AN INTEGRATED STUDY ON THE HYDROGEOLOGY OF BHARATHAPUZHA RIVER BASIN, SOUTHWEST COAST OF INDIA

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by

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SEPTEMBER, 2009

Dedicated to my beloved husband

DECLARATION

I, **SREELA S. R,** do hereby declare that the thesis entitled **"AN INTEGRATED STUDY ON THE HYDROGEOLOGY OF BHARATHAPUZHA RIVER BASIN, SOUTH WEST COAST OF INDIA"** is an authentic record of research work carried out by me under `the supervision and guidance of **Dr. K. SAJAN**, Professor, Department of Marine Geology and Geophysics, School of Marine Sciences, Cochin University of Science and Technology. This work has not been previously formed the basis for the award of any degree or diploma of this or any other University/institute.

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CERTIFICATE

This is to certify that the thesis entitled **"AN INTEGRATED STUDY ON THE HYDROGEOLOGY OF BHARATHAPUZHA RIVER BASIN, SOUTH WEST COAST OF INDIA"** is an authentic record of research work carried out by **Ms. SREELA S. R** under my supervision and guidance in partial fulfilment of the requirements for the degree of Doctor of Philosophy and no part thereof has been presented for the award of any degree in any University/Institute.

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Water is food and fire is the eater of the food,
Fire is established in water and Water is established in fire

- **Taittiriya Upanishad 3.8**

PREFACE

Water is the most precious and widely distributed natural resource. It is not only a basic need for sustaining human society and economic activity but also a major force in shaping the surface of the earth. Man depends upon water for domestic, agricultural and industrial purposes. Growing populations, wastage of water, inefficient irrigation and pollution exert pressure on this resource. Since water plays a pivotal role in sustaining life on earth, water must be accessible and safe. Groundwater, being a fundamental resource, needs to be developed with proper understanding on its occurrence in space and time. Groundwater management on scientific lines has become inevitable for the sustainability of this vital resource. The purpose of Sustainable Water Management (SWM) is to manage the water resources of present and future.

India is the country having diversified geological formations ranging from the oldest crystalline rocks to the recent alluvium. The spatio-temporal variation in meteorological conditions has correspondingly given rise to widely varying groundwater situations across the country. In recent years, over exploitation of the groundwater has become inevitable and this in turn has led to depletion of water table and quality at many places. This emphasizes the importance of systematic study of various hydrogeological aspects of groundwater and the need for a better scientific exploration and its efficient management in conjunction with surface water resources. So an attempt has been made to develop a scientific data base on the hydrogeological aspects of the Bharathapuzha river basin, Kerala, (latitudes 10° 25′ and 11° 15′ N and longitudes 75° 50′ and 76° 55′ E), which will enable the littoral state of Kerala to address the groundwater crisis to some extent that the state now encounter.

The present study deals with the different hydrogeological characteristics of the Bharatapuzha river basin. Geologically the Bharathapuzha basin is characterised by Precambrian crystalline rocks and recent to sub recent deposits alluvial sands. Laterite forms a thick capping over a major part of the Bharathapuzha river basin. The groundwater storage is mostly controlled by the thickness and hydrological properties of the weathered zone and the aquifer geometry.

The study area covers 17 block Panchayats. Of these, Chitoor block is 'over exploited', Kollengode, Trithala, and Palakkad are 'critical' in category and Kuttippuram and Sreekrishnapuram blocks are 'semi critical' in terms of groundwater development. There is a sharp decline in the groundwater level in Kollengode, Chittoor and Sreekrishnapuram blocks. Eventhough the average annual rain fall of the area is very high (~280 cm), there is acute shortage of drinking water. The reason for this scarcity is the unscientific exploitation of ground water by the agricultural fields, industries and water based multi-national companies working in and around this basin.

Except a preliminary study by Central Groundwater Board (CGWB), no attempt has been made so far to study the aquifer parameters to make a reliable groundwater potential map of the area, so as to evaluate the quality of groundwater, to appreciate the control of lithology, geomorphology, and surface/sub surface structure on the groundwater potential, better management of the water resources in the river basin etc. Therefore a proper assessment of quality and quantity of water resources and its management of the Bharathapuzha river basin have been undertaken. Geographic Information System (GIS), the best tool to create scientific groundwater database has also been employed in the present investigation. Conventional survey as well as remote sensing techniques are simultaneously carried out in the present work to get good insight towards the groundwater potential for Bharahapuzha river basin. A very reliable useful database on the hydrogeological aspects of the river basin can be attained as an outcome which can be ultimately useful for policy decisions on groundwater exploitation. The study may reveal answers to many controversial issues regarding the water resources of this region.

The whole work is presented in six chapters with further sub divisions.

The first chapter gives a brief introduction followed by a description about the study area, geological settings, review of previous works, relevance and objectives of the present study. It also gives an idea about international and national groundwater scenario and hydrometeorology.

Chapter 2 titled as hydrogeology enfolds the behaviour of the groundwater system and aquifer parameter evaluation. Water level fluctuation, long term trend of water level, correlation between water level and rainfall are the main aspects discussed to ascertain the behaviour of the groundwater system. Also the chapter discusses the aquifer parameters such as aquifer transmissivity, storativity, optimum yield, time for full recovery and different types of specific capacity indices.

In the Chapter 3, presents the geoelectrical prospecting which briefly explain basic principles, master curves and interpretation of Vertical Electrical Sounding (VES) data and an analysis of the subsurface parameters such as resistivity and thickness of 1st and 2nd layer, depth to the aquifer basement, depth wise isoresistivity and Dar Zarrouk parameters is being done.

Chapter 4 deals with the hydrochemistry of the river basin. Physical parameters, chemical constituents dissolved in the groundwater, evaluation of groundwater quality for drinking and agricultural purposes, hydrochemical facies, classification of water types through Wilcox, USSL diagrams and statistical analysis of groundwater chemistry are the highlights of this chapter.

Chapter 5 describes the integrated approach of the remote sensing data (Hydrogeomorphology, lineament, landuse etc.), terrain parameters (slope, drainage etc.) and Geophysical data with the help of Gerographic Information System (GIS) to demarcate the groundwater potential zones of the basin and to identify suitable sites for artificial recharging. Also cover the estimation of groundwater recharge through rainfall infiltration and hydrodynamic methods, annual draft, groundwater balance, static groundwater reserve and various techniques for artificial recharging of the study area.

A summary of the work and the major conclusions drawn are thereof given in chapter 6. The pertinent literature are furnished under references are given at the end of the thesis concisely this could be claimed as the first substantial and integrated study on the Bharatapuzha river basin.

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CHAPTER 1

INTRODUCTION

Water is the lifeblood of our planet. It is essential for our survival, crucial for relieving poverty, hunger and disease and critical for economic use. All the great civilisations of the world grew up around water bodies, which provided the key not only for supplying freshwater, but also to agriculture, trade, transport and defence. Growing populations, wastage of water, inefficient irrigation and pollution exert pressure on this resource. The Intergovernmental Panel on Climate Change (IPCC, 2008) reported that observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly affected by climate change, with wide-ranging consequences for human societies and ecosystems. Observed warming over several decades shows the changes in the large-scale hydrological cycle such as increasing atmospheric water vapour content, changing precipitation patterns, reducing snow cover, widespread melting of ice changing the soil moisture and runoff. Since water plays a very vital role in sustaining life on earth, water must be accessible and safe.

The demands for water have increased over the years and lead to water scarcity in many parts of the world which in turn triggered the problem of water pollution or contamination. In recent years, several studies around the globe show that climatic change is likely to impact significantly upon freshwater resources availability. The atmospheric concentration of carbon dioxide has increased from about 280 parts per million by volume (ppm) to about 369 ppm and the global temperature of the earth has increased by about 0.6°C. This has lead to a continous rise in MSL. There has been a 40% decline in Arctic Sea ice thickness in late summer to early autumn in the past 45 – 50 years (Fauchereau et al. 2003; Balling Jr, et al. 2003 and Domonkos, 2003). The frequency of severe floods in large river basins has increased during the 20th century (Milly et al. 2002).

According to Intergovernmental Panel on Climatic Change (IPCC), it is certain that at least 90% temperatures will continue to rise, with average global surface temperature projected to increase by between 1.4° and 5.8°C above 1990 levels by 2100 and associated sea level rise is projected between 9 cm and 88 cm. This increase in global temperature and rising sea level results in more intense precipitation events in some countries and increased risk of drought in others; and adverse effects on agriculture, health, and water resources. According to WHO, 1.1 billion people still don't have access to safe drinking water and about 1.4 million children die each year attributable to lack of access to safe drinking water. After 2010, key aquifers in China, India, West Asia and North Africa will begin to fail (Mark et al. 2002). In the last few decades, increasing demand for water led to inter-state and international frictions over water and competition among different sectors.

In India, groundwater has played the pivotal role in fulfilling the demands of domestic, industrial and agriculture sectors. According to some estimates, it accounts for nearly 80% of the rural domestic water needs, and 50% of the urban water needs. Around two-fifths of India's agricultural output is contributed from areas irrigated by groundwater (Mall et al. 2006). Contribution from groundwater to India's Gross Domestic Product (GDP) has been estimated as about 9% (Burjia et al. 2003). Reports from various sources suggest that by 2025 demand for industrial water will increase by 33% or over, but industrial output will remain the same. Food production will decline significantly. The National Environment Policy (2004) also advocated that anthropogenic climate changes have severe adverse impacts on India's precipitation patterns, ecosystems, agricultural potential, forests, water resources, coastal and marine resources.

Groundwater development has been intensive in alluvial area of Indo-Ganga-Yamuna plains of Punjab, Haryana, Uttar Pradesh, Uttaranchal and in parts of hard rock terrain in southern states. Though over-exploitation of the resource in some parts of the country has created serious problems, a large portion of the available resources still remains untapped, particularly in northeastern areas, where precipitation is high and the demand for irrigation is low and in the eastern states, the fragmented nature of landholdings stands in the way of groundwater development.

As per the Groundwater Resource Estimation Methodology (GREM) – 1997, the annual groundwater resources for the country have recently been assessed as 433 BCM. The total groundwater draft for irrigation, domestic and industrial uses is around 231 BCM and stage of development is 58%. However stage of groundwater development is highly uneven in the country – more than 100% in the states of Punjab, Haryana, Delhi and less than 45% in the states of Bihar, Chattisgarh, Goa, Himachal Pradesh, Jammu & Kashmir, Jharkhand, West Bengal, Orissa, northeastern states etc. Out of 5723 assessment units blocks/mandals/taluks/watersheds), 839 are categorised as 'over exploited', 226 blocks/watersheds as 'critical' and 550 as 'semi-critical' units. The remaining, 4078 units are 'safe' and 30 units are 'saline' (Central Groundwater Board, 2004).

Kerala state is popularly known as "Gods own country" due to its greenery, water resources and with copious rain fall, it is generally believed that the state has abundant water resources for all need. The state has an average rainfall of about 3000 mm, in which 60% from the southwest and 30% from the northeast monsoons and the remaining as summer/pre monsoon showers. In fact a good portion of the state experiences shortage of groundwater especially during the summer months between February and April. The uneven topography of the state with high slope towards sea promotes the surface run off while the escape of groundwater as subsurface run off.

The Kerala state accounts for 1.18% of India's land area but the population density of the state is much higher (747/km^2) than the national average (267/ km^2) and it has only about 4.8% of the country's water resources. Even though the state has heavy annual rainfall, high well density and numerous rivers and ponds, it is paradoxically situated among the country's lowest per capita groundwater availing state. It is observed that Kerala has less freshwater per capita than the desert state of Rajasthan (Sooryamoorthy and Antony, 2003).

Status of Water resources in Kerala is considered as '*Scarcity in the midst of plenty*'. A few numbers of site-specific studies explained the '*scarcity in the midst of plenty*' due to several reasons such as high rain water runoff, loss of forest cover, sand mining, reclamation of paddy fields, etc. (State Planning Board, 2003; James, 2003; Bhattathirippad, 2003; Mathai, 2003; Sooryamoorthy and Antony, 2003). It was observed that even under the normal rainfall conditions, the cities in lowland area of the state experience severe floods more often than in the earlier times. The density of open wells is also very high in Kerala and it is approximately 250/ km^2 in the coastal belt, 150/km^2 in the midlands and 25/km^2 in the highlands. Many household wells in Kerala are drying up and need to be dug deeper and deeper to obtain water (Verone, 2000). It is estimated that surface water of the state is utilising only 25% of the annual utilisable yield (State Planning Board, 2003). Thus, even with abundant availability of water in the state, its beneficial use is constrained by many factors.

Owing to the high demand of groundwater to cater a large population in the coastal zones, mitigation of the deterioration in the quality of groundwater in shallow coastal aquifers was initiated through groundwater recharge (Rajendran et al. 2002).

The groundwater scenario of the state shows a spurt in the groundwater development for all purposes during the last decade. The groundwater resources computed as on March 2004 by Central Groundwater Board (CGWB) found that the stage of development has gone to 47% and one third of the blocks (50) have gone to 'sensitive' category. Of these, 5 blocks are 'over exploited', 15 are 'critical' and remaining 30 are 'semi-critical' condition. According to CGWB, 2004 the rapid change in the groundwater scenario is due to several factors like:

1. Urbanisation demand for more groundwater for daily consumption
2. Heavy draft of groundwater for non domestic purposes
3. Reduction in the recharge due to urbanisation, filling up of low lying areas and large scale reclamation of wet lands for developmental purposes
4. Poor management practices

So the state needs proper planning and management of groundwater development in a judicious and socio economically equitable manner.

1.1 STUDY AREA

The Bharathapuzha river, popularly known as Nila or Peraar is the broadest and second longest river in Kerala. It has a length of 209 km and basin area of 6186 km^2 in which 4400 km^2 falls within the Kerala state, of which 28% is occupied by forest. The river is a 6^{th} order stream with a gradient of 9.2 m/km (CGWB, 1992) with an average annual stream flow of 5082.9 mm^3 (CWRDM, 1991).

For the present investigation, the Bharathapuzha river basin lying between latitudes 10^0 25' and 11^0 15' N and longitudes 75^0 50' and 76^0 55' E has been selected (Fig.1.1). The headwaters of main tributary of Bharathappuzha originates in the Anaimalai Hills in the Western Ghats at a height of 1964 m above the Mean Sea Level (aMSL), and flows westward through Palghat Gap, across Palghat, Thrissur and Malappuram districts of Kerala, with many tributaries joining it. Finally it empties into the Arabian Sea at Ponnani. The main tributaries are Gayatri puzha, Chittur puzha, Kalpathi puzha and Tutha puzha. The river below the confluence of Kalapthi puzha near Parali is known as Bharathapuzha. The river section below the confluence of Bharathapuzha and Gayathri puzha near Ottapalam is known as Ponnani puzha. Bharathapuzha is the one of the most heavily dammed rivers in Kerala, which accommodate nine reservoirs at present on its drainage area, among which seven are in Kerala (Walayar, Malampuzha, Chulliyar, Nenmara, Pothundi, Mangalam and Cheerakuzhi) and two are in Tamilnadu (Thirumurthi and Aliyar).

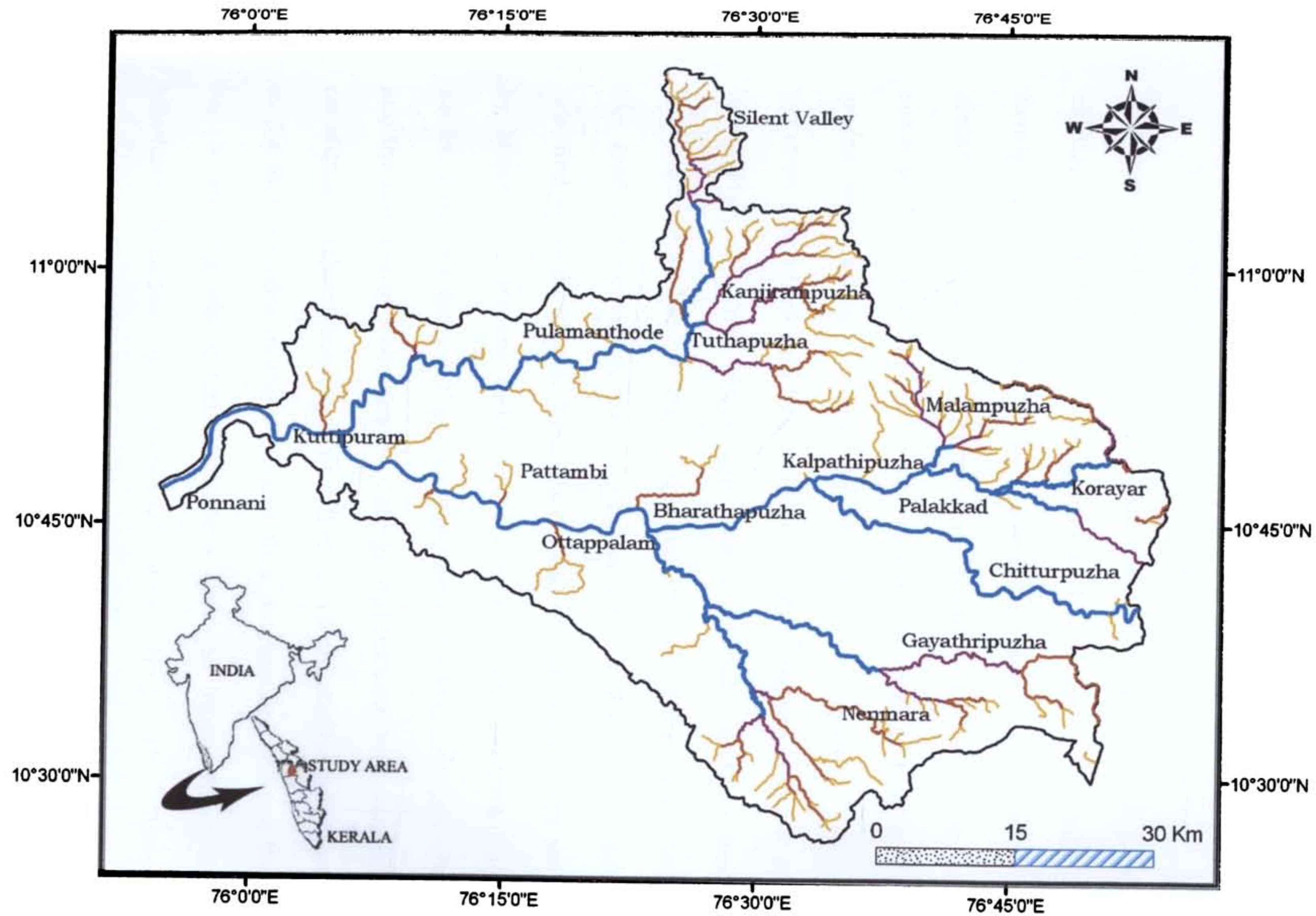


Fig. 1.1 Location map of the Bharathapuzha river basin

1.1.a GEOLOGY

The Bharathapuzha river flows through different geological sequences that occurs in east west transect from the high land (>75 m aMSL), middle land (8-75 m aMSL) and low land (<8 m aMSL) of the Kerala region. Major part of the study area is underlained by Precambrian metamorphic rocks like charnockite, hornblende-biotite gneiss and in some part represented by quarto-feldspathic gneiss, biotite-hornblende gneiss with schist, quartz syenite and pink granite. Charnockites, pyroxene granulites and associated migmatites occupy a major part of the basin (Fig. 1.2). The Palghat gap area is covered mainly by hornblende-biotite gneiss and also occupies the western part of the basin. Acidic rocks like granulite pyroxene, norite and basic rocks like gabbro, dolerite are intruded at many places. Towards coastal planes crystallines are overlain by Miocene to Recent sedimentary deposits like alluvium and coastal sands. Laterites form a thick capping over the Precambrian crystallines and the sedimentary sequences. Calc-granulites and crystalline lime stone constitute northern border of the hill ranges from Madhukkarai in the east to the Malampuzha in the west and thin patches are seen at Walayar. It has a striking characteristic with a grooved appearance along the foliations because of differential weathering. The limestone is characterised by intense fracturing and solution cavities have developed at places. A prominent dolerite dyke about 42 km length, having a trend

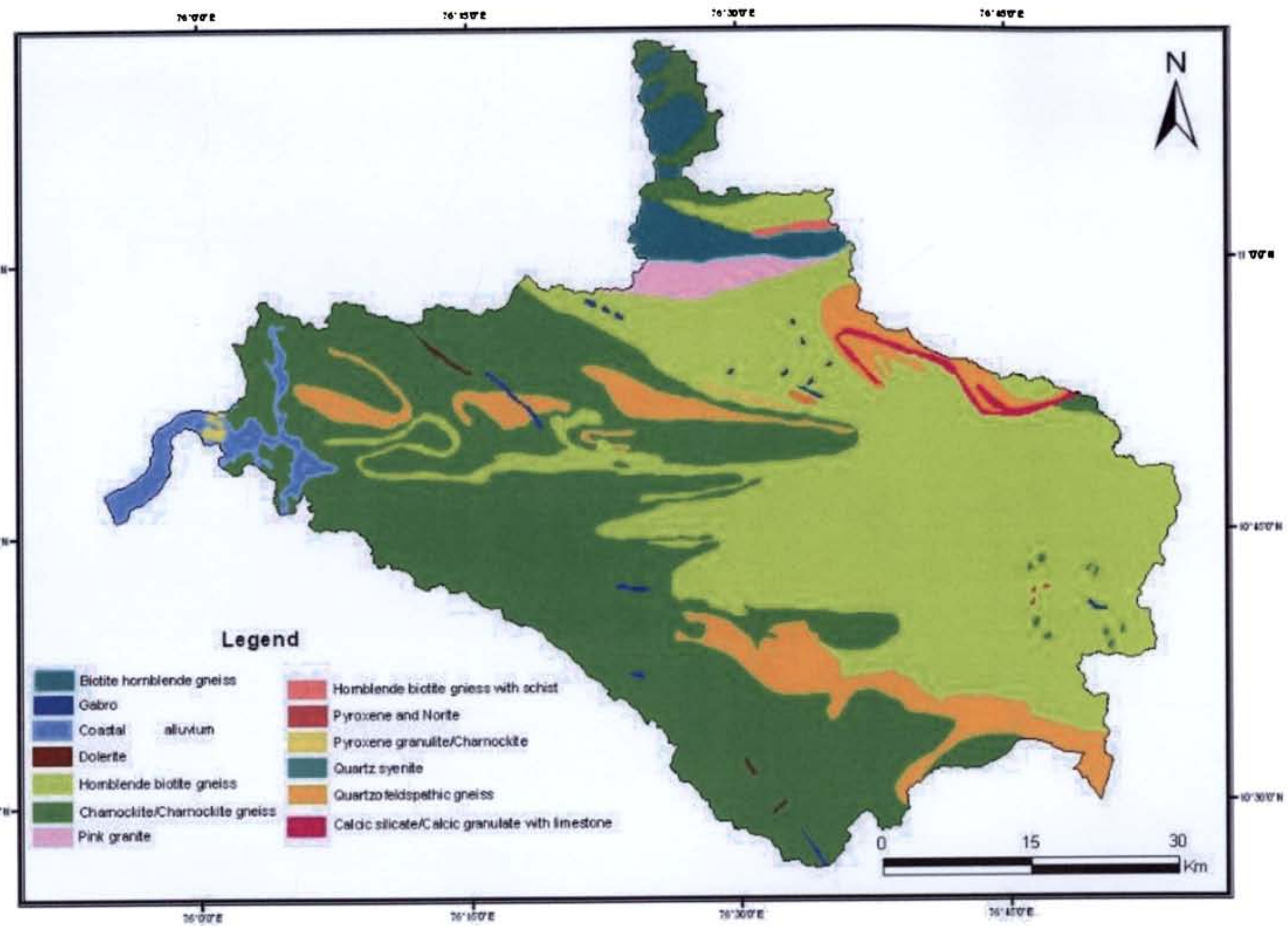


Fig. 1.2 Geology of the Bharathapuzha river basin

NNW–SSE direction is traceable in the SW part of the basin. . Laterite is predominant in the western parts of Ottapalam. The thickness is more in the western part where it is 20 to 50 m. The alluvial formation of the basin can be divided into three namely the coastal alluvium seen along the coast, the river alluvium seen by the sides/banks of rivers and valley fills seen all along the midland area along the valleys. Alluvium is composed of sand, silt and clay and its occurrence is mainly restricted in the Ponnani river course with 2 to 8 m thickness. The topographic lows and planes generally show a thick alluvial soil cover over the weathered rocks. The river alluvium is seen along Chamaravattom, Thiruvegapuram, Kuttippuram (Plate 1) and also by the side of the Bharathapuzha river. Valley fill deposits are seen along the major valleys in the basin. Most of the paddy lands of the basin are occupying the valley filled areas. They are generally made up of flood plain deposits and materials eroded from the neighbouring hills and slopes.

1.1.b CLIMATE

Since the drainage basin extends from the western coast of India to the Tamil Nadu region, the climate also shows a very wide variation. In the Kerala part of the basin, wet rain forest type of tropical climate is experienced. Broadly four seasons can be identified which are the hot summer season from March to May, SW monsoon from June to September, NE monsoon from October to December and a cool post monsoon period from January to February.

Plate 1.1 River alluvium seen along the banks of the Bharathapuzha river basin near Kuttipuram Bridge.

• **Humidity**

The catchment area of the river experiences tropical humid climate with humidity range of 80-96%. The basin has a humid climate with very hot season extending from March to June in the western part of the basin whereas it is less humid in the eastern sector.

• **Temperature**

The temperature of the basin ranges from 20 °C to 45 °C. The maximum temperature recorded at Palghat was 43 °C. Average annual temperature ranges from 22.7 °C to 32.5 °C.

• **Rain fall**

Bharathapuzha river basin exhibits different types of rain fall areas. The dry areas are in the Tamil Nadu portion of the basin. The wet plain areas are found in the Palghat Gap, medium wet mountains of Anamalai hills to south, and wet mountain areas covered with vegetations. Annual rain fall of the area is more than 3000 mm in the hills and 600 mm towards eastern side near Coimbatore. Maximum rainfall is received during SW monsoon (over 70%) and the rest during the NE monsoon (about 20%) and balance as pre monsoon rains. The river basin within the Kerala part has the average rain fall varying from about 3700 mm in the coastal area to about 800 mm in the eastern most part within the Palghat Gap region. In the Tamil Nadu region which gradually falls to around 700 mm in the extreme North. On the whole it can be summarised that, the average rainfall in the mountainous terrain is about 3000 mm and in the planes about 1500 mm and over 3500 mm in the coastal region. The average rainfall for overall computation for the entire basin can be taken as 2650 mm.

1.2 REVIEW OF LITERATURE

Groundwater studies have gained greater importance in recent years and is evidenced from several special publications, 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, previously groundwater investigations were mostly restricted to the unconsolidated alluvial and semi-consolidated sedimentary tracts (Singhal, 1984), but in recent years, the studies have been extended to hard rock areas also.

Exploration of groundwater is carried out following one or combination of few methods (Karanth, 1987). Philip and Singhal (1991) have compared the groundwater levels of different geomorphologic features. Karanth (1987) has also pointed out that water level fluctuation maps are indispensable for estimation of storage changes in aquifers. Todd (1980) suggested that the land subsidence could occur due to changes in underlying groundwater conditions.

Chabdler and Whorter (1975) have estimated the salt-water intrusion in Indus river basin applying pumping test methods. A number of techniques are available to analyse the pumping test data of wells. The pump test data are interpreted, either manually or with the aids of computers. However, the graphical and isoline representation of permeability, transmissivity and specific capacity indices were adopted by many workers (Adyalkar et al. 1966; Sammel, 1974; Nightingale and Bianchi, 1980; Ruston and Sing, 1983). Pumping test data can be analysed by the conventional Theis and Cooper-Jacob methods (Eagon and Johe, 1972; Wesslen et al. 1977). Leaky and unconfined aquifer models are also used for aquifer parameter determination in crystalline rocks (Sridharan et al. 1990; Boehmer, 1993; Sekhar et al. 1993; Levns et al. 1994; Kaehler and Hsieh, 1994; Saha, 2007).

(LeGrand, 1967; McFarlane et al., 1992; Henriksen, 1995) has stated that the topography and landforms have strong influence on well yield, especially of shallow wells. In central Malawi, higher well yield are reported from areas of low relief as compared with areas with high relief adjacent to inselbergs (McFarlane et al. 1992; Sridharan et al. 1995). The influence of landforms on well yields and the fault-controlled buried pediments, where the weathered horizon is thicker, will also give higher water yield has been demonstrated by Perumal (1990) from a study of granite-gneiss and charnockite formations in the Athur valley of Tamil Nadu.

The concept of optimum depth of wells holds good in crystalline fractured rocks as the permeability usually decreases with depth. An overall decrease in well yield with depth is reported from various crystalline rock terrains in different parts of the world (Davis and Turk, 1964; UNESCO, 1979; Woolley, 1982; Henrisken, 1995).

Geophysical survey is necessary to ascertain the subsurface geological and hydrogeological conditions and its applications for groundwater exploration has been reviewed by a few workers (Zohdy et al. 1974; Beeson and Jones, 1988; deStadelhofen, 1994). Using Schlumberger electrical soundings, Worthington (1977) has attempted to evaluate groundwater resources of the Kalahari basin, South Africa. Verma et al. (1980) have used histograms, curve types and iso-apparent resistivity (based on apparent resistivity) and Schlumberger sounding curves to investigate the groundwater potential in metamorphic areas near Dhanbad, India. Vertical Electrical Sounding (VES) surveys are highly useful, economical and reliable in groundwater investigation and assessment. (Paliwal and Khilnani, 2001) has used VES for the direct assessment of aquifer parameters (excluding storativity), which in turn can be used for the estimation of dynamic and static groundwater reserves. The significance of contouring the apparent resistivity is an important method through which one can easily identify the groundwater potential areas, movement pattern etc. has been highlighted by Sarma and Sarma, 1982; Balakrishna et al. 1984; Balasubramanian et al. 1985.

The chemical composition of groundwater is mainly related to soluble products of rock weathering with respect to space and time (Raghunath, 1987). Sakthimurugan, 1995; Laluraj et al. 2005; Sudhakar and Mamatha, 2004 has stated that in addition to the leaching of minerals, man can adversely alter the chemical quality of groundwater by permitting highly polluted water to enter into the fresh water strata through improper construction of wells, disposal of animal and municipal wastes, sewage and other industrial wastes . The disposals of effluent from the tanneries are the main source causes the change in physical, chemical and biological characteristics of groundwater in Sempattu area, Tiruchirappalli (Manivel and Aravindan, 1997). The hydrogeochemistry and groundwater flow patterns in the vicinity of Stratford-Upon-Avon have been studied by Lloyd (1976). Similar type of work has been attempted by Daly et al. (1980) for Castle Comer plateau, Ireland.

Zaporozec, 1972; Freeze and Cherry, 1979; Matthess, 1982 and Lloyd and Heathcote, 1985 have given a detailed account of various methods of plotting the water quality data. In 1983, based on the dominance of anions and cations, the groundwater of Vaippar basin has been classified by Sivaganam and Kumaraswamy. Gupta (1987) has evaluated the groundwater quality of the northern part of Meerut district, Uttar Pradesh. Changyan Tang (1989) used Collin's bar graph, Hill-Piper trilinear diagram, Durov's diagram and U.S.S.L diagram. Stiff and bar diagrams to analyse the groundwater quality of Dejima upland. Kelley

(1940), Eaton (1950) and Wilcox (1955) have proposed certain indices by considering the individual or paired ionic concentrations, to find out the alkali hazards and Residual Sodium Carbonate (RSC). Factors controlling the salinity in groundwater in parts of Guntur district, Andhra Pradesh, India, were studied by Subba Rao (2008). The Statistical Analysis and interpretation of water quality data of the Vitens well fields was done by Selim et al. (2008).

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

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

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

Applications of GIS are to identify and display locations of well, tapping of particular aquifer or a group of aquifers (Barker, 1988). Kalkoff

(1993) has attempted to relate stream water quality with the geology of the catchment area of the Roberts Creek watershed, Iowa. Groundwater pollution can be effectively evaluated by GIS and for developing pollution potential map (Aller et al. 1987; Halliday and Wolfe, 1991). In the northern part of Australlia, salinity hazard mapping has been carried out by Tickell (1994) using GIS. Groundwater modelling based on GIS has been attempted by many (Richards et al., 1993; Roaza et al. 1993; El-Kadi et al. 1994; Shahid et al. 2000; Boutt et al. 2001). Groundwater prospecting zones in Dala – Renukoot area, Uttar Pradesh has been mapped through integration of various thematic maps using Arc/Info GIS (Pratap et al. 2000). In recent years many workers such as Teeuw, 1995, Goyal et al. 1999; Saraf and Chowdhary, 1998; Murthy, 2000 and Lobo Ferreirae Catarina Diamantino, 2008 have used remote sensing and GIS techniques for groundwater exploration and identification of artificial recharge sites. Ravi and Mishra, 1993; Krishnamurthy et al. 1996; Shahid and Nath, 2001; Singh and Prakash, 2002; Jaiswal et al. 2003; Mondal and Singh, 2004; Erhan Sener et al. 2005; Vijith, 2007; Prasad et al. 2008; Girish Kumar et al. 2008; Kahya and Cuneyd Demirel, 2009; Sreedhar Ganapura et al. 2009; Rajesh Reghunath et al. 2009 have used GIS to delineate groundwater potential zone. Srinivasa Rao and Jugran (2003) have applied GIS for processing and interpretation of groundwater quality data.

1.3 PREVIOUS STUDIES IN BHARATHAPUZHA RIVER BASIN

Persual of literature reveals that although many studies are available on the hydrogeochemical aspects of Indian rivers, studies are limited in the case of Kerala rivers (Paul and Pillai, 1978, 1983; Sankaranarayanan, 1986; Padmalal and Seralathan, 1993) and not much information exist in regard to the Bharathapuzha river, (CESS, 1997). Geomorphological studies of Bharathapuzha in Kuttippuram and Pattambi has been carried out by Thirugnanasambandam (1980), textural and mineralogical variations of sediments of Bharathapuzha river system by Anirudhan (1991), roles of relief and climate on composition of detrital sediments of Bharathapuzha basin, Kerala by Anirudhan et al. (1994), heavy mineral and geochemical studies of lower Bharathapuzha sediments by Rajendran et al. (1996), water quality variation of Bharathapuzha river; its problems and solutions by Narendra Babu et al. (2003) and very scanty on the hydrogeological charectersistics of Bharathapuzha river basin.

1.4 RELEVANCE OF THE STUDY

The state Kerala is a narrow stretch of coastal land with an average width of 45 km. The state is blessed with 44 rivers and network of numerous water bodies and copious rainfall averages from 184 cm to 405 cm per annum. Groundwater occurs under phreatic semi confined and confined conditions in different formations. Even though the conditions are favourable, the rate of depletion of subsurface water is indeed alarming. Many parts of the state clearly shows the signs of acute water crisis and salt water intrusion along the coastal belts especially during summer.

All rivers of Kerala maintain a steep profile in its entire course from source in the Western Ghats to almost the low reaches of the midland with its various nick points, cascades, river captures etc. The Bharathapuzha river in its major stretch flows through the Palghat Gap with a low gradient. Its steep course is restricted to its initial course in the Western Ghat hills flanking the Palghat Gap. However, its entire stretch of flow within Kerala is through the flat Gap region. It originated on the eastern slope of Western Ghats and flow towards west through the broad valley within Palghat Gap. The river channel is broad with the banks having terraces of alluvial sediments. As far as Bharathapuzha draining through the flat Palghat Gap region of Precambrian gneissic formation is concerned, these alluvial deposits are the main sources of base flow and bank flow. Any depletion of these deposits due to severe sand mining and urbanisation can adversely affect the river.

The study area spreads over 3 districts and 17 blocks of the Kerala state. Of these, Chitoor block is 'over exploited', Kollengode, Trithala, and Palghat are 'critical' in category and Kuttippuram and Sreekrishnapuram blocks are 'semi critical' in terms of groundwater development. There is a sharp decline in groundwater level in Kollengode, Chittoor and Sreekrishnapuram blocks (CGWB, 2004).

Even though with a high rain fall, of 280 cm, the region is facing acute shortage of domestic and irrigation water. There are numerous agricultural fields, industries and water based multi national companies working in the basin extracting the groundwater in an unscientific way. The existing water resources face over exploitation and poor management in recent years. The over exploitation of groundwater beyond the "safe yield" limit, cause undesirable effect like continuous reduction in groundwater levels, reduction in river flows, reduction in wet land surface, degradation of groundwater quality and many other environmental problems. A detailed and systematic hydrogeological study of the entire Bharathapuzha basin is still lacking. Hence in the present scenario, an integrated study of Bharathapuzha river basin is warranted. The present study encompasses the aquifer parameters to make a reliable groundwater potential map of the area, to evaluate the quality of groundwater, to appreciate the control of lithology, geomorphology, and surface/sub surface structure on the groundwater potential, better management of the water resources of river basin etc. Therefore the proper assessment of quality and quantity of water resources and its management of the Bharathapuzha river basin has been under taken for the sustainable groundwater management. The present study have employed both conventional survey (hydrological characteristics and geophysical and groundwater chemistry) and remote sensing techniques to decipher the aquifer characteristics, to demarcate the suitable sites for artificial recharging and to find out the groundwater potential zones of the Bharathapuzha river basin.

1.5 OBJECTIVES

The major objectives of the present investigation are

1) To study the spatial and temporal behaviour of the groundwater system of the Bharathapuzha river basin.
2) To discover the sub-surface parameter by ground resistivity surveys.
3) To determine the groundwater quality of the Bharathapuzha river basin for the different seasons (pre monsoon and post monsoon with reference to the domestic and irrigational water quality standards.
4) To find out the groundwater potential zones and demarcate suitable sites for the augmentation of groundwater recharge in the Bharathapuzha river basin.
5) To recommend a sustainable groundwater management.

Present study will provide a good database on the hydrogeological aspects within the river basin. Such database will not only enable a better understanding of the problems of groundwater in many areas of the basin but also helps in making policy decisions on groundwater exploitations. Moreover the study will throw light on many disputed problems of the water resources in the region. A similar type of database can be generated for other river basins of major perennial rivers of Kerala. This will sort out the current groundwater crisis that the state encounters.

CHAPTER 2
HYDROGEOLOGY

2.1 INTRODUCTION

Safe drinking water is the primary motto of every population. Sustainable development of groundwater needs an understanding of its behaviour and potentiality. Different land forms like structural hills, inselbergs, pediments, buried pediments, erosional valleys, valley fills etc., play a vital role in groundwater occurrence and movements. In crystalline rocks the extent of weathering and fracture characteristics also decide the hydraulic conductivity.

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

1. Steady state flow and
2. Unsteady state flow.

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

Groundwater resource evaluation requires a detailed study on the occurrence and behaviour of groundwater and various aquifer parameters such as transmissivity, storage coefficient, optimum yield, recovery rate, time for full recovery and specific capacity. The present investigation is aimed to study the behaviour, occurrence, movement of groundwater, diagnostic characteristics of aquifer parameters and the long term trend of water level and its correlation with rainfall in the Bharathapuzha river basin.

2.2 AQUIFER TYPES

An aquifer is an underground formation of either a permeable rock or loose material, which can supply useful quantities of water when tapped through a well (Todd, 1980). Aquifer may vary in size, it may be small, only a few hectares in area, or very large, covering thousands of square kilometers of the earth's surface and its thickness may vary from a few meters to hundred meters from top to bottom. Basically aquifers are of two types: 1) confined aquifers and (2) unconfined aquifers.

Confined Aquifers

A confined aquifer or artesian aquifer, is invariably sandwiched between confining beds (layers of impermeable materials) impede the movement of water into and out of the aquifer. Groundwater in this aquifer is always under high pressure, which makes the water level in a well to rise to a level higher than the water level at the top of the aquifer.

The water level, in the well is referred to as the piezometric surface or 'pressure surface'. It is important that confining beds are not only hampering the movement of water into and out of the aquifer but also serve as a barrier to the flow of contaminants from over lying unconfined aquifers (Canter, 1985; Taylor and Howard, 1994). For the same reason, however, contaminants that reach a confined aquifer through a poorly constructed well or through natural seepage can be extremely difficult to remove and if attempted, it will be expensive.

Unconfined Aquifers

In unconfined aquifer, the groundwater fills the aquifers partially and the upper surface of the groundwater (the water table) is free to rise and fall. The water table typically mimics the topography of the land surface in a subdued way. It is important to note that those unconfined aquifers, which are close to the surface, can be vulnerable to contamination from activities on the land. In the present investigation, the dug wells penetrating through unconfined aquifers are taken into account.

2.3 BEHAVIOUR OF GROUNDWATER

The water table contour map of an area summarises the information on extent of the zone of saturation, gradient, direction of movement of groundwater etc. Long and short term fluctuation of groundwater level study will help to understand the depletion and recharging conditions of an aquifer. Stress and strain in water level due to groundwater recharge, discharge and intensity of rainfall are reflected in water level fluctuation with time.

Groundwater draft in the Bharathapuzha river basin is mainly through dug wells. There are about 18000 energised wells in the eastern parts of the basin forming parts of Tamil Nadu State over an area of 1500 km^2. The annual draft from the well varies from 8000 to 34000 m^3 is appropriate and also for domestic needs. In Kerala, 70% of the agricultural land is served by canals and lift irrigation. In the study area, groundwater is mainly used for irrigation purposes and domestic need (CGWB, 2003).

For delineating the zones of Bharathapuzha river basin, groundwater data from 67 National Hydrographic Stations (NHS) maintained by CGWB, were obtained for a period of 15 years from1991 to 2005. The locations are sited in the Fig. 2.1. Water table contour maps, water level fluctuation maps, grid deviation maps and well hydrographs for the study area have been prepared. Water level fluctuation to grid deviation was computed from data and presented in the Table 2.1. For delineating the zones of recharge and discharge in the Bharathapuzha river basin, grid deviation method has been employed by several workers (Balasubramanian, 1986; Subramanian, 1994).

