the dominant aquifers of the midland regions and also parts of the lowland regions. Weathered crystalline and laterites are the aquifers of the highland regions. Pumping test has been carried out in all these environments. From the analysis it is inferred that the maximum transmissivity is observed in the midland region where laterite is the dominant aquifers of the region. The transmissivity of the aquifers of the highland and lowland are less compared with the midlands. Optimum yield of the wells of different locations are also calculated. About 60 percent of the basin area is Low/Moderate yield zones. Based on the hydrogeological and hydrochemical studies, the groundwater resource map of the Periyar River Basin is prepared (Fig. 7.15).

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Chapter VIII
Summary and Conclusions

In India in the last three decades, watersheds have become the pivotal unit for rural development programmes. The development of watershed basins to increase the groundwater recharge potentials is becoming a major issue in India due to acute shortage of groundwater resources, resulting from the marked expansion of land-use activities and the explosive growth in population. The Government of India in November 2000 introduced the revised guidelines for watershed development known as the National Watershed Development Programme for Rainfed Areas (NWDPRA). The hydrogeological and hydrochemical information is very essential to prepare the watershed development plans of any basin. Appropriate policies and practices based on validated scientific findings are essential for the development, management and also to evaluate the impacts of watershed development on water resources. With this perspective, a sincere attempt has been made to evaluate the Hydrogeological and Hydrochemical aspects of the Periyar River Basin, Central Kerala and to illustrate as to how this study is helpful in the watershed development of the basin. The information thus acquired is very helpful to pin point areas of study on a local scale and thus facilitate programmes for detailed investigation, development and management of the groundwater resources of the area.

An integrated approach has been adopted in the present study to assess the occurence, availability and distribution of groundwater of the Periyar River basin. The River Periyar is the longest river of Kerala and also the largest in water discharge potential having a length of 244 km. It originates from the Sivagiri malai (hills) in the Western Ghats, at an elevation of 1830 m above the mean above the mean sea level (MSL). The Chalakkudy river also joins the Periyar at Elanthikara and finally drains into to the Lakshadweep Sea. The maximum width of the river is 405 m. In the present study an analysis of the geomorphology, geology, structure, metereology, hydrogeology, hydrogeophysics , hydrogeochemistry and the application of remote sensing has been attempted. The morphometric characterisation of the watersheds were carriedout using ARCINFO software and the parameters intepreted. Remote sensing is one of the important tools used in the present study. IRS IB and IC data products have been interpreted. IRS 1B LISS II data was used for visual interpretation and IRS 1C LISS III multiband digital data were used for image processing. The geology, geomorphology, landuse and lineament analyse were carriedout using IRS data.

The area is characterized by highly undulating topography with steeply dipping hill ranges,valleys and plains. The drainage pattern is mainly dendritic to parallel. The Periyar River originating from Idukki in the south to

Perinjakutti in the north shows a parallel drainage pattern parallel to the main lineament. The drainage is thus structurally controlled and most of the streams are flowing in deep gorges with steeply sloping symmetrical valleys. The main tributaries of the Periyar river are Muthirapuzha, Mullayar, Panniyar, Puyankuttiyar and Cheruthoniyar, Perinjankutti and Edamalayar.

The study area exhibits varied physiographic features with elevation ranging from 1830m in the south-east to the sea level in the west. Major part of the study area falls in the hilly ranges of the Western Ghats. The slope of the watershed ranges from nearly plain to steeply sloping. Based on the elevation, the river basin has been divided into five physiographic units namely the lowlands, midlands, foothill region, plateaus region and the highlands. The foothills, plateaus and the highlands are collectivey grouped as the highland region. The low lands are having an elevation of 0 – 6 m, midlands 6 – 80 m, foothills 80 – 500 m, plateaus 500 – 1500 m and the high lands above 1500 m above MSL. About 10% of the basin area is occupied by the coastal plains, 30% midlands, 15% the foothill region, 20% the plateau region and 25%, the highlands region.