Table 2.1 Grid deviation and water table fluctuation computations for NHS of the Bharathapuzha river basin

Sl.No	Station name	Water Level (m)		Grid deviation	Water Level (m)		Fluctuation (m)
		bgl	aMSL		Maximum	Minimum	
1	Ponnani	2.40	-0.87	-84.39	2.56	2.23	0.34
2	Chamravattom	2.07	-1.57	-85.09	3.30	1.18	2.12
3	Iswaramangalam	2.54	-2.04	-85.56	4.49	1.17	3.32
4	Thavanur	10.12	-8.11	-91.63	11.64	9.19	2.46
5	Kuttippuram	2.82	17.18	-66.34	5.01	1.31	3.70
6	Thirunavaya	4.91	-2.50	-86.02	5.73	4.09	1.64
7	Valanchery	9.04	10.96	-72.56	10.23	7.97	2.26
8	Pukatteri	7.56	12.44	-71.08	9.32	4.70	4.62
9	Karipol	10.18	29.82	-53.70	11.03	9.54	1.49
10	Kulattur	4.49	35.51	-48.01	6.37	2.57	3.81
11	Pulamanthode	7.20	12.80	-70.72	8.46	6.36	2.10
12	Koppam	7.27	362.54	279.02	10.08	5.69	4.39
13	Trittala	6.71	13.29	-70.23	8.22	4.82	3.40
14	Tannirkod	7.71	12.29	-71.23	8.88	6.47	2.40
15	Chalissery	8.20	19.43	-64.09	10.11	6.69	3.42
16	Cheruthuruthi	4.07	35.93	-47.59	5.52	3.16	2.36
17	Pattambi	4.99	15.01	-68.51	5.95	3.77	2.18
18	Shornur	6.55	33.45	-50.07	7.40	5.97	1.43
19	Vaniyamkulam	5.28	54.72	-28.80	6.88	3.96	2.93
20	Vallapuzha	4.97	35.03	-48.49	6.88	3.52	3.36
21	Cherpalassery	8.23	37.50	-46.02	9.12	7.39	1.73
22	Paral	6.73	38.87	-44.65	8.96	4.94	4.02
23	Tazhekode	6.83	53.24	-30.28	7.52	5.90	1.62
24	Cherukara	6.73	33.27	-50.25	7.59	5.90	1.69
25	Perunthalmanna	5.89	54.11	-29.41	7.81	3.43	4.37
26	Ariyur	8.97	87.72	4.20	9.94	6.27	3.67
27	Tachanattukara	8.43	71.57	-11.95	9.78	6.26	3.51
28	Kottapuram	8.29	71.71	-11.81	9.78	6.87	2.92
29	Kumaramputtur	4.89	55.11	-28.41	6.35	3.76	2.59
30	Karimpuzha	2.38	77.62	-5.90	3.23	1.73	1.49
31	Punchapadam	6.91	79.82	-3.70	7.49	6.32	1.17
32	Ambalappara	7.47	75.27	-8.25	9.47	6.40	3.07
33	Ottapalam	7.68	32.32	-51.20	9.34	6.60	2.74
34	Palappuram-11	7.58	52.42	-31.09	8.99	6.67	2.32
35	Chelakkara	3.78	56.22	-27.30	5.70	2.30	3.40

36	Kombazha	4.82	95.18	11.66	6.34	3.21	3.14
37	Athipetta	3.31	56.69	-26.83	5.24	1.80	3.45
38	Kuzhalmannam	2.93	77.07	-6.45	5.48	1.76	3.73
39	Tholannur	2.65	77.37	-6.15	4.60	1.62	2.98
40	Mankara	4.29	64.03	-19.49	5.60	3.57	2.03
41	Vattassery	3.42	91.96	8.44	5.05	2.43	2.63
42	Kalladikode	8.42	71.58	-11.94	10.34	7.07	3.28
43	Thachanpara	2.99	77.01	-6.51	3.82	2.04	1.78
44	Kanjirapuzha	2.67	77.33	-6.19	3.81	1.86	1.95
45	Mannarghat	3.70	96.30	12.78	4.42	2.97	1.45
46	Tenkara	1.24	78.76	-4.76	1.46	1.03	0.43
47	Tavalam	4.86	721.21	637.69	5.54	4.51	1.03
48	Mundar	2.88	97.12	13.61	5.03	1.32	3.71
49	Odannur	4.34	75.66	-7.86	6.49	3.15	3.34
50	Palghat	5.73	94.27	10.75	8.17	3.48	4.69
51	Malampuzha	2.43	97.57	14.05	3.25	1.91	1.34
52	Kanjikode	5.47	104.53	21.01	8.22	3.40	4.83
53	Chullimade	7.75	132.25	48.73	10.02	6.11	3.91
54	Walayar	6.44	173.56	90.04	7.59	5.55	2.04
55	Velanthavalam	5.81	212.82	129.30	8.96	3.43	5.54
56	Gopalapuram	11.73	148.27	64.75	13.69	10.48	3.21
57	Kozhinjampara	5.01	154.99	71.47	6.41	3.91	2.50
58	Chittoor	4.09	115.91	32.39	5.29	3.02	2.27
59	Kodavayur	4.75	95.25	11.73	6.58	3.40	3.18
60	Alathoor	4.84	54.95	-28.57	7.21	3.36	3.86
61	Vadakkancherry	4.08	73.10	-10.42	5.44	3.14	2.30
62	Nemmara	2.31	81.98	-1.54	3.04	1.55	1.49
63	Adiparanda	5.35	74.65	-8.87	7.04	3.66	3.38
64	Kollengode	3.32	96.68	13.17	4.48	2.52	1.95
65	Meenkara	4.64	122.20	38.68	6.18	3.38	2.79
66	Chemmampathi	7.40	250.24	166.72	9.12	6.38	2.74
67	Meenakshipuram	6.76	193.24	109.72	8.46	5.49	2.97

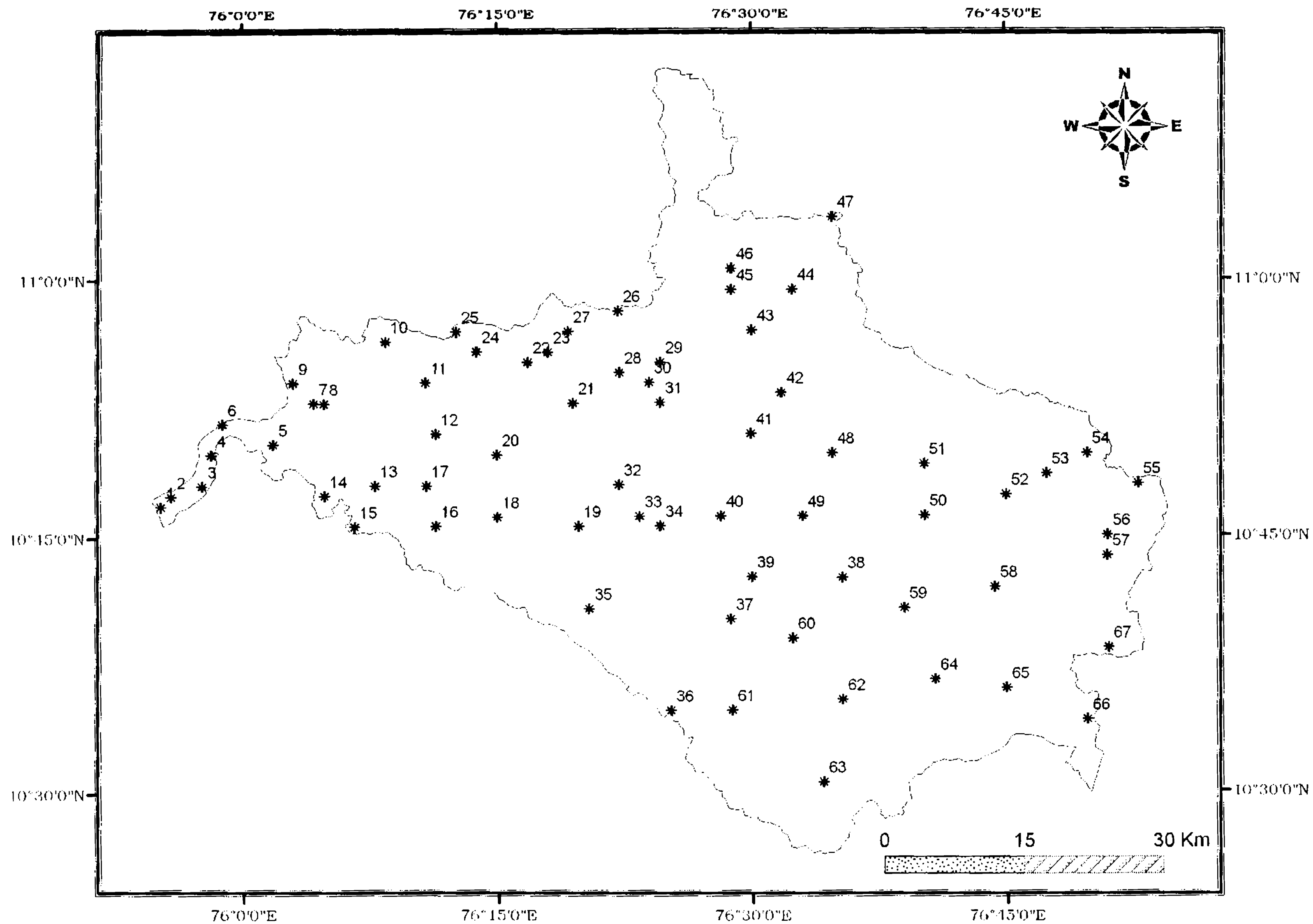


Fig. 2.1 Locations of National Hydrographic stations (NHS) in the study area.

2.3.1 Water table

Water table is the subdued replica of the topography. The local unequal weathering modifies the flow patterns creating a number of mini basins in the sub-surface where groundwater accumulates and moves to larger basins (Karanth, 1958). Investigation on water table characteristics which is an important component of many hydrogeological studies, provides solid database for groundwater resource management, hydrogeology, aquifer parameter analysis etc (Kresic, 1997).

Long term average depth to water level data (xb) have been used for preparing the water table map (Fig. 2.2). In the present study area, the water below ground level ranges from 1.24 m at Tenkara (northen side) to maximum of 11.73 m at Gopalapuram (Eastern side) with an average of 5.53 m (Table 2.1).

The northeastern part of the basin shows shallow water table even though this area is marked by steeply sloping structural hills. It is due to the effect of Silent Valley reserve forest. The thick humus of the Silent Valley triggers the infiltration rate and keeps the water table fluctuation stagnant. The eastern side shows a deeper water table due to the influence of Palghat Gap which is a rain shadow region where the natural recharge of groundwater is very low. The central portion of the basin shows shallow water level due to the confluence of the tributaries of the river.

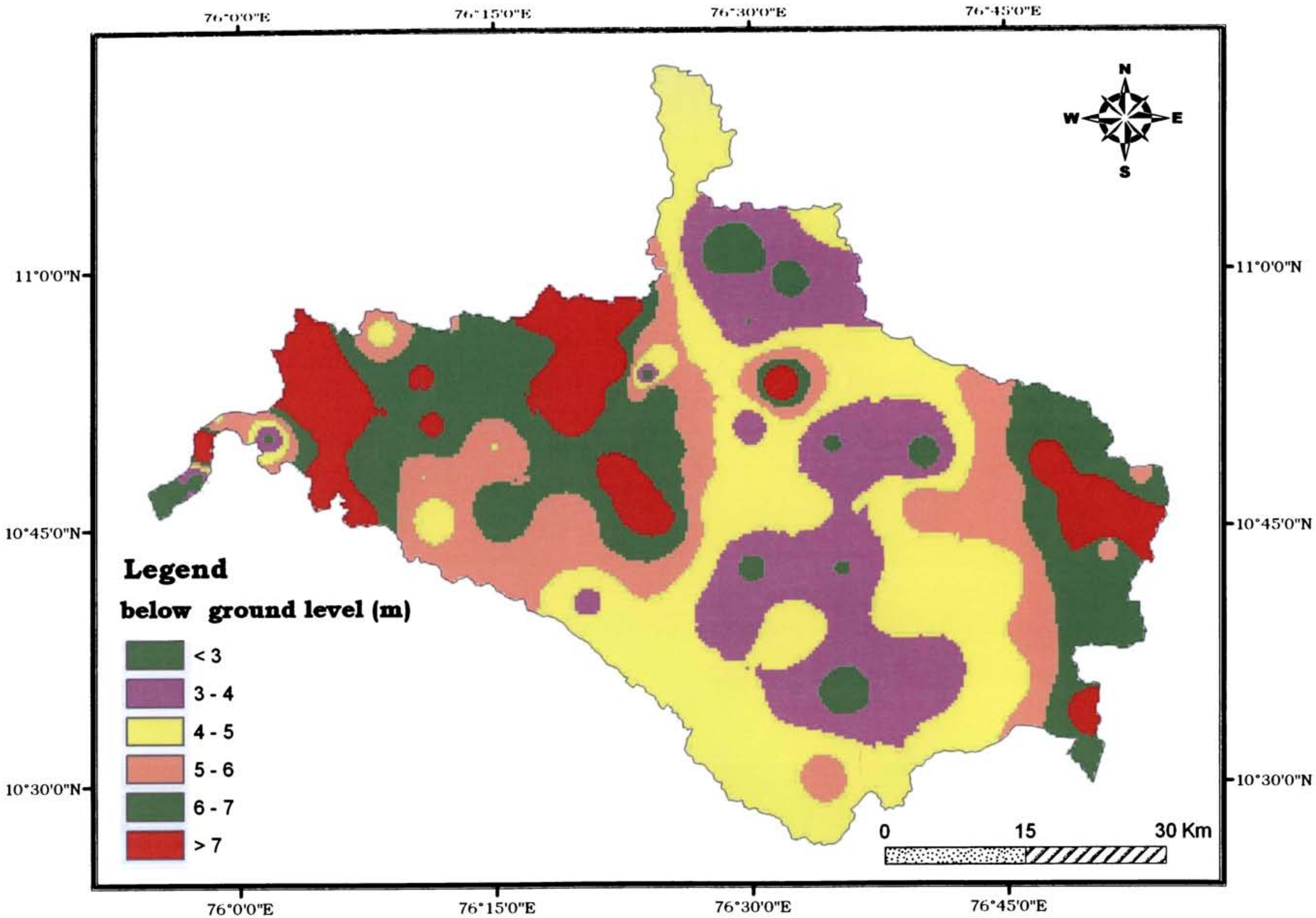


Fig. 2.2 Depth to the water table map of the Bharatahpuzha river basin.

2.3.2 Groundwater flow direction

Contour map of water levels can provide information on groundwater flow directions. In most cases, water flow direction is perpendicular to the water level contour lines (from high to low values of water level). Groundwater moves through the subsurface much like water on the ground surface, except that it travels a great deal more slowly. Like streams and rivers, groundwater moves from high areas to low areas. Groundwater is assumed to flow at right angles to water table contours, and this is because of its movement downhill in the path of least resistance due to gravity.

The water level data was averaged for 15 years (1991 to 2005) and is represented as height of water table in aMSL (Table 2.1). The groundwater flow detection is given in the figure 2.3 and arrows drawn perpendicular to the groundwater contours indicates the direction of groundwater flow. Average elevation of water table varies from 8.11m aMSL at Tavanur (down stream) and 721.21m aMSL at Thavalam (upstream) with an average of 83.52m aMSL. Groundwater flow directions are generally (Fig. 2.3) towards the western portions of the study area. Water confluences at the centre from the northern, eastern and southern sides and move towards the western side of the basin.

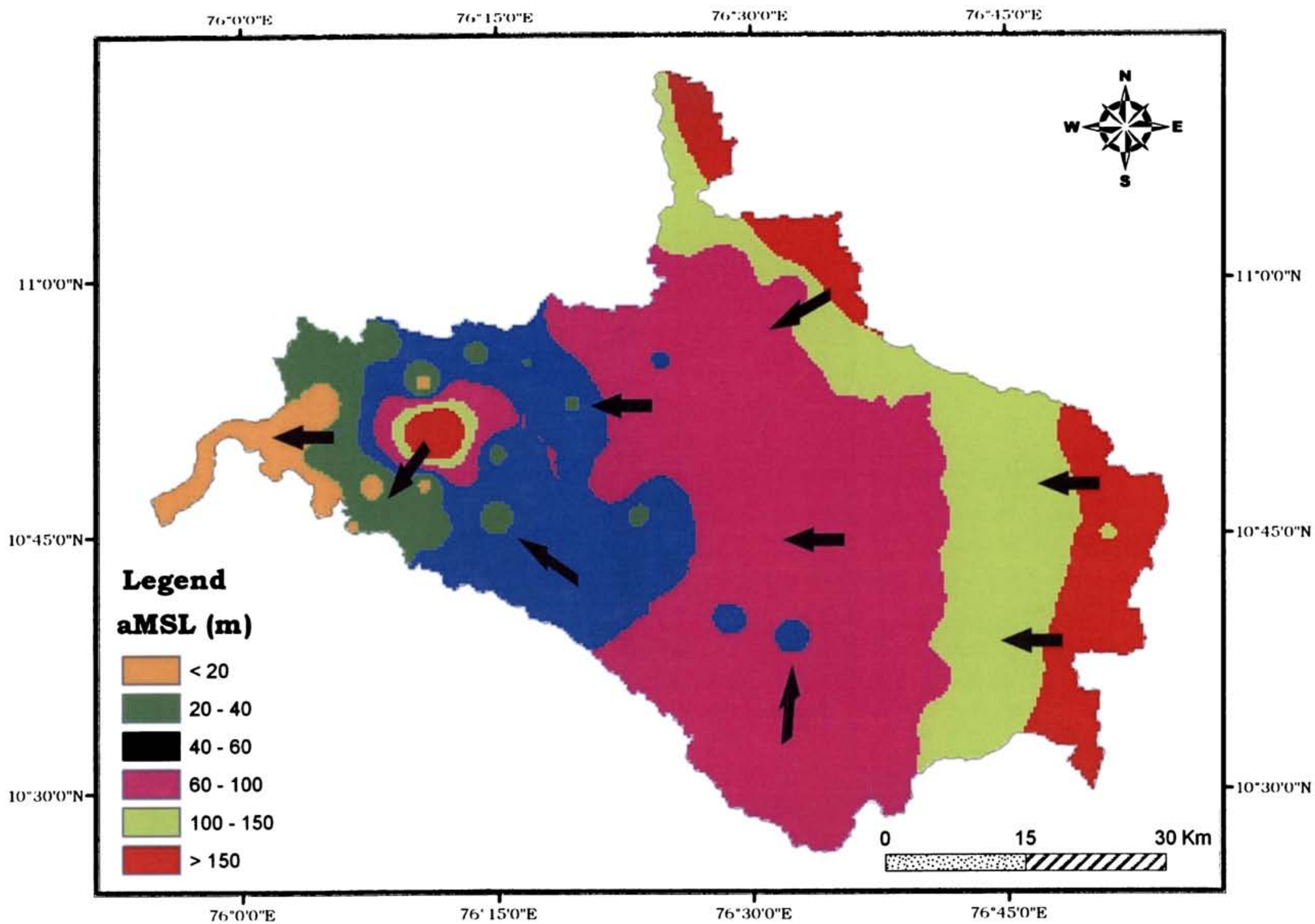


Fig. 2.3 Map showing height of the water table above mean sea level of the study area.

2.3.3 Grid Deviation

Representation of water table by the conventional maps like water table contours showing the elevation of water level above Mean Sea Level (aMSL) or below ground level (bGL) is more generalised in nature, not capable of projecting out the prominent features of the dynamics of groundwater flow and liable to subjective errors. Biswas and Chatterjee, (1967) and Narayana Rao (1972) pointed out that the subjective errors are more frequent in groundwater contour maps prepared for hard rock terrain, where groundwater occurs only in weathered, jointed, fractured and fissured pockets of variable sizes.

Grid deviation method of representing the hydrogeological data seems to be more convenient, objective, informative and brings out more sharply the regional trend by eliminating the local interferences (Saha and Chakravarthy, 1963; Biswas, 1976). This method has been used in the present study to delineate the zones of positive recharge and negative recharge (or discharge) in the basin.

The average monthly water levels (depth to water table) for the years 1991 to 2005, collected from the NHS maintained by CGWB were utilised for the present study. The following steps were adopted in preparing the grid deviation water table map of the basin.

1. Monthly water level data which is depth to water table below Ground Level (bGL) is converted to height of water table above Mean Sea Level (aMSL).

2. The monthly data averaged for each month and then the mean of this average is taken which represents mean yearly value (Xo). This has been done for all observation wells.

3. An average value (xb) of all the average elevation of water table computed individually for each observation well earlier (Xo) has been calculated. This is called the basin average.

4. The deviation (D) between the basin average water level altitude and the average elevation of water levels of individual observation wells have been determined [D= (Xo-Xb)]. This deviation is known as grid deviation.

An area can be delineated by recharge and discharge areas depending on whether water is added to or abstracted from the zone of saturation. Recharge areas are characterised by elevated positions of water tables or piezometric surfaces from where groundwater moves towards positions of lower elevation in discharge areas. Between the recharge and discharge areas, there lies an intermediate transit zone characterised by the existence of recharge conditions during some period of the year and discharge conditions during the rest. Hence it should be noted that the boundaries or even the classification of areas into recharge or discharge areas cannot be rigid in view of the fact that the depth of the water table is uneven (Karanth, 1987).

The grid deviation of each location of the basin is shown in Table 2.1. Based on these grid deviation values, the basin has been classified into positive and negative zone that represents recharge and discharge area respectively and is separated by a zero line (Fig. 2.4). The major recharge area which lies in the upstream, ie., eastern part of the basin which is highly elevated and extends almost to the central basin In addition to this, there are small pockets of positive zones found at the northwest (Pulamanthode, Koppam and Trittala), north (Vattasseri and Kalladikode), southwest (Walayar Velenthakavu) parts of the basin The major negative zone that is discharge areas extends from almost central part of the basin to western part of the basin where the river enters the Sea. Small patches of negative zones are at the Tenkara and Kanjirapuzha (northern side) of the basin.

From the study it is observed that the upstream portions are the major recharging areas where as the mid and lower reaches are the discharge zones. A comparison of figures 2.3 and 2.4 shows that the groundwater flow direction more or less coincides with grid deviation map suggesting that topography play a considerable role in the groundwater recharge and movement.

2.3.4 Water level fluctuation

Water level fluctuation can be calculated from the differences between maximum and minimum water table levels observed in dug wells.

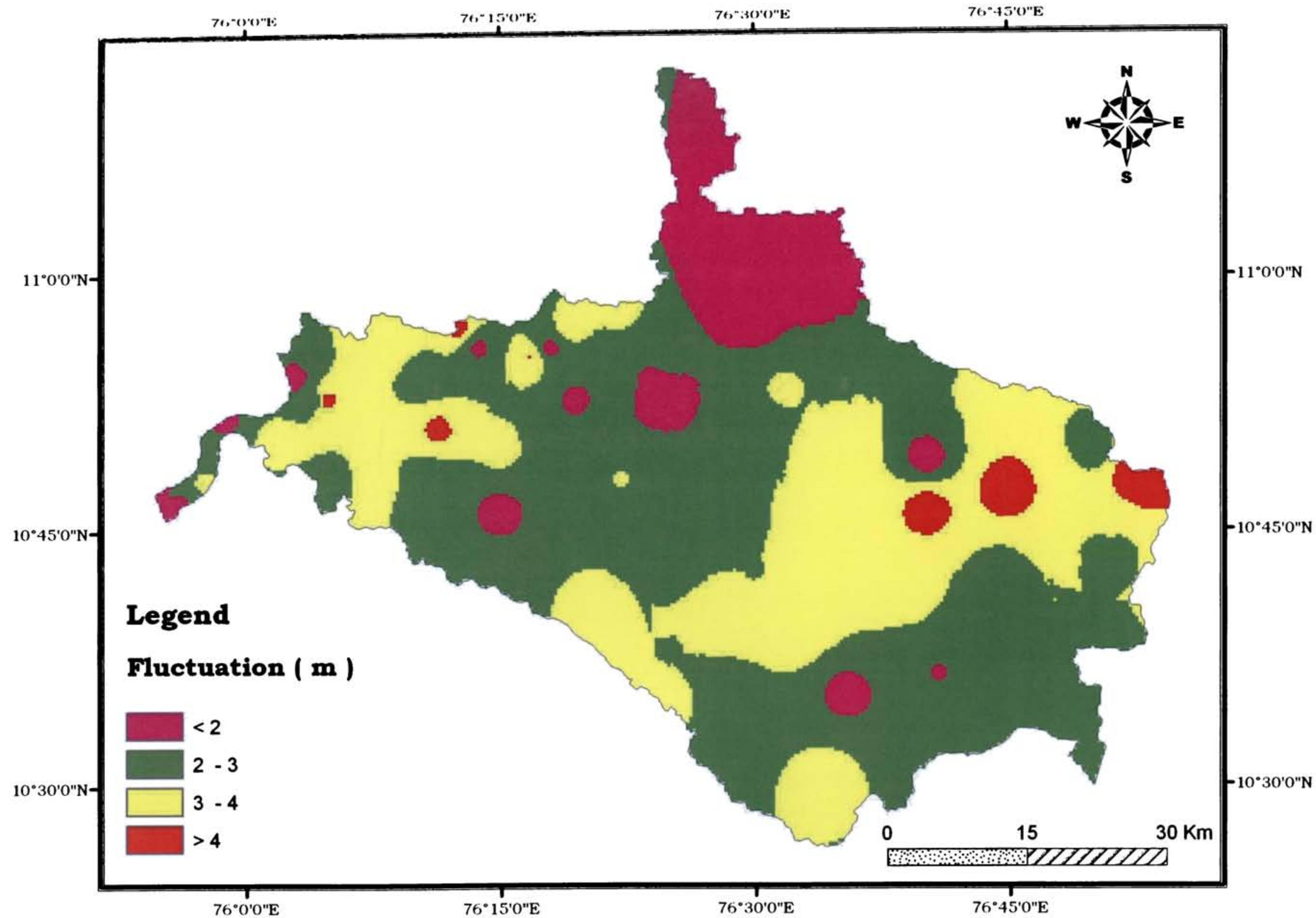


Fig. 2.5 Average water level fluctuation (bgl) for the period From 1991 to 2005 in the Bharathapuzha river basin.

The magnitude of the water level fluctuation depends on factors such as drainage, topography and geological conditions. Groundwater fluctuation monitoring is very important especially for agricultural practices, aquifer recharge and drought monitoring. Normally groundwater moves towards valleys, topographic lows and depressions with ridges and topographic heights forming the zone of divergence.

According to Davis and De Weist (1960) water table fluctuations may be affected due to

1. Change in groundwater storage
2. Variation in atmospheric pressure in contact with water surface in wells
3. Deformation of aquifers
4. Disturbance within the well, i.e. minor fluctuation and
5. Chemical or thermal changes in and around the well

Groundwater fluctuation is also caused by other reasons such as

a. Evaporation and transpiration of water by phreatophytes which includes palms, willows, salt grasses and sedges (Taylor and Oza, 1984)

b. Glacial fill aquifer in Ohio (Klein and Kaser, 1963)

c. Winter frost conditions (Schneider, 1961)

d. Earth tides (Robinson, 1939

e. Ocean tides (Greg, 1996)

f. Distance from the river course (Abbi et al. 1971).

A comparison of Figures 2.3 and 2.5 reveals that areas having maximum fluctuation are characterised with deeper water table and vice – versa..

The average water level fluctuation of 67 wells of the present study area for a period of 15 years (1991 to 2005) is calculated and presented in Table 2.1. The maximum value is found at Velanthavalam (5.54 m) whereas the minimum value (0.34 m) is recorded in Ponnani. The mean fluctuation of the entire basin is 2.75 m. Minimum water level fluctuation is noticed in the Silent Valley area (northern region) and in the coastal area (western part) of the basin (Fig.2.5). The higher water level fluctuation zones are seen in the Palghat Gap area (eastern side).

Water level fluctuation in different rock types of the basin is also determined. In the charnockitic terrain, water level fluctuation ranges from 1.43 m to 4.39 m. The area composed of hornblende-biotite gneiss has a water level fluctuation of 1.03 to 5.54 m and the coastal sand area has a water level fluctuation of 0.34 to 2.62 m. It is found that coastal sand alluvium has low water level fluctuation due to the high thickness of alluvial deposits. Generally charnockite and hornblende-biotite gneissic terrain shows a higher water level fluctuation. But on the eastern side, hornblende-biotite gneiss shows higher water level fluctuation than charnockite, whereas hard rock terrain seen at the northern side of the basin comprising of the biotite-hornblende gneiss, charnockite, pink

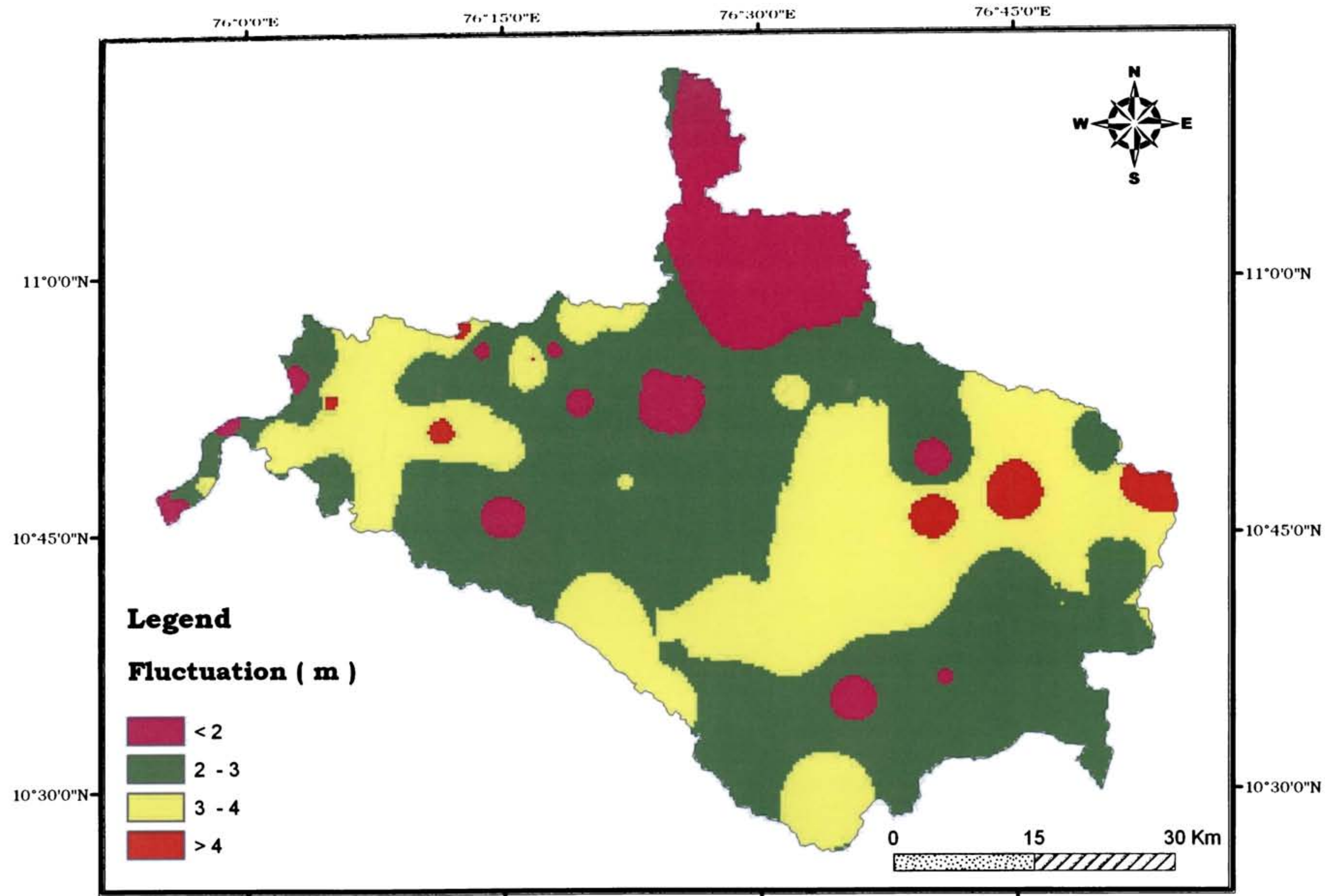


Fig. 2.5 Average water level fluctuation (bgl) for the period From 1991 to 2005 in the Bharathapuzha river basin.

granite, hornblende-biotite gneiss with schist has low water level fluctuation due to the presence of thick humus in the Silent Valley bioreserve forest.

Water level fluctuation map (Fig.5.1) of the basin has been compared with various maps such as geomorphology, landuse (Fig. 5.2), lineament density (Fig.5.4) and relative relief (Fig.5.7) of the basin. The comparison with geomorphological map reveals that valley fills, coastal planes and pediment zones have low water level fluctuation and the plateau regions in the eastern side have higher water level fluctuation. Even though southern and northern part of the basin is characterised with structural hills, northern part of the basin shows low water level fluctuation due to the effect of Silent Valley bio reserve. The collation with land use map, the Bharathapuzha basin shows that lower levels of fluctuation is seen in the dense mixed jungle, sand deposits and paddy fields where as high water level fluctuation is seen at the waste land without and with scrub. While at the same time, the comparison with lineament density map reveals that majority of the high lineament density areas have low water level fluctuation and vice versa. The comparison of the relative relief map shows that majority area of the basin is marked by low relative relief and has a medium water level fluctuation except eastern and northwestern sides. In contrary, the high relative relief area is characterised by medium water level fluctuation (2 to 3 m).

2.3.5 Long term trends

The determination of long term trends in hydrogeological studies will help in sustainable management planning and development of water resources. The long term trend in the water table fluctuation of seven observation wells, for which data for 15 years has been determined by using the method of moving average of time series analysis. A best fit line for the observed moving averages is drawn to determine the long term trend (Fig 2. 6). It is observed that the water table has a declining trend except for two places viz: Malampuzha and Ottappalam (Fig.2.6).

The depletion of water table may be due to the combined effect of many factors such as sand mining, over exploitation by industries and agricultural activities etc. In Malampuzha region, the positive trend may be due to the presence of Malampuzha dam and in Ottappalam the increasing water level trend is due to the confluence of the Gayathripuzha with the Bharathapuzha.

2.3.6 Correlation of water level with rainfall

The water table of an area is mainly controlled by variations in groundwater recharge, discharge and rainfall (Todd, 1980). The hydrographs of the four selected wells (Malampuzha, Ottappalam, Ponnani and Walayar) along with their monthly rainfall distributions are shown in figure 2.7. In these figures the line diagrams at the top represent the

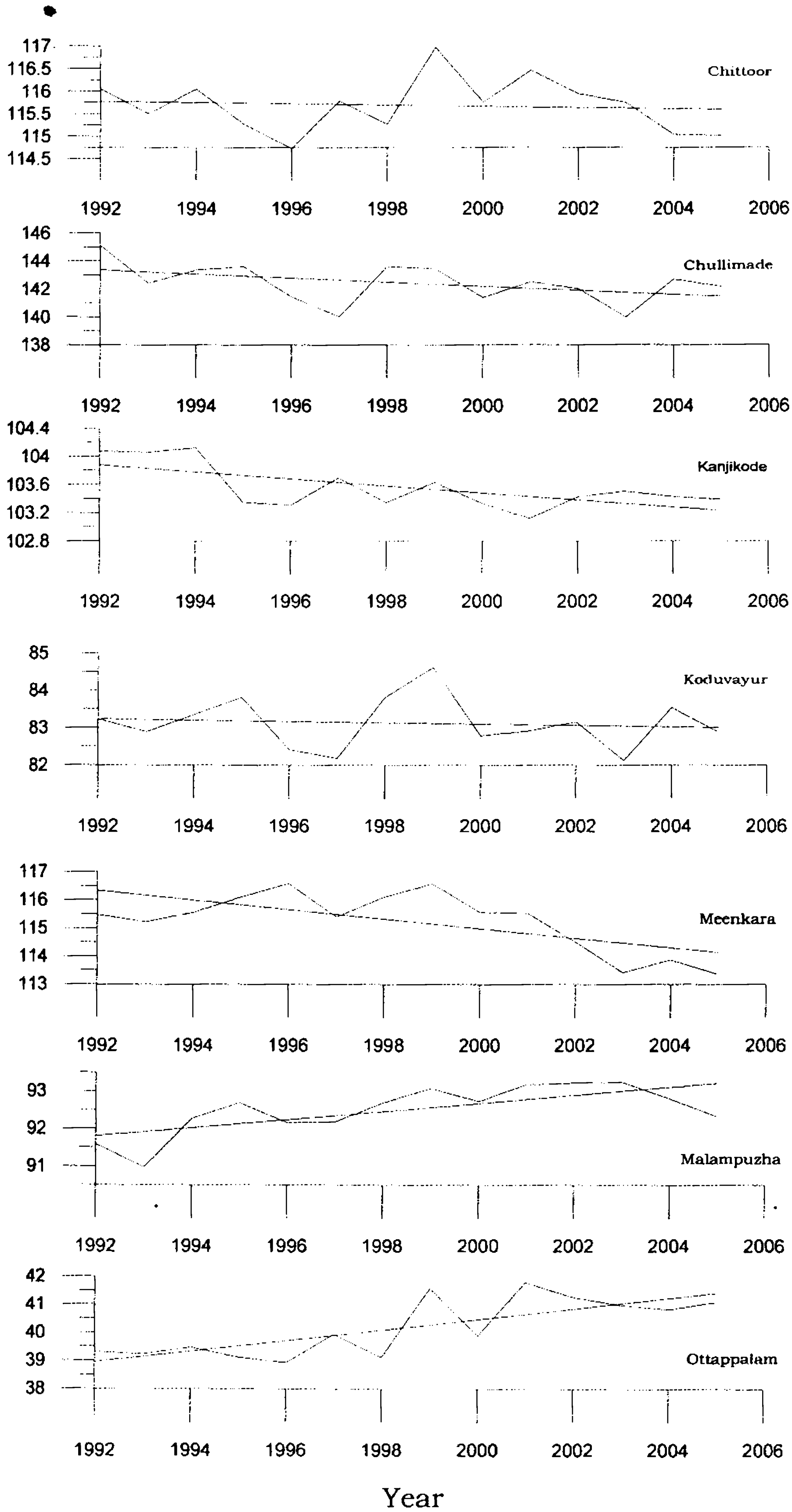


Fig 2. 6 Long term trend of water table fluctuation of the observation wells.

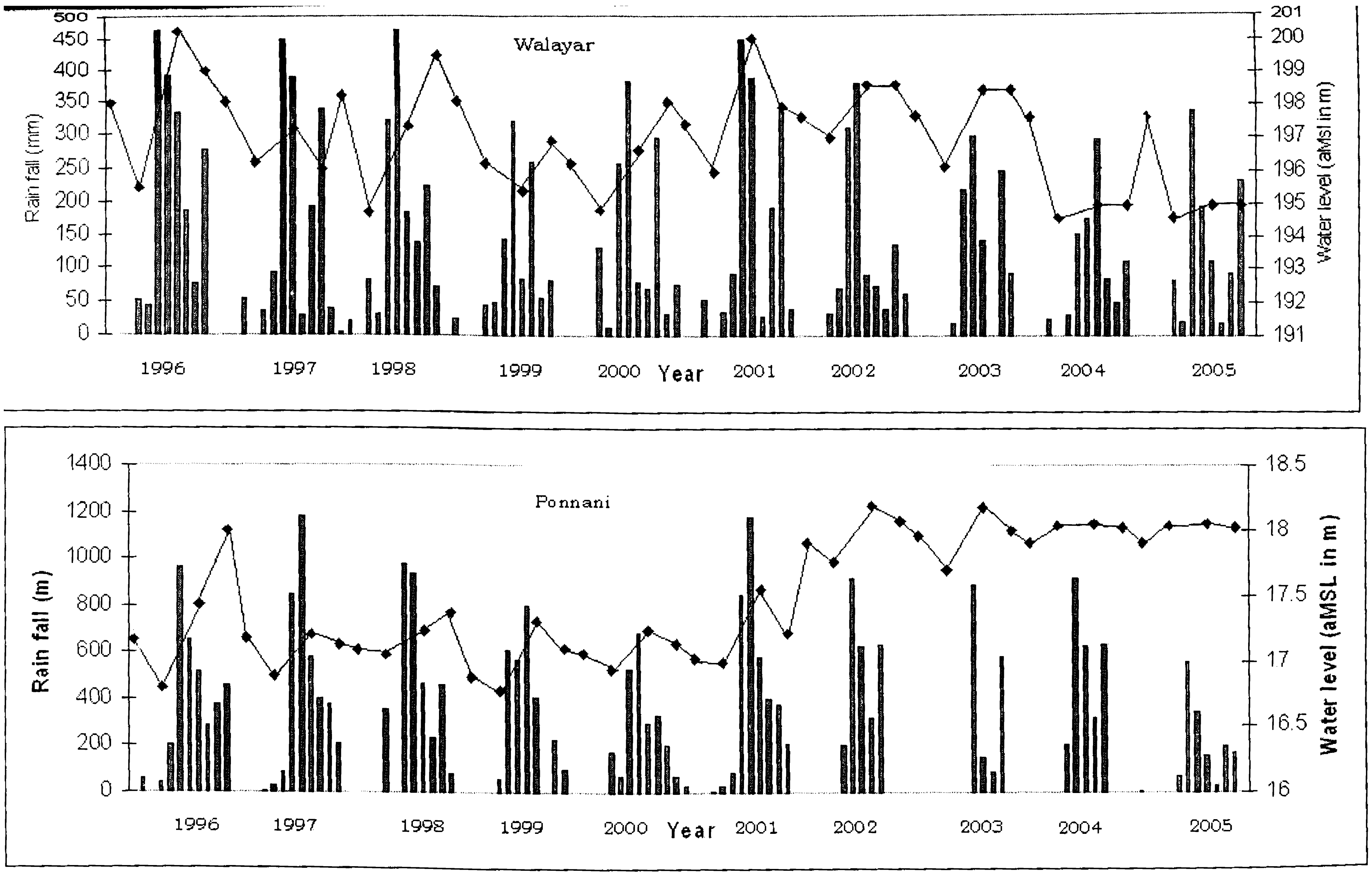


Fig 2.7 Correlation between monthly variation of rain fall with water table fluctuation in certain selected stations of the study area

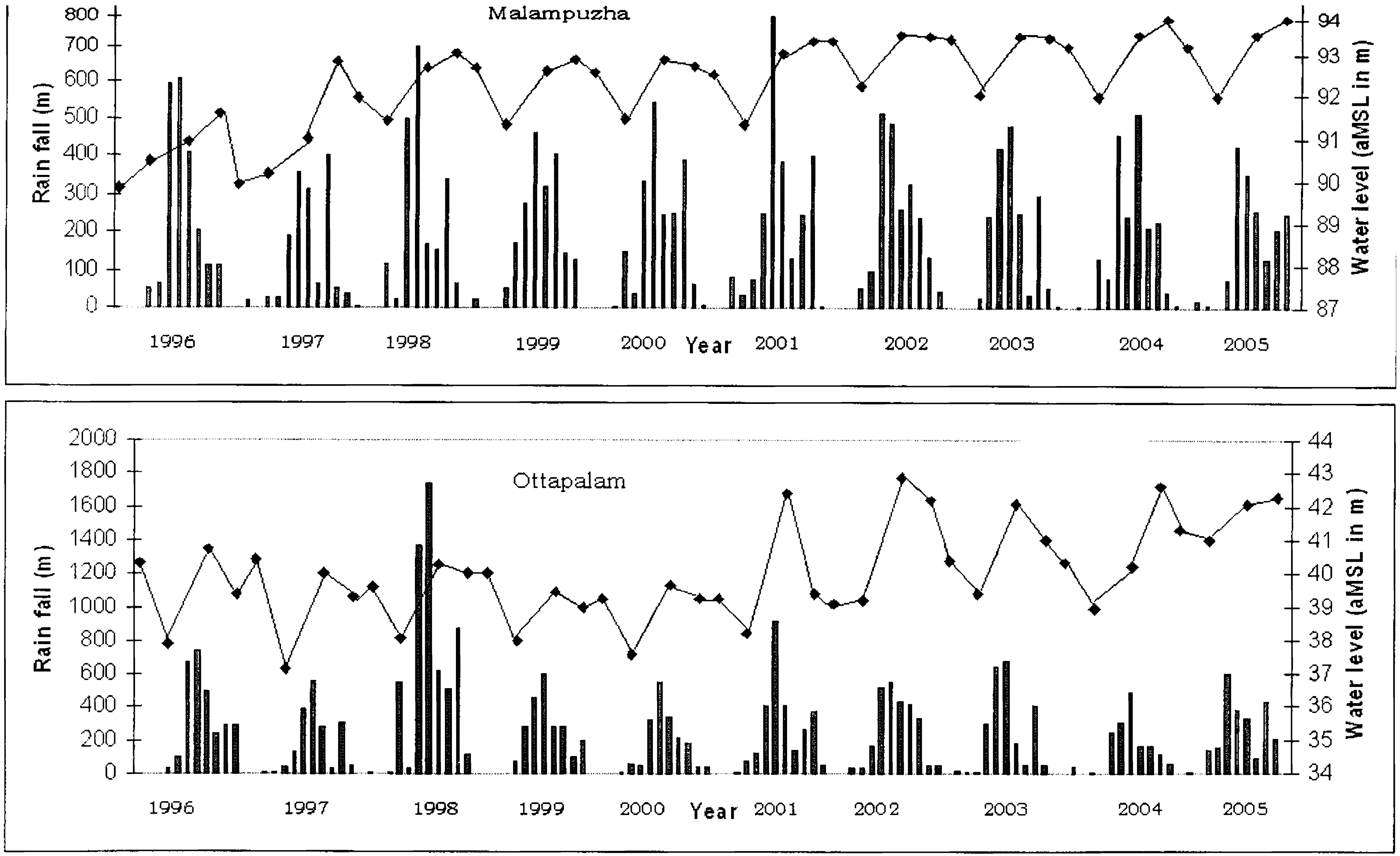


Fig 2.7 Continues)

quarterly water levels above mean sea level in meter for 10 years while the bar diagram represents the variations of rainfall from1996 to 2005.

The hydrographs of selected network of stations (Fig 2.7) show corresponding peaks and valleys (variations in water level) with rainfall distributions. The best fit line for the hydrographs will bring out the secular trend of water table with time. The valleys represent low groundwater storage whereas the peaks correspond to more groundwater storage. The hydrographs show that water level rises are closely related to increasing rainfall and vice versa. Thus in nut shell, the rainfall has a major control over the water level fluctuation. It is observed that there is a time lag between the water level fluctuation and the rainfall in the study area and this is due to the infiltration rate of the terrain which inturn depends on the permeability and porosity of the soil.

2.4 AQUIFER PARAMETER EVALUATION

An aquifer being a source of water has the ability to store and transmit water. In areas of massive crystalline rocks the large aerial extend of the aquifer is not very common (Narayana Rao, 1972). Water usually enters the aquifer from natural or artificial recharge, it flows under the influence of gravity and is extracted by the wells. The exploitation of groundwater in any region leads to water level declines which result in limited yields. Pumping test is the commonly used method for estimating hydraulic characteristics of crystalline rocks such as

Transmissivity (T,) Storativity (S), Optimum yield, Specific capacity (C) and Time for Full Recovery (TFR).

The hydraulic properties of hard rock formations depend on the nature of weathering and fracturing which are more pronounced near the surface. The permeability of hard rock formations generally decreases with depth. Hence the analysis of the hydraulic properties of the shallow aquifer is attempted in the present study.

2.4.1 Field Measurements

Hydraulic properties of rock formations can be estimated following several techniques within the field itself. The choice of a particular method depends on the purpose of the study and scale of investigations. For small-scale problems like seepage of water into mines the preferable tests are: packer test, slug test and tracer test. In case of groundwater development and management on a regional scale, usually pumping method is preferred. In the present investigation pumping test has been conducted for 35 dug wells (Fig 2.8).