The soils of study area have been clasified based on USDA (1995) taxonomic scheme. The area has soils of 3 orders such as Entisols, Ultisols and Inceptisols, 7 sub-orders such as Aquemts, Fluvents, Humults, Orthents, Psamments, Ustolls,Ustults and 9 sub-groups such as Typic Sulfaquents, Oxyaquic Ustrothents, Typic Ustrothents, Ustic palehumults, Ustic Kandihumults, Typic Kandihumults, Ustic QuartziPsamments, OxicDystrustepts and Typic Plinthustults. There is a direct relation between the occourence and movement of soil and groundwater. The Vypin series of soil is fine mixed, isohyperthermic and included in the Typic Sulfaquents subgroup. These soils are very dark clay, very sticky and plastic and saline soil. These are coastal alluvial soil formed under ill drained conditions. The soil is poorly drained and with a low permeability. The groundwater of the area exhibits the chemical quality of the aquifer material. The water quality of the region is poor as per the BIS standards and WHO guidelines. This may be due to the influence of the of soil chemistry on the groundwater of the area. The Manathala series under Ustic quartzipsamments subgroup is isohyperthermic. Here adjacent to the coastal palnis, the quality of water of the clayey sand aquifer is poor. The groundwater of the soils of Koratty, Perumbavoor, Ikarnad and Odakkali and Punnamattom series are of good quality falling within the BIS standards and WHO guidelines. The soils of the region are highly porous and permeable and ideal for groundwater recharge. The thickness of soil also high. The average thickness of soil in the area is 2 m underlined by the laterites. This region is highly potential for the development of groundwater. The quality of groundwater of the region is generally good for all purposes.

The soils of Venmani series and Thommankuthu series are clayey, mixed and isohyperthermic. The thickness of laterite in the region is negligible. The average thickness of soil in the region is 1 to 1.5 m. The soils are porous and permeable. The area is moderately potential for the development of groundwater. The quality of groundwater of the region is generally good for all purposes. The Anamudi and Pampadumpara soil series are mainly clayey, mixed, isohypethermic forest soils. The thickness varies from 0.5m to 2m. The porosity and permeability of the soils of this region are poor and hence the surface and subsurface runoff is relatively high and correspondingly the rate of infiltration is also very less. Hence the area is generally poor for the development of groundwater.

The geological formations in the area play a major role in shaping the landscape. The study area is a Pre-Cambrian metamorphic terrain. The most spread rocks in the area are charnockites and the associated gneisses. These are pyroxene-bearing granulites and gneisses and occupy the highlands and midlands of the area. Textural, mineralogical and geochemical variations are observed in charnockites from different localities. The charnockite is well foliated showing foliation in NNE – SSW to N – S direction with a gentle dip towards west.The second major rock type encounteed in the area is the hornblende-biotite gneiss. It is mesocratic and medium grained. It occurs mainly in the Idukki block. Minor occourence of Hornblende-biotite gneiss is encountered in Devikulam block especially in Devikulam and Kanthalloor grama panchayats. These rocks follow the regional trend of foliation. Hornblende-biotite gneiss, biotite gneiss and garnet-silliminate gneiss are spatially associated with charnockites in many places. They are the resultant of the regional migmatisation of the older rocks. At places, the migmatisation are complete and the paleosome and neosome are well developed. The rocks have a general trend of foliation of NW-SE to NNE TO SSW. In general, the river flow along the regional slope of the coastal lowlands and midlands and reflect only local control of the underlying geology or structure and along the highlands run parallel to the Ghats escarpment indicating that the regional NNW-SSE and NNE-SSW trending lineaments have exerted control over the overall orientation of the river.

The Tertiary formations occur all along the coastal belt underlying the recent alluvium. These formations are ranging in age from Eocene to Miocene. These are formations underlained by the crystalline and overlain by the unconsolidated recent sediments. From the lithology of the tube well drilled by the Central Ground Water Board and the State Groundwater Department These Tertiary sediments have been classified as Vaikom, Quilon and Warkalli sequences of beds.

The laterite formation occurs as a cover over the crystalline rocks. They occur mainly in the midland region and are in-situ formed due to the weathering of either crystalline or sedimentary rocks. The thickness of laterite varies from place to place and reaches a maximum of 20 m along the midland region whereas in the eastern part, they are either absent or observed as thin capping over the country rock. In the western coastal part, laterite is considered to be the marker horizon to differentiate between the Tertiary and Recent alluvial formations.