Pumping tests: Pumping test is one of the most useful means for determining the aquifer hydraulic characteristics. It is also used in the determination of yield and drawdown, specific capacity and designing of wells. Pumping test is an expensive procedure and therefore should be properly planned. The cost of testing depends on the number of pump

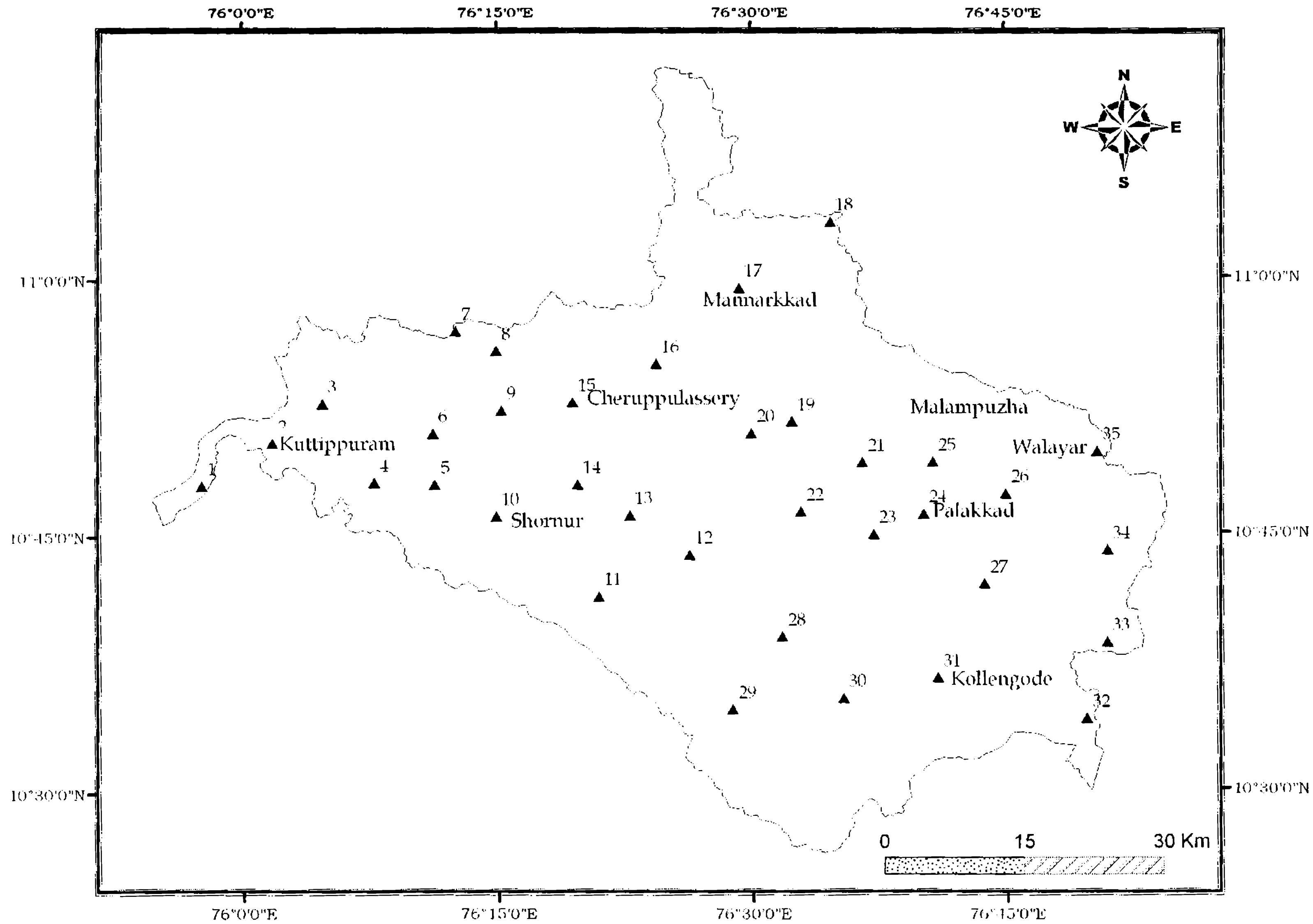


Fig. 2.8 Pump test locations in the Bharathapuzha river basin.

tests and the duration of the tests. Before conducting pump test, certain factors should be kept in mind such as geology of the area and hydrological conditions of the test locations.

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

Choice and shape of well: For selection of wells for pump test, it is necessary to know the geological and hydrological conditions of the area. In the Bharathapuzha river basin majority of the wells are situated within plateau and a very few in the hilly terrain. In this work while selecting wells, due representation has been given for each of the rock types of the river basin. But in the north eastern and southern parts of the study area only a few pump test are conducted because of the forest cover and hilly region. All the pumping test wells are circular in shape. Circular wells are preferred as they have equivalent perimeter from top to bottom.

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

Time interval of water level measurements: The duration of the pumping test depends on the type of aquifer and the purpose of the test. Usually the test is continued till the water level is stabilised so that both the non-steady and steady state methods of analysis can be used for computing aquifer parameters. In pumping test, immediately after starting the pump or its stoppage, the fall or rise of water levels is very rapid and hence the water level measurements should also be very rapid during this period. Kruseman and de Ridder (1990) have proposed a range of time intervals for pumping measurements of wells in confined, leaky and unconfined aquifers and are at 24, 48 and 72 hrs respectively. The time intervals adopted during pumping and recovery phase of the present investigation are given Table 2. 2.

Table 2.2 Time intervals for pumping and recovery phases

Time since pumping started (m)	**Time interval (m)**
1. Pumping Phase	
0 – 50	5 –10
50 – 120	10 –15
120 - shut down of the pump	15 – 30
2. Recovery phase	
0 – 30	5
30 - Final recovery reading	15 – 30

Discharge and recharge measurements:

In order to avoid the complications of calculations, the discharge rate should preferably be kept constant throughout the test. The discharge measurements have been made using the standard procedures of Kruseman and de Ridder (1970) during the pumping phase whereas the recharge rate or recovery phase has been computed by multiplying the drawdown with the cross-sectional area of the well.

2.4.2 Data Processing Techniques

Aquifer parameters could be evaluated using classical and digital methods. Many of the available classical pumping test analyses are graphical (Cooper and Jacob 1946; Papadopulos and Cooper, 1967; Raju and Raghava Rao, 1967, Narasimhan, 1968; Adyalkar and Mani, 1972; Trilochan Das, 1972, Samuel, 1974; Streltsova, 1974; Zadankush, 1974; Newman, 1975; Boultan and Streltsova, 1976; Black and Kipp, 1977; Rushton and Singh, 1983) which require data plotting and individual judgment during the curve fitting procedures. Therefore, it is tedious and time consuming and errors may occur during these procedures (Yeh, 1987).

Many computer methods have been proposed and successfully utilised during the last two to three decades for analysing the pumping test data. (Saleem, 1970; Walton, 1970; Rayner, 1980; Mc Elwee, 1980; Dumble and Cullen, 1983; Bradbury and Rothschild, 1985;

Mukhopadhyay, 1985; Butt and Mc Elwee, 1985; Balasubramanian and Sastri, 1989). The composite computer programme (APE) in Basic language developed by Balasubramanian and his research group at Mysore University has been followed in the present study for analyzing the pumping and recovery test data.

Hydraulic properties of water bearing formations are important because they govern the groundwater storage and transmitting characterisation. The different transmissivity values using the Jacob's straight line method (Rayner, 1980), sensitivity analysis (Mc Elwee, 1980) and recovery method (Theis, 1935), storage coefficient by Jacob's straight line method, different specific capacity indices such as Slichter, Walton's, Narasimhan's, Singhal and Limaye's by sensitivity analysis (Slichter, 1906; Walton,1962; Narasimhan 1965; Singhal, 1973; Limaye; 1973), time for full recovery (Rajagopalan et al. 1983 and optimum yield (Karanjac, 1975) were computed using APE programme.

2.4.3 Transmissivity

Transmissivity is defined as the rate of flow under a unit hydraulic gradient through a cross section of unit width over the whole saturated thickness of the aquifer (Todd, 1980). Hence it is the product of the average hydraulic conductivity and saturated thickness of the aquifer (Theis, 1935). It has a dimension of length and thickness expressed in m^2/day. Transmissivity is good for confined aquifers but in unconfined aquifer the saturated thickness of the aquifer changes with time and so the transmissivity also changes accordingly.

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

The transmissivity values are computed following Cooper and Jacob straight line methods (1946), Theis recovery method (1935) and sensitivity analysis (Mc Elwee, 1980 a). The results are shown in Table 2.3.

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

$$T = \frac{2.30\,Q}{4\Pi\Delta S'}$$

Where,

T = Transmissivity in m^2/day

Q = Rate of recharge in m^2/day

$\Delta S'$ = Residual drawdown in m

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

$$T = \frac{2.30\,Q}{4\Pi\Delta S}$$

Where,

T = Transmissivity in m^2/day

Q = rate of recharge in m^2/day

ΔS = drawdown in m

Sensitivity analysis

Sensitivity analysis is the study of a system in response to various aquifer disturbances. Mc Elwee, 1980a; Cobb et al. 1982 and Mukhopadhyay, 1985 have proposed algorithms for computer automated least square fit yielding transmissivity, storage coefficient and average drawdown error by sensitivity analysis. The sensitivity analysis provides both Transmissivity (T) and Storage coefficient (S). The best fit of T and S

Table 2.3 Transmissivity and storage coefficient values of the study area

Well No	Location Name	**Transmissivity** (m²/d)			**Storage Coefficient**
		Jacob's	Sensitivity	Theis Recovery	(Sensitivity)
1	Iswaramangalam	141.53	114.82	65.99	0.36
2	Kuttippuram	156	115.47	139.8	0.33
3	Valanchery	116.38	116.59	24.09	0.20
4	Tritala	115.46	79.68	31.5	0.32
5	Pattambi	192.52	141.16	23.02	0.35
6	Koppam	122.2	73.92	56.63	0.30
7	Perunthalmanna	157.25	147.66	14.2	0.35
8	Mankara	254.64	250.28	15.867	0.31
9	Kulakallur	244.89	110.92	103.5	0.32
10	Shornur	81.67	58.66	25.45	0.31
11	Chelakkara	39.57	35.24	5.66	0.31
12	Thiruviluamala	168.31	85.54	29.34	0.34
13	Ottapalam	197.41	149.47	35.38	0.37
14	Anakkara	238.88	224.37	39.81	0.24
15	Cherupallassery	119.8	95.3	55.7	0.32
16	Kumarampattur	149.4	91.76	53.72	0.31
17	Mannarkkad	58.65	57.51	6.09	0.27
18	Thavalam	52.2	50.18	2.99	0.20
19	Mundoor	18.78	13.07	7.93	0.28
20	Vattassery	101.16	32.97	45.84	0.33
21	Puthupariyarum	25.47	13.91	29.98	0.31
22	Odannur	140.2	112.1	63.2	0.34
23	Kannady	62.72	32.02	8	0.35
24	Palakkad	322.56	194.92	93.38	0.37
25	Malampuzha	12.32	5.87	6.69	0.39
26	Kanjikode	12.32	8.96	6.29	0.29
27	Chittur	10.89	10.23	2.48	0.35
28	Alathur	80.9	48.24	18.26	0.35
29	Vadakkanchery	74.89	67.56	17.87	0.25
30	Nenmara	129.8	105.39	57.77	0.33
31	Kollengode	9.7	6.12	7.31	0.25
32	Chemmampathi	104.9	75.14	110.9	0.29
33	Meenakshipuram	67.83	61.79	123.78	0.29
34	Kozhinjampara	61.37	64.45	6.44	0.19
35	Walayar	162.31	160.49	8.24	0.31

are obtained by comparing the computed and observed drawdown values. The computed and observed drawdown values have matched perfectly well with very little drawdown error (RMS error). So the Transmissivity values obtained through sensitivity analysis are considered for further interpretation in this work.

In the present study Transmissivity value (T) observed through sensitivity analysis method have a maximum value of 250.28 m^2/d at Mankara and a minimum value of 5.87 m^2/d at Malampuzha and the average being 86.05 m^2/d (Table 2.3). From the figure 2.9, it is observed that the aquifer transmissivity is showing a values ranging between 60 and 180 along the extreme eastern regions which is followed by a sudden decrease in transmissivity which is less than 60 . From central part of the basin to western region again the transmissivity values increase and even reach greater than 180. In middle part of low transmissivity region there are patches of high transmissivity whose value rises even greater than 180 It is noted from the Table 2.3 that highest transmissity values are seen at Malampuzha, Anakkara, Ottapalam, Kulakallur, Nenmara Mankara. In the Palghat Gap region, we can observe that the aquifer transmissivity is very low. In hard rock areas, values more than 100 m^2/d are treated as good Transmissivity values (Sridharan et al.1995).

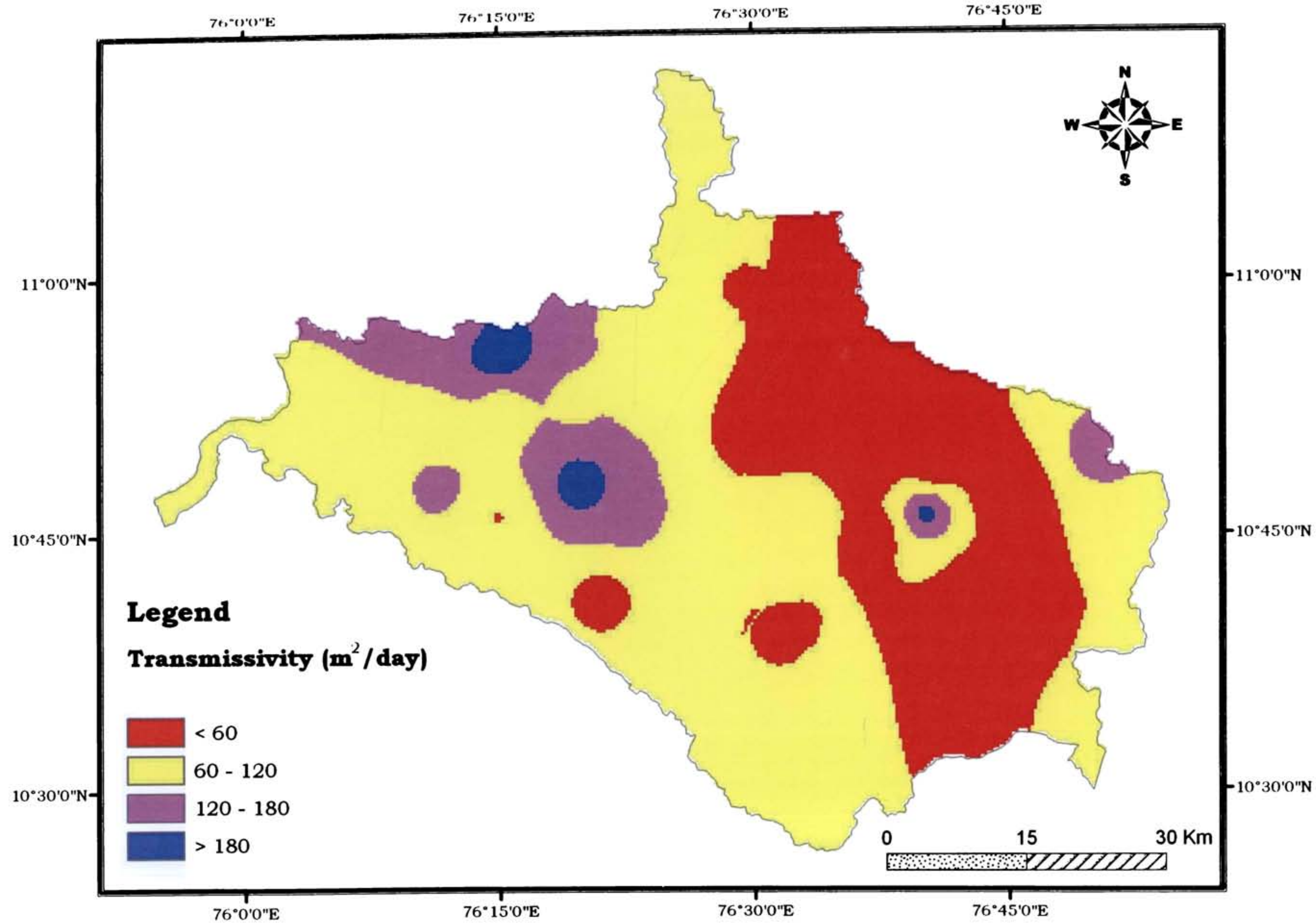


Fig. 2.9 Aquifer Transmissivity map of the study area

2.4.4 Storage coefficient or Storativity

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

In the present study, storage coefficient obtained through sensitivity analysis ranges from 0.19 (Kozhinjanpara) to 0.39 (Malampuzha) with an average value of 0.31 (Table 2.3). The contour map (Fig. 2.10) shows lowest storativity values at the western, northern and Palghat Gap area. The majority area of the basin is marked by high storativity values.

According to Singhal and Gupta (1999) storativity values of an unconfined aquifer ranges from 0.05 to 0.30 and in the study area majority of storativity values fall within this range supporting the unconfined nature of the dug wells. The positive correlation of transmissivity and storativity values shows that good aquifer conditions exists in the present study area.

In the study area, good storativity areas exhibits low level groundwater fluctuation as increased from the Figures 2.10 and 2.5. Even though Kanjikode and Palghat areas have good storativity, they show a high water level fluctuation. This is due to the over exploitation of the groundwater in these areas especially in the industrial belt. It is also

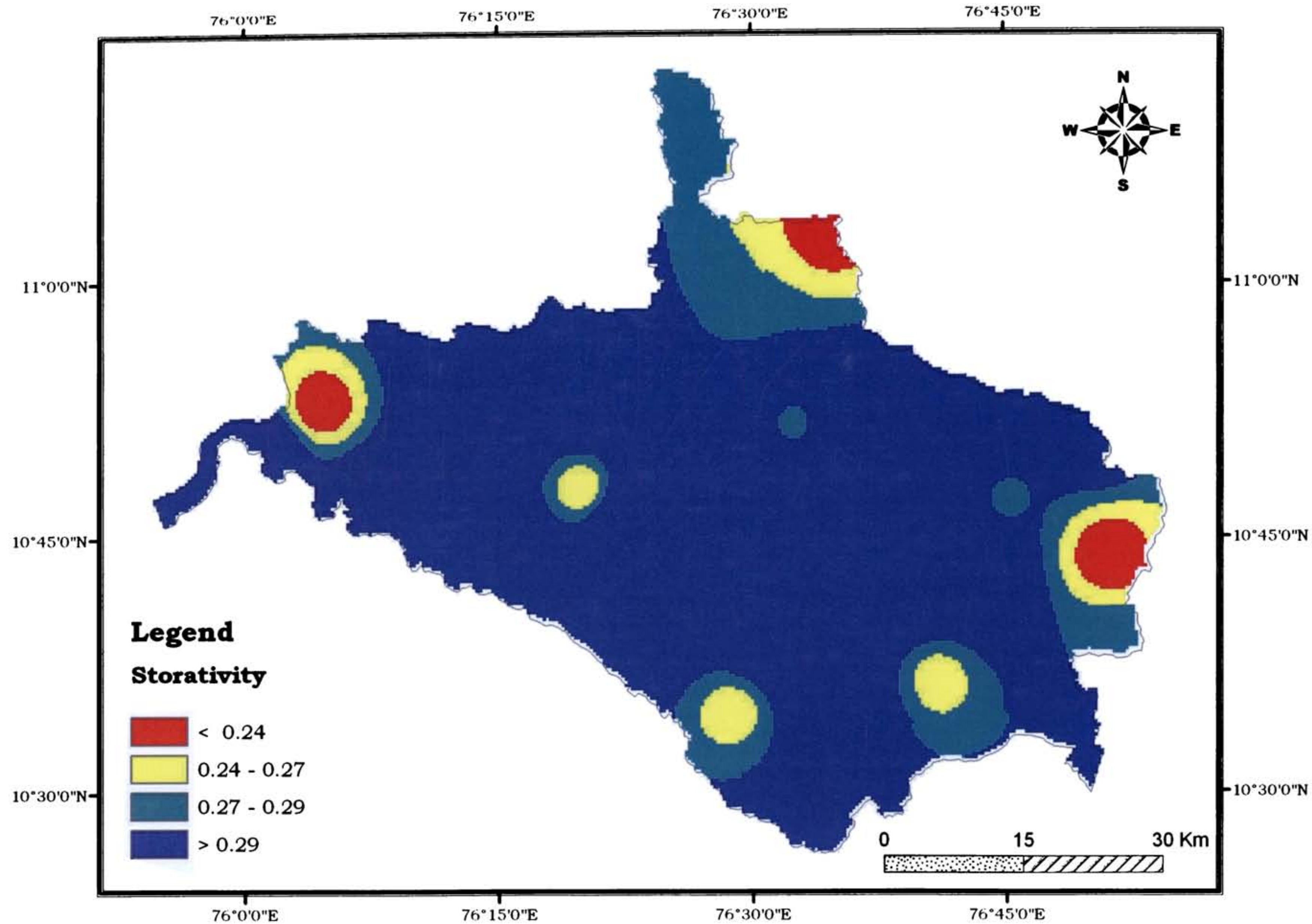


Fig. 2.10 Storage coefficient map of the study area

reported that Chittoor Block of Palghat district is an 'over exploited' area (CGWB,2004).

2.4.5 Optimum yield

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

In the study area optimum yield ranges from 0.1 m^3/d at Meenakhipuram to 43.2m^3/d at Iswaramangalam and the average is 5.74 m^3/d (Table 2.4). The highest value is recorded at the western part of the basin. Majority areas of the basin have optimum yield below 10 m^3/d. (Fig 2.11) Higher optimum yield imparts higher permeability. Regions of higher optimum yield can be chosen for well development.

2.4.6 Specific capacity

Specific Capacity of a well is the ratio of discharge to drawdown (Summers, 1972). It is not a constant index because the draw down varies with a number of factors like,

a. length of time since pumping began
b. Rate of pumping
c. Type of well construction
d. Boundary conditions within the aquifer and
e. The influence of near by areas from pumping well

Table 2.4 Recovery rate, time for full recovery and optimum yield values of the study area

Well No	Location Name	Recovery rate (m³/d)	Total Time for Full Recovery (Hrs)	Optimum yield (m³/d)
1	Iswaramangalam	106.2	8.06	43.2
2	Kuttippuram	136.9	22.55	22.5
3	Valanchery	15.5	5.5	2.4
4	Tritala	11.1	55	3.3
5	Pattambi	6.8	8.25	1.2
6	Koppam	43.1	65.3	11.6
7	Perunthalmanna	2.7	28.1	0.3
8	Mankara	3.4	5.35	0.8
9	Kulakallur	10.4	2.7	2.8
10	Shornur	41.2	42.1	11.2
11	Chelakkara	2.5	3.25	0.7
12	Thiruviluamala	15.2	7.4	3.1
13	Ottapalam	13.2	3.5	2.4
14	Anakkara	12.3	15.2	1.8
15	Cherupallassery	133.6	23.6	23.1
16	Kumarampattur	41.1	43.8	11.1
17	Mannarkkad	4.8	2.85	1.8
18	Thavalam	1.1	7.95	0.6
19	Mundoor	8.4	2.65	2.5
20	Vattassery	26.2	2.1	7.1
21	Puthupariyarum	15.6	2.7	2.8
22	Odannur	20.9	46.2	4.6
23	Kannady	5.3	15.9	1
24	Palakkad	115.3	4.55	20.9
25	Malampuzha	4.8	3.4	1
26	Kanjikode	15.3	29.3	0.11
27	Chittur	1.4	5.8	0.5
28	Alathur	5.7	11.9	0.8
29	Vadakkanchery	5.4	6.4	0.9
30	Nenmara	48	31.5	10.6
31	Kollengode	17.2	27.6	0.13
32	Chemmampathi	16.9	28.25	0.12
33	Meenakshipuram	17.1	32	0.1
34	Kozhinjampara	15.1	4.8	3.7
35	Walayar	1.1	8.8	0.3

Table 2.5 Different specific capacity indices of the study area

Well No.	Location Name	Specific Capacity Indices				
		Slichter's (lpm/mdd /m²)	Walton's (lpm/md d/m²)	Narasimhan's (lpm/mdd/m²)	Singhal's (lpm/md d/m²)	Limaye's (lpm/md d/m²)
1	Iswaramangalam	182.6	91.2	8.6	5.5	3.4
2	Kuttippuram	55.98	26.66	3.09	1.77	1.13
3	Valanchery	118.07	30.75	17.75	3.36	2.83
4	Tritala	58.01	25.1	1.62	1.2	0.7
5	Pattambi	132.26	129.66	15.27	12.43	6.85
6	Koppam	32.07	27.3	0.96	1.3	0.55
7	Perunthalmanna	9.25	26.43	2.23	3.66	1.38
8	Mankara	189.68	421.52	26.82	44.72	16.77
9	Kulakallur	66.84	85.14	1.53	3.6	1.07
10	Shornur	41.3	33.8	0.75	1.31	0.47
11	Chelakkara	45.99	19.57	29.86	4.44	3.87
12	Thiruviluamala	125.54	57.85	13.82	5.42	3.89
13	Ottapalam	189.68	77.74	26.82	8.25	6.31
14	Anakkara	84.95	50.26	6.75	4	2.51
15	Cheruppallassery	223.4	107.4	10.15	6.4	3.9
16	Kumarampattur	62.3	82.4	1.4	3.2	1.01
17	Mannarkkad	80.39	64.83	39.97	12.89	9.75
18	Thavalam	36.31	4.7	11.55	0.79	0.74
19	Mundoor	52.23	33.69	30.76	7.29	5.89
20	Vattassery	255.12	637.79	41.41	72.5	26.35
21	Puthupariyarum	101.93	56.63	32.43	9.01	7.05
22	Odannur	189.01	91.1	8.6	5.5	3.4
23	Kannady	24.61	5.08	7.1	0.77	0.69
24	Palakkad	405.42	168.92	22.39	11.2	7.46
25	Malampuzha	21.69	15.6	24.11	4.64	3.89
26	Kanjikode	4.35	7.01	1.87	1.29	0.76
27	Chittur	17.82	7.27	15.75	1.93	1.72
28	Alathur	47.19	393.21	11.55	54.89	9.54
29	Vadakkanchery	73.39	34.29	19.12	4.94	3.93
30	Nenmara	220.4	103	9.1	6.2	3.8
31	Kollengode	5.47	1.24	1.51	0.18	0.16
32	Chemmampathy	35.54	5.47	1.78	0.345	0.289
33	Meenakshipuram	72.2	79.35	3.04	4.59	1.83
34	Kozhinjampara	56.15	62.88	22.3	11.18	7.45
35	Walayar	64.94	29.38	14.59	3.93	3.09

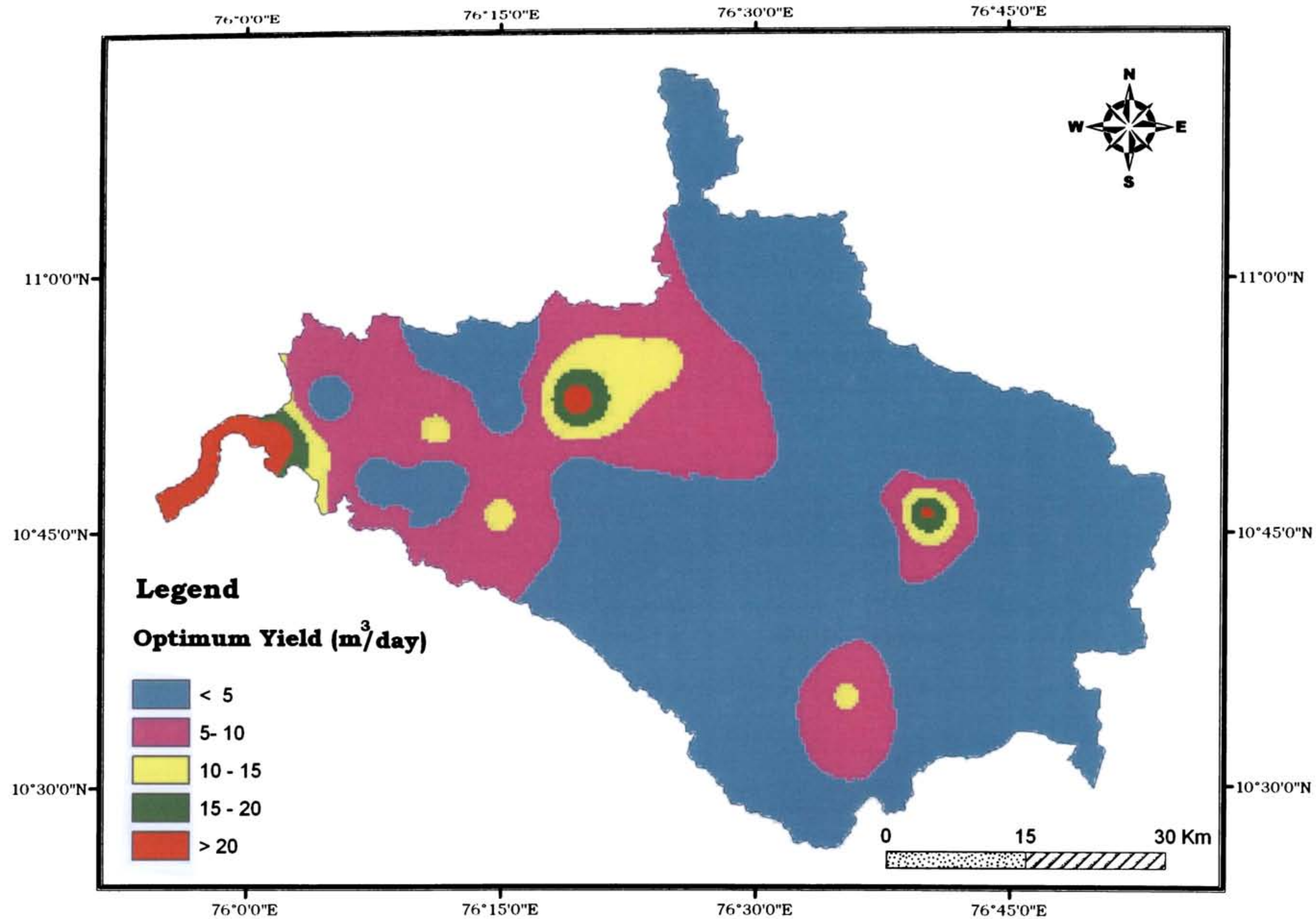


Fig. 2.11 Optimum yield map of the Bharathapuzha river basin

Hence it is a measure of the productivity of the well (Todd, 1980) i.e. the larger the specific capacity, the better the well.

Different specific capacity indices of the basin are calculated following the methods adopted by Slichter (1906); Walton (1962), Narasimhan (1965); Singhal (1973) and Limaye (1973) using APE programme and results are shown in the Table 2.5.

Slichter (1906) formula for computing the specific capacity is

$$C = 2303 \times \left(A / t' \right) \times \log \left(s / s'' \right)$$

Where,

C = Specific capacity of the well in lpm/mdd,

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

t' = Time since pumping stopped in minutes

s = drawdown in just before pumping stopped and

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

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

Slichter specific capacity values cannot be used directly for the purpose of comparison. So Walton (1962) introduced the concept of specific capacity index, which is obtained by dividing the Slichter's specific capacity (average) with the saturated thickness of the aquifer. Zeizel et al. (1962); Nautiyal and Gopalappa (1980) and Sastri et al. (1983) have used this index in determining the relative productivity of different units in predicting aquifer yields.

Narasimhan (1965) introduced the unit area specific capacity by dividing the Slichter's specific capacity with the cross sectional areas of the well. This formula has been successfully utilised by many scholars (Summers (1972); Krupanidhi et al. (1973); Subramanyan (1975); Viswanathiah; Sastri (1978)) to describe the hydrogeological characteristics of hard rock.

Singhal (1973) suggested that since both the diameter and the saturated thickness of the aquifer tapped vary, it would be better if the Slichter's specific capacity values were divided by the total contributing surface area of the aquifer tapped by the well. But Limaye (1973) suggested that instead of the use of total contributing surface area of the aquifer tapped, it should be sum of the total surface area of the well under study.

The Table 2.5 shows the various specific capacity indices calculated for the basin. Slichter's (1906) and Limaye's (1973) specific capacity values have been considered in the present study as these values are best suited for hard rock terrains (Venugopal, 1988; Aravindan, 1999; Rajesh et al. 1999; Girish, 2003).

In the study area the Slichter's (1906) specific capacity values shows range from 4.35 lpm/mdd/m at Kanjikode to 405.42 lpm/mdd/m at Palghat with an average of 96.63 lpm/mdd/m (Fig 2.12). The central and extreme end of the western part of the river basin exhibits higher specific capacity values. Limaye's (1973) specific capacity index shows low value at Kollengode (0.16 lpm/mdd/m) and high value at Vattassery (26.35 lpm/mdd/m) with an average of 4.41 lpm/mdd/m (Table 2.5). Figure 2.13 shows the spatial variations of Limaye's specific capacity indices. The thematic map of Slichter's specific capacity (Fig 2.12) and Limaye's specific capacity values (Fig 2.13) of the study area match well.

In the basin it is found that well radius increase leads to an increase in specific capacity (Table 2.5). In well location No.24 at Palghat (northeastern side of the basin) the equatorial radius of the well is 2.4 m and the corresponding Slichter's value is 405.42 lpm/mdd/m. But in well location No.25, Malampuzha (northeastern side of the basin) the equatorial radius of the well is 0.54 m and the corresponding Slichter's (1906) value is 21.69 lpm/mdd/m. Singhal and Gupta (1999) and Girish

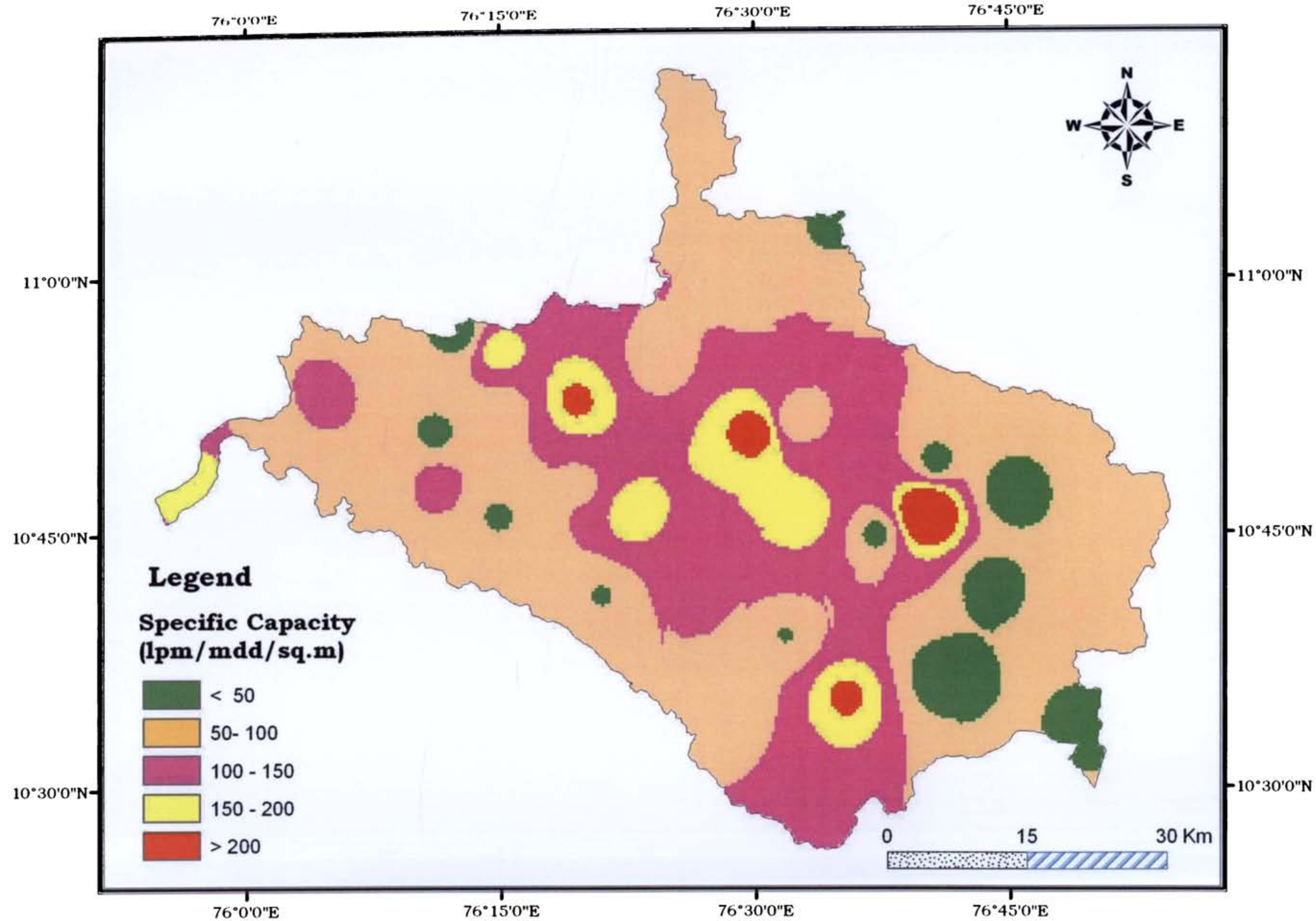


Fig. 2.12 Slichter's specific capacity indices map of the study area.

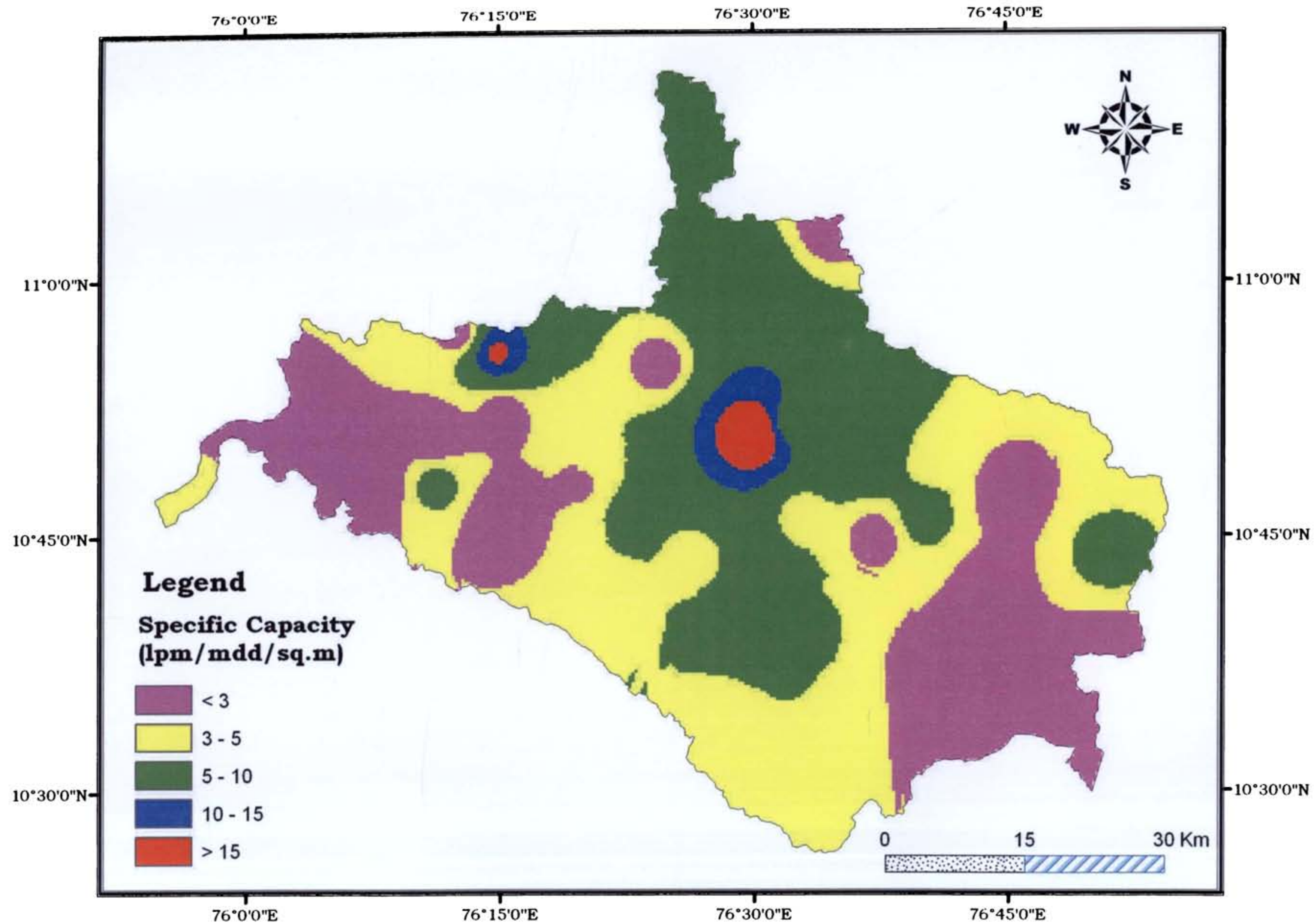


Fig. 2.13 Limaye's Specific capacity indices map of the study area

(2003) have observed that an increase in the radius of the wells results in the increase of specific capacity values and had been statistically verified by the study of Knopman and Hollyday, (1993). So it may be concluded that in the Bharathapuzha river basin the specific capacity of the dug well is controlled mainly by equatorial radius rather than the lithology of the terrain.

2.4.7 Time for full recovery

In the present study the total time required for full recovery of the wells after pumping has been found out (Rajagopalan et al. 1983). The result is shown in the Table 2.4. The M1 and M2 values are identical in nature which clearly reveals the matching of the computed and observed field values.The maximum time required for full recovery is 65.3 hrs at Koppam and minimum is 2.1 hrs at Vattaserry with an average of 17.55 hrs.

Figure 2.14 shows that the time required for full recovery is minimum at northeastern region whereas maximum time required is for the southwest region. Majority area of the basin takes 10-20 hrs for full recovery. This major area of the basin show a negative correlation between time required for full recovery and transmissivity values

2.4.8 Recovery Rate

Recovery rate values of the study area range from 1.1 m^3/d (Thavalam) to 136.9 m^3/d (Kuttipuram) and mean is 26.88 m^3/d (Table

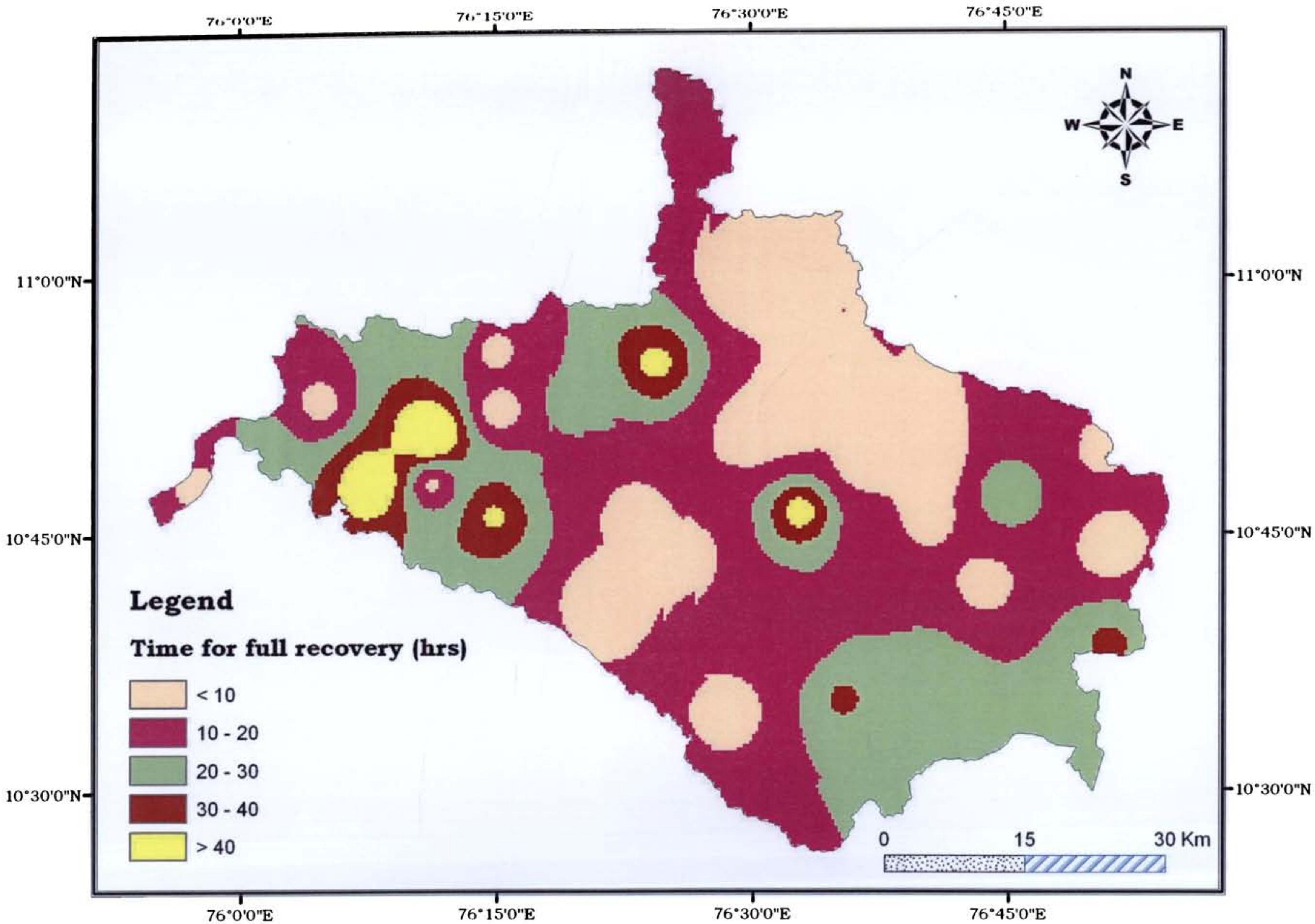


Fig. 2.14 Map showing Time for full recovery of the wells of the study area.

2.4). The highest recovery values are found near the coast and foot hillsof the western region whereas the lowest values are found in the extreme northeastern and southern part of the basin (Fig 2.15). The water level fluctuation in the costal region is low due to the presence of thick costal alluvial deposit which increases the water holding capacity (Fig 2.5 and 2.15). This may be the reason for the highest recovery values near the coast.

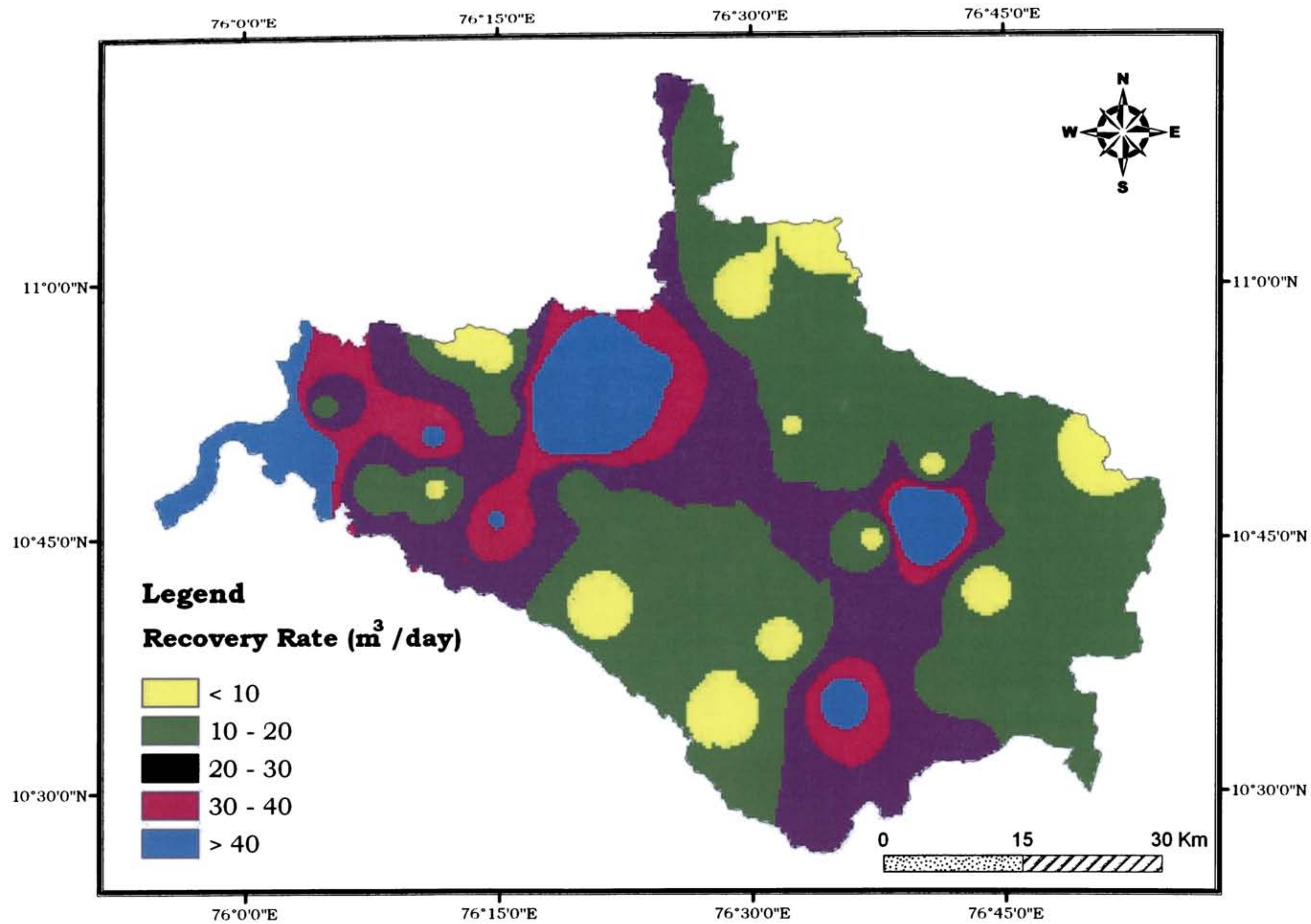


Fig. 2.15 Recovery rate map of the study area

CHAPTER 3

GEO-ELECTRICAL PROSPECTING

3.1 INTRODUCTION

Geophysical survey is necessary to ascertain subsurface geological and hydrogeologic conditions and helps to delineate regional hydrogeological features, even pinpoint locations for drilling of boreholes. Geophysical data provides information on local geological environment such as type and extent of surface material, extent and degree of weathered mantle, the nature and extent of underlying bedrock, the structural elements etc. that influence ground water occurrence and movement. The important geophysical method involved in ground water exploration is Geo - Electrical prospecting and several scientists like Bhimasankaram et al. (1975 & 1976); Benergy (1969); Bindumadhavan (1975); Zambre (1980); Bagdhan (1976); Mani (1989) and Ranga Rao (1978) have applied the geoelectrical methods to solve various ground water problems. Patangay (1977) is of the opinion that the electrical methods have greater advantage over the other methods. The proper use of geoelectric techniques reduces the risk of drilling poor yield wells and can also supplement the geological evaluation of proposed well locations. In an area of salt water intrusion that arises due to over exploitation of ground water can be studied using electrical resistivity techniques which provides additional data to improve the accuracy of ground water models, which in turn can be used to determine the extent of the non-saline ground water resource (Singh and Mesh, 1982; Sathyamoorthy and Banerjee, 1985; Ahemed et al. 1987; Basak and Nazimuddin, 1987).

Electrical resistivity methods are widely used for both regional and detailed survey for ground water exploration because of their great resolving powers, low expense compared to drilling and wide range of field applicability (Keller and Frischnecht, 1966; Balakrishna et al.1978; Chandra and Athavale, 1979; Chandrasekharan, 1988). Hence in the present study electrical resistivity, in particular Vertical Electrical Sounding (VES) is followed.

3.2 RESISTIVITY OF GEOLOGICAL FORMATIONS

The resistivity of geological formations in ground water exploration varies widely and depends on the factors like

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

Usually, the porous geological formations saturated with ground water of high ionic strength is having very low resistivity. However, low resistivity value need not always depict a water bearing zone. Similarly carrying out offset sounding in the above area which is underlain by charnockites), a clear cut low resistivity anomaly has been observed in the VES curve and is inferred as horizontal discontinuity (Ballukraya et al. 1981). It is possible that such anomaly/discontinuity can be mistaken for water bearing zones at depth. A resistivity range from 10 to 46 Ωm may attribute to water bearing zone, either a gravel or weathered/fractured granite (Singhal and Gupta, 1999). Apparent resistivity maps and profiles are commonly used to delineate potential ground water source (Zohdy et al. 1974; Todd, 1980).

Bhimashankaram and Gour (1977), Patangay and Murali (1984) and Telford et al. (1990) have given comprehensive list of resistivity values of various rock types, minerals and soils. The representative resistivity values for different kinds of earth materials is shown in Table 3.1 (Mooney, 1980).

Table 3.1 Resistivity values of the earth materials (Mooney, 1980).

Low resistivity materials	<100 Ωm
Medium resistivity materials	100-1000 Ωm
High resistivity materials	>1000 Ωm
1 Regional soil resistivities	
Wet regions	50-200 Ωm
Dry regions	100-500 Ωm
Arid regions	200-1000 Ωm
(Some time as low as 50 Ωm if the soil is saline)	
2 Waters	
Soil water	1-100 Ωm
Rain water	30-100 Ωm
Sea water	order of 0.2 Ωm
Ice	10^5-10^8 Ωm
3 Rock type below the water table	
Igneous and metamorphic	100-10000 Ωm
Consolidated sediments	10-1000 Ωm
Unconsolidated sediments	1-100 Ωm
4 Ores	
Massive sulphides	10^{-4}-1 Ωm
Non-metallic	Order of 10^{10} Ωm

The range of bulk resistivity values of common hard rocks and their water bearing weathered products of Peninsular India are tabulated in Table 3.2 (Sakthimurugan and Balasubramanium, 1991).

Table 3.2 Hydrogeological significance of bulk resistivity values Sakthimurugan and Balasubramanian (1991).

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

Singhal and Gupta (1999) have given a range of resistivity values of common rock/materials under dry and saturated conditions and is shown in Table 3.3.

Table 3.3: Ranges of resistivity values (Ω.m) of common rocks/materials (Singhal and Gupta, 1999)

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

Electrical resistivity survey provides basic information on

1) depth to water table
2) basement topography in hard rock and in coastal terrain
3) thickness of weathered layers
4) fissures, fractures and fault zones
5) depth/thickness and lateral extent of aquifers in sedimentary terrain
6) structural and stratigraphical conditions
7) formation characteristics
8) quality of ground water in terms of dissolved salt content
9) location of zones of salt water encroachment in coastal areas or location of fresh water pockets in saline and or brackish water environment.

3.3 BASIC PRINCIPLES

The vertical electrical soundings, otherwise known as electric drilling, depth sounding or depth probing, is used to determine the resistivity variation with depth and provide the information about the vertical distribution of fresh, brackish and saline water bodies and their aerial extent. A VES is typically carried out in Schlumberger array, where the potential electrodes are placed in fixed position with a short separation and the current electrodes are placed symmetrically on the outer sides of the potential electrodes. 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. The positions of the current electrodes are typically logarithmically distributed with at least 10 positions per decade. 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 in the instrument. With the expansion of electrical array, the depth of penetration of electrical current is increased there by detailed information and the vertical succession of various conductive zones, their individual true resistivity and thickness can be obtained. Some of the most common electrode arrays are Wenner, Schlumberger, pole-pole, pole-dipole and dipole-dipole array. In reality, the subsurface ground does not conform to the homogenous medium and hence the resistivity obtained is 'apparent resistivity' (ρ_a), rather than the 'true resistivity' (ρ_t). Apparent resistivity values calculated from measured potential differences can be interpreted in terms of overburden thickness, water table depth, and the depths and thicknesses of subsurface strata. The apparent resistivity is obtained as the product of measured resistance(R) and geometric factor K, which depends on the geometric spread of electrodes.

$$\rho_a = (\Delta V/I) \times K$$

where ΔV is the measured potential, I is the transmitted current, and K, the geometrical factor .

The apparent resistivity values along the y-axis can be plotted against logarithmic value of current electrode half spacing along the x-axis to obtain apparent resistivity curves, which is also known as field curves. Further these field curves are interpreted by different techniques like curve matching, curve breaks etc to get the different layer parameters, such as, depth to water table, depth to basement topography, thickness of weathered layers, detection of fissure fractures as well as fault zone and also the quality of ground water in terms of dissolved salt content. In the present study the curve matching techniques are used to interpret the field curves obtained. The VES data together with the subsequent borehole information help to compile the hydrogeological potential.

Table 3.4 Vertical Electrical Sounding (VES) data of the Bharathapuzha river basin

SL NO	LOCATION	Thickness (m)				Resistivity (ohm.m)				
		h1	h2	h3	h4	p1	p2	p3	p4	p5
1	Vellanchery	0.36	6.21	16.40		32	103	136	66883	
2	Kuttippuram	2.54	7.17	25.40		110	260	968	2	
3	Perassanur	1.81	0.99	15.40	23.40	214	555	1683	175	37983
4	Irumbilium	16.50	16.10			1527	123	55644		
5	Valiyakunnu	1.20	1.33	12.47		1051	4784	557	41933	
6	Valanchery	2.58	2.68	16.70	20.30	1391	4482	499	94	50801
7	Vadakkumbram	1.07	4.54	17.40	20.50	576	1526	353	2353	13
8	Pukkatteri	0.60	1.16	7.00		287	14636	721		
9	Moorkkanad	1.81	18.30	20.80		153	504	1333	9	
10	Vilayur	6.00	7.10			65	1870	397		
11	Thiruvegappuram	0.83	1.39	2.87	14.20	830	4028	50	891	129
12	Vilattur	0.38	3.10	6.63	9.87	9634	286	156	1433	158
13	Pattithara	4.80	5.68	46.40		188	4016	235	12006	
14	Challissery	1.20	1.21	3.24	16.90	489	227	854	365	1472
15	Nagallassery	2.93	2.57	21.20		594	1168	205	568	
16	Tritala	0.34	11.20			198	18	6077		
17	Mezhattur	4.80	6.49			654	129	168		
18	Malarkkara	1.20	4.65	7.03	51.60	280	227	658	205	1143
19	Pattambi	1.32	3.58	5.35	14.40	208	24	781	33	3441
20	Kalladipetta	1.44	2.06	96.50		744	138	581	6279	
21	Netirimangalam	3.34	9.71			606	378	622		
22	Ongallur	3.60	5.72	96.50		277	183	1072	6279	

23	purakkad	1.25	1.34	3.05	7.72	516	195	9632	229	1143
24	Kozhikkottusseri	3.73	61.50			194	358	20		
25	Koppam	4.93	3.38			145	2449	500		
26	Saithalippadi	0.97	2.70	6.38	11.00	1462	704	163	912	193
27	Karinganad	1.86	1.81	8.08		690	1319	86	814	
28	Kulakallur	7.93	44.70			118	2527	69		
29	Vallapuzha	5.39	14.30			24	13	19252		
30	Koyiliyod	5.35	5.91			324	677	1858		
31	Chalavara	0.60	25.20			70	10511	377		
32	Nellaya	4.42	21.80			27	808	22189		
33	Ezhuvanthala	1.56	1.74			119	61	594		
34	Kulakallur	4.33	3.61			259	123	509		
35	Natyamangalam	1.87	26.50	24.50		125	308	939	39210	
36	Eravimangalam	5.16	3.53			250	71	298		
37	Tazhekkod	5.26	4.36	8.50	20.50	981	2377	115	1149	4
38	Mannarkkad	6.00	11.30			897	391	2842		
39	Athikkod	9.78	12.10			253	37666	655		
40	Kanjirampuzha	1.65	0.69	4.69		202	1026	136	13236	
41	Karimpuzha	1.88	13.40			514	697	3975		
42	Sreekrishnapuram	5.11	28.40	33.00		739	1893	341	59190	
43	Nedungattur	4.33	22.50			45	519	2625		
44	Mundamuga	8.17	53.41			20	251	3		
45	Shornur	1.20	10.00	12.50		414	881	238	2544	
46	Desamangalam	0.85	0.27	16.90		66	632	118	40340	
47	Mullurkkara	0.82	5.70			43	181	2450		

48	Thonnurkkara	1.20	5.70	9.72		303	95	2491	97	
49	Chuduvalattur	4.80	6.49			52	14164	400		
50	Vaniyamkulam	5.75	26.94			1039	288	588		
51	kanniyampuram	1.18	2.48	7.60		169	32	14	132	
52	Ottapalam	3.70	2.52	60.20		426	1155	279	1214	
53	Palappuram	2.09	2.22	5.84	21.70	273	1893	218	6101	31
54	Mankara	1.21	5.69	5.90	33.10	1458	407	184	4900	108
55	Tekkumangalam	2.61	3.12	28.50		153	34	769	33	
56	Thiruviluamala	2.48	28.10			104	193	3480		
57	Tarur	6.00	44.00			34	29757	4055		
58	Alathur	2.27	10.20			157	190	1570		
59	Erattukulam	0.61	5.53			57	20	1497		
60	Kannampara	6.45	2.08			57	1064	3506		
61	Vadakkanchery	3.76	3.90	13.40		80	1718	117	2005	
62	Kizhakkanchery	1.65	23.80			145	435	3721		
63	Melangod	1.25	1.48	2.90		101	243	27	1838	
64	Trippanur	1.20	4.14	5.91	39.30	234	122	582	223	1111
65	Elavanpadam	1.60	6.09	40.10		431	57	310	36420	
66	Vandazhy	4.15	4.17	11.60		82	2069	163	2625	
67	Adiparanda	1.20	4.27	5.91	12.50	209	467	2727	121	47493
68	Tengumpadam	0.65	0.98	2.81	11.10	78	751	39	13405	41
69	Ayilur	1.20	1.68			31	15	2158		
70	Thiruvazhiyad	3.49	3.67			114	58	3196		
71	Kizhakkethara	2.04	1.26			9553	332	1073		
72	Nellikkode	3.78	6.25			116	38	29153		

73	Nenmara	2.53	8.71			36	2610	464		
74	Elavancheri	0.65	3.35	15.20		36	22	250	2400	
75	Kollengod	1.80	8.20	20.00		22	330	2300	1300	
76	Nenmeni	1.10	3.30	7.60		24	15	255	1050	
77	Pattanchery	5.81	14.30			78	333	1447		
78	Erumayur	2.89	4.37			31	15	44692		
79	Tripallur	6.00	9.50			28	3436	67		
80	Pannikkod	3.97	2.15			48	12948	358		
81	Vemballur	1.90	11.40			16	320	1500		
82	Kuzhalmannam	7.93	44.70	3.04	14.70	118	2527	69	3554	13
83	Koduvayur	0.91	1.30	15.60		24	26	166	4065	
84	Pudunagaram	1.13	5.20			183	28	4247		
85	Peruveppu	4.80	18.10			34	218	19301		
86	Kodumbu	6.00	24.80			14	981	21		
87	Alamcode	6.00	11.32			8	173	48		
88	Polpully	1.21	1.19	11.70		61	7	36	15734	
89	Perugottukurissi	4.13	0.00			25	564			
90	Tachangod	5.98	0.59			8	9	18080		
91	Kannady	0.97	2.55	4.38		139	66	12	21537	
92	Kadallakkurussi	2.79	3.58			883	2056	220		
93	Pallasana	4.95	7.78			48	6	2430		
94	Pizhakkad	6.00	7.10			45	12240	70		
95	Palakkad	0.35	2.61	2.87		725	21	6	10060	
96	Akathethara	2.00	1.70			139	86	1041		
97	Pappadi	1.20	2.80	5.91		2335	561	14	8330	58

98	Puthupariyarum	2.54	2.80	5.91	33.10	207	492	80	32	108
99	Puduppariyaram	1.15	4.55			77	191	15547		
100	Arupuzha	3.42	7.63			633	190	1826		
101	Parali	4.80	5.68			88	25822	146		
102	Kerallassery	0.57	0.98	2.29	4.02	121	400	57	6704	259
103	Mundoor	5.63	89.80			283	3287	60928		
104	Pudanur	1.22	15.80			122	425	4980		
105	Nochipully	0.98	1.39	3.11		44	381	24	29047	
106	Nochupulli	0.64	1.32	3.04	14.70	143	664	15	3554	13
107	Malampuzha	1.44	1.42	20.20		341	10	53	42294	
108	Marutharoad	2.59	6.14			101	13	10914		
109	Nirvallam	0.62	1.48	6.60		125	13	90	750	
110	Vengod	1.30	3.35	15.20		36	22	250	2400	
111	Elapulli	5.33	10.16			10	1576	5258		
112	Kuttiyampal	3.69	9.42			803	1530	13254		
113	Tenari	0.38	8.83			142	23	50625		
114	Nalleppilly	0.47	5.91			782	27	11517		
115	Attikkod	8.74				243	5449			
116	Kozhinjampara	0.94	5.40			303	18	11612		
117	Kadambazhipuram	1.14	1.67	4.15		131	818	28	1598	
118	Meenakshipuram	2.30	10.50			34	340	3800		

3.3 DATA

In the present study, VES data of 118 locations in the Bharathapuzha river basin, which was collected by Central Ground Water Board (CGWB) and Kerala State Ground Water Board using Schlumberger configuration has been adopted. These locations of the VES points are given in the Figure 3.1. The maximum electrode separation (AB/2) in VES was kept as 150 m. The data was interpreted by curve matching technique using master curves of Orellana and Mooney (1966) and the results are presented in the table 3.4.

3.4 CURVE TYPES

For the purpose of delineating the subsurface parameters, secondary data on vertical electrical survey based on Schlumberger configuration has been obtained for 118 locations in the basins.

The shape of the VES curve is controlled by the underlying formation distribution, ie., the resistivity and thickness of the layers and total depth investigated. In the case of two layered sequence, the simplest sounding curve are ascending types ($\rho_1<\rho_2$) and descending types ($\rho_1>\rho_2$). For example, the ascending type curve is characterized by either top soil or weathered layer followed by hard compact basement which is also known as resistant basement. In the descending type curve, a compact top layer is underlain by a thick clay layer or saline water aquifer and is also called conductive basement.

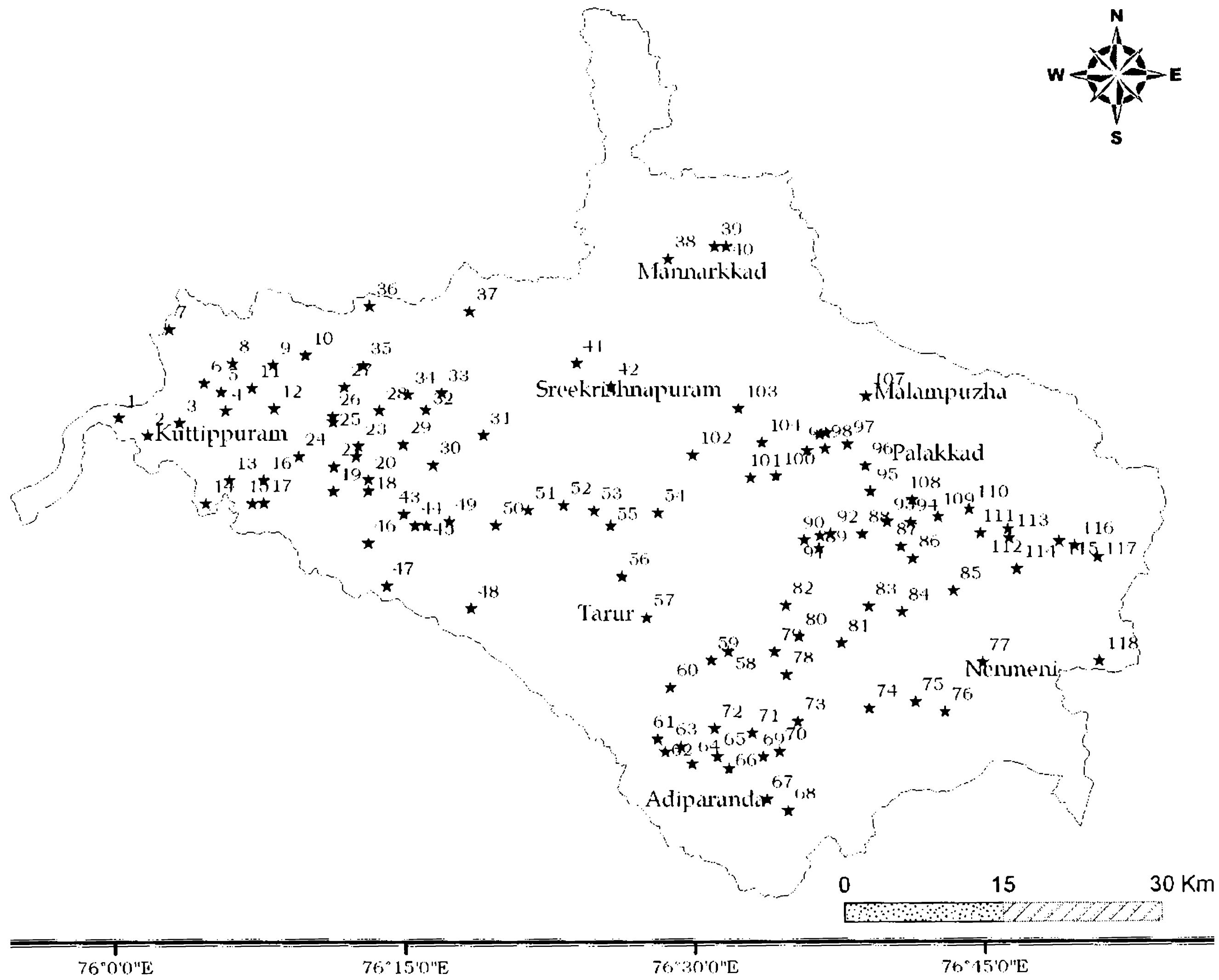


Fig. 3.1 Locations of VES points in the Bharathapuzha river basin

The three layered section with different combinations of resistivity distribution can yield four types of curves

- A type $\rho_1 < \rho_2 < \rho_3$
- Q type $\rho_1 > \rho_2 > \rho_3$
- H type $\rho_1 > \rho_2 < \rho_3$
- K type $\rho_1 < \rho_2 > \rho_3$.

The 'A' type curve is obtained when the resistivity of the layers continuously increase with depth. The field curve with a continuously decreasing resistivity can be called as 'Q' type. 'H' type curves are characterized by first layer of high resistivity followed by a layer of low resistivity and then by a third layers of high resistivity. The Field curves of 'K' type show a maximum peak flanked by a low resistivity values.

Depending on the resistivity distributions, total of 8 filed curves are possible in four layered sequence and are mentioned below

- HA type $(\rho_1 > \rho_2 < \rho_3 < \rho_4)$,
- HK type $(\rho_1 > \rho_2 < \rho_3 > \rho_4)$,
- AA type $(\rho_1 < \rho_2 < \rho_3 < \rho_4)$,
- AK type $(\rho_1 < \rho_2 < \rho_3 > \rho_4)$,
- KH type $(\rho_1 < \rho_2 > \rho_3 < \rho_4)$,
- KQ type $(\rho_1 < \rho_2 > \rho_3 > \rho_4)$
- QH type $(\rho_1 > \rho_2 > \rho_3 < \rho_4)$
- QQ type $(\rho_1 > \rho_2 > \rho_3 > \rho_4)$

Similarly for a five layer case, the possible relationships increase to 16 field curves. For further sequences, the calculation becomes more complicated.

3.5 INTERPRETATION OF VES DATA

The vertical electrical field data are interpreted both qualitatively and quantitatively using simple curve shapes, semi quantitatively with graphical model curves and quantitatively with computer modeling. The field data from shorter separation tend to be more reliable than those with large separation. Various techniques of qualitative and quantitative interpretation are described by Zohdy et al. (1974); Patangay and Murali (1984) and Akos Gyulai and Tamas Ormos (1999).

3.5.1 Qualitative Interpretation

Qualitative interpretation of VES is done by analysing the iso-apparent resistivity maps (Venugopal, 1998; Aravindan, 1999). For example if we are considering the groundwater aspects only, the case of a two layered sub surface condition, the simplest sounding curve are ascending and descending types. An ascending type curve ($\rho_1<\rho_2$) may be characterised by either top soil or weathered layer followed by hard compact basement and is known as resistant basement. In the descending type curve ($\rho_1>\rho_2$), a compact top layer is underlain by a thick clay layer or saline water aquifer and is called conductive basement. ' A' type curve is obtained in typical hard rock terrain having a thin conductive top soil. 'Q' types are usually obtained in coastal areas where saline waters predominate or obtained along shear zones. 'H' type curves are obtained generally in hard rock terrain consisting of dry top soil of high resistivity followed by either a water saturated or weathered layer of low resistivity and then a compact hard rock of very high resistivity. The 'K' types are characteristic of basaltic areas, where compact and massive traps exist between top black cotton soil and bottom vesicular basalt. In coastal areas also these types of curves will be encountered due to the fresh water aquifer occurring in between clayey at the top and a saline zone in the bottom.

3.5.2 Quantitative interpretation

The VES curves are quantitatively interpreted by analytical and empirical methods. The two geological parameters obtained through quantitative methods are resistivity (ρ) and thickness (h) of layer. In the analytical methods, the curve matching technique is adopted. The observed sounding curve (field curve) is prepared to the same modulus as that of a set of theoretical master type curve of apparent resistivity calculated for horizontal, isotropic and homogenous earth layers for various combinations of thickness and resistivity (Orellana and Mooney, 1966; Bhattacharya and Patra, 1968; Zohdy et al. 1974; RijiksWaterstaat, 1975 etc). The field curve and master curve is then matched and the best fit position, the thickness, resistivity of the first layer is read from the master curve. The thickness and the resistivity of the second, third and fourth layer, as the case may be, are determined from the ρ_2/ρ_1, ρ_3/ρ_1, ρ_4/ρ_1 and h2/h1, h3/h1 ratios given on the master curve interpretations are reliable to go away if field conditions do not conform to the assumption that form the basis for the preparation of the master curve. Different layers having different resistivity and thickness may produce same electrical field distribution on the surface. This phenomenon is known as equivalence of layers. For this reason a perfect match of data plots with the same master curve does not necessarily mean that the parameter determined are unique (Karanth, 1995).

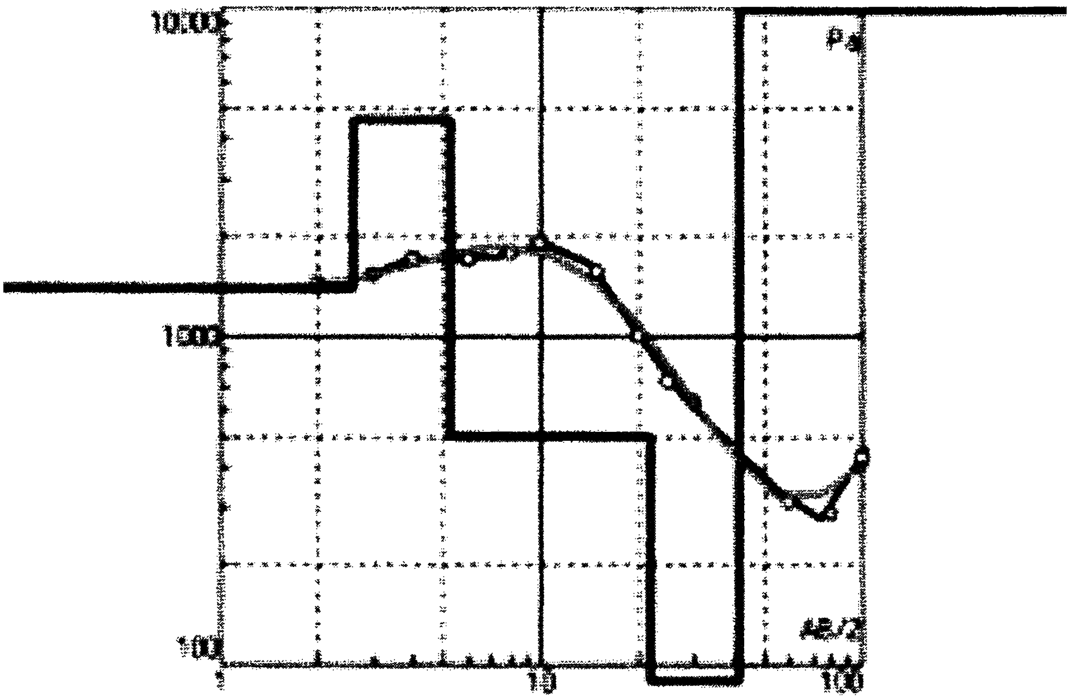
3.6 ANALYSIS OF THE SUB-SURFACE PARAMETER

The secondary data having 118 VES stations of Bharatapuzha River basin based on Schlumberger configuration having a half electrode separation (AB/2) of 150 m, which is obtained from CGWB and Kerala State Ground water board is used to compute different layer thickness and apparent resistivity values (Table 3. 4). Out of 118 VES points, 21 points fall in the five layer curve, 31 curves falls in the four layer curve and remaining in the three layer curve. Among the plotted field curves, 30 H type curves, 19 K type curves, 16 A type curves and 1 Q type curves, 9 HA type curves, 7 KH type curves, 6 KQ type curves, 4 HK type curves, 3 QH type curves, and 2 AK type curves are present. H type curve are common in hard rock terrains which consists of dry top soil of high resistivity as the first layer, a water saturated weathered layer of low resistivity as the second layer and a compact hard rock of high resistivity as the last layer. Q type curve shows salt water intrusions through underground fractures. A few sounding curve of the study area are given in Figures 3.2 (a) & (b).

3.6.1 Resistivity of first and second layers

Resistivity of the first layer varies from 8 Ωm (Alamcode) to 9553 Ωm (Kizhakkethara). The second layer varies from 6Ωm at Pallasana to

(a) Valanchery (Station : 6, curve type : KQH)



(b) Mankara (Station : 54 , curve type : QHA)

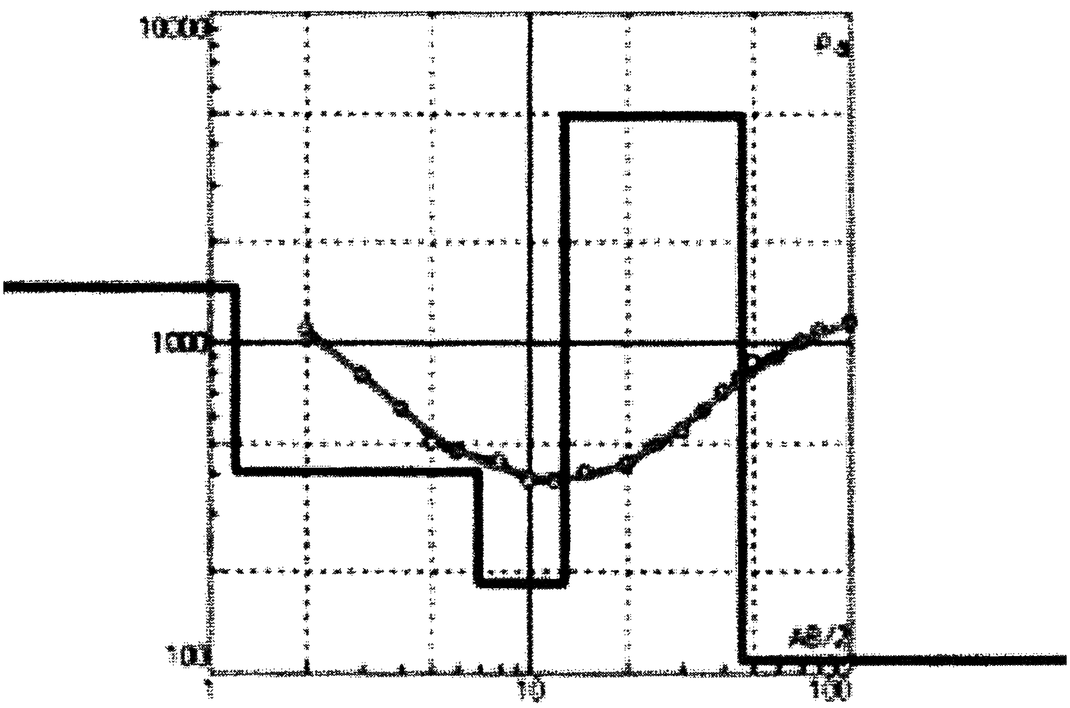


Fig. 3.2 Interpretation of VES data and selected curve pattern of the Bharathapuzha river basin (a) Valanchery and (b) Mankara

37666 at Atticode as shown in the Table 3.4. In majority of the cases, second and third layer is the aquifer except in Q type curve. Figure 3.3 and 3.4 respectively shows the spatial distribution of resistivity of the 1^{st} and 2^{nd} layer of the study area.

3.6.2 Thickness of the first and second layer

The thickness of the first layer varies from 0.34 m (Trithala) and 16.5 m (Irimibilium) and that of second layer varies from 0.25 m (Desamangalam) to 89.8 m (Mundoor), (Table 3.4). The thickness of the first layer (Fig. 3.5), that is the topsoil layer, which has wide application in geoengineering. Majority of the top soil shows 2-4 m thickness. The Palghat Gap region is characterised with the minimum thickness of the second layer which indicates the less water holding capacity and maximum thickness at the centre and western region of the basin - Tarur, Kulakkaloor, Kuzhalmannam, Mundamuga, Kozhikottusseri and Mundoor reflects the presence of thick coastal alluvium. Most of the second layer has a thickness of less than10 m (Fig. 3.6).

3.6.3 Depth to Aquifer Basement

Depth to aquifer basement (Fig 3.7) can help the hydrogeologist to have an idea about the total depth to be drilled. The deepest portions are found around Ongallur, Kalladipetta, Mundoor, Sreekrishnapuram, Pattithara, Kuzhalmannam and Tarur. In most of the areas, depth to aquifer basement is between 20-40 m (Fig. 3.7). The shallow basement is in the Palaghat gap area. Depth to aquifer basement is positively correlated to the thickness of the second layer resistivity i.e. minimum