Detailed groundwater investigation has been carried out in the study area. Hitherto, exploration geophysics has not played an important role in ground water studies of the basin. In the present study, electrical resistivity surveys were carried out for evaluating the hydrogeological conditions of subsurface sequences of the area. Vertical electrical soundings were carried out in the study area using the Schlumberger array and deleniated the groundwater potential zones of the area.and also the extent of salt water intrusion. Various thematic maps were prepared using the field data. . From the analysis of the data, it is infered that the lowlands and midlands are highly feasible for the development of groundwater. The highlands are moderately to poorly feasible for groundwater development. The present study reveals that the coastal plains and parts of some lowlands are under the influence of salinity. The extent of salinity and the salt water – fresh water interface has been delineated.

Groundwater occurs under phreatic condition in the laterite, lithomargic clay, weathered crystallines, valley fills and clayey sands, under semi-confined condition within the crystalline fractures and joints and under confined conditions in the Tertiary formations of the study area.The magnitude of the groundwater table fluctuations of the area depends mainly on the usage, climate, drainage, topography and the geological conditions. The groundwater of the terrain has varied hydrogeological setup depending upon the hetrogenous country rocks and their structure. Water level data for the period from January 1985 to December 2006 of 79 monthly observation wells of the basin were collected and analysed. Analysis of hydrographs of these wells shows that 33.33 percent of the NHS shows decrease in water level in the range of 0 to -1m and 42.86 percent shows increase in water level within the range of 0 to 1m, 14.29 percent of the hydrographs show increase in water level in the range of 1 to 2 m and 9.52 percent show increase in water table of more than 2 m. The continuous declining of water levels, as evident from the hydrographs, reveals that the discharge is more than the recharge of groundwater. To reverse this situation it is indispensible to adopt rainwater harvesting and artificial recharge in these areas. It is evident from the grid deviation contour map of the area that the groundwater flow direction reflects the surface topography.

The occurrence and distribution of groundwater are controlled by various geological and structural factors. The movement of groundwater is established by hydraulic properties. Pumping tests were conducted in the selected open dug wells of the area to estimate the hydraulic characteristics of the aquifers. Hydraulic properties of the aquifers are very important as they depict the groundwater storage and transmitting characteristics. The different transmissivity values and the optimum yield were computed. From the analysis of the data, it is infered that the lowlands and midlands are highly feasible for development of groundwater, while the highlands are moderately to poorly feasible for groundwater development.

Groundwater quality studies of the phreatic aquifer have been carriedout with the groundwater samples collected from the selected 70 open dug wells distributed uniformly throughout the study area. Water samples were analysed for physical, chemical and bacteriological parameters during the three consecutive pre-monsoon and post-monsoon seasons from 2004 to 2006. The hydrochemical investigation in the present study is restricted to the major ion concentrations, their relative relative abundance, distributions and the pattern of the variability in groundwater chemistry. On the basis of the groundwater chemistry, an evaluation of groundwater for domestic and irrigation uses is established. The chemical composition of the groundwater which moves from the recharge area to the discharge area reflects changes by various geochemical processes. Groundwater of the study area in general is alkaline in nature and higher EC values were noted during the pre-monsoon season. HCO3 in the study area was higher in pre-monsoon season due to weathering of silicate rocks. Chloride was higher in indicating leaching from the upper soil layers due to industrial and domestic activities and dry climates. Sulphate is higher in pre-monsoon season indicating breaking of organic substances from topsoil/water, leachable sulphate present in fertilizer and other human influences. NO3 was higher in pre-monsoon indicating leaching of fluoride rich rocks and organic substances from weathered soil. The general dominance of anion is in the order of Cl > HCO3 > SO4 > NO3. For cations Na was higher in pre-monsoon season indicating weathering from plagioclase bearing rocks. K was lesser in both the seasons indicating its lower abandunce as compared to Na. Ca and Mg were higher in pre-monsoon indicating the weathering from primary mineral sources. The general dominance of cations was in the order of Na > Ca > Mg > K. The results from the water analysis were used as a tool to identify the process and mechanisms affecting the chemistry of groundwater from the study area.

The Hill-Piper diagram is used to infer the hydro-geochemical facies of the study area. 44 percent of the samples are falling under Ca-Na-HCO3-Cl type, 16 percent Ca-HCO3 type, 15 percent under Ca-Na-Cl type, 14 percent under Ca-HCO3-Cl type, 8 percent under Na-Cl type, 2 percent under Ca-Na-HCO3 type and 1 percent under Na-HCO3-Cl type. There is no significant change in the hydrochemical facies noticed during the pre-monsoon and post-monsoon periods.