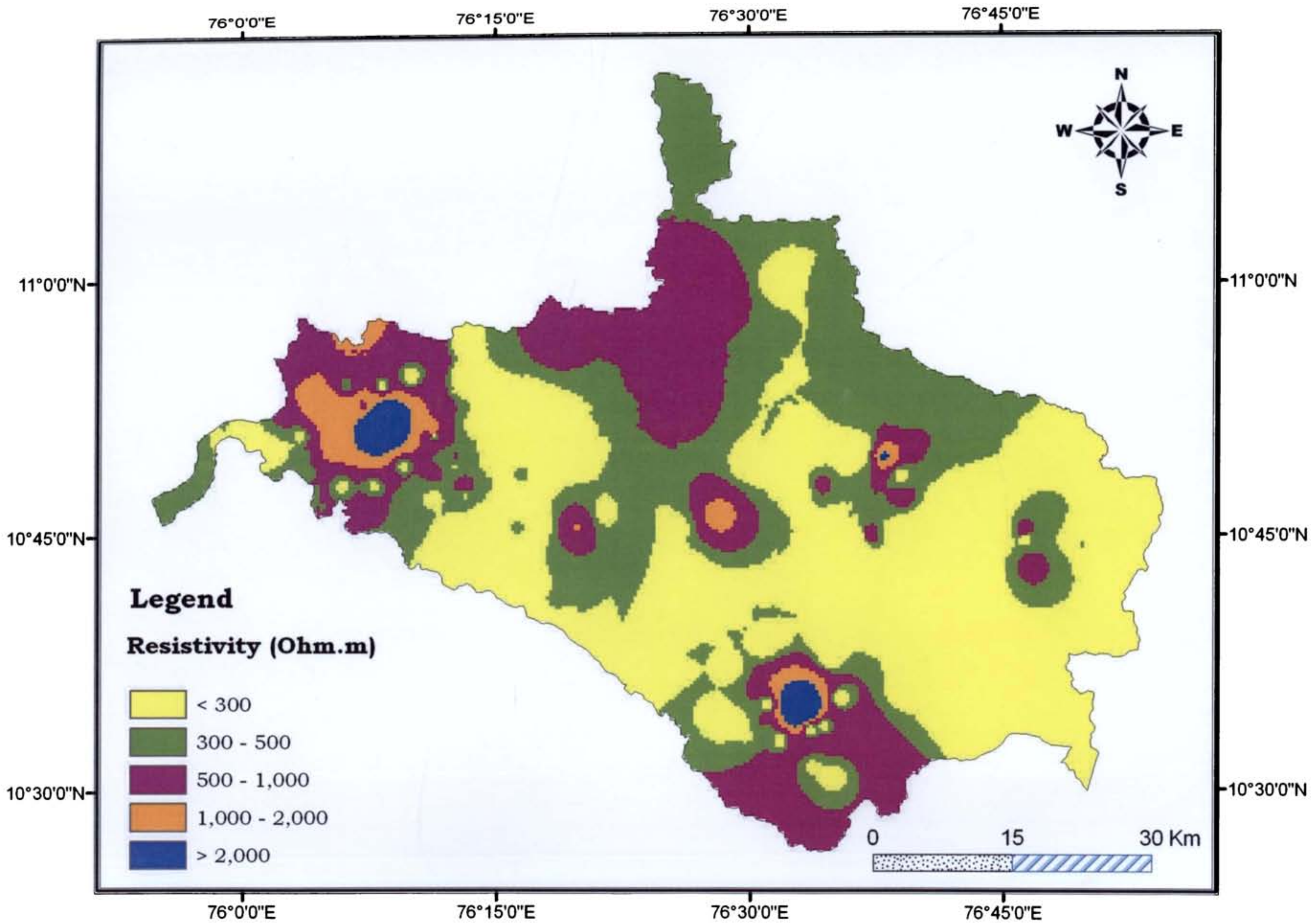


Fig. 3.3 Resistivity of the first layer of the Bharathapuzha river basin

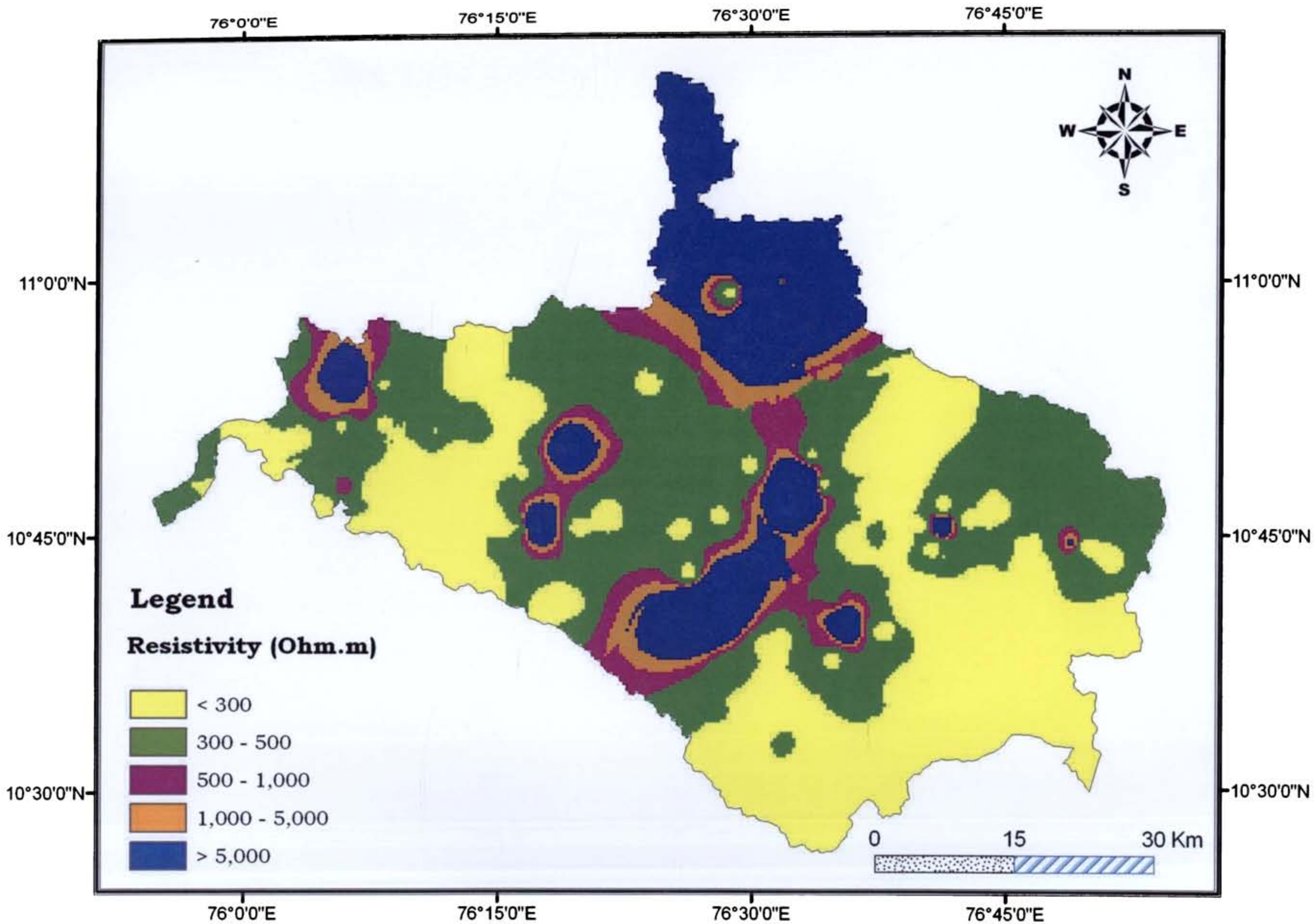


Fig. 3.4 Resistivity of the second layer of the Bharathapuzha river basin

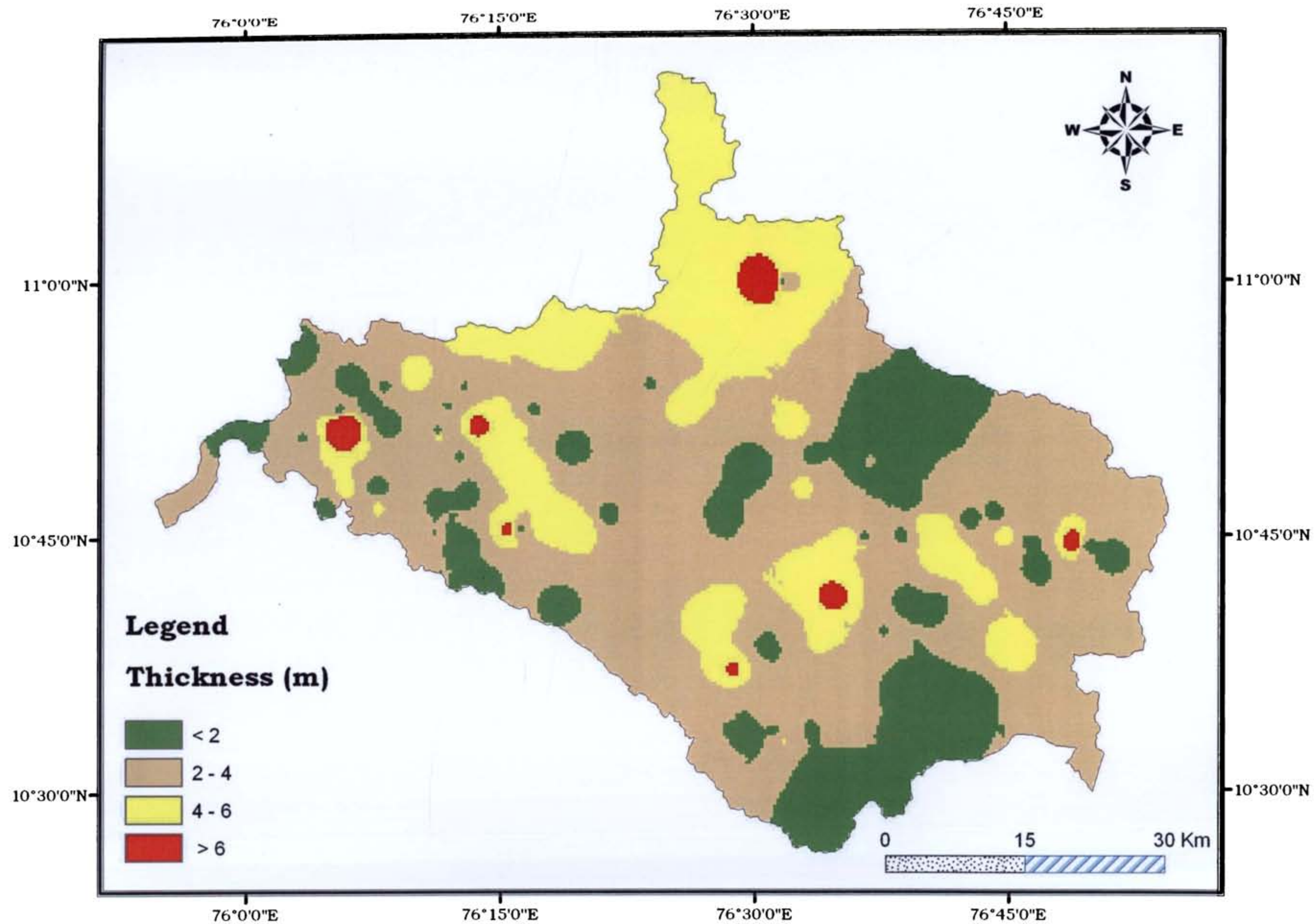


Fig. 3.5 Thickness of the first layer of the Bharathapuzha river basin

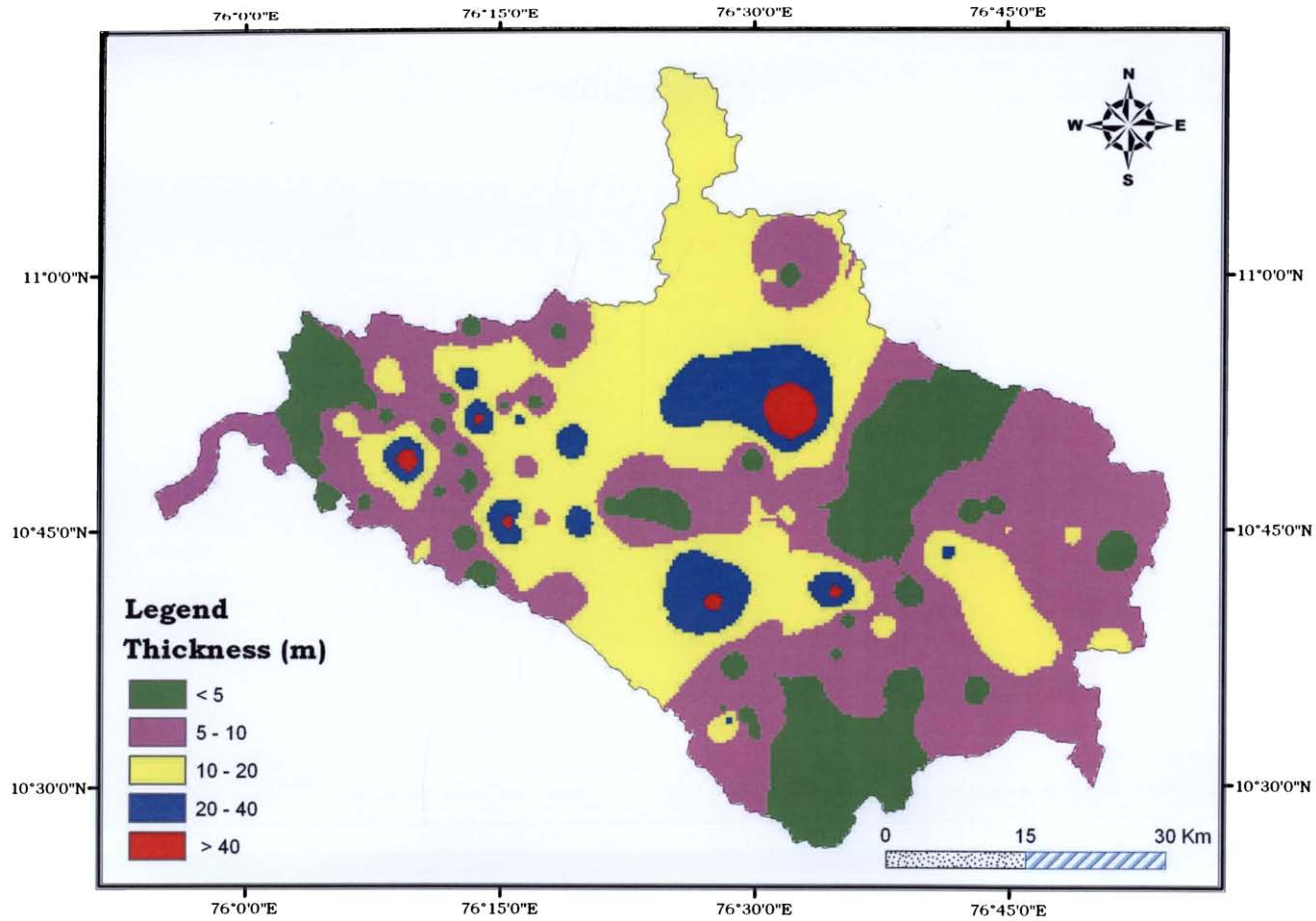


Fig. 3.6 Thickness of the second layer of the Bharathapuzha river basin

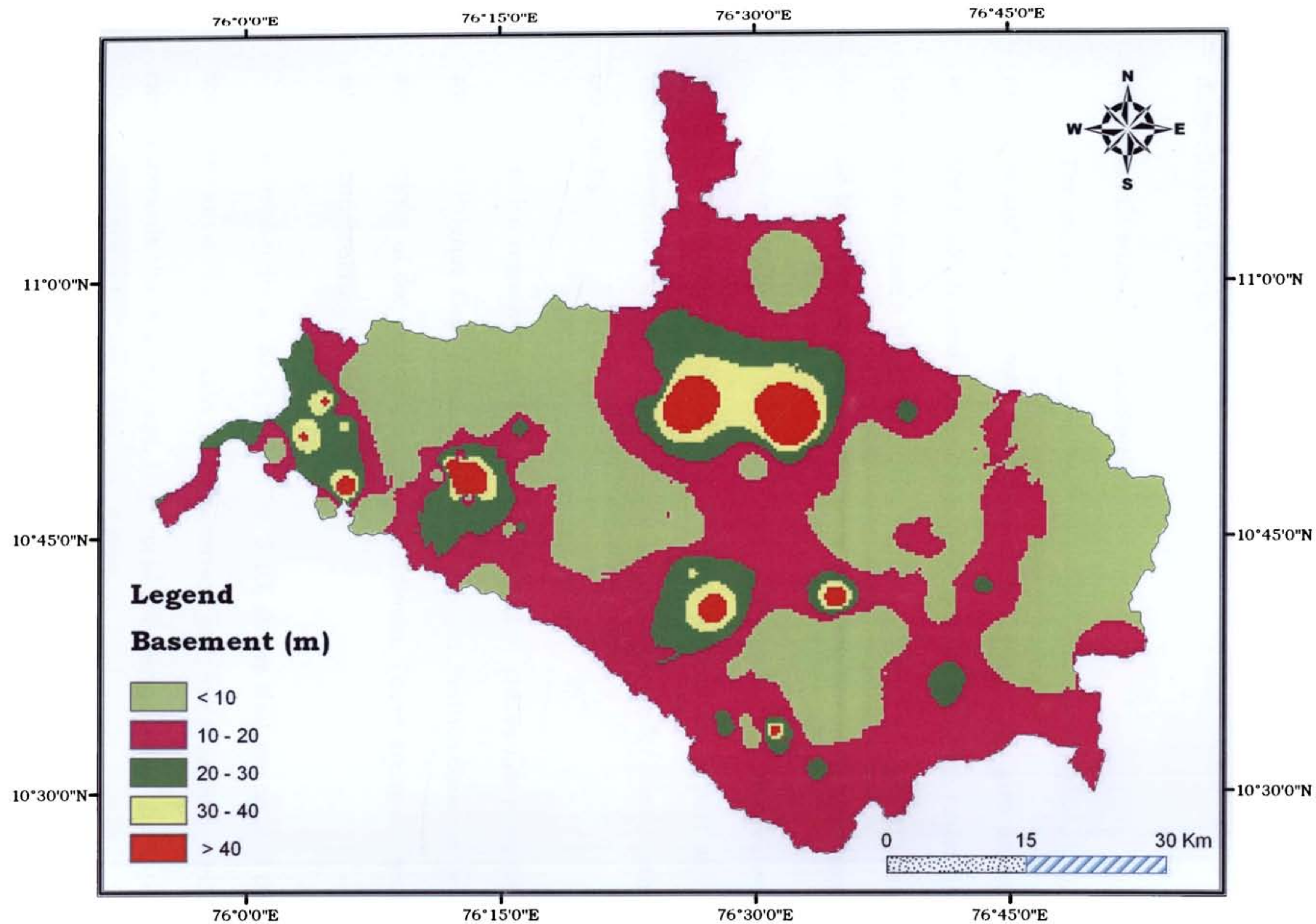


Fig. 3.7 Depth to the aquifer basement of the Bharathapuzha river basin

thickness of the second layer result in the minimum depth to the basement vice versa. From the Figure 3.7, it can be inferred that the regions in and around the central part of the basin is ideal for both dugwells and borewells.

3.6.4 Depth wise Iso-Resistivities

The iso-resistivity maps have been prepared with reference to 5 m, 10 m and 20 m depths (Fig. 3.8, 3.9 & 3.10), which give an idea about the underground structure and vertical changes in resistivity. Here the interpreted (true) resistivity values at 5 m, 10 m and 20 m of each VES location derived through curve matching is considered here.

Iso-resistivity at 5 m depth (Fig. 3.8) shows that low restivity horizons exists at the Palghat Gap area and also at major part of the western region of the basin. So these areas are suitable for constructing open wells.

The iso-resistivity at 10 m depth (Fig. 3.9) shows low resistivity zones at Palghat Gap area, Ghats and around Perinthalmanna and some pockets of the central portion of the basin. These areas are good sites for constructing open wells.

Iso-resistivity at 20 m depth (Fig. 3.10) shows that majority of the southern portion of the basin is characterised with low resistivity which extend towards the western part. High resistivity is noticed at the upper part of the basin. Hence bore wells or open wells in the low resistivity regions of the basin can be productive if it is drilled more than 20 m depth.

At the extreme western part of the river basin, where the river joins with the sea, the resistivity values are high at 5 m depth and it is comparatively low at 10 m depth. There is no further decrease of resistivity values at 20 m depth. Hence it can be concluded that there is no severe salt water intrusion near the river mouth.

The linearity of the contour lines found at some locations may be due to the presence of underground lineaments. They can be underground fractures, joints or faults. In hard rock areas water occupies in secondary pore spaces such as fractures and faults. A comparison of the lineament map (Fig. 5.3) with the maps of iso-resistivity at different depths (Fig. 3.8, 3.9 & 3.10) of the Bharathapuzha river basin shows that many of the underground lineaments recognized through geophysical studies have surface expressions as surface lineaments.

Mapping and analysis of under ground lineaments which indicates faults, fractures etc is crucial before taking up any engineering geological projects like dam, reservoir site selection, road or tunnel alignment, harbour, major industries, major bridge sites etc. These fractures and faults are weak planes permitting large scale migration of groundwater. Hence identification and analysis of underground lineaments are more crucial in hard rock terrains (Rajesh,

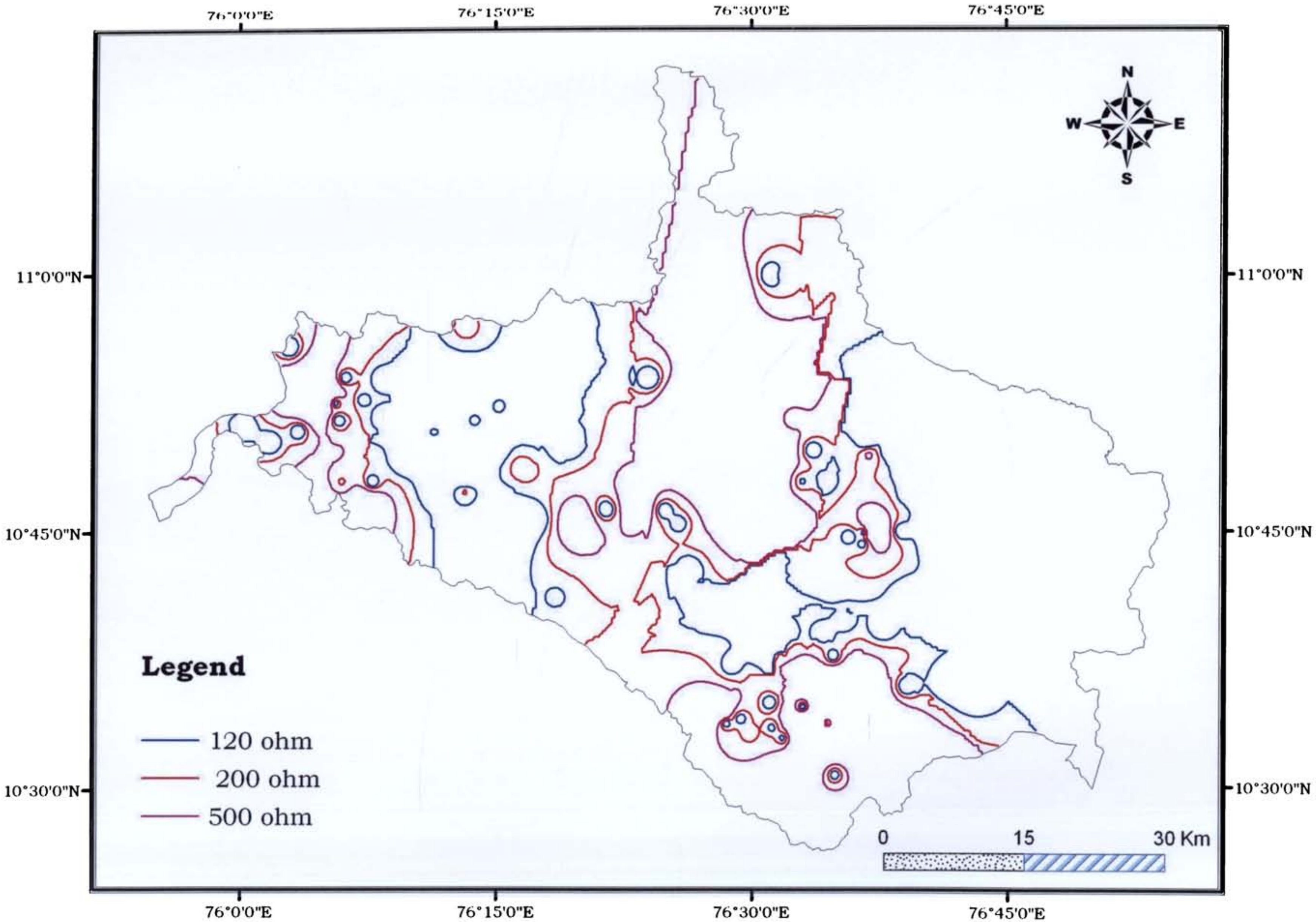


Fig. 3.8 Iso resistivity map at 5m depth of the Bharathapuzha river basin

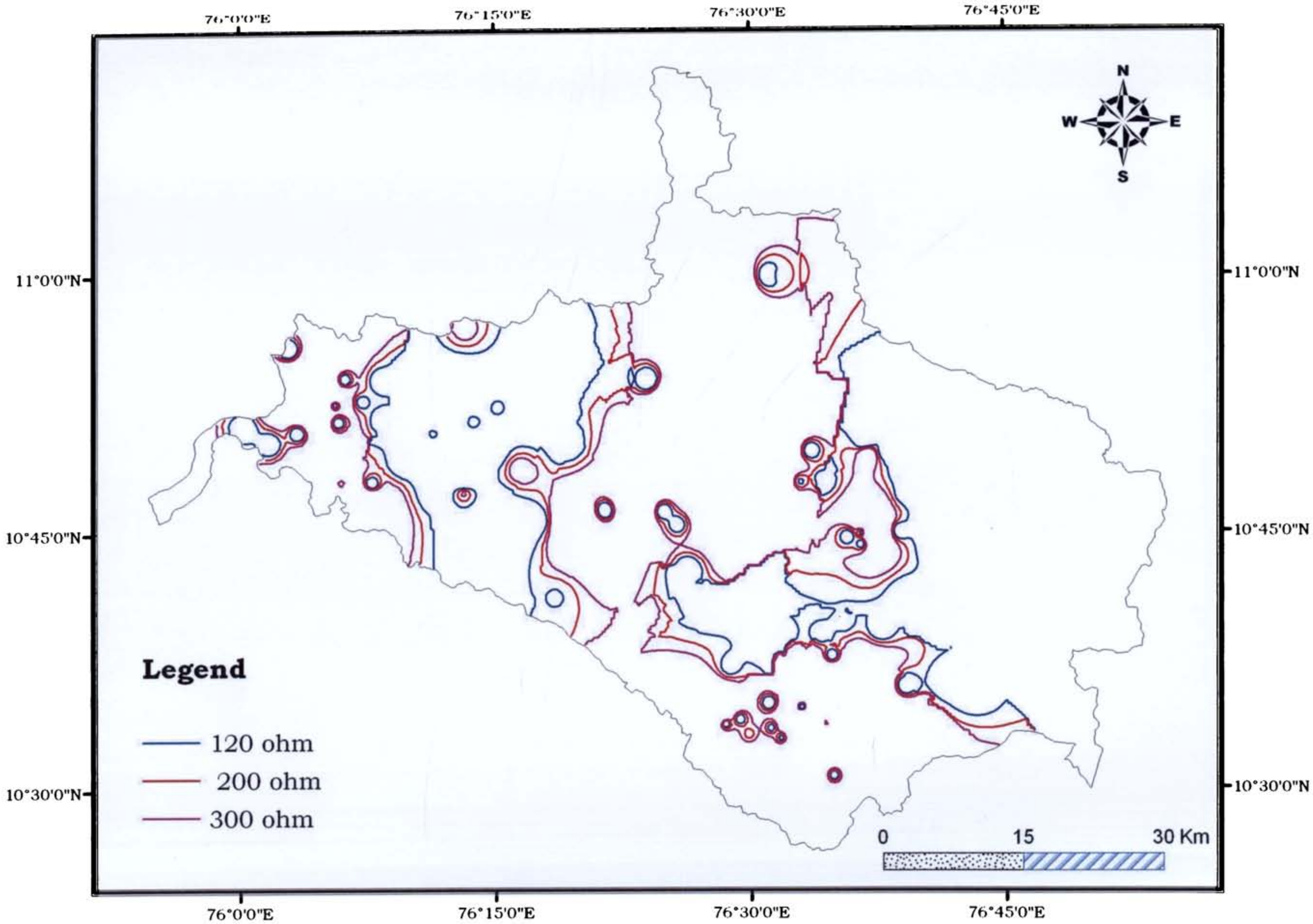


Fig. 3.9 Iso resistivity map at 10m depth of the Bharathapuzha river basin

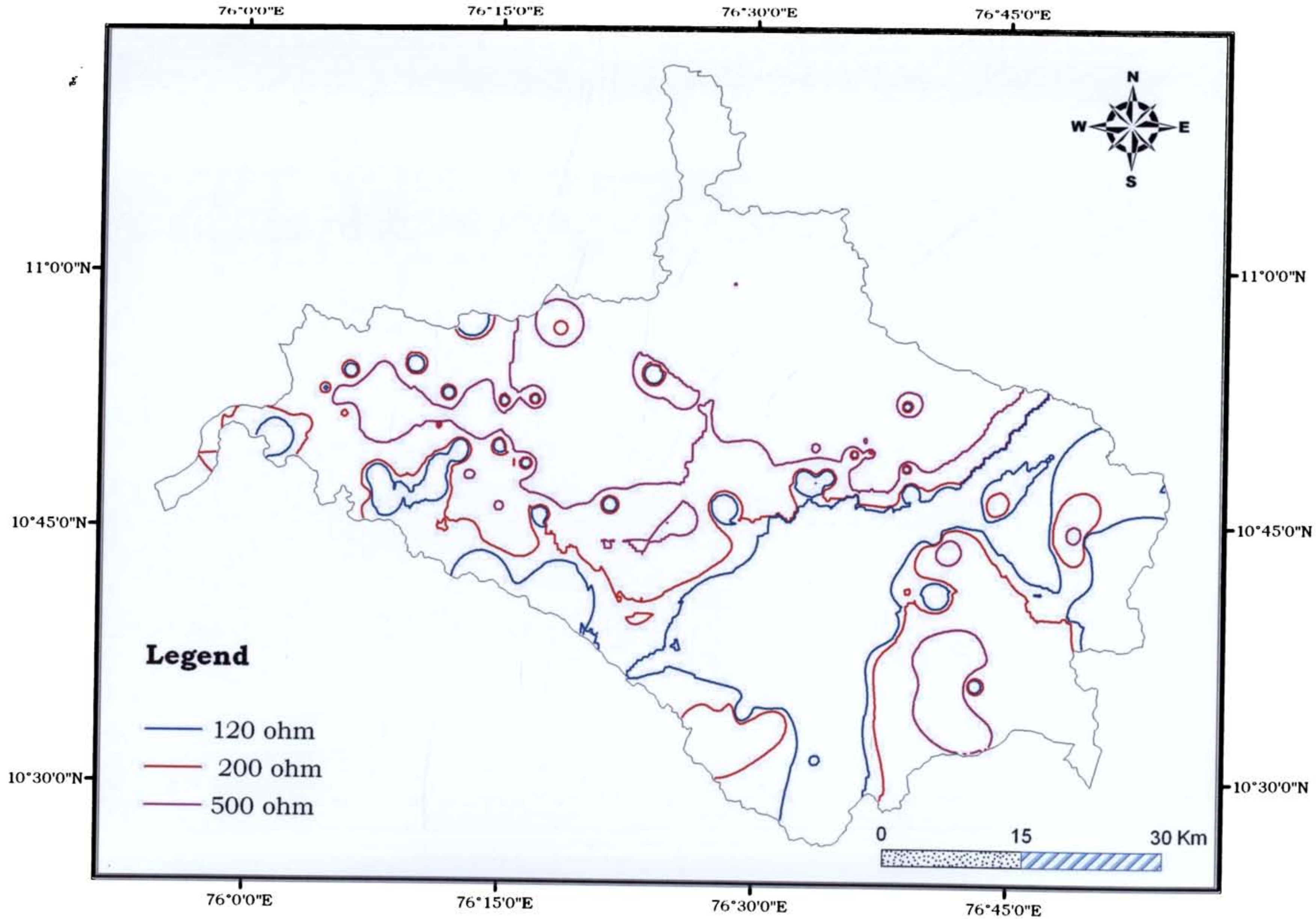


Fig. 3.10 Iso resistivity map at 20m depth of the Bharathapuzha river basin

1999). It will be always advisable to avoid such weaker zones (Ganesh raj, 1994).

A comparison of the thematic maps depicting the spatial variation of transmissivity, optimum yield, Slichter's specific capacity and Limaye's specific capacity (Fig. 2.9, 2.11, 2.12 & 2.13) with the iso-resistivity Figures (Fig. 3.9 & 3.10) at 10m and 20m depth, which reveals higher transmissivity, optimum yield, Slichter's specific capacity and Limaye's specific capacity; reflects the presence of under ground fractures at Ottappalam and Tarur.

3.6.5 Dar Zarrouk parameters

A geoelectric layers are described by two fundamental parameters, its resistivity 'ρ' and its thickness 'h'. The other geoelectical parameters can be derived from these two are:-

a) Longitudinal unit conductance(S)
b) Transverse unit resistance (Tr) and
c) Aquifer anisotropy (λ)

The transverse unit resistance and longitudinal unit conductance are known as Dar-Zarrouk parameters (Millot, 1964) and play a significant role in the interpretation of the sounding data.

3.6.6.a Longitudinal unit conductance

The Longitudinal unit conductance S can be determined by the equation:-

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \dots\dots\dots \dots + \frac{h_n}{\rho_n}$$

Table 3.5 Dar zarrouk parameters and aquifer anisotropy values of the Bharathapuzha river basin

SL NO	LOCATION	Longitudinal Conductance(Ω)	Transverse Resistance(Ωm²)	Aquifer Anisotropy
1	Vellanchery	0.1277	8792.05	1.46
2	Kuttippuram	0.0292	71302.92	1.30
3	Perassanur	0.1439	39409.26	1.81
4	Irumbilium	0.1417	27175.80	1.90
5	Valiyakunnu	0.0131	442286.31	3.02
6	Valanchery	0.2514	25846.10	1.91
7	Vadakkumbram	0.0628	61923.06	1.43
8	Pukkatteri	0.0119	22197.25	1.85
9	Moorkkanad	0.0637	37226.53	1.19
10	Vilayur	0.0910	13667.00	2.69
11	Thiruvegappuram	0.0750	19084.32	1.96
12	Vilattur	0.2356	24121.38	1.58
13	Pattithara	0.2244	34617.28	1.55
14	Challissery	0.0579	35704.13	1.13
15	Nagallassery	0.1105	9088.18	1.19
16	Tritala	0.6104	273.99	1.12
17	Mezhattur	0.0576	3976.41	1.34
18	Malarkkara	0.2872	16595.29	1.07
19	Pattambi	0.6026	5010.43	2.23
20	Kalladipetta	0.1830	57422.14	1.02
21	Netirimangalam	0.0312	5694.42	1.02
22	Ongallur	0.1343	105491.96	1.12
23	purakkad	0.0433	32051.78	2.79
24	Kozhikkottusseri	0.1910	22740.62	1.01
25	Koppam	0.0354	8992.47	2.15
26	Saithalippadi	0.1914	19441.63	1.29
27	Karinganad	0.0979	4366.48	1.76
28	Kulakallur	0.0849	113892.64	1.87
29	Vallapuzha	1.3658	309.73	1.04
30	Koyiliyod	0.0252	5734.47	1.07
31	Chalavara	0.0110	264918.96	2.09
32	Nellaya	0.1901	17734.18	2.21
33	Ezhuvanthala	0.0418	291.26	1.06
34	Kulakallur	0.0461	1565.50	1.07
35	Natyamangalam	0.1271	31401.25	1.19
36	Eravimangalam	0.0705	1539.92	1.20
37	Tazhekkod	0.0990	40055.78	1.63
38	Mannarkkad	0.0356	9800.30	1.08
39	Athikkod	0.0390	458232.94	6.11

40	Kanjirampuzha	0.0433	1678.05	1.21
41	Karimpuzha	0.0229	10306.12	1.01
42	Sreekrishnapuram	0.1187	68790.49	1.36
43	Nedungattur	0.1402	11871.05	1.52
44	Mundamuga	0.6289	13576.85	1.50
45	Shornur	0.0578	12281.80	1.12
46	Desamangalam	0.1565	2217.56	1.03
47	Mullurkkara	8.7011	48.63	2.52
48	Thonnurkkara	0.0629	25117.62	2.39
49	Chuduvalattur	0.0916	92173.96	8.14
50	Vaniyamkulam	0.0991	13737.13	1.13
51	kanniyampuram	0.6273	385.18	1.38
52	Ottapalam	0.2266	21282.60	1.05
53	Palappuram	0.0392	138437.85	2.31
54	Mankara	0.0536	167355.61	2.06
55	Tekkumangalam	0.1453	22422.53	1.67
56	Thiruviluamala	0.1694	5681.22	1.01
57	Tarur	0.1748	1309512.00	9.57
58	Alathur	0.0681	2294.39	1.00
59	Erattukulam	0.2943	142.43	1.05
60	Kannampara	0.1159	2578.19	2.03
61	Vadakkanchery	0.1640	8567.30	1.78
62	Kizhakkanchery	0.0661	10592.25	1.04
63	Melangod	0.1344	564.69	1.55
64	Trippanur	0.2255	12989.40	1.07
65	Elavanpadam	0.2409	13464.69	1.19
66	Vandazhy	0.1238	10858.83	1.84
67	Adiparanda	0.1204	19873.96	2.05
68	Tengumpadam	0.0823	149691.69	7.14
69	Ayilur	0.1577	61.80	1.08
70	Thiruvazhiyad	0.0940	608.87	1.06
71	Kizhakkethara	0.0040	19906.44	2.71
72	Nellikkode	0.1962	677.23	1.15
73	Nenmara	0.0709	22824.18	3.58
74	Elavancheri	0.2311	3897.10	1.56
75	Kollengod	0.1154	48745.60	2.50
76	Nenmeni	0.2956	2013.90	2.03
77	Pattanchery	0.1178	5212.76	1.23
78	Erumayur	0.3885	154.27	1.07
79	Tripallur	0.2094	32810.00	5.35
80	Pannikkod	0.0847	28027.17	7.96
81	Vemballur	0.1544	3678.40	1.79
82	Kuzhalmannam	0.1329	166347.11	2.11
83	Koduvayur	0.1808	2645.65	1.23

84	Pudunagaram	0.1946	350.31	1.30
85	Peruveppu	0.2226	4110.92	1.32
86	Kodumbu	0.4220	24424.76	3.30
87	Alamcode	0.7900	2007.78	2.30
88	Polpully	0.5257	497.72	1.15
89	Perugottukurissi	0.1686	101.19	1.00
90	Tachangod	0.7879	54.82	1.00
91	Kannady	0.4023	355.39	1.51
92	Kadallakkurussi	0.0049	9824.05	1.09
93	Pallasana	1.5016	282.84	1.62
94	Pizhakkad	0.1342	87174.00	8.26
95	Palakkad	0.5815	324.41	2.36
96	Akathethara	0.0342	423.86	1.03
97	Pappadi	0.1925	4453.06	2.95
98	Puthupariyarum	1.1191	3443.25	1.40
99	Puduppariyaram	0.0388	957.26	1.07
100	Arupuzha	0.0456	3614.56	1.16
101	Parali	0.0539	147168.83	8.50
102	Kerallassery	0.0478	33835.93	1.25
103	Mundoor	0.0472	296765.89	1.24
104	Pudanur	0.0472	6863.84	1.06
105	Nochipully	0.1534	648.78	1.82
106	Nochupulli	0.2160	53257.36	5.44
107	Malampuzha	0.5261	1568.19	1.25
108	Marutharoad	0.5168	338.34	1.51
109	Nirvallam	0.1967	690.00	1.34
110	Vengod	0.2492	3920.50	1.57
111	Elapulli	0.5520	16064.23	6.08
112	Kuttiyampal	0.0108	17375.67	1.04
113	Tenari	0.3800	260.01	1.08
114	Nalleppilly	0.2195	530.24	1.69
115	Attikkod	0.0390	2123.82	1.04
116	Kozhinjampara	0.3014	381.05	1.69
117	Kadambazhipuram	0.1600	1630.77	2.32
118	Meenakshipuram	0.0985	3648.20	1.48

h is thickness in meters and ρ is the resistivity in Ωm and i represents the total number of layers.

Variations of S from one VES point to the other have been used in a qualitative sense to indicate changes in the total thickness of low resistivity materials (Zohdy, 1969; Henriet, 1975; Worthington, 1977; Galin, 1979). Large values are indicative of deeper basement and small values are indicative of shallow basement.

In the study area, value of S ranges from 0.0040 mho at Kizhakkethara to 1.5016 mho at Pallasana. (Table 3.5). Majority of the river basin possesses a longitudinal conductance value less than 0.3 mho indicating shallow basement (Fig. 3.11).

3.6.6.b Transverse unit resistance

Total Transverse unit resistance (Tr) can be determined by using the equation:-

$$Tr = \sum_{i=1}^{n} h_i \rho_i = h_1 \rho_1 + h_2 \rho_2 + \dots \dots \dots \; \dots \dots \dots \; h_n \rho_n$$

where h is thickness in meters and ρ is the resistivity in Ωm and i represents the total number of layers.

Transeverse unit resistance values vary from 54.82 Ωm^2 at Thachancode to 1309512 Ωm^2 at Tarur (Table 3.5). In the eastern and western portion the Transeverse unit resistance values are less than 50000 $ohmm^2$ and relatively high values are seen at the mid

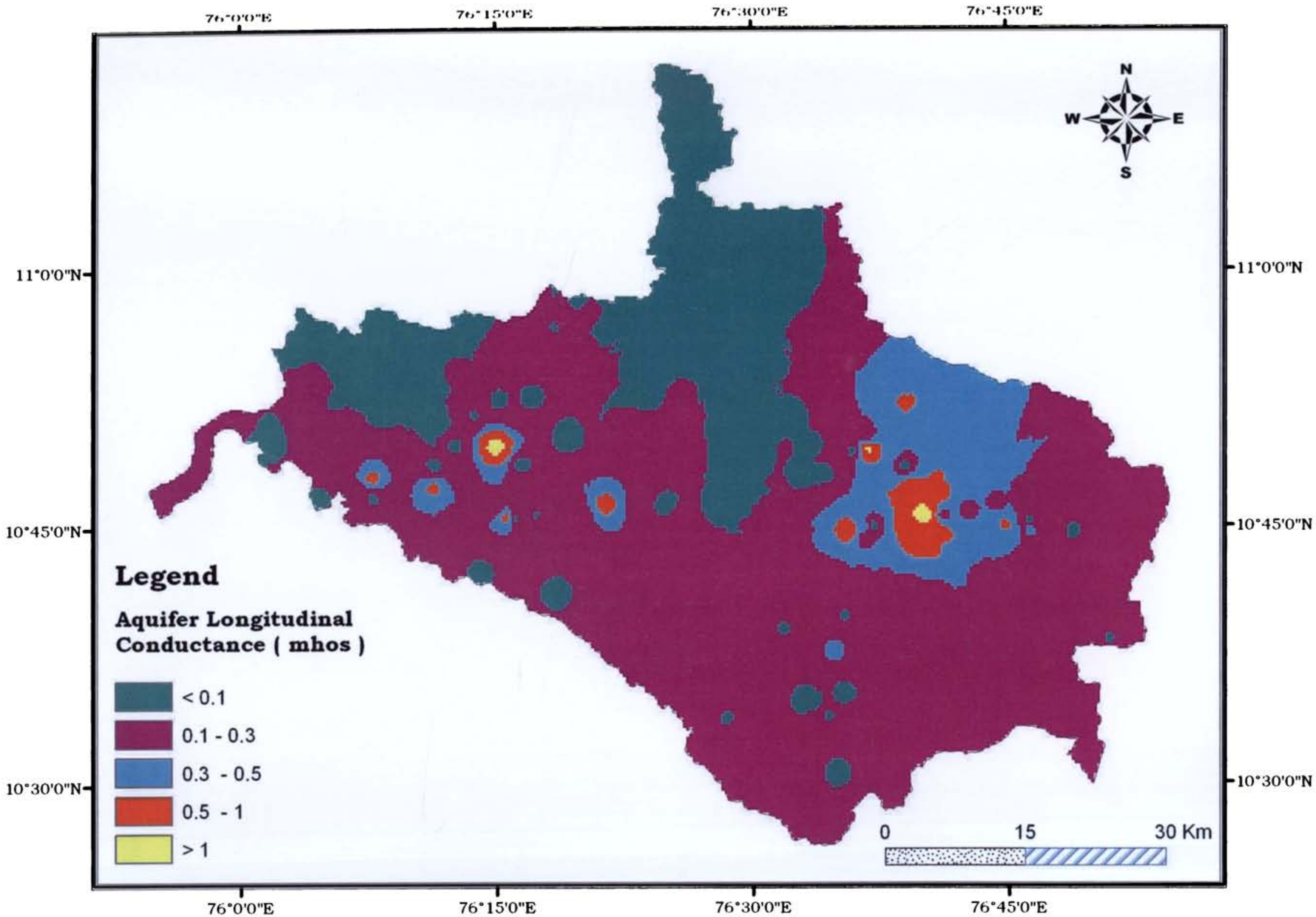


Fig. 3.11 Aquifer longitudinal conductance map of the Bharathapuzha river basin

portion of the basin (above 100000 Ωm^2), (Fig. 3.12). Increasing Tr values indicate high transmissivity of aquifers. Hence the central region along north south direction indicates aquifers of high transmittivity.

3.6.6.c Coefficient of anisotropy

Coefficient of anisotropy (λ) can be computed by using the formula:-

$$\lambda = \sqrt{TrS/H}\,\lambda$$

Where

Tr = Longitudinal unit conductance (mho)

S = Transverse unit resistance (Ωm^2) and

H = Total thickness of the formation

This coefficient is usually greater than 1.00 but does not often exceed 2.00 (Zohdy et al. 1974). As the hardness and compaction of the rock increases, the coefficient of anisotropy also increases (Keller and Frischknecht, 1966) and hence such areas can be associated with low porosity and permeability. It can be used as a measure of finding out the extent of anisotropism prevailing in an area of interest.

The coefficient of anisotropy ranges from 1.00 (Perigottukurissi) to 9.65 (Tarur) with an average of 2.09 (Table 3.5), and it is presented in the distribution map (Fig. 3.13). The area having lowest water table fluctuation is related with low anisotropy values and highest water table fluctuation area is associated with higher anisotropy values (Fig. 3.13 & 2.5). Thus it can be identified that the western part of the basin shows lowest water table fluctuation.

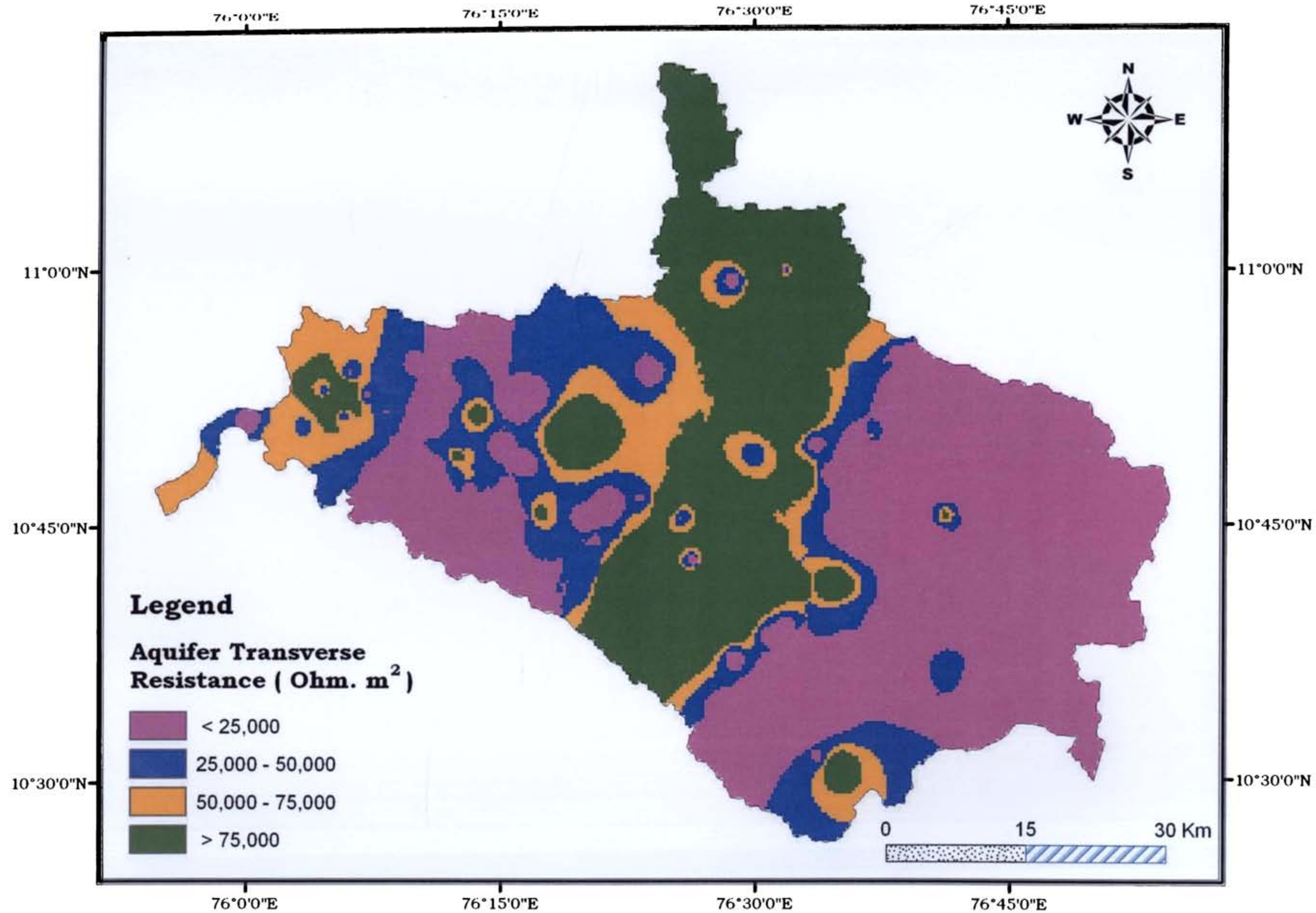


Fig. 3.12 Aquifer transverse resistance map of the Bharathapuzha river basin

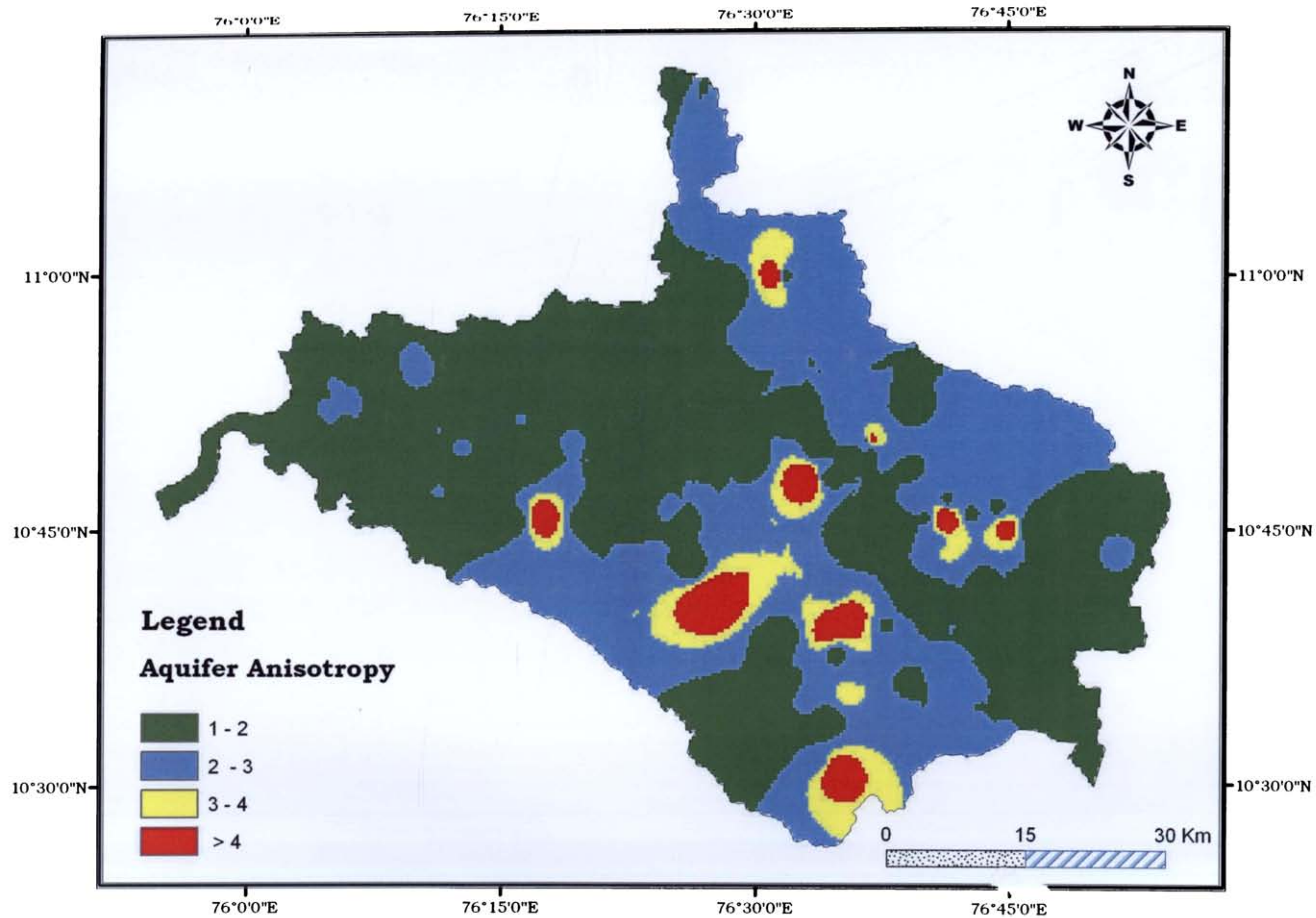


Fig. 3.13 Aquifer anisotropy map of the Bharathapuzha river basin

CHAPTER 4
HYDROGEOCHEMISTRY

4.1. INTRODUCTION

Groundwater is a very important constituent of our ecosystem and plays a significant role in augmenting water supply to meet the ever increasing demand of domestic, agricultural and industrial uses. It is now generally recognised that the quality of groundwater is as important as its quantity. The suitability of natural water for a particular purpose depends upon the standards proposed by the various international bodies such as World Health Organization (WHO), Central Public Health and Environmental Engineering Organisation (CPHEEO), Ministry of Urban Development, Government of India and Bureau of Indian Standard (BIS). The preservation and improvement of groundwater quality is of vital importance for human well being as well as for the sustainability of clean environment. Groundwater gets polluted by several anthropogenic and natural sources such as industrial and domestic waste, artificial recharging by polluted water, pesticides, fertilisers, intrusion of saline water, soluble pollutants such as arsenic, fluoride, etc., present in the rock formations (Raj, 2003).