Based on the U.S.S.L. classification, 90% of the groundwater of the area fall low to medium salinity and low alkalinity field and considered good for all irrigation purposes. 8% of the area falling in the high salinity and low alkalinity field, 1% in the high salinity and low alkalinity field and 1% of the area falls under very high salinity and high alkalinity. Hence the groundwater of this region is not suitable for irrigation under ordinary conditions. Selecting more tolerant crops is a practical solution to the toxicity problem.

The groundwater in the study area is a unique example for the impact of weathering, ion exchange and anthropogenic process controlling water chemistry. The chemical composition of groundwater of the study area is strongly influenced by rock- water interaction and dissolution and deposition of silicates group of minerals. Weathering of silicate minerals controls the major ion chemistry of calcium, magnesium, sodium and potassium. Chloride (Cl^-) was dominant due to the weathering and erosion of the crystalline rocks and also the anthropogenic impacts (human sources). The ion exchange and reverse ion exchange control the water chemistry of the study area. In general, water chemistry is guided by lithological influences on water chemistry by complex weathering process, ion exchange along with influence of chloride ions from anthropogenic impact.

The rapid industrial and urban growth along the banks and adjacent area of Periyar river had its origin in the early 1960s and since then, it has been growing rapidly. These industries discharge their solid waste as well as effluents without any proper treatment into the river channel or on the low lying areas. The deterioration of quality of groundwater of Eloor and other parts of the lowland coastal region is due to the impact of these industrial effluent discharges and also due to the saline water incursion. In the highland region, it is due to the excessive use of fertilizers and pesticides for agriculture. A high TDS (levels above 1,000 mg/L) may cause corrosion of pipes and plumbing systems. To bring down TDS to acceptable levels, a water softener with a reverse osmosis (R/O) system is usually effective.

Discharge and leakages from open drains and septic tanks, unscientific construction of septic tanks, open defecation etc., are common problems in the study area and this condition paves the way for the production of bacterial colonies, which may contaminate the groundwater of the area. In pure water, nitrate (NO3-) is seldom present. NO3- occurs in groundwater, however, due to decaying of organic matter, fertilizers, poor sanitation, septic tank leakage, open sludge drains and unscientific disposal of Municipal wastes.

It is observed that the aquifer of the study area is getting over exploited and as a consequence groundwater resources are being depleted. The coastal area is polluted due to saline water ingression. The basic problem in groundwater management is its development without further invasion of the saltwater/freshwater interface towards land. This may be acieved by economical use of groundwater and limiting groundwater draft, through artificial recharge of overexploited aquifers, conjunctive use and also adoption of optimal groundwater development strategies. Strict enforcement of the groundwater rules to control groundwater extraction is the need of the hour.

The following are the major conclusions arrived at from the present study of the Periyar River basin:

1. The movement of groundwater is mainly controlled by topography, lithology and structures.
2. The soils identified mainly are of 3 orders, such as Entisols, Ultisols and Inceptisols.
3. The recharge and discharge zones were delineated and it is found that the highland region and the eastern part of the midland regions are the recharge zones and the lowlands and the western part of the midland region are the discharge zones.

4. The aquifer transmissivity in the area ranges from 14.02 to 265 m^2/day.
5. The increase in nitrate content during the post-monsoon is due to the agriculture activities of the region.
6. The suitability of water for various purposes have been identified. The groundwater of the Vypin and Eloor regions are not suitable for drinking purposes as per the BIS and WHO standards. The water in these locations are not suitable for tolerant crops.
7. The groundwater recharge is maximum during the post-monsoon period.
8. The total dissolved solids has a linear relationship with the length of the flow pattern in the region.
9. Groundwater developmet in the region is only 50% and hence further development is possible in many parts of the basin.
10. Based on the isoresistivity maps, the various subsurface layers have been identified. The area feasible for the development of various groundwater abstrraction structures have been identified and demarcated.
11. The groundwater potential zones of the watershed has been demarcated based on the hydrogeological and hydrochemical studies of the area and the groundwater resource map of the basin is prepared.