Taking into consideration of the fact that groundwater occurs in alliance with geological materials, generally high concentration of dissolved constituent are found in groundwater than in surface water because of its greater exposure to soluble minerals of the geological formations. Groundwater passing through igneous rocks dissolves only

Table 4.1 Various Sources of ions in water (Hem, 1959)

Major ions	**Sources**
Calcium Ca_2^+	Carbonates, gypsum
Magnesium Mg^{2+}	Olivine, pyroxene, amphibole
Sodium Na^+	Clays, feldspars, evaporates, industrial waste
Potassium K^+	Feldspar, fertilizers, K-evaporates
Bicarbonate HCO_3^-	Soil and atmospheric CO2, carbonates
Chloride Cl^-	Windborne rain water, sea water and natural brines, evaporates deposits; pollution
Sulphate SO_4^{2-}	Gypsum and anhydrite, sea water, windborne, oxidation of pyrite
Nitrate NO_3^-	windborne, oxidation of ammonia or organic nitrogen, contamination
Silica,SiO_2	Hydrolysis of silicates
Minor ions (1 to 0.1 mg/l)	
Iron, Fe_2^{2-}	Oxides and sulphides, e.g. heamatite and pyrite; corrosion of iron pipes
Manganese Mn_2^{2-}	Oxides and hydroxides
Boron B	Tourmaline, evaporates, sewage, sea water
Fluoride F^-	Fluorine-bearing minerals, viz. fluorite, Biotite
Trace elements (< 0.1 mg/l)	
As	Arsenic minerals, e.g. arsenopyrite, arsenic insecticides
I	Marine vegetation, evaporates
Zn	Sphalerite, industrial waste
Heavy metals (Hg, Pb, Cd, Cr)	Industrial waste and igneous rock weathering, under mild reducing conditions
Radioactive elements (U, Ra, etc.)	Uraniferous minerals, nuclear tests and nuclear power plants.

a small quantity of mineral matter because of the relative insolubility of the rock composition (Todd, 1980).

The characteristics of groundwater as to whether hard or soft (mineralised or non mineralised) depend on the extent of reactions it made with the country rock (Edmunds, 1994). Compared to surface water, the groundwater moves very slowly through the pore spaces found in the surrounding country rocks. Thus it gets more residence time and hence more ions will be dissolved into the groundwater as a result of the interaction between the groundwater and the wall rocks. In contrast to surface water bodies, if groundwater body is polluted once, it will remain as it is for a considerable time (up-to tens of hundreds of years) because the natural processing of flushing is very slow. Hydrochemical data can help to estimate such properties like the amount of recharge, the extent of mixing, the circulation pathways, maximum circulation depth, temperature at depth and residence time of groundwater (Edmunds, 1994).

The quality of groundwater is controlled by several factors, viz., climate, soil characteristics, interaction with the country rocks, saline water intrusion in coastal areas and the human activities on the ground. A source of various ions in water as given by Hem (1959) is furnished in the Table 4.1. The analysis of groundwater for its quality includes the determination of the cations like Na, K, Ca, Mg and Fe anions CO_3, HCO_3, Cl, SO_4, NO_3 and PO_4, trace elements, pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS) etc. An attempt has been made in this chapter to understand the quality of groundwater for the domestic and irrigation purpose.

4.2 GROUNDWATER SAMPLE COLLECTION

Groundwater samples have been collected from 81 dug wells in the Bharathapuzha river basin during pre monsoon and post monsoon (Fig. 4.1). Groundwater samples were collected in pre cleaned plastic polyethylene bottles. Prior to sample collection, the plastic bottles were rinsed two to three times with the respective groundwater sample. The parameters like pH, EC and TDS were measured in the field itself. For fixing total iron, samples were preserved in the field by adding concentrated HCl (2ml/100ml) as a preservative agent and transported to the laboratory for the analysis.Cations and anions were determined following the standard procedures recommended by American Public Health Association (APHA, 1985), standard methods for examination of water and waste water (Table 4.2)

4.3 LABORATORY WORK

4.3.1 Physical parameters

The non ionic substances like pH, TDS & EC present in groundwater affect the general quality of water and are discussed below.

pH

pH is a measure of hydrogen ion concentration and determines the acidity or alkalinity of water sample. The desirable range of pH of water

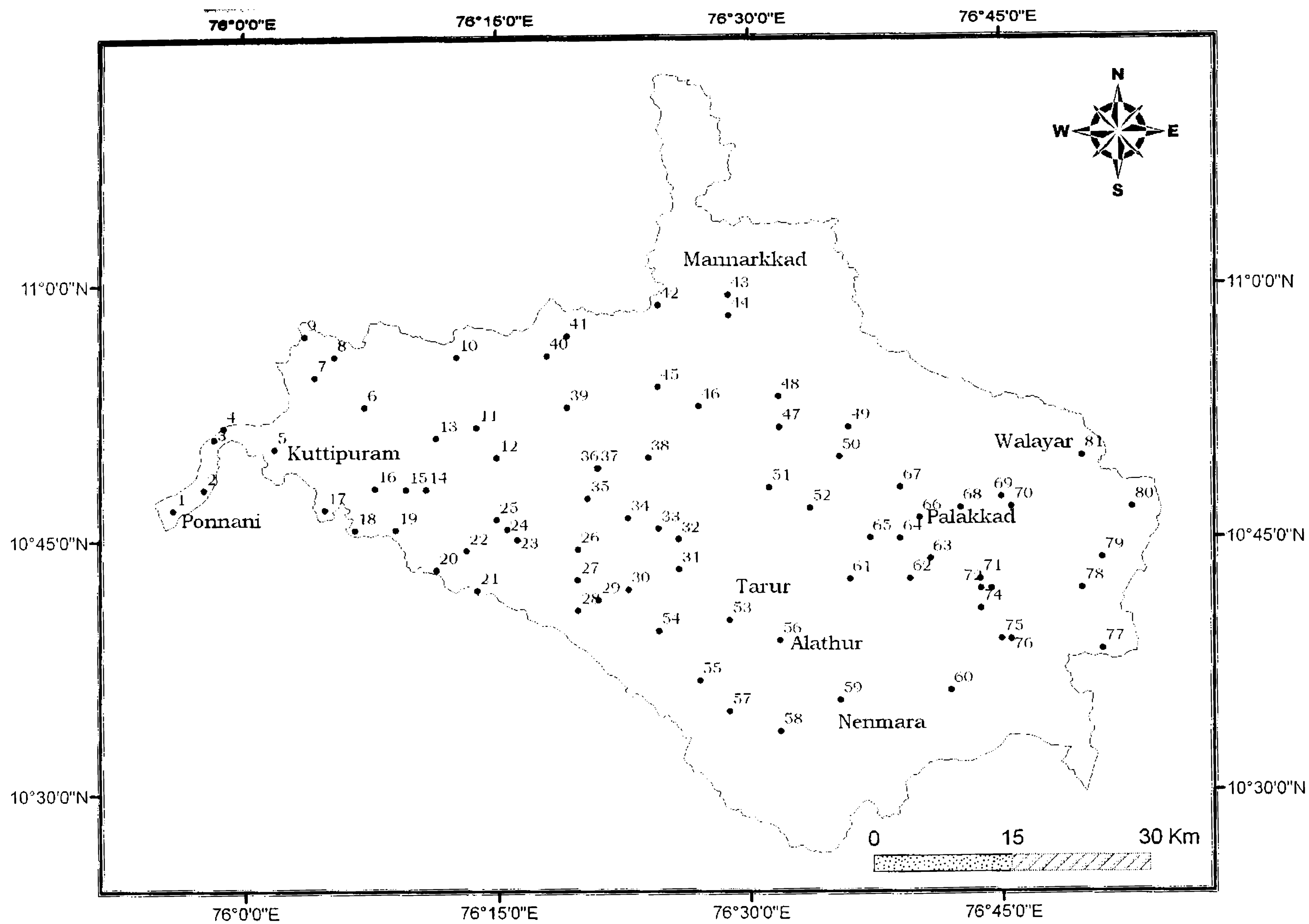


Fig. 4.1 Location of open wells for the groundwater sampling

Table 4. 2 Methods followed for the determination of various physical and chemical parameters of groundwater

S.No.	Constituents	Equipments and methods used
1	pH (Hydrogen ion concentration)	PH meter, pH Scan 1
2	Electrical Conductivity (EC)	Conductivity meter CM 183
3	Calcium	EDTA
4	Magnesium	EDTA
5	Sodium & Potassium	Flame photometer
6	Chloride	Argentometry
7	Sulphate & Nitrate	Spectro photometer
8	Carbonate & Bicarbonate	Acidimetry
9	Fluoride	SPADNS
10	Total Dissolved Solids (TDS)	TDS meter CM 183
11	Alkalinity	Volumetric method
12	Hardness	ETDA
13	Total Iron	Spectrophotometer

prescribed for drinking purpose by BIS and WHO (1984) is 6.5 to 8.5. The pH of natural waters is slightly acidic (5.0 - 7.5) and is caused by the dissolved carbon dioxide and organic acids (fulvic and humic acids), which are derived from the decay and subsequent leaching of plant materials (Langmuir, 1997). The water with pH value above 10.0 is exceptional and may reflect contamination by strong bases such as NaOH and CaOH.

Table 4.3a Chemical analysis of groundwater of the Bharathapuzha river basin (Pre monsoon)

Sl No	Location	pH	E.C µs/cm	TH	ppm concentration (mg/l)												
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F	T.Fe	TDS	Alkalinity
1	Ponnani	8.5	420	170	52	10.5	16	9	16	71	46	42	38.50	0.00	0.18	256	148
2	Iswaramangalam	9	490	83	10	15	69	2.3	20	90	78	36.3	3.50	0.19	0.20	305	956
3	Tavanur	7.9	125	22	16	7	10.5	3	0	36	21	23	15.20	0.19	0.20	85	174
4	Thirunavaya	7.3	99	25	5	13	19.5	3.4	0	85	20	5.3	10.12	0.20	0.20	59	24
5	Kuttipuram	9	128	96	21	16	40	8	32	28	53	25	39.00	0.26	0.13	81	129
6	Thiruvegappuram	7.85	213	207	61	28	15	12.7	18.6	132	88	17.5	22.90	0.36	0.08	136	119
7	Valancheri	6.7	462	45	15	10	25	8.2	4	96	30	8.1	3.00	0.51	0.26	298	152
8	Edayur	7.5	482	48	15.3	10.24	9.1	8.2	4	65	23	8.94	3.09	0.51	0.26	300	160
9	Karakkod	7.09	86	10	12	15	16	3	0	97	18	8.60	10.00	0.25	0.08	60	448
10	Cherupplassery	8.2	162	52	33	15	16.5	8	0	152	32	6.2	9.20	0.21	0.12	103	42
11	Kulakallur	8.5	470	58	44	38	17	1	0	165	89	15	9.30	0.20	0.13	302	46
12	Vallapuzha	8.50	250	97	18	16	13	5	9	126	22	6	0.10	0.30	0.30	150	119
13	Koppam	7.20	160	300	36	24	52	6.5	4	145	120	12	5.20	0.40	0.03	101	102
14	Pattambi	8.20	300	76	10.5	13	12.3	3.1	0	54	33	12.30	2.00	0.19	0.80	183	42
15	Nethirimangalam	8.60	590	210	44	24.4	43.5	4.1	0	209.3	46	45.7	7.20	0.249	0.00	354	171
16	Trithala	7.60	383	117	15	13	14	3	2	75	28	10.80	11.00	0.09	0.02	226	27
17	Kunanallur	7.64	352	35	16.3	7.5	27.5	6.5	6	85	35	8.9	4.31	0.31	0.19	210	164
18	Kootanand	8.4	260	40	16	6.3	27.8	2.8	6	102	25	6	5.70	1.00	0.95	156	85

19	Nagalaseery	7.7	150	54	14	5.9	12.1	2.7	0	48	27	5.1	2.50	0.67	0.10	95	31
20	Pilakkad	7.8	915	39	44	37	51	40.6	14	162	152	26.4	3.10	0.04	0.20	605	182
21	Mullurkara	6.3	278	61	21	14	12.5	4.8	20	58	42	8.6	5.00	0.08	0.25	163	138
22	Desamangalam	6.84	428	24	18.5	14.8	40	6.4	34	90	28	15.6	0.00	0.04	0.10	272	127
23	Cheruthuruthi	8.2	247	132	22	18	26	0.6	3	132	38	25	4.50	0.53	0.22	158	236
24	Kulapully	8.5	240	105	14	17	13.9	4	12	80	30	8.3	0.08	0.80	2.42	144	80
25	Shornur	8.30	408	45	29	8	30	15	11	103	43.8	23.00	2.30	0.04	2.30	244	104
26	Thozhupadam	7.2	103	30	29	14	8.5	3.5	3	102	20	21.4	10.30	0.08	0.12	61	180
27	Killimangalam	6.68	628	122	61	25	22	6.8	21	135	76	28	4.31	0.62	0.12	390	144
28	Thonurkara	6.11	134	107	68	15.7	14.6	5.2	21	132	61	16.5	9.00	0.07	0.09	95	234
29	Chelakara	6.9	610	53	55	24.6	25	16	25	131	88	25.1	8.00	0.12	0.20	364	143
30	Chelakara	6.58	615	180	53	26	22	15	5	148	92	26.00	8.00	0.05	0.05	356	176
31	Thiruviluamala	8.5	560	140	61	2	55	6.1	32	145	53	14.3	13.2	0.9	0.2	330	170
32	Lakkidi	8.90	610	255.00	65	36	30.5	7.6	30	239	59	20.00	11.60	0.61	1.28	366	224
33	Palappuram	7.6	680	210	33	32	56	20	0	126	95	28	110.00	0.24	0.11	384	142
34	Ottappalam	8.2	190	55	18	2.4	16.2	6.1	0	64	21	7.1	3.34	0.73	2.46	114	45
35	Vaniyamkulam	8.25	353	109.50	32.25	7.40	17.15	8.25	3.00	85.00	43.00	12.00	2.75	0.70	1.48	211	73
36	Kadakkurrissi	8.40	415	108	30	8.9	23	15.8	11.9	106	45	23.20	2.60	0.00	0.08	247	106
37	karakurussi	8.4	200	75	24	3.8	16.4	6	6	87	14	5.6	10.05	0.60	1.2	131	70
38	Ambalapara	8.3	420	170	33	21	18	7	29	112	35	11	3.80	0.30	0.30	252	209
39	Cherukara	7.8	148	38	36	6.4	8.5	5.7	4	75	48	4.2	4.95	0.18	0.11	100	168
40	Thazekkod	7.5	100	20	19	3.3	9	2	0	40	20	12	6.30	0.00	0.08	70	172

41	Thachanattukara	6.65	227	42	16.8	8	24.3	3.5	6	95	17	6.1	11.75	0.09	0.11	140	168
42	Kumarampattur	8.6	220	80	27	3.6	71.9	7.5	6	120	79	9	9.40	1.00	0.15	132	60
43	Mannarkad	8.2	401	85	28	3.7	17.9	7.6	6	86	22	5.5	10.30	0.80	0.16	239	65
44	Kottiyode	8.3	200	65	26	3.8	16.2	4.5	0	69	32	12.4	1.48	0.66	0.04	120	50
45	Sreekrishnapuram	8.10	119	42	8.6	4.6	9.8	4.1	2.4	61	5.9	5.60	4.00	0.08	0.60	72	52
46	Kadambazhipuram	8.33	22C	74.5	24.7	2.9	15.6	3.5	5.7	87	17	4.25	4.35	0.11	0.30	132	79
47	Kongad	8.3	200	65	25	2	16.5	4.7	6	61	31	2.4	5.50	0.55	0.05	119	50
48	kalladikode	7.8	392	46	10	8.5	6	2.7	0	35	31	3	3.04	0.76	0.08	226	20
49	Chulanur	6.73	189	37	25	20	13.5	4.8	12	81	62	18.9	0.03	0.67	0.20	135	128
50	Nochipulli	8.30	240	70	14	8.5	20.1	4	0	89	27	1.03	6.30	0.585	0.03	144	72
51	Tenur	8.40	340	73	21.3	4.7	23	18.8	4.8	86.3	30	22.3	3.16	0.04	2.10	230	78
52	Parali	8.3	365	134	39.5	8.4	27.1	12.1	11	109	43	24.3	5.40	0.91	0.10	220	94
53	Tarur	8.60	310	102	29	22	18	6	9.2	186	34	6	0.10	0.25	0.45	182	142
54	Pazhayannur	6.37	317	32	9.82	19.5	18.4	6.8	12	85	35	20.5	0.00	0.09	0.14	215	153
55	Kannapara	8.9	450	265	57	29	95	50	42	153	174	58	7.00	0.80	0.07	276	195
56	Alathur	8.8	570	230	35	23	25	3.1	24	110	53	17	13.00	0.90	0.00	342	135
57	Vadakancheri	8.3	632	174	39.5	17.9	40.2	5.5	5	98	92	24.6	7.90	0.84	0.05	389	71
58	Vandazhi	8.7	480	39	25	12	26	2.1	6	91	55	6	7.10	1.10	0.85	278	84
59	Nemmara	8.6	520	240	41	, 30	23	12	12	185	59	14	1.66	1.00	0.08	312	150
60	Nenmeni	8.80	640	265	58	19.3	36	5.6	7.1	236.4	55	13	2.36	0.895	0.00	384	203
61	Kuzhalmannam	8.60	620	280	65	31	23	6	28	261	44	47	0.10	1.20	1.24	389	262
62	Kinnassery	6.63	649	11.1	32	32	64	2.8	0	198	99	20	4.00	0.15	0.09	400	94

63	Thiruvalathur	7.81	220	248.00	30	17	18	2.5	4	120	37	8.50	9.66	0.01	0.74	132	77
64	kodumbu	6.23	682	245	42	30	54	1.8	0	159	115	27	2.00	0.04	0.09	455	118
65	Kannady	8.2	1040	418	73.8	54.6	104.7	3.6	0	293	260	11	0.60	1.10	0.15	605	110
66	Palakkad	9.1	557	179	32.6	27.6	44.5	3.9	23	160	69	7.5	8.20	0.81	2.57	325	32
67	Olavakkod	8.70	364	123.50	21.13	19.15	28.25	3.55	14.50	115.00	42.00	6.85	4.43	0.41	0.23	216	39
68	Marutharoad	8.60	630	215	42	26	33	5	10.8	121	97	13	6.00	0.88	2.59	386	117
69	Kanjikode	8.3	1435	432	37	98	145	13	60	248	262	63	104.00	0.63	0.10	802	210
70	Nallepilly	8.70	681	173	32	23	37	1.5	18	162.5	37	19.5	3.10	0.93	0.05	436	163
71	Palathully	6.9	810	348	77	24.5	58	56	16	248	136	29	8.00	0.26	0.09	456	304
72	Chittur	8.7	886	320	76	25	78	51.6	59	239	92	53	8.12	0.82	0.05	556	260
73	Chittur	8.8	950	325	72	35.4	80.6	12	60	229	99	49.1	8.18	0.84	0.01	570	265
74	Thathamangalam	8.8	670	290	40	42	42	8.8	36	161	89	38.2	5.20	0.85	2.21	450	180
75	Vandithavalam	8.50	330	90	36	12	10.6	1.4	12	98	29	9.4	1.50	0.60	0.24	198	100
76	Perumatti	8.50	338	95	39	14	11	1.8	13	99	40	10	1.80	0.60	0.24	201	102
77	Meenakhipuram	8.1	1216	468	135	31.3	132	10.1	0	351	183	87	101.00	0.51	0.05	803	201
78	Nattukal	8.9	560	205	54	17.1	50.4	6.7	36	161	61	19.2	2.10	1.00	0.07	336	185
79	Kozhinjampara	8.6	850	160	64	24	78.6	3.8	18	55	227	29.4	8.60	0.85	2.70	530	100
80	Ozhalapathy	8.5	856	570	48	35.6	12	2.6	16	182	64	4.7	9.93	0.06	0.11	580	90
81	Walayar	8.3	610	412	77	46	60	4.9	16.2	238	140	51.3	7.20	1.20	0.17	401	215

Table 4.3b Chemical analysis of groundwater of the Bharathapuzha river basin (Post monsoon)

Sl No	Location	pH	E.C µs/cm	TH	ppm concentration (mg/l)												
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F	T.Fe	TDS	Alkalinity
1	Ponnani	6.03	395	114	22	9	35	1.7	15	75	27	38.00	3.00	0.38	0.05	227	192.00
2	Iswaramangalam	6.89	265	88	22	8.8	37	1.6	18	94	29	38.00	2.80	0.17	0.08	155	988.00
3	Tavanur	7.56	120	20	27	12	25	2	15	92	27	32.00	3.00	0.18	0.08	80	226.00
4	Thirunavaya	7.30	98	24	26	14	18	3.3	12	94	26	31.00	8.00	0.29	0.11	57	23.00
5	Kuttipuram	7.30	78	40	13	3	36	4.5	32	23.5	17	5.90	38.00	0.14	0.23	54	230.00
6	Thiruvegappuram	7.50	124	175	49	26	41	10.5	18	130	75	41	36.00	0.27	0.13	87	167.00
7	Valancheri	6.5	452	43	36	14.1	43	8.1	3.5	81	98	23	8	0.5	0.8	265	149
8	Edayur	6.94	470	37	12	14	70.1	7	3	120	82	8.63	2.24	0.25	0.00	282	242.50
9	Karakkod	6.9	76	57	16	16.4	17.4	3.5	0	70	55	8.7	11.28	0.5	0.20	50	456
10	Cherupplassery	7.40	150	95	18	12.2	25.7	24	0	77	69	4	8.58	0.045	0.70	96	11.40
11	Kulakallur	7.30	480	90	19	12.6	8.6	24	0	45	68	0.49	8.40	0.05	0.84	290	11.00
12	Vallapuzha	8.60	300	115	26	12	18	5	4.3	112	32	8.7	0.10	0.71	0.30	180	99.80
13	Koppam	7.70	170	310	36	24	52	6.5	4	145	120	12	5.20	0.40	0.03	96	104.00
14	Pattambi	7.9	270	93	23	8.4	21.5	6.1	0	82	39	10.2	7.20	0.73	0.90	166	41
15	Nethirimangalam	8.2	640	180	38	12	60	4	11	140	58	53	8.50	1	0.10	380	102
16	Trithala	7.0	341	138	33	26	18.4	2.5	4	81	100	11.3	16.59	0.13	0.12	211	116
17	Kunanallur	7.45	310	29	23	11	26.5	6	6	89	43.7	8.60	3.60	0.21	1.51	186	67.20
18	Kootanand	8.10	130	40	6	6.1	17	1.8	0	52	16	4.1	5.40	0.032	0.02	78	26.60

19	**Nagalaseery**	7.50	138	29	7.8	2.4	19.2	2	0	31.4	25	5	4.42	0.36	0.00	84	17.10
20	Pilakkad	7.63	920	27	42.7	36.7	40	30	8	149	137	32.00	8.00	0.03	0.27	552	250.00
21	Mullurkara	6.05	270	49	18	12.2	11.7	3.8	19	74	19	8.70	0.30	0.04	0.00	162	95.90
22	Desamangalam	6.44	420	11	17.5	13	49.7	5	30	82	47.5	14.50	0.00	0.01	2.47	252	160.00
23	Cheruthuruthi	7.30	178	125	20	16	26	0.8	3.2	126	37	23.00	4.50	0.12	0.09	80	232.00
24	Kulapully	8.60	280	131	19.4	20.1	13.7	4.2	7.1	113	28	8.6	0.34	0.53	0.15	168	102.60
25	Shornur	8.2	366	163	45.9	12.2	18.4	10.1	6	96	72	13.9	2.10	0.61	2.56	215	102
26	Thozhupadam	6.50	53	16	32	29	20	19	2	103	98	20.10	12.10	0.04	0.08	35	212.00
27	Killimangalam	6.39	620	108	32	20	22	2.7	21	94	43.7	22.90	4.00	0.00	1.24	372	262.00
28	Thonurkara	6.29	124	30	30	18	21	2	20	99	35	16.25	5.00	0.01	0.06	90	214.00
29	Chelakara	6.34	510	126	22	18	21	1.7	19	90	37	10.90	0.00	0.09	0.06	301	196.00
30	Chelakara	6.58	500	130	25	22	26	2.7	20	92	75	11.50	0.00	0.05	0.05	280	180.00
31	Thiruviluamala	8.1	540	140	62	2	54	6.2	33	148	53	13	13.10	1	0.20	320	171
32	Lakkidi	8.7	580	156	65	2.1	58	6.4	35	153	55.2	15.8	14.32	1	0.20	347	184
33	Palappuram	6.21	407	26	32	30	56	14	0	80	110	31.00	120.00	0.11	0.28	238	224.00
34	Ottappalam	8.40	290	60	16	4.9	24	8.3	0	87.9	31	8.6	2.10	0.168	2.10	174	72.40
35	Vaniyamkulam	8.40	273	84	23	6.9	23.5	12.1	5.95	97	38	15.9	2.35	0.084	0.04	163	89.20
36	Kadakurrissi	8.3	355	164	46.5	12.4	18.1	10.4	6	115	58	14.8	2.16	0.67	0.50	211	101
37	karakurussi	8.1	210	34	7.8	3.6	10.5	6.9	3.9	51	6	6.5	10	0.55	1.2	121	41
38	Ambalapara	7.10	397	205	110	23.1	17	8.1	35	373	12.1	10.8	3.20	0.25	0.07	222	78.59
39	Cherukara	7.55	140	24	19	5.92	8.4	4.4	2	75	13.6	3.70	4.50	0.17	2.12	84	65.28
40	Thazekkod	7.05	87	56	23	13	12	3	0	81	42	6.00	7.50	0.19	0.05	60	206.00

41	Thachanattukara	6.14	220	38	25	14	13	3.1	5	82	45	5.90	10.89	0.07	0.20	132	25.00
42	Kumaramputhur	7.40	390	58	15.5	4.7	29.6	26	0	66	57	3.7	8.70	0.11	2.80	234	11.40
43	Mannarkad	7.50	392	59	16	4.9	30	27	0	75	58	3.9	8.80	0.19	2.90	236	11.80
44	Kottiyodi	7.80	120	15	15	3.4	6.1	4.3	0	52	9.07	11.3	0.20	0.557	0.05	72	51.15
45	Sreekrishnapuram	8.1	109	44	8.25	6.8	12.5	4.7	0	52	20	3.5	4.52	0.81	0.04	65	49
46	Kadambazhipuram	8.0	115	45	7.13	7.65	13.4	3.7	0	60	20.5	3.25	1.78	0.785	0.06	81	34.5
47	Kongad	8.10	300	75	18	7.3	29.7	7	0	67	56	1.69	5.00	0.086	0.00	180	45.60
48	kalladikode	8.57	320	107	40.7	1.2	21.4	2.9	9	113	28	2.9	4.70	0.14	0.00	192	106.40
49	Chulanur	6.37	187	104	10	14	12	4	10	75	16	18.70	0.01	0.25	0.11	126	212.00
50	Nochipulli	8.3	170	68	9.7	10.7	12	3.2	6	56	20	6.2	6.60	0.6	0.15	102	45.60
51	Tenur	8.40	340	73	21.3	4.7	23	18.8	4.8	86.3	30	22.3	3.16	0.04	2.10	204	77.90
52	Parali	8.30	341	74	21.8	4.8	23.5	19	5	87	31	23.00	3.50	0.04	2.20	205	78.00
53	Tarur	8.50	260	95	25	8.5	21	3.2	2.2	123	22	2.9	0.10	0.31	0.04	156	83.00
54	Pazhayannur	6.54	310	15	9.7	18.9	17.8	6.1	11	80	34	18.30	0.00	0.06	0.14	186	142.08
55	Kannapara	8.90	421	286	72	26	100	48	76	183	172	53.00	8.60	0.64	0.22	256	237.00
56	Alathur	8.60	430	125	36	8.5	36.4	3.36	6.7	128	48	3.3	11.30	0.94	0.00	258	115.80
57	Vadakancheri	8.20	612	150	34	14.2	44	8.4	2.3	72	104	24.7	8.58	0.4	0.87	368	49.40
58	Vandazhi	8.40	250	55	10	7.3	32.3	2.3	4.6	71	31	5.3	6.10	0.689	0.02	150	60.80
59	Nemmara	8.40	240	92	27.2	5.9	11.3	10.3	4.2	96.8	12	14.7	1.00	0.73	1.90	161	89.30
60	Nenmeni	8.6	570	145	61	4.9	51	4.7	32	157	52	14	2.30	1.2	0.17	342	180
61	Kuzhalmannam	8.60	550	225	40	31	28	7	4.5	226	52	15	4.00	1.01	0.85	330	191.00
62	Kinnassery	6.43	642	164	38	31	28	2	2	220	48	8.30	3.50	0.09	0.09	360	142.00

63	Thiruvalathur	6.0	657	280	34	28	22.7	3.8	5	112	109	8.7	10.68	0.51	0.18	460	102
64	kodumbu	6.08	670	216	42	33	61	1.5	0	256	90	20.00	1.84	0.00	0.00	402	188.20
65	Kannady	7.97	880	310	74	52	103	3	0	281	271	12.00	0.50	1.10	0.08	502	210.00
66	Palakkad	8.10	342	94	31	24	45	3.9	23	143	64	25.00	8.30	0.43	2.60	208	27.00
67	Olavakkod	8.20	291	82	32.3	5.5	16	3.45	11.5	111	18.2	0.81	3.42	0.378	1.31	171	49.60
68	Marutharaod	7.9	520	265	31	26	43	3.7	20	149	67	7.3	7.90	0.89	0.12	372	30
69	Kanjikode	8.1	1325	426	29	89	136	10.5	49	255	268	62	104	0.61	0.1	758	202
70	Nallepilly	8.4	480	283	52	34	54	2.1	35	201	92	21.2	2.43	0.9	0.60	291	194
71	Palathully	6.84	880	279	66	35	56	57.5	80	226	80	39.00	9.00	0.81	0.32	528	286.20
72	Chittur	8.70	880	326	70	36	57	59	85	224	77	38.50	8.00	0.81	1.80	530	307.00
73	Chittur	8.80	880	314	68	35	58	58	84	222	74	38	8.10	0.84	1.70	528	306.00
74	Thathamangalam	8.90	640	179	27.2	27.2	77.6	8.8	49	175	68	32.1	4.40	0.75	2.10	444	222.30
75	Vandithavalam	8.40	270	111	37	12	9	1.2	10	96	29	12	5.00	0.50	0.72	162	89.00
76	Perumatti	8.40	320	90	36	13	10	1.7	12	135	16	9.8	1.70	0.50	0.20	200	100.00
77	Meenakhipuram	8.00	1104	452	130	29	129	7	0	316	189	82.00	90.00	0.25	0.04	720	104.00
78	Nattukal	8.70	440	102	27.2	8.3	49.6	5.9	18.6	148	40	19.4	0.56	1.45	0.48	264	150.10
79	Kozhinjampara	8.40	820	233	54.3	23.7	94.9	3.6	4.9	109	197	26.6	6.90	0.4	2.10	518	87.40
80	Ozhalapathy	8.20	802	106	46	32	31	2	14	148	130	4.20	9.10	0.01	0.09	556	172.00
81	Walayar	8.50	586	332	43	30	28	4.5	19	152	48	19.00	42.00	1.30	0.03	378	364.00

The pH distribution of groundwater of the basin for both season are given in the Table 4.3a & 4.3b and Figure 4.2a & 4.2b. The pH value ranges from 6.11 at Thonurkara to 9.1 at Palakkad for the premonsoon with a mean value of 8.01 (Table 4.3a). While, for the post monsoon it varies from 6 at Thiruallathur to 8.9 at Thathamangalam and Kannapara with an average value of 7.67 (Table 4.3b). During the pre monsoon, the pH value shows (Fig. 4.2a) that majority of the area falls within the 8 - 8.5 category reflecting the alkaline nature. The acidic nature of the basin is seen at the southwestern and northwestern areas for both the seasons, whereas the alkaline nature of the basin is noticed in the eastern and southern part (Fig. 4.2a & 4.2b). It is also observed that there is a decreasing trend of pH values from pre monsoon to post monsoon season. The acidic nature of the groundwater can be attributed to the dissolution of CO_2, which is being incorporated into the groundwater system by bacterial oxidation of organic substances (Matthess and Pekdeger, 1981) and the addition of CO_2 through rainwater. Moreover the acidic nature of basin is related to the wide distribution of lateritic soil (CESS, 1984). Further the study area encompasses extensive agricultural fields and the observed acidic nature could be related to the use of acid producing fertilisers like ammonium sulphate and super phosphate of lime as manure for agriculture purpose (Rajesh et al. 2001). The higher pH values in the basin may due to the higher concentration of bicarbonates. Except few locations all other areas of the basin are fall within the permissible limit of BIS and WHO standards (6.5 to 8.5).

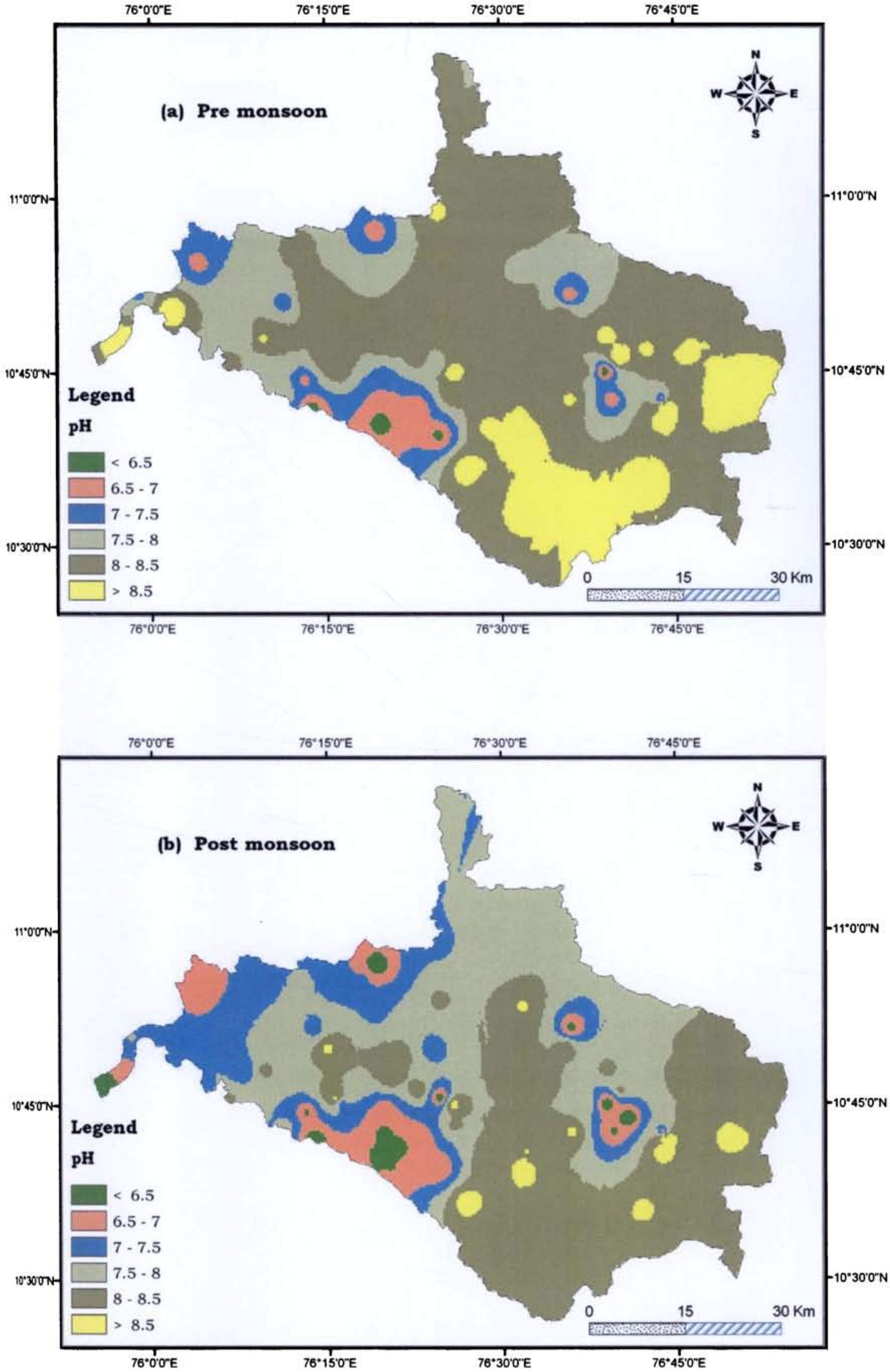


Fig. 4.2 Distribution of pH in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

Electrical conductivity (EC)

Electrical conductivity is a measure of salt content of water in the form of ions (Karanth, 1987). It is measured in micro siemens/cm (µS/cm). In the present study, EC during pre monsoon ranges from 86 µS/cm at Karakkod to 1435 µS/cm at Kanjikode and the mean value is 443 µS/cm (Table 4.3a), while in the post monsoon it ranges from 53 µS/cm at Thozhupadam to 1325 µS/cm at Kanjkode and with a mean value of 403 µS/cm (Table 4.3b). The spatial distribution maps of EC for the study area (Fig. 4.3a & 4.3b) reveals that for both the seasons, low EC values are recorded at north and northwest region, while higher values are observed at eastern part. The high EC values on the eastern part may be due to the addition of some salts from the agricultural practices. The map also reveals that majority area of the basin in both seasons, the EC values fall within the range of 250 - 750 and the water is good for drinking and domestic uses. The lowering of EC values during the post monsoon than in pre monsoon season is due to the dilution of soluble salts by rain fall.

Total dissolved solids (TDS)

Total dissolved solids generally indicate the nature of water quality/salinity. The concentration of TDS in water is determined by weighing the dry residue. The values are expressed in mg/l. The TDS can be estimated from the formula

$$S = K \times A$$

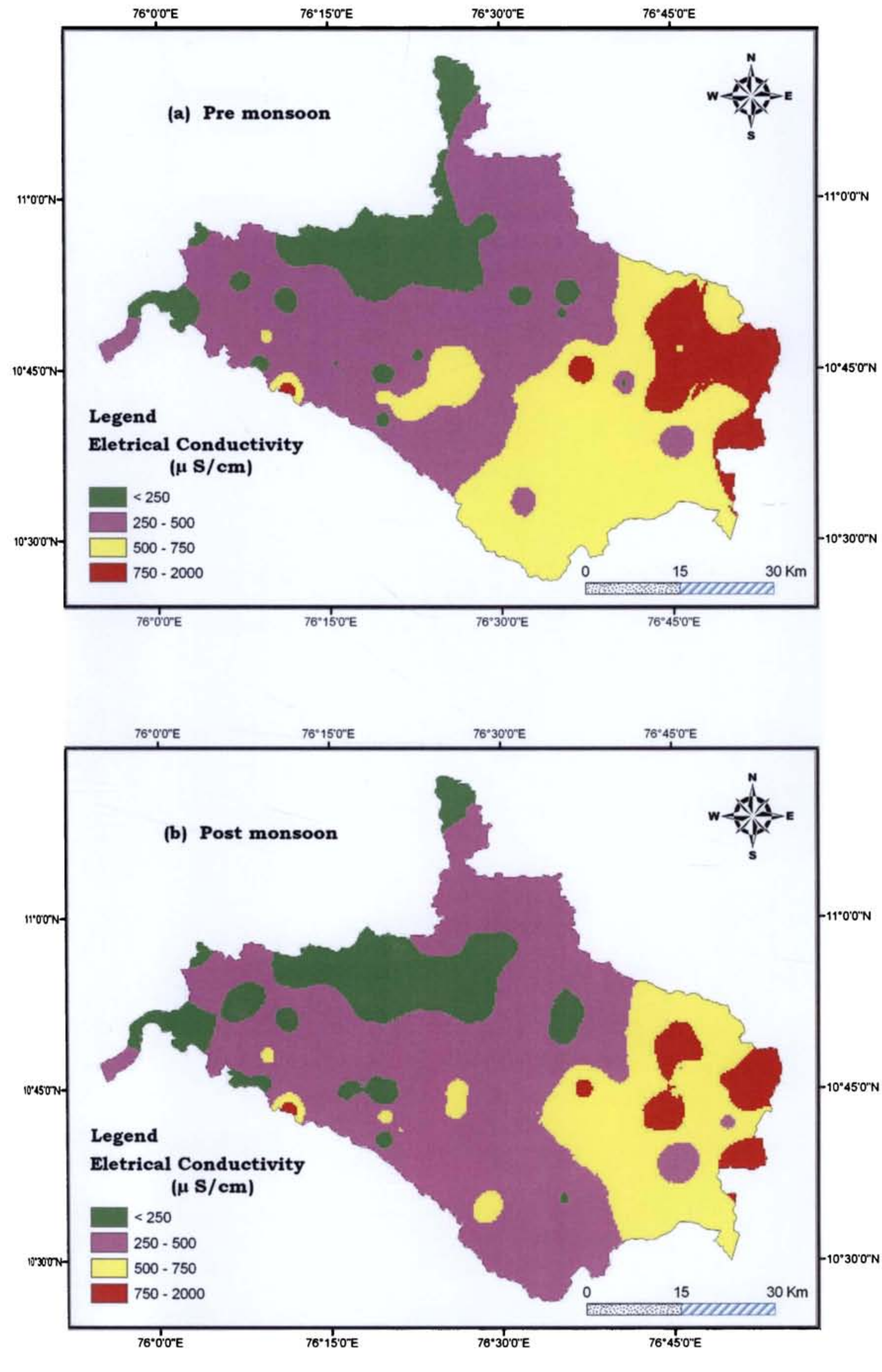


Fig. 4.3 Distribution of Electrical conductivity in the Bharathapuzha river basin. (a) Pre monsoon (b) Post monsoon

Where,

K = conductance in micro mhos/cm at 25^{0}C

A = is a conversion factor ranges from 0 .55 to 0 .75

The build of TDS include carbonates, sulphates and chlorides of calcium, magnesium as well as sodium. Higher the TDS values, the greater will be the EC. Drinking water quality is affected by the presence of soluble salts.

Table 4.4 The potability of water in terms of TDS (mg/l) as per WHO (1984).

Water class	TDS (mg/l)	No of samples		Percentage	
		pre monsoon	post monsoon	pre monsoon	post monsoon
Excellent	<300	46	58	60.49	71.60
Good	300-600	28	21	35.56	25.93
Fair	600-900	4	2	4.94	2.46
Poor	900-1200	-	-	-	-
unacceptable	>1200	-	-	-	-

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

In the present study TDS values of pre monsoon ranges from 59 mg/l Thirunavaya to 803 mg/l Meenakshipuram and the mean value is 272 mg/l (Table 4.3a) whereas in post monsoon it ranges from 35 mg/l at Thozhupadam to 758 mg/l at Kanjikode and the mean value is 245 mg/l (Table 4.3b). The spatial distribution maps of the study area in both seasons reveal that low TDS values are seen at the western region while the higher values are seen at eastern part of the basin (Fig. 4.4a & 4.4b). The potability of water in terms of TDS as per WHO (1984) is given in the Table 4.4. and it reveals that the groundwater of the basin is excellent for above 60% of the samples and good for 35 % of the samples for both the seasons. Except two locations, the entire area of the basin falls within the desirable limit of water quality standards of BIS (500mg/l). When the TDS values are more than 500 mg/l, palatability decreases and may cause gastrointestinal irritation (Park and Park, 1980) and is not ideal for drinking purposes.

The distribution map of TDS (Fig. 4.4) is compared with the distribution map of water level fluctuation (Fig. 2.5) and it reveals that higher TDS values shows higher water level fluctuation in the eastern side of the basin where as lower TDS values reflecting low water level fluctuation. Similarly, the same figure is compared at the western side with the geomorphology map (Fig. 5.1) and reveals that the high TDS values are noticed in the Plateaus whereas the lower TDS values are seen in the valley fills and pediment zones.

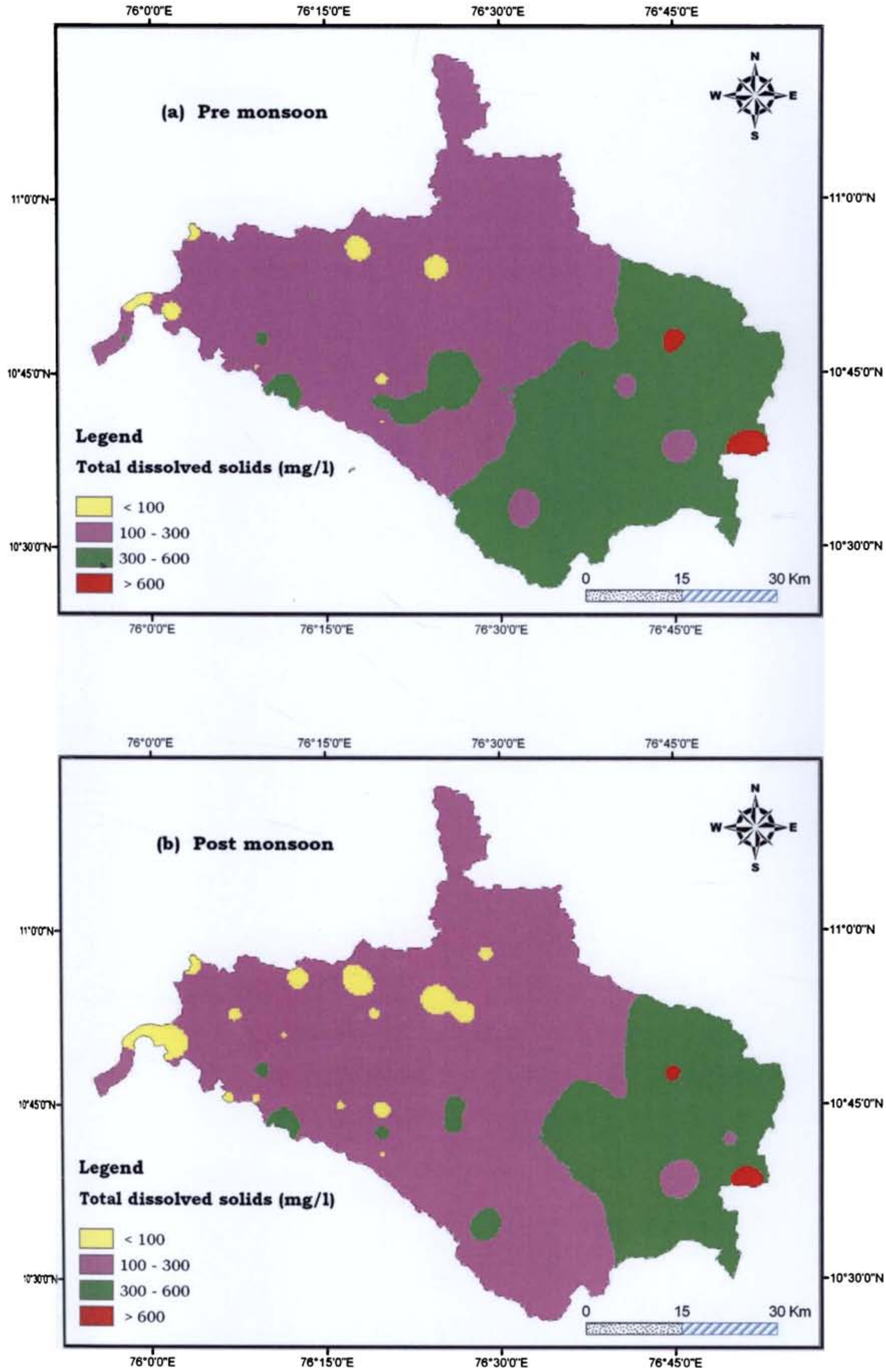


Fig. 4.4 Distribution of TDS in the Bharathapuzha river basin (a) Pre monsoon (b) Post monsoon

Hardness

Groundwater hardness is defined as the sum of divalent cation in solution but depends largely upon the concentrations of aqueous calcium and magnesium (Taylor and Howard, 1994). Hardness of water is caused by the presence of carbonates and bicarbonates of calcium, magnesium, sulphate, chlorides and nitrates. Hardness is temporary, if it is caused by carbonates and bicarbonates salts of the ions, it can be removed easily by boiling. Permanent hardness is caused mainly by sulphate and chloride of the metals. Water of high hardness is not suitable for household cleaning purpose and it increases the boiling point of water. A low pH of groundwater favours the dissolution of carbonate mineral, which in turn enhances the hardness by dissolving carbonate minerals in the country rock (Todd, 1980). Based on the hardness (Sawyer and McCarty, 1967), water is classified into soft, moderately hard, hard and very hard (Table 4.5).

In the present study, the hardness for the premonsoon ranges from 10 mg/l at Karakkod to 570 mg/l at Ozhalapathy and the mean value is 143.11 mg/l (Table 4.3a). In the post monsoon, it ranges from 11 mg/l at Desamangalam to 452 mg/l at Meenakshipuram and the mean value is 125.6 mg/l (Table 4.3b). From the spatial distribution of hardness of Bharathapuzha river basin (Fig. 4.5a & 4.5 b), it is noticed that for both the seasons, the low values are seen at the northern region whereas higher values are seen at eastern part of the basin, Meenakshipuram, Kanjikkode and Walayar, reflecting the host rock composition calc-silicate/ calc-granulite with limestone. Generally there

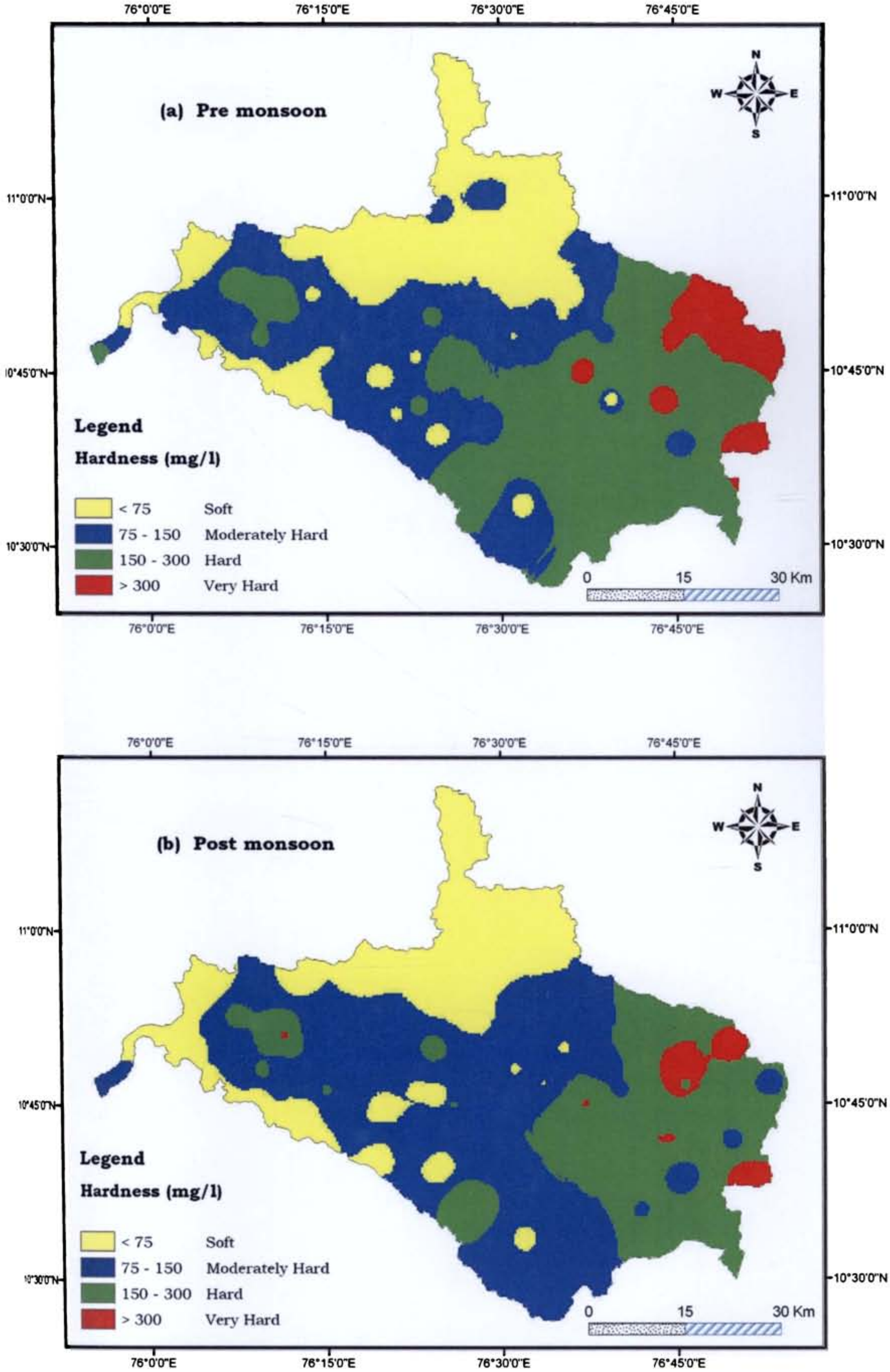


Fig. 4.5 Distribution of Hardness in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

is a decreasing trend of hardness values from east to west. Most of the areas in the basin, the hardness values ranges from 75-150 mg/l and moderately hard water class.

Table 4.5 Classification of degree of hardness in water (Sawyer and McCarty 1967)

Groundwater class	Hardness, (mg/l) as $CaCO_3$	No. of samples		Percentage	
		Pre monsoon	Post monsoon	Pre monsoon	Post monsoon
Soft	0-75	31	30	38.27	37.04
Moderately hard	75-150	20	27	24.69	33.34
Hard	150-300	21	17	25.93	20.98
Very hard	>300	9	7	11.11	8.64

Alkalinity

It is a measure of quantity of compounds that shift the pH to the alkaline side or the capacity of water to neutralise the acids. There is no standard established neither for surface or groundwater. A range of 100 to 250 mg/l for river water is considered normal. The study area shows a range of 20 mg/l at Kalladikode to 956 mg/l at Iswaramangalam and with an average value of 142 mg/l in pre monsoon (Table 4.3a) and in post monsoon it ranges from 11 mg/l at Kulakkalur to 988 mg/l at Iswaramangalam and the mean value is 144.91 mg/l (Table 4.3b). The spatial distribution map of alkalinity (Fig. 4.6a and 4.6b) shows that majority of the area falls within the desirable limit (300mg/l –BIS) except Iswaramangalam and Karakkod for both the seasons.

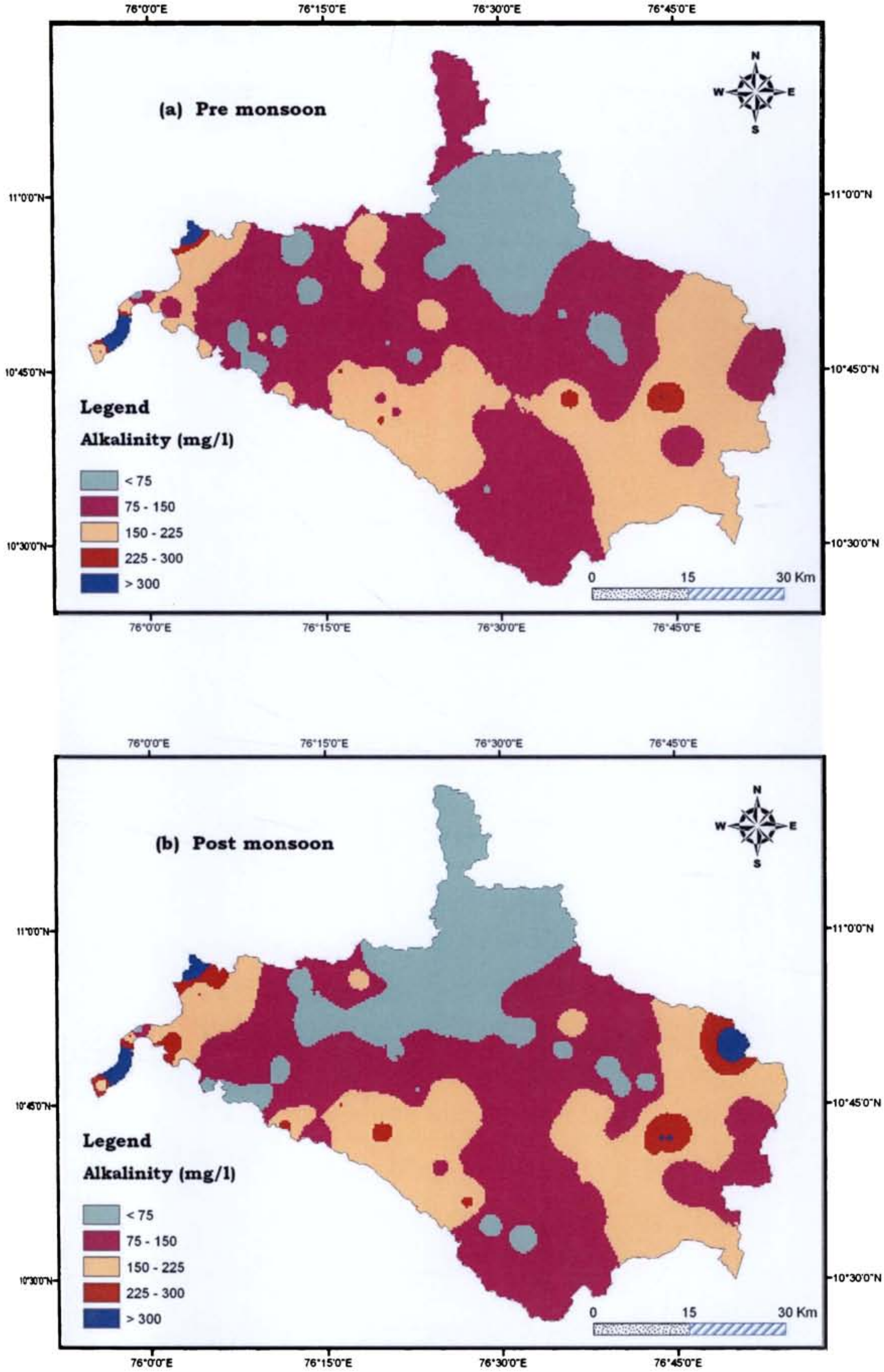


Fig. 4.6 Distribution of Alkalinity in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

4.3.2 Chemical analysis

The concentration of various anions and cations for the two seasons were determined following the APHA,1985 and is given in the table 4.2. The values of TDS and EC were validated using the following relationship 1μS/cm= 0.65mg/l. Cation-anion balance is important in the case of groundwater analysis. The accuracy in the chemical analysis of water samples can be checked by calculating the cation-anion balance, in that the sum of major cations should be equal to the sum of major anions which is expressed in meq/l. To account for source dependency an allowable error limit of 10% is acceptable. The percentage error is termed as ion balance error (e), which can be determined following the equation given by Matthess (1982).

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

γc = cation sum in meq/l

γa = anion sum in meq/l

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

i) The mg/l (parts per million, mg/l) concentration and
ii) The epm (equivalent per million, meq/l) concentration

The evaluation of data was carried out by using several standard techniques of groundwater hydrochemistry. These techniques include graphical methods like hydrochemical diagrams, such as Hill-Piper, the U.S Salinity Laboratory (U.S.S.L, 1954) diagram and Wilcox diagram (1955).

Ca^{+}, Mg^{2+}, Na^{+} and K^{+} and Cl^{-}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-} and NO_3^{-} are the major cations and anions estimated in the groundwater of Bharathapuzha river basin. The concentration of these ions in ppm and epm for the samples during pre and post monsoon are given in the Table 4.3a & 4.3b and 4.3c & 4.3d respectively.

Calcium

Calcium is a major constituent of rocks and soils. The principal sources of calcium in groundwater are silicate minerals like feldspars, pyroxenes and amphiboles among igneous and metamorphic rocks and lime stone, dolomite and gypsum among sedimentary rocks. In addition to this, disposal of sewage and industrial waste are the main sources of calcium. Hardness of water is due to the presence of calcium with magnesium and concentration upto 1800 mg/l and does not impair any physiological reaction in man (Lehr et al. 1980). The low content of calcium in drinking water causes rickets and defective teeth. It is essential for nervous system, cardiac function and in coagulation of blood (Khurshid et al. 1998). It also has some disadvantages

- High concentration of Calcium not desirable in washing, laundering and bathing.
- Initiates scale formation in boilers.
- Calcium with sulphate inhibits malt fermentation and with chlorides inhibits growth of yeast.

Calcium concentration in the groundwater of Bharathapuzha river basin during pre monsoon varies from 5 mg/l at Thirunavaya to 135.2 mg/l at Meenakshipuram and the average value is 35.87 mg/l

(Table 4.3a). Calcium concentration in the groundwater of Bharathapuzha river basin during post monsoon varies from 6 mg/l at Kootanad to 130 mg/l at Meenakshipuram and the average value (mean) is 32.75 mg/l (Table 4.3b). The thematic maps (Fig. 4.7a and 4.7b) show that calcium concentration in both seasons is high at eastern side and there is a decreasing trend towards western region irrespective of the fact that the extent has been reduced in post monsoon.

In the basin calcium concentration in both seasons fall within the highest desirable limit of WHO and BIS standards (75 ppm) except for Chittor, Palathully, Walayar and Meenakshipuram where the limit is confined to permissible limit (200 ppm) during pre monsoon and in post monsoon to that Ambalapara, while Meenakshipuram remains well within permissible limit irrespective of the seasons. These variations can be attributed to the soil type present in the area. The most livelyhood source is of weathering of plagioclase feldspar and other feldspars of the host rock.

Magnesium

It is an important component of igneous, metamorphic and sedimentary rocks. Minerals like chlorite, serpentine, biotite, hornblende, olivine and augite are the main source of magnesium and the main rock type in the study area are hornblende biotite gneiss and

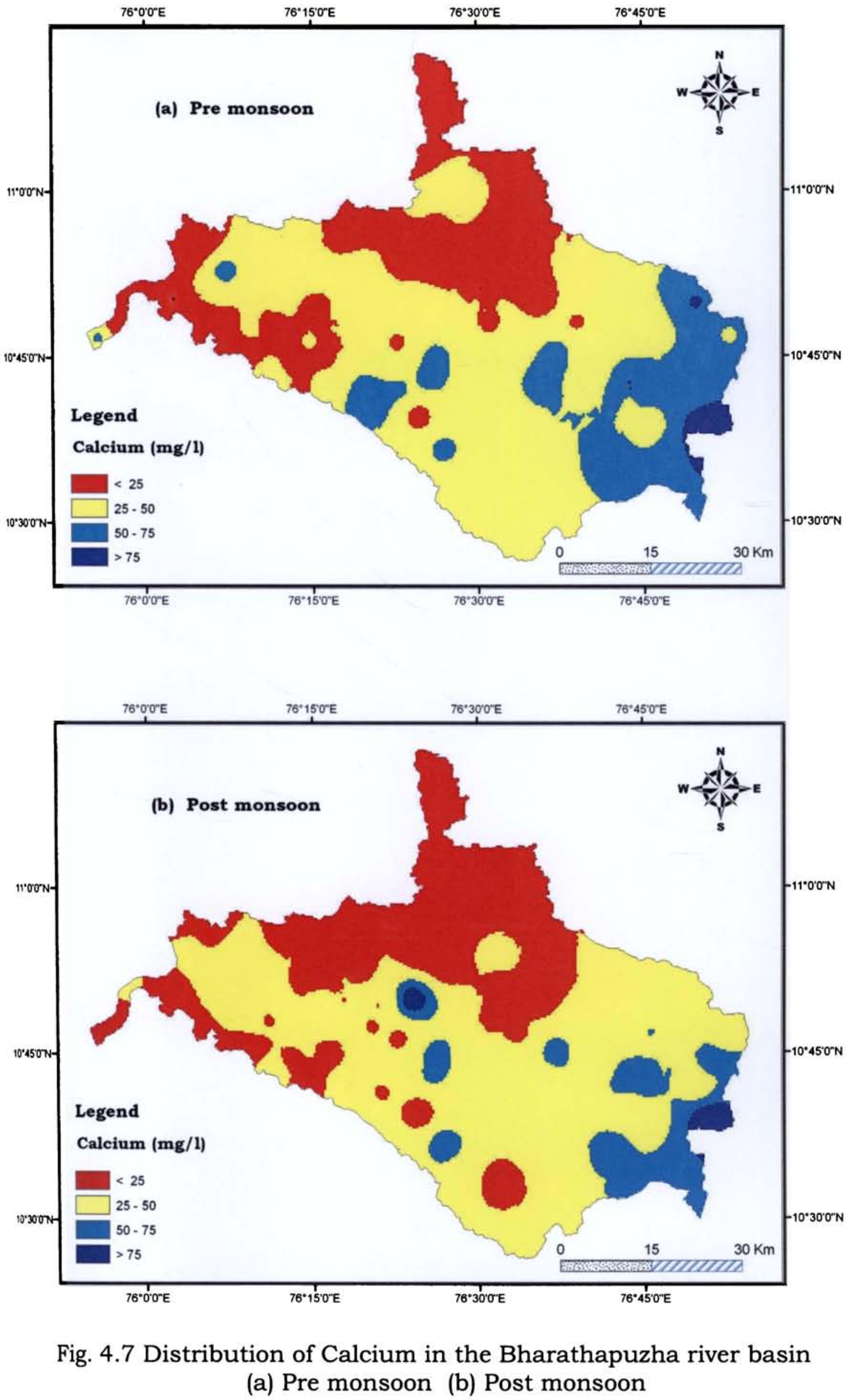


Fig. 4.7 Distribution of Calcium in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

charnockite. Magnesium adds to the hardness of water and with calcium.

In the study area, magnesium content of groundwater during pre monsoon ranges from 2 mg/l (Kongad) to of 98 mg/l (Kanjikode) and with an average value of 19.03 mg/l (Table 4.3a) whereas in post monsoon ranges from 1.2 mg/l at Kalladikode to a maximum of 89 mg/l at Kanjikode with an average value of 17.12 mg/l (Table 4.3b). The spatial distribution maps (Fig. 4.8a and 4.8b) of magnesium in both seasons reveals that the northeastern region exceeds the highest desirable limit (35 ppm) but within the maximum permissible limit and the remaining area fall within the highest desirable limit of WHO and BIS standard. In general the Mg content in study for the seasons remains within the desirable limit. Magnesium and calcium form bicarbonates in the presence of CO_2. The solubility of magnesium carbonate is nearly ten times more than $CaCO_3$ under atmospheric conditions. Magnesium is also more soluble in water containing sodium salts. The concentration of magnesium values in the study area are decreasing from pre monsoon to post monsoon. The variation at the northeastern part may be due to the presence of Palghat Gap.

Sodium

Sodium salts are highly soluble in water and once leached from rocks and soil they remain in solution. The main source of sodium in groundwater is plagioclase feldspars, feldspathoids and clay minerals.

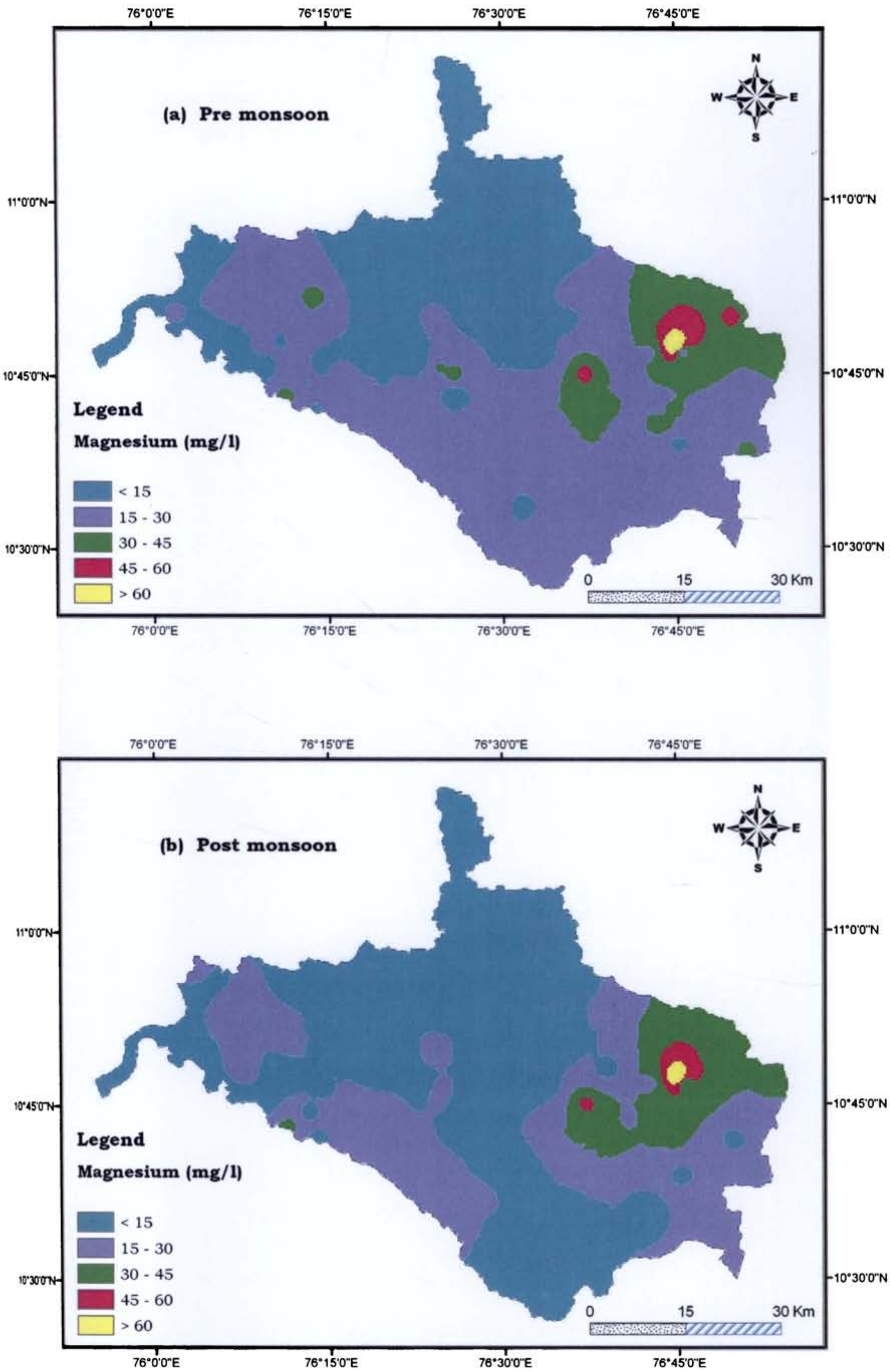


Fig. 4.8 Distribution of Magnesium in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

It has a tendency to get absorbed/adsorbed on the clay particles but may effectively be exchanged by calcium and magnesium.

National Academy of Sciences report (1977), the higher concentration of sodium can be related to cardiovascular diseases and in women, toxemia associated with pregnancy. Sodium content around 200 mg/l may be harmful to persons suffering from cardiac and renal disease pertaining to circulatory system (Khurshid et al. 1998). More than 65 mg/l of sodium can cause problems in ice manufacture (Todd 1980). High concentration of sodium affects soil permeability and texture which leads to puddling and reduced rate of water intake.

Sodium concentration values in the Bharathapuzha river basin during pre monsoon varies from 6 mg/l at Kalladikode to 145 mg/l at Kanjikode and with an average value of 33.08 mg/l (Table 4.3a). While in the post monsoon, it vary from 6.1 mg/l at Kottiyodi to 136 mg/l at Kanjikode and with an average value of 34.78 mg/l (Table 4.3b). In the study area, during pre monsoon low values are seen in the north eastern region of the basin (Fig. 4.9a) whereas higher values are seen in eastern region especially around Meenakshipuram. In the post monsoon period lower values are seen in the north and north western part of the basin (Fig. 4.9b). The thematic maps (Fig. 4.9a and 4.9b) of sodium concentration in the Bharathapuzha river basin during the both seasons reveal that the eastern side of the basin exceeds the highest desirable limit (50 mg/l), but within the maximum permissible limit of WHO standard (200mg.l). Sodium concentration more than 50

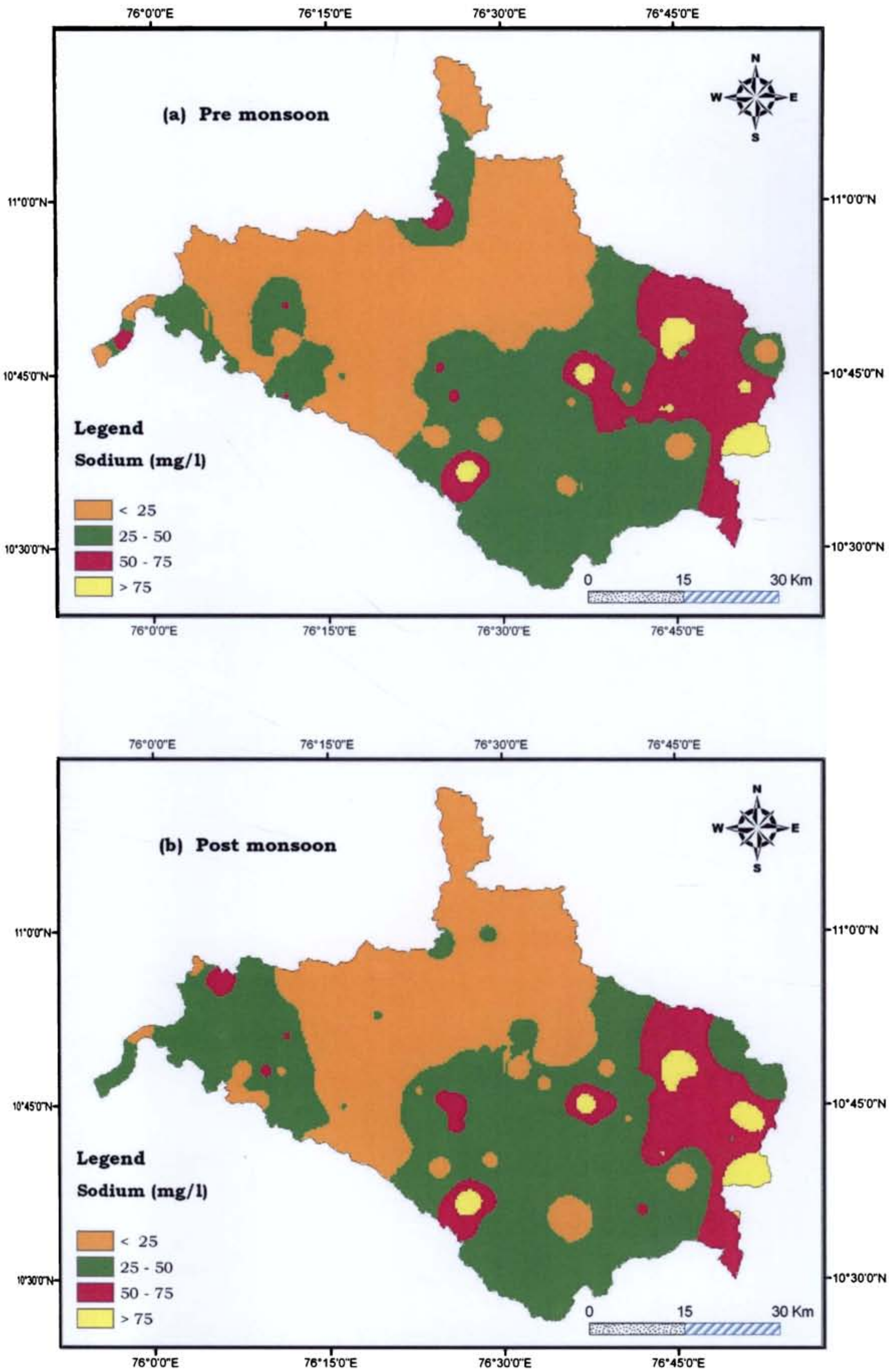


Fig. 4.9 Distribution of Sodium in the Bharathapuzha river basin (a) Pre monsoon (b) Post monsoon

mg/l makes the water unsuitable for domestic use (Jain et al. 1996). At the eastern side of the basin the sodium concentration exceeds this limit and make the water unsuitable for domestic use. From the distribution map, it is clear that there is a general decreasing trend of sodium concentration from east to west.

Potassium

Potassium is abundant in igneous and metamorphic rocks. The source of potassium content in groundwater is a function of weathering rate of silicate minerals such as orthoclase, microcline, nepheline, leucite and biotic in igneous and metamorphic rocks. The concentration of potassium in most natural water is very low due to the resistance of potassium minerals to decomposition by weathering (Golditch, 1938) and fixation of potassium ions in clay minerals.

In the study area, the potassium concentration in pre monsoon ranges from 0.6 mg/l at Cheruthuruthi to 56 mg/l at Palathully and the mean value is 8.3 mg/l (Table 4.3a) while in post monsoon it ranges from 0.8 mg/l at Cheruthuruthi to 59 mg/l at Chittur and the mean is 9.21 mg/l (Table 4.3b). The concentration of potassium ranges from 1 mg/l or less to about 10 to 15 mg/l in potable water (Karanth, 1987). The Spatial distribution maps of potassium in both seasons shows (Fig. 4.10a and 4.10b) that majority area of the basin falls within the category of below 10 mg/l reflecting the suitability of water for domesic use. During both seasons lower values are seen in the western part of

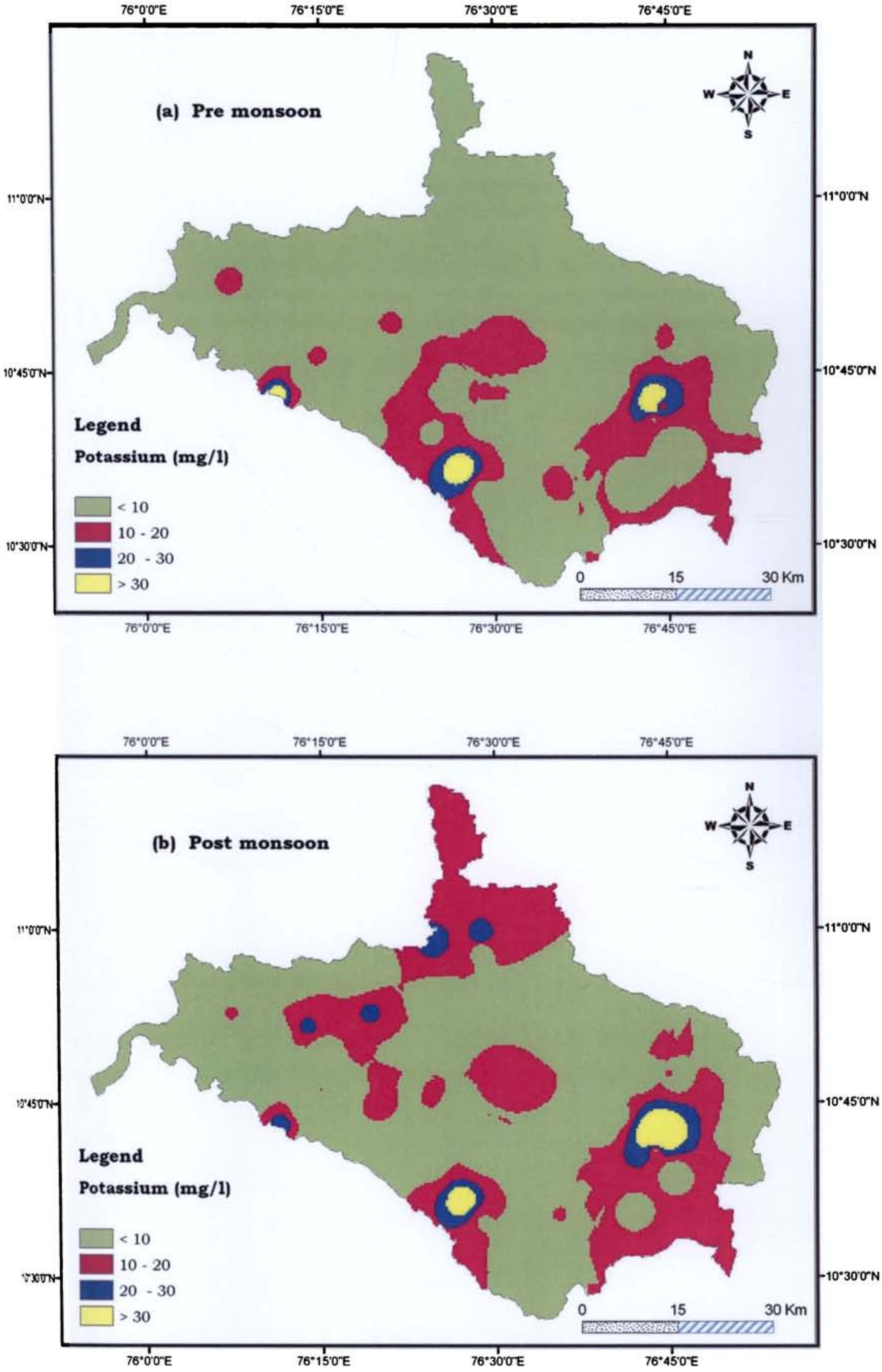


Fig. 4.10 Distribution of Potassium in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

the area where as the higher values are seen at the southeast and southwest part of the basin (Fig. 4.10a and 4.10b).

Chloride

The main sources of chloride are sodalite, apatite, micas and hornblende and in groundwater are present as sodium chlorides. The chloride content in rainwater is usually less than 10 mg/litre. Man and other animals excrete very high chloride quantities together with nitrogenous compounds. Chloride in water is a stronger oxidising agent than oxygen, chloride with oxygen slowly decompose water. Concentration in excess of 100 mg/l may cause physiological damage. So also higher concentration of chloride can also corrode concrete by extracting calcium in the form of calcides. Abnormal chloride concentration may result due to pollution of sewage waste and leaching of saline residues in the soil.

Chloride concentration values of Bharathapuzha river basin in the pre monsoon varies from 5.9 mg/l at Sreekrishnapuram to 262 mg/l at Kanjikkode and the average value is 63.13 mg/l (Table 4.3a) while during post monsoon it ranges from 6 mg/l at Karakurussi to 271 mg/l at Kannadi and the average value is 61.08 mg/l (Table 4.3b). The chloride content of the Bharathapuzha river basin has been classified based on the procedure given by Stuyfzand (1988 &1989) and is given in the Table 4.6 and it is plotted in the Figure 4.11a and 4.11b. Based on the chloride content in the study, the water type can be classified into three types namely, oligo haline, fresh and fresh brackish. Fresh

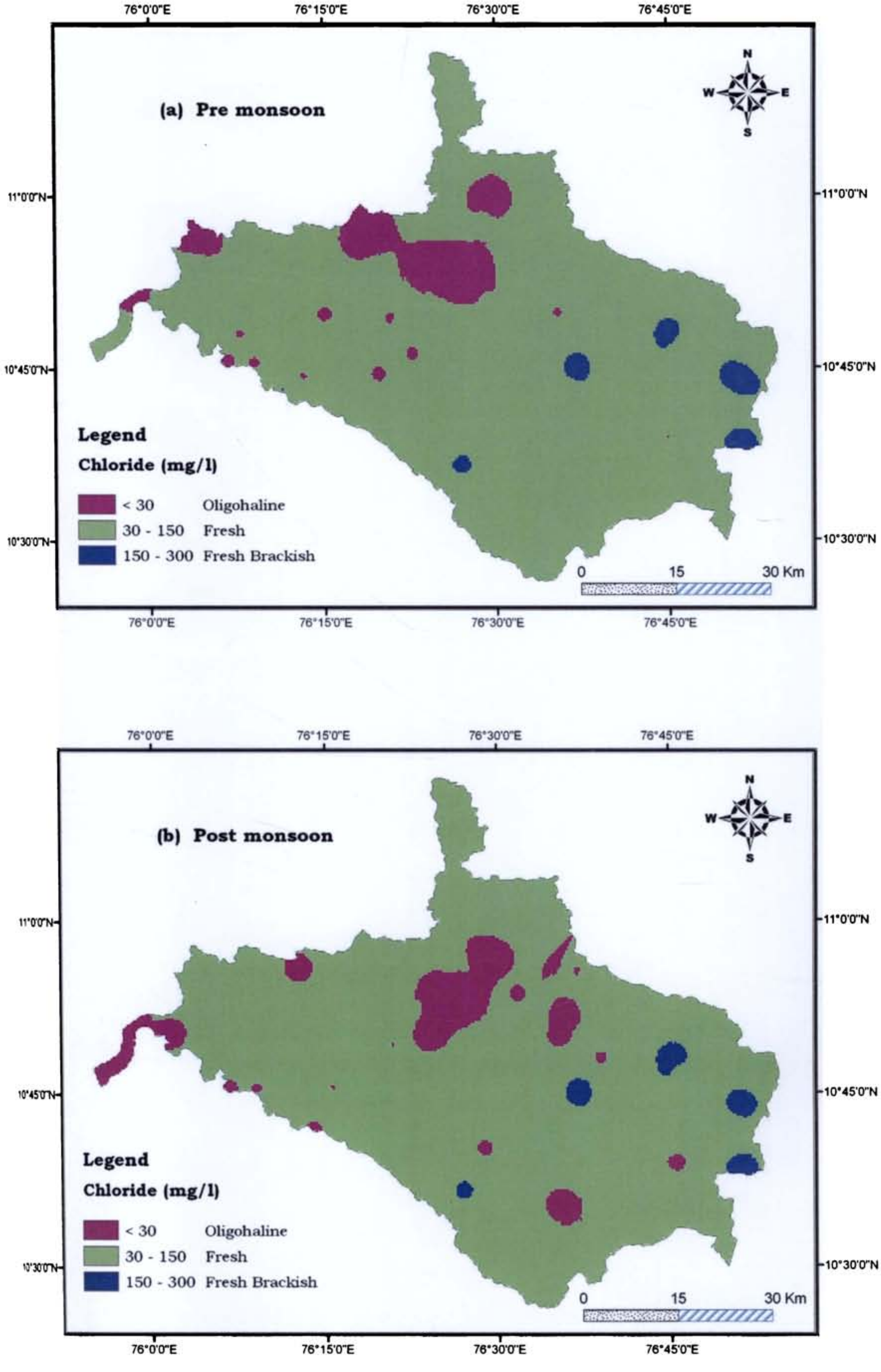


Fig. 4.11 Distribution of Chloride in the Bharathapuzha river basin (a) Pre monsoon (b) Post monsoon

water type are the dominant category seen in the basin during both the seasons while only a small portion falls in the fresh brackish category which is seen in the eastern part of the basin.