Chapter **IX**

Recommendations

Based on the detailed hydrogeological, geophysical and hydro-chemical studies carried out in the Periyar river basin and discussions presented in previous chapters, the following recommendations are made on the sustainability of the water resources of the area:

- It is observed that the aquifers of the study area are getting over-exploited in some parts of the basin and as a consequence, the groundwater resources are being depleted. The continuous declining of water levels reveals that the discharge is more than the recharge of groundwater. To reverse this situation, it is mandatory to adopt rainwater harvesting and artificial recharge measures in these areas. The active involvement of the households and local community is to be ensured to achieve this objective. Appropriate artificial recharge structures should be constructed only after a detailed study. Rainwater harvesting structures such as gulley plugging is recommended in the hard rock region with good soil cover and highly undulating or steeply sloping topography. Percolation pits, ponds etc can be constructed, along the foothill region and percolation pits, check dams, subsurface dams can be constructed in the gently sloping or plain area.

- Existing tanks and ponds should be protected, reclaimed and rejuvenated to facilitate groundwater recharge as the first step.

- The basic problem in groundwater management is its development without disturbing the saltwater/freshwater interface along the highly sensitive coastal aquifers. This may be achieved by economical use of groundwater and limiting groundwater draft, through artificial recharge of overexploited aquifers, conjunctive use and also adoption of optimal groundwater development strategies. Strict enforcement of the groundwater rules to control groundwater extraction is the need of the hour.

- The groundwater quality deterioration is seen increased in the industrial areas and the extent of contamination exceeds the limit of potability standards prescribed by BIS and WHO. The present practice of discharging the industrial wastes and chemical effluents and dumping of municipal wastes in low lying areas and water bodies should be stopped. Proper effluent treatment facilities and solid waste management techniques should be adopted.

- Discharges and leakages from open drains and septic tanks is a common problem in the study area and this condition paves the way for the production of bacterial colonies which may contaminate the groundwater. Causes of $NO3^-$ pollution in groundwater are due to poor sanitation and septic tank leakages, open sludge drains and leaching from municipal solid and liquid wastes. All these conditions prevail in the study area and are increasing day by day. Shallow two-pit latrines should be constructed instead of the present deep single pit latrine, which may contaminate the groundwater. Groundwater of the area should be used only after proper treatment for disinfectant.

- Modern technologies should be adopted to dispose the solid and liquid wastes and industrial effluents before final disposal to check the groundwater quality deterioration of the area.
- Strict legislation to be enforced to regulate further development of groundwater in the critical area. Such legislation should be guided by equitable distribution of available water.
- There is a need to take a holistic approach to tackle the over exploitation of groundwater in parts of the area. Integrated water management and integrated governance should be evolved. Drilling of borewells other than for domestic purposes should be regulated. Groundwater monitoring activities should be strengthened.
- Groundwater sanctuaries should be created in wasteland zones.
- Groundwater monitoring activities should be strengthened.
- There should be an institutional set up to protect the river basin. An interdisciplinary approach using expertise from academicians.

hydrogeologists, hydrologists, agronomists, farm scientists, economists, sociologists, environmentalists are to be included in this set up.

- The agricultural community should be educated as to the undesirable consequences of over exploitation and the need to manage the resource scientifically.

- The freshwater- saline water balance should be maintained along the coastal regions. This can be achieved by economical use of groundwater and limiting groundwater draft, through artificial recharge of overexploited aquifers, conjunctive use, and also adoption of optimal groundwater development strategies. The norms prescribed in the National Water Policy have to be followed in respect of the development of the coastal aquifers, keeping the sensitive environmental conditions.

- Limit the sand and clay mining activity within the carrying capacity of the river basin. Regulate the clay mining activity under the well laid guidelines. Scientific reclamation must be made mandatory. The mining is now being supervised by the concerned Grama Panchayats and mined unscientifically. This poses threat to the environment. Hence, all the smaller mining activities should be amalgamated under a single agency under the government for better management of the resources and to minimise the adverse impact on the environment.

- Treatment for the reduction of iron can be done by several methods depending upon the concentration and the pH of the water. Initially, a water softener can be used to eliminate iron to tolerable levels. Secondly, potassium permanganate or "green sand" filters are highly successful. Finally, aeration, the addition of oxygen to the water can aid in the precipitation of iron, thus removing it from the water.
- Generate awareness among the public on personal hygiene to ensure potability of water and educate them about the standards of drinking water. Chlorination is highly effective in destroying pathogenic (disease causing) organisms. Other more expensive methods include ultraviolet light radiation and physical filtration.

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