Table 4.6 Classification of groundwater quality based on chlorine content using the procedure given by Stuyfzand (1988, 1989).

Sl. No.	Groundwater Types	Chloride Concen-tration Ranges (mg/l)	No. of samples		Percentage	
			Pre monsoon	Post monsoon	Pre monsoon	Post monsoon
1	Very Oligohaline	<5	-	-	-	-
2	Oligohaline	5-30	19	23	23.50	28.40
3	Fresh	30-150	56	53	69.10	65.43
4	Fresh – Brackish	150-300	6	5	7.40	6.17
5	Brackish	300-1000	-	-	-	-
6	Brackish – Salt	1000-1000	-	-	-	-
7	Salt	10000-20000	-	-	-	-
8	Hyper saline	>20000	-	-	-	-

Figure 4.11a and 4.11b reveals that except two places at the eastern side of the river basin (Kanjikode and Kannadi), all other areas are fall within the highest desirable limit of WHO (200 mg/l) and BIS (250 mg/l) standards. In general, high concentration of chloride in groundwater is attributed to rain water, sea water, natural brines, evaporates deposits and pollution (Junge and Wrby, 1958; Johnson, 1987). High concentration of chloride values in the study area may be due to Industrial pollution (Kanjikode) and use of fertilisers.

Distribution maps of chloride concentration during both seasons (Fig. 4.11a and 4.11b) shows that majority area are fresh groundwater types.

Nitrate

In groundwater, very small quantities of nitrates are present through nitrogen cycle in the earth's hydrosphere and biosphere. The presence of nitrate in groundwater is from decomposition of organic matters like plant debris, animal waste, sewage wastes, nitrate fertilisers and industrial waste chemicals. Natural nitrate concentration in groundwater ranges from 0.1 to 10 mg/l (Davis and Dewiest, 1960).

Nitrate concentration in water more than 45 mg/l may cause methemoglobinemia in infants. High concentration of nitrates is reported to cause more mortality in pigs and calves and abortion in brood animals. Even though high concentration of nitrate is useful in irrigation, their entries into the water resources increase the growth of certain algae and trigger eutrophication.

In the present study area, the nitrate concentration of groundwater in the monsoon ranges from 0.03 mg/l (Chulanur) and 110 mg/l at (Palapuram) and the average value is 10.28 mg/l (Table 4.3a) while in post monsoon it ranges from 0.01 mg/l at Chullanur to 120 mg/l at Palapuram and the average value is 10.16 mg/l (Table 4.3b). Three locations (Meenkara, Kanjikkode and Palapuram) of the study area exceed the highest desirable limits of drinking water standards of WHO and BIS (45 mg/l) in both the seasons (above 45 mg/l). From the distribution map (Fig. 4.12a and 4.12b) it is observed

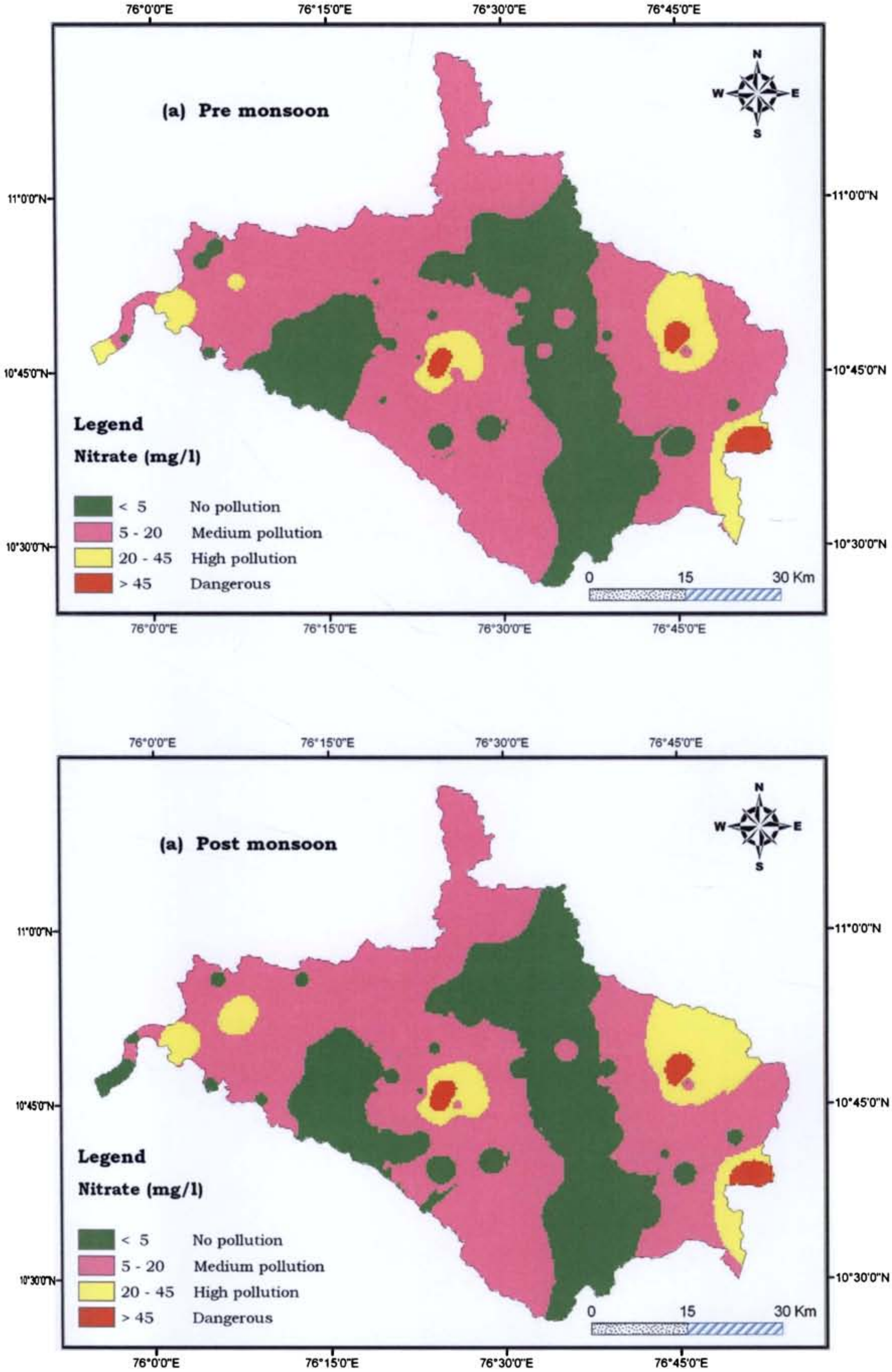


Fig. 4.12 Distribution of Nitrate in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

that majority of the area in the basin for both the seasons are comes under the medium polluted category and the dangerous category is seen in the eastern part of the basin.

Sulphate

The sulphate concentration of atmospheric precipitation is only about 2 mg/l, but the sulphate content in the groundwater varies widely due to oxidation and precipitation processes as the water traverse through rocks. The source of sulphates are sulphur minerals, sulphides of heavy metals which are commonly found in the igneous and metamorphic rocks, gypsum and anhydrite found in some sedimentary rocks. The oxidation and hydrolysis of pyrite also produce sulphuric acid and soluble sulphate. Sulphate concentration around 1000 mg/l is laxative and cathartic (U.S.E.P.A, 1971). Sulphate with sodium interferes with normal functioning of the intestine.

In the Bharathapuzha river basin in the groundwater during pre monsoon season the sulphate content ranges from 1.03 mg/l at Nochipulli to 87 mg/l at Meenakshipuram and average value is 19.03 mg/l. (Table 4.3a) whereas in the post monsoon season ranges from 0.49 mg/l at Kulakkalur to 82 mg/l at Meenakshipuram and average value is 17.23 mg/l (Table 4.3b). The spatial distribution maps of sulphate concentration in both seasons (Fig. 4.13a and 4.13b) reveals that the entire river basin is within the desirable limit of WHO and BIS standards (200mg/l).

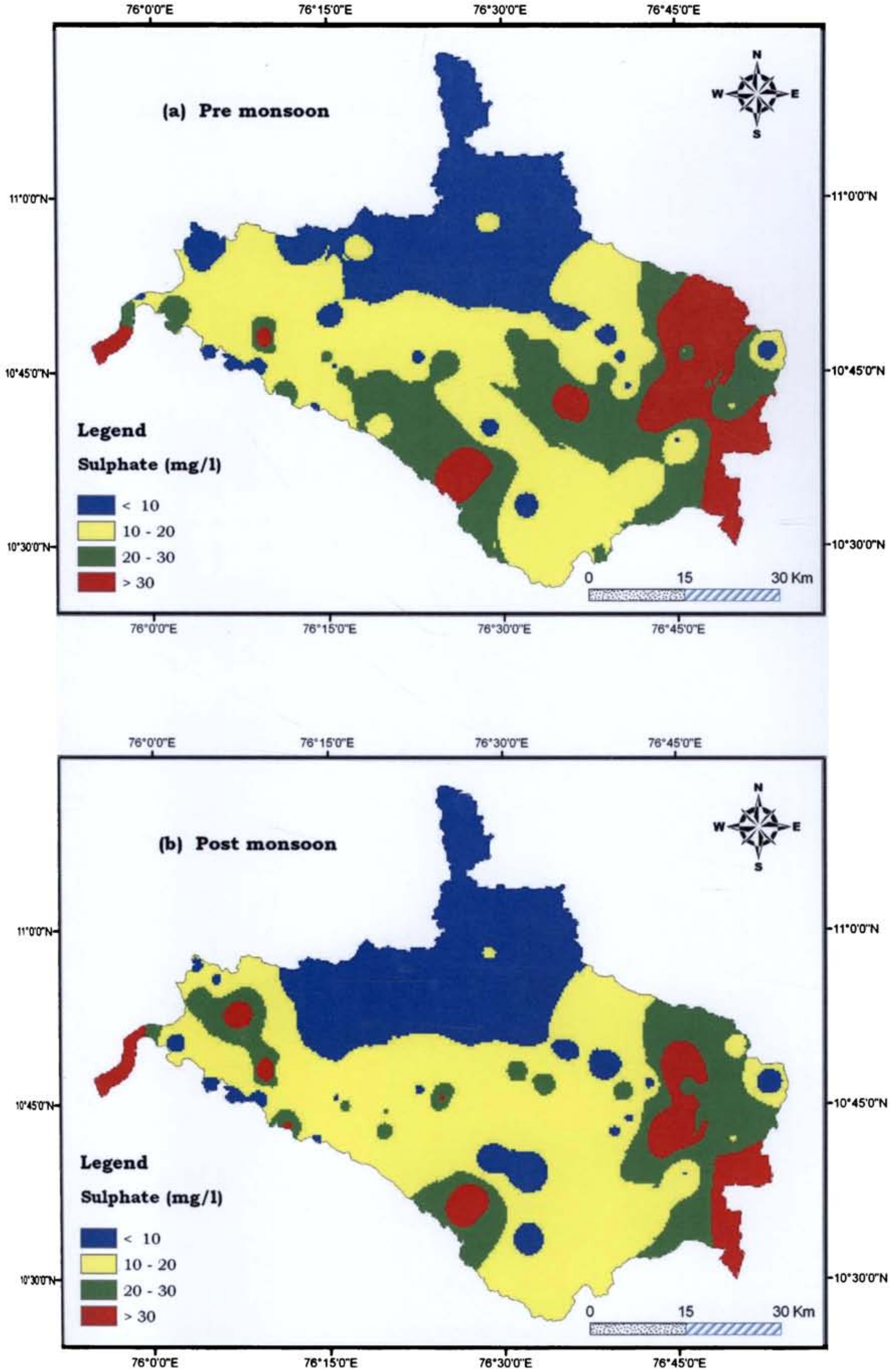


Fig. 4.13 Distribution of Sulphate in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

Carbonates and bicarbonates

The primary sources of CO_3 and HCO_3 in groundwater is the dissolved CO_2 in rain water as it falls through the atmosphere and water flowing through the soil dissolves large amount. The solubility of CO_2 in water decreases with increase in temperature or decreases in pressure. Water charged with CO_2 dissolves carbonate minerals as it passes through soil and rocks giving rise to bicarbonates.

Carbonates and bicarbonates along with hydroxides are responsible for the alkalinity of water. Alkalinity is defined as the acid neutralising capacity of water. In unpolluted water, the major anions that can neutralise the positive H^+ ions are HCO_3, CO_3 and OH. But in polluted waters, other negative ions like PO_4, NO_3 may contribute alkalinity (Raymahashay, 1996).

Large amount of bicarbonate and alkalinity in water is undesirable in many industries. High amount of CO_3 in drinking water result in heart ailments and artery blockage.

In the study area carbonate concentration values during the pre monsoon ranges from 2 mg/l at Trithala to 60 mg/l at Chittur and Kanjikkode and the average value is 12.64 mg/l (Table 4.3a), but for post monsoon the values ranges from 2 mg/l at Kinnasseri to 85 mg/l at Chittur and the mean value is 13.92mg/l (Table 4.3b). Bicarbonate values during pre monsoon ranges from 28 mg/l at Kuttipuram to 351 mg/l at Meenakhipuram and the mean value is 126.36 mg/l (Table 4.3a) while in post monsoon values varies from 23.5 mg/l at

Kuttipuram to 373 mg/l at Ambalapara and the mean value is 119.75mg/l (Table 4.3b). The spatial distribution map for both the seasons' show (Fig. 4.14a and 4.14b) low values in the north and western part of the basin. Higher values are seen in and around Meenakshipuram and Ambalapara. In general, the groundwater of the study area falls within the desirable category.

Fluoride

Of the many natural geochemical substances contaminating groundwater, fluoride is most hazardous. Fluorine is the most electro-negative element. It occurs in water as fluoride ion. The source of fluoride in groundwater is fluorite and other hydroxyl minerals like micas and amphiboles. It is capable of forming complexes with silicon and aluminium and is believed to be exist at a pH below 7.

Impact of fluoride in drinking water on health has been well studied by Dissanayake, (1991) and is given in Table 4.7. According to him, fluoride is beneficial when present in small concentration (0.8 to 1 mg/l) in drinking water for calcification of dental enamel but it causes dental and skeletal fluorosis if present in higher amount.

In the Bharathapuzha river basin the fluoride content of groundwater during pre monsoon ranges from 0.01mg/l at Thirualathur to 1.2 mg/l at Walayar the mean value is 0.48 mg/l (Table 4.3a) whereas in post monsoon it varies from 0.01mg/l at Thonnurkara

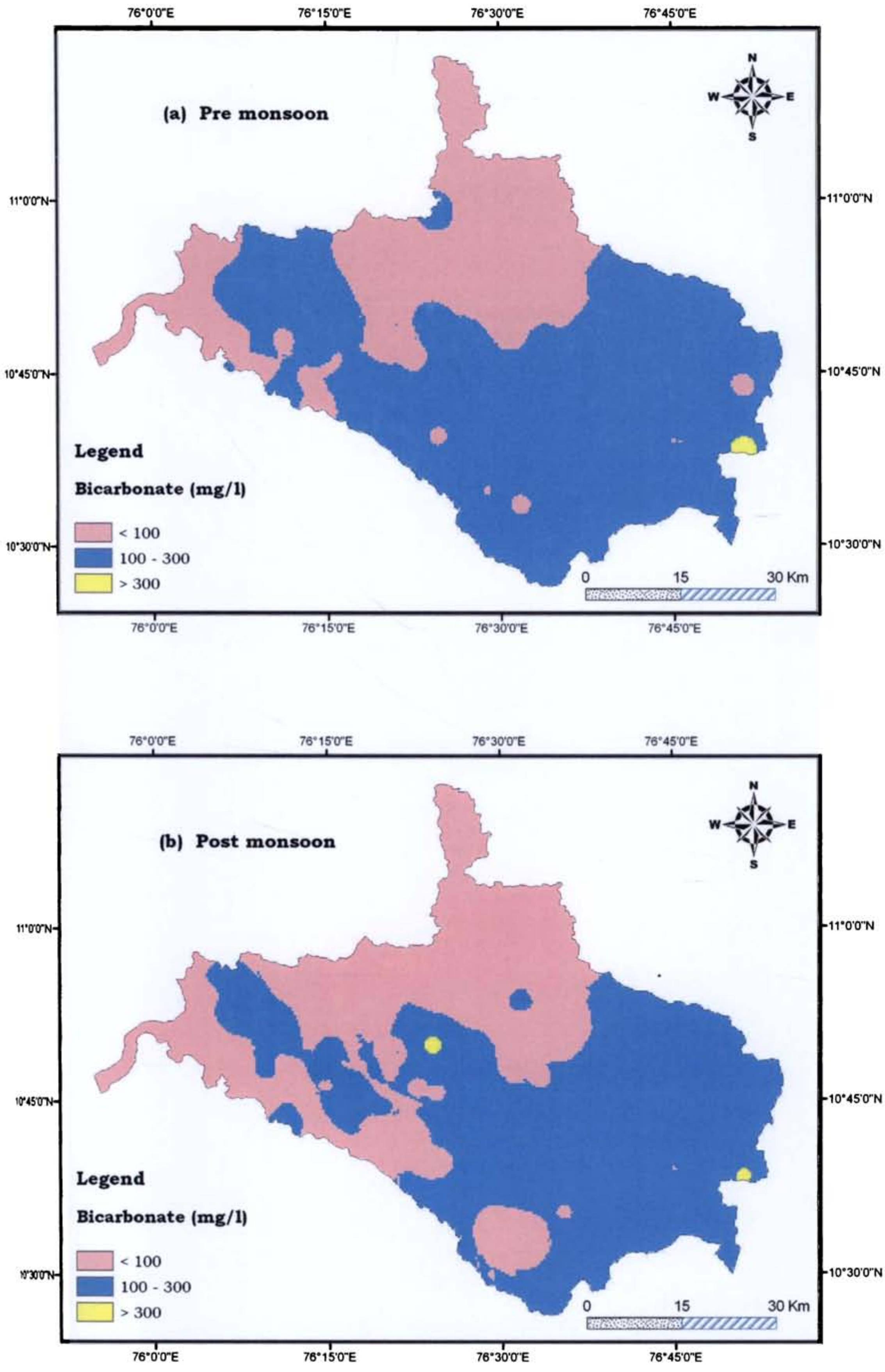


Fig. 4.14 Distribution of Bicarbonate in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

to 1.45 mg/l at Nattukal and the average value is 0.42 mg/l (Table 4.3b).

Table 4.7 Impact of fluoride in drinking water on health (Dissanayake, 1991)

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

The spatial distribution maps of fluoride concentration in both the seasons (Fig. 4.15a and 4.15b) reveals that in Vandazhi, Kuzhalmannan, Kannadi and Walayar are in the permissible limit of BIS 1.5mg/l and the rest of the study area falls with in the desirable limits (1.0 mg/l). Also it reveals that lower values are seen at northern and western part of the study area, higher values are seen at eastern part of the basin. The major rock type (hornblende biotite gneiss) and the semi arid climatic condition of the Palghat gap (eastern region) favours the leaching of the fluoride bearing minerals may be one of the reason for the higher concentration of the fluoride. The leaching of fluoride from the fluoride bearing minerals are Apatite, Hornblende and Biotite and very low fresh water exchange due to the semiarid climate of the region and long residence time of groundwater in the aquifer attributes for it content (Wodeyar and Sreenivasan, 1996). An abnormal

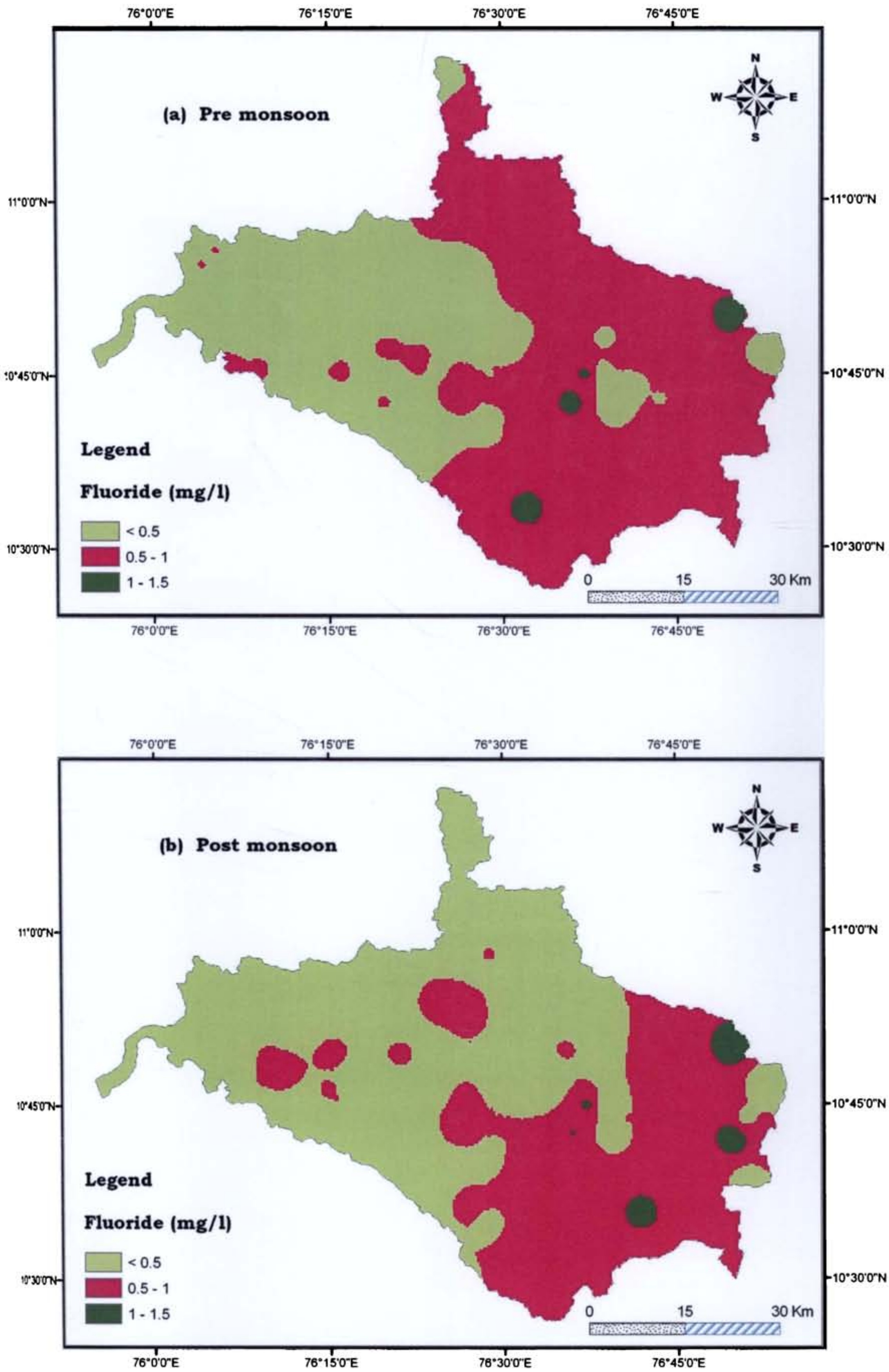


Fig. 4.15 Distribution of Fluoride in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

concentration of fluoride (>1.5 mg/l) is recorded in the Rift valley of Ethiopia calcium fluoride and is derived from bed rocks (Ashley & Burley, 1995). In the region, high degree of weathering and easy accessibility of circulating waters to the weathered rocks due to intensive and long time irrigation are responsible for the leaching of fluoride from their parent minerals (Wodeyar and Sreenivasan, 1996). The pH of the circulating water is a factor which controls the leaching of fluoride from the Fluoride bearing minerals. Hence it can be inferred that the fluoride in the study area comes from the fluoride minerals in bed rock.

Total Iron

The concentration of iron in groundwater will be higher under more reducing conditions due to bacteriological attack on organic matter which lead to the formation of various humic and fluvic compounds (Applin and Zhao,1989; White et al. 1991). Under reducing condition, the iron from biotite and laterites are leached into solution in the ferrous state. According to Singhal and Gupta, (1999) iron content in groundwater is mainly due to the dissolution of iron oxides. A common method of removal of iron from water is by aeration followed by sedimentation. In high rainfall state like Assam, Kerala and Orissa total iron ranges from 6.83 to 55 mg/l (Singhal and Gupta, 1999). Higher content of iron at certain regions of the study area may be due to the leaching of Iron from the lateritic top soils as iron can be easily leached out in anoxic conditions.

In the study area, for the pre monsoon the total iron values ranges from 0.01mg/l at Chittur to 2.7mg/l at Kozhinjanpara with an average of 0.46 mg/l (Table 4.3a) where as during the post monsoon it ranges from 0.02 mg/l at Vandazhi to 2.9mg/l at Mannarkad with an average of 0.61mg/l (Table 4.3 b). The spatial distribution maps (Fig. 4.16a and 4.16b) of total iron concentration during both the seasons reveals that majority of the area falls within the 0.3mg/l to 1 mg/l category which is of desirable category (BIS).

4.4 Groundwater quality standards

The suitability of groundwater for a particular purpose depends up on the criteria for the purposes such as drinking, agricultural and industrial.

4.4.1 Drinking water standards

The standard values of the groundwater quality for drinking water represent the level of constituents present in the water which does not result in any significant risk to health. Groundwater is mainly used for drinking and other domestic purposes, for which a detailed chemical analysis of water is very much important, as certain chemical constituents became toxic beyond particular concentrations, although they may be beneficial at lower amount (Singhal and Gupta, 1999). In the present study drinking water standards prescribed by WHO, (1984) and BIS (BIS 10500:1994) is followed and is given in the Table 4.8. The physico-chemical parameters of the basin is compared with the drinking water standards and found that drinking water standards in

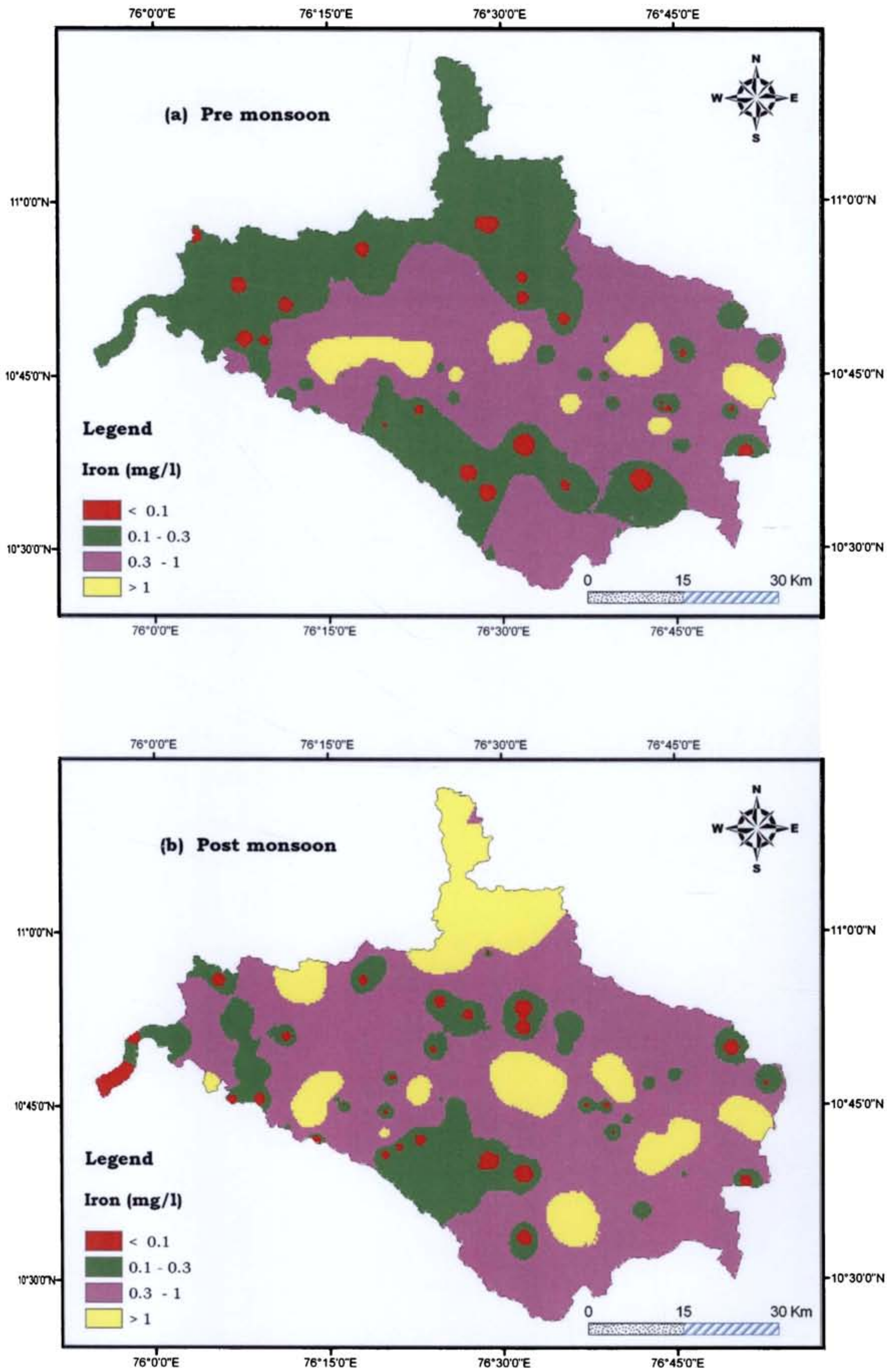


Fig. 4.16 Distribution of Total Iron in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

Table 4.8 Mean and Range values with various Drinking Water Standards.

Parameters	Pre monsoon		Post monsoon		WHO(1984)		BIS (1994) ISO: 105000	
	Range	Mean	Range	Mean	Highest desirable	Max. permissible	Desirable	Permissible limit
pH	6.11-9.1	8.01	6-8.9	7.67	7-8.5	6.5-9.2	6.5-8.5	NR
EC	86-1435	443	53-1325	403	-	1400	-	-
TDS	59-803	272	35-758	245	500	1500	500	2000
Cl	5.9-262	63.13	6-271	61.08	200	600	250	1000
HCO_3	28-351	126.36	23-373	119.75	-	-	-	-
Na	6-145	33.08	6.6-136	34.78	50	200	-	-
K	0.6-56	8.3	0.8-59	9.21	-	-	-	-
Ca	5-135	35.87	6-130	32.75	75	200	75	200
Hardness	10-570	143.11	11-452	125.6	100	500	300	600
Mg	2-98	19.03	1-89	17.12	150	150	35	150
SO_4	1.03-87	19.03	0.49-82	17.23	200	400	200	400
NO_3	0.3-110	10.28	0.01-120	10.16	-	45	45	100
Alkalinity	20-950	142	11-988	144.91	-	-	300	600
Fe	0.01-2.7	0.46	0.02-2.9	0.61	0.3	-	0.3-1	1
Fluoride	.01-1.2	0.48	.01-1.45	0.42	-	-	1	1.5

All values are expressed in mg/l except EC (μ S/cm) and pH.

the various physico-chemical constituents of the groundwater fall within the prescribed levels of BIS and WHO standards. Generally, the groundwater quality of the Bharathapuzha river basin is good and potable.

4.4.2 Classification of Groundwater for Agriculture/Irrigation utility

The suitability of groundwater for irrigation/agriculture have been evaluated by the methods suggested by Piper (1944), Kelly (1974), Wilcox (1948, 1955) and U S salinity Laboratory (1954). The quality criteria for irrigation suitability proposed by Wilcox, is generally used in which EC and sodium content are taken into consideration. The Wilcox (1948, 1955) classification was later modified by the workers of the US Salinity Laboratory (USSL, 1954). USSL classification is used in determination of salinity hazard, sodium hazard and specific effects of certain toxic constituents like chloride, bicarbonate, boron, lithium etc (Devis and Dewiest 1960).

The criteria for the irrigation water depend on the types of plants, amount of water used for irrigation, soil texture and composition, type of crops, irrigation practices and climate. Important chemical criteria for the agricultural use are the salinity and sodium hazard. Soluble salts reduce water availability to the crop, Relatively high proportion of sodium and or high concentration of bicarbonates reduces the rate of at which irrigation water enters soil where by sufficient water cannot be infiltrated to supply the crop adequately (Gupta, 1999).

The important parameters used to assess the general suitability of groundwater for irrigation are total dissolved solids, sodium absorption ratio, sodium percentage and residual sodium carbonate and other classification schemes based on these parameters.

Evaluation of groundwater quality for irrigation

Classification of irrigation water by Wilcox (1955) is based on EC, TDS, Sodium percentage and boron concentration.

Table 4.10 Classification of groundwater quality for irrigation (after Wilcox,1955)

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

4.4.2.a TDS

During rainy season, salts get leached and reach the groundwater table which lead to pollution of the groundwater regime. Water with TDS content less the 500 mg/l and 500 to 1000 mg/l are considered as good and fair for irrigation purpose (Suresh et al. 1991). Based on the Wilcox,1955 classification (Table 4.10) about 33 % of the samples of the pre monsoon comes under excellent, 55 % as good for irrigation and the remaining samples of permissible, water class for the irrigation In general, the groundwater in the river basin is ideal for irrigation.

4.4.2 b Sodium Percentage

Percentage of sodium in water is a parameter computed to evaluate the suitability for irrigation (Wilcox, 1948). The main effects of sodium are

a) Reduction in soil permeability and
b) Hardening of soil.

The sodium in irrigation waters is usually denoted as percent sodium and can be determined using the following formula,

$$\% \, Na = (Na^{+}) \times 100 / (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})$$

where the quantities of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} are expressed in milliequivalents per litre (epm).

Excess sodium combining with carbonate will lead to the formation of alkaline soils while with the chloride, saline soils are formed. Either of the soils will not support the growth of crops.

The sodium percentage in the study area ranges from 8.76% to 62.92% during the pre monsoon where as during the post monsoon it varies from 8.84% to 61.03% (Table 4.9a and 4.9b). The spatial distribution maps (Fig. 4.17a and 4.17b) of the sodium percentage shows that majority of the area fall in the excellent (Pre monsoon (av) - 28%, post monsoon (av)- 19%) to good (Pre monsoon (av)-63%, post monsoon (av) 60%) water class and the remaining small areas are seen as patches which are the permissible water class. As per the Indian

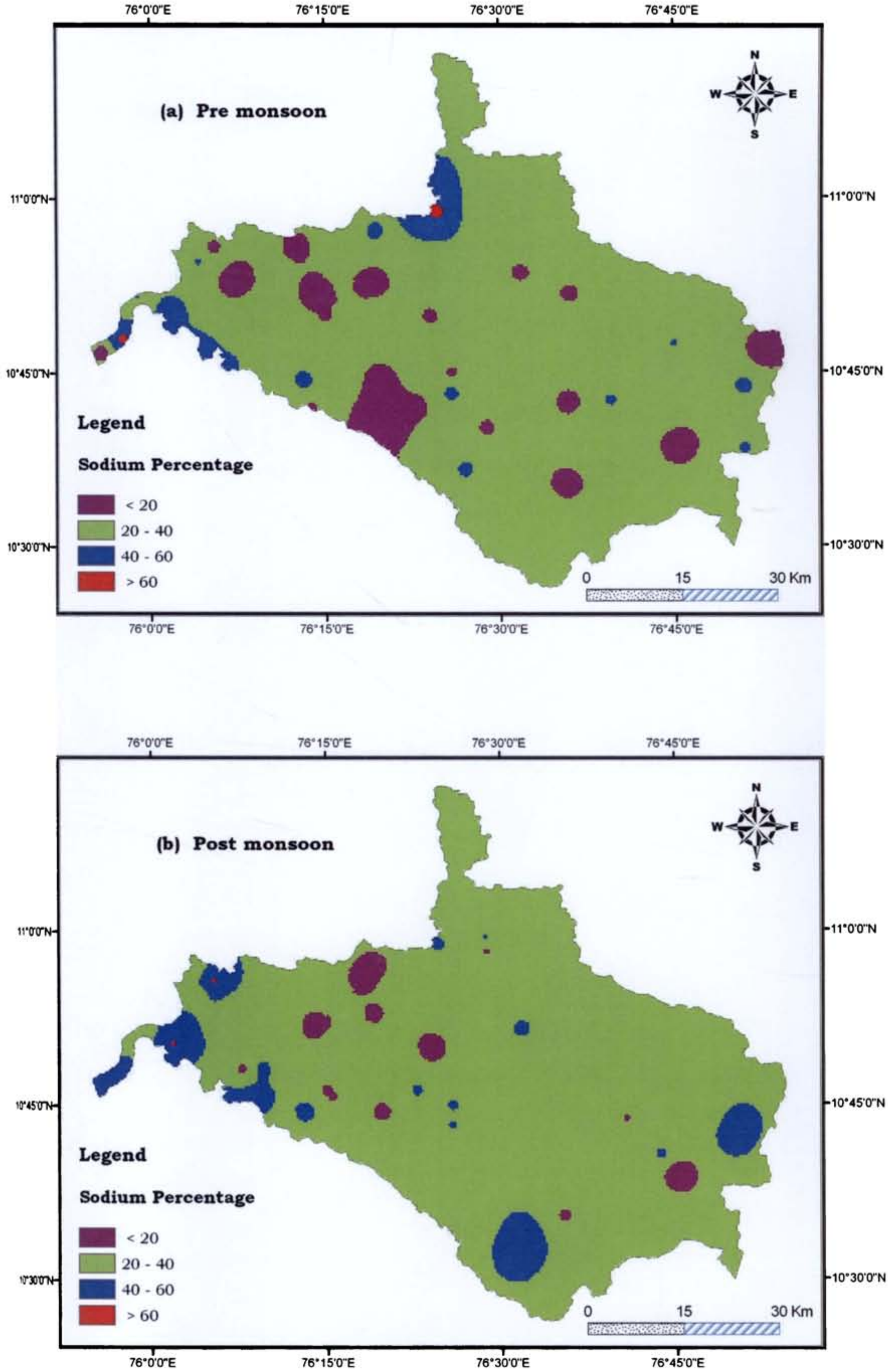


Fig. 4.17 Distribution of Sodium percentage in the Bharathapuzha river basin. (a) Pre monsoon (b) Post monsoon

Standard a maximum of 60% sodium is permissible for irrigation water. (Jain et al. 1996).

4.4.2c EC

The map also reveals that majority area of the basin in both seasons, the EC values fall within the range of 250 - 750 and the water is good for irrigation (Fig. 4.3a & 4.3b). The spatial distribution maps of EC for the study area reveals that for both the seasons, low EC values are recorded at north and northwest region, while higher values are observed at eastern part. The high EC values on the eastern part may be due to the addition of some salts from the agricultural practices

4.4.2d Wilcox diagram

Wilcox (1955) proposed a diagram based on the percent sodium and electrical conductivity in order to know the suitability of water for irrigation. This diagram which is known as Wilcox diagram classifies the irrigation water into different classes based on their quality as Excellent to Good, Good to Permissible, Permissible to Doubtful, Doubtful to Unsuitable and Unsuitable. The plotting of percent sodium and EC values in the Wilcox diagram shows that (Fig. 4.18a and 4.18b) in both seasons majority of the area falls in the excellent to good category where as few locations are in the good to permissible category. It is concluded that the groundwater quality based on Wilcox classification, the values of EC, sodium percentage and TDS of the Bharathapuzha river basin is good for irrigation purpose.

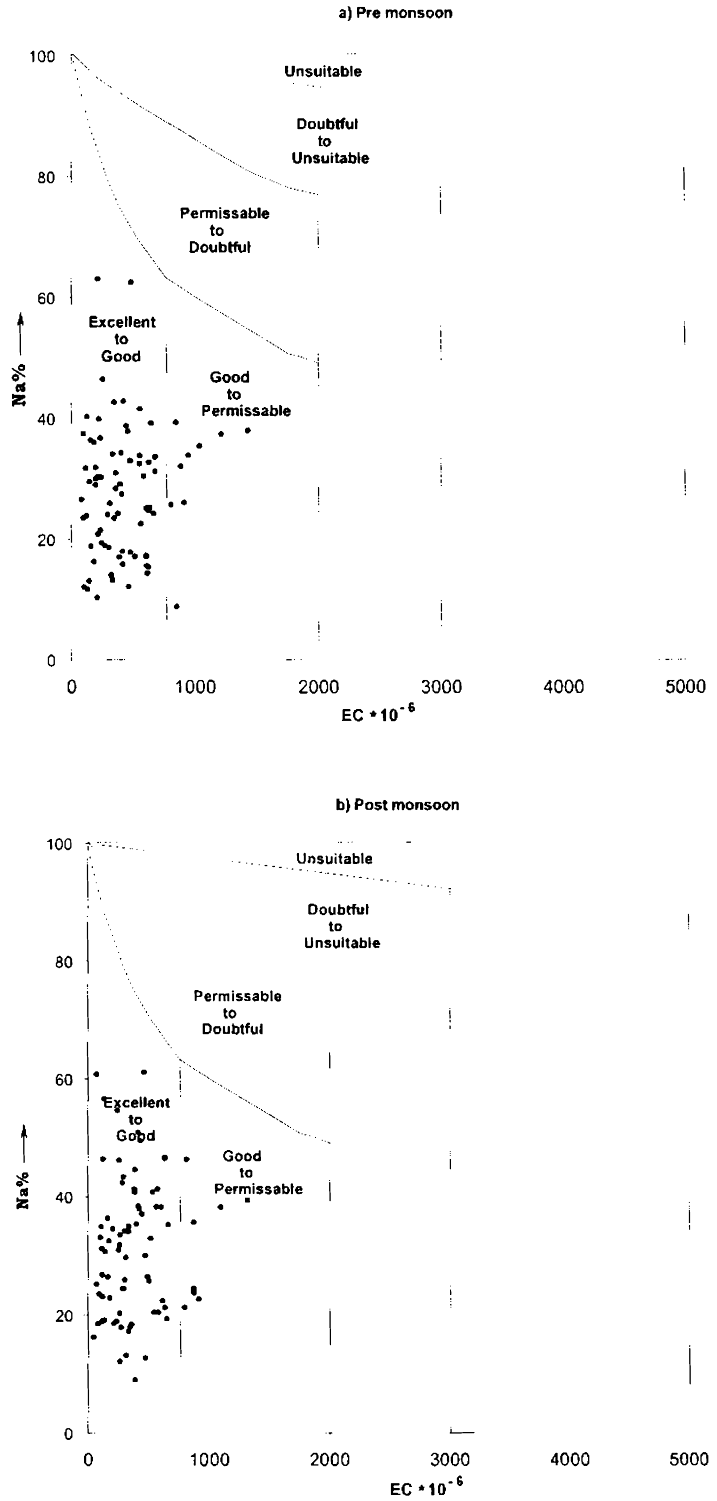


Fig. 4.18 Wilcox classification diagram for suitability of irrigation water in the Bharathapuzha river basin

4.4.2e Sodium Adsorption Ratio

Sodium Adsorption Ratio (SAR) is the value of adsorption of sodium by soil, when water percolates. A high value of SAR implies soil structure damage. The SAR is given by the formula as

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

Where the ionic concentration is expressed in meq/l

Excess sodium in water produces undesirable effects of changing soil properties and reducing soil permeability (Kelley, 1951). Hence, the assessment of sodium concentration is important while considering the suitability for irrigation.

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in the plant tissue when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil. Water has been classed into four groups as excellent, good, fair and poor based on SAR values (Richards, 1954) and is given in the Table 4.11

Table 4.11 Suitability of groundwater for irrigation purpose based on SAR (Richards, 1954) in the Bharathapuzha river basin.

Range of values	Water class	No of samples		Percentage	
		Pre monsoon	Post monsoon	Pre monsoon	Post monsoon
<10	Excellent	81	81	100	100
10-18	Good	-	-	-	-
18-26	Fair	-	-	-	-
>26	Poor	-	-	-	-

During the pre monsoon the SAR values of the study area ranges from 0.32 to 3.44 (Table 4.9a) and in post monsoon it ranges from 0.33 to 3.24 (Table4.9b). The distribution map shows that lower values of SAR seen in central part of the area. Majority of the area shows the SAR values between 1 and 2 (Fig. 4.19a and 4.19b). Table 4.11 reveals that the water samples of the Bharathapuzha river basin belongs to excellent category for irrigation in both seasons.

4.4.2f Suitability of water through USSL diagram

The classification of water for irrigation proposed by the US Salinity Laboratory (USSL, 1954), Department of Agriculture is based on the salinity and sodium hazards. Salinity hazard is of specific conductance and sodium hazard is expressed in terms of Sodium Adsorption Ratio (SAR)

The classification of water for irrigation purpose is determined graphically by plotting the values of specific conductance on the horizontal axis and SAR values on the vertical axis of the USSL diagram (Fig. 4.20). Sodium and salinity hazards are the two parameters which can indicate the suitability of water for irrigation.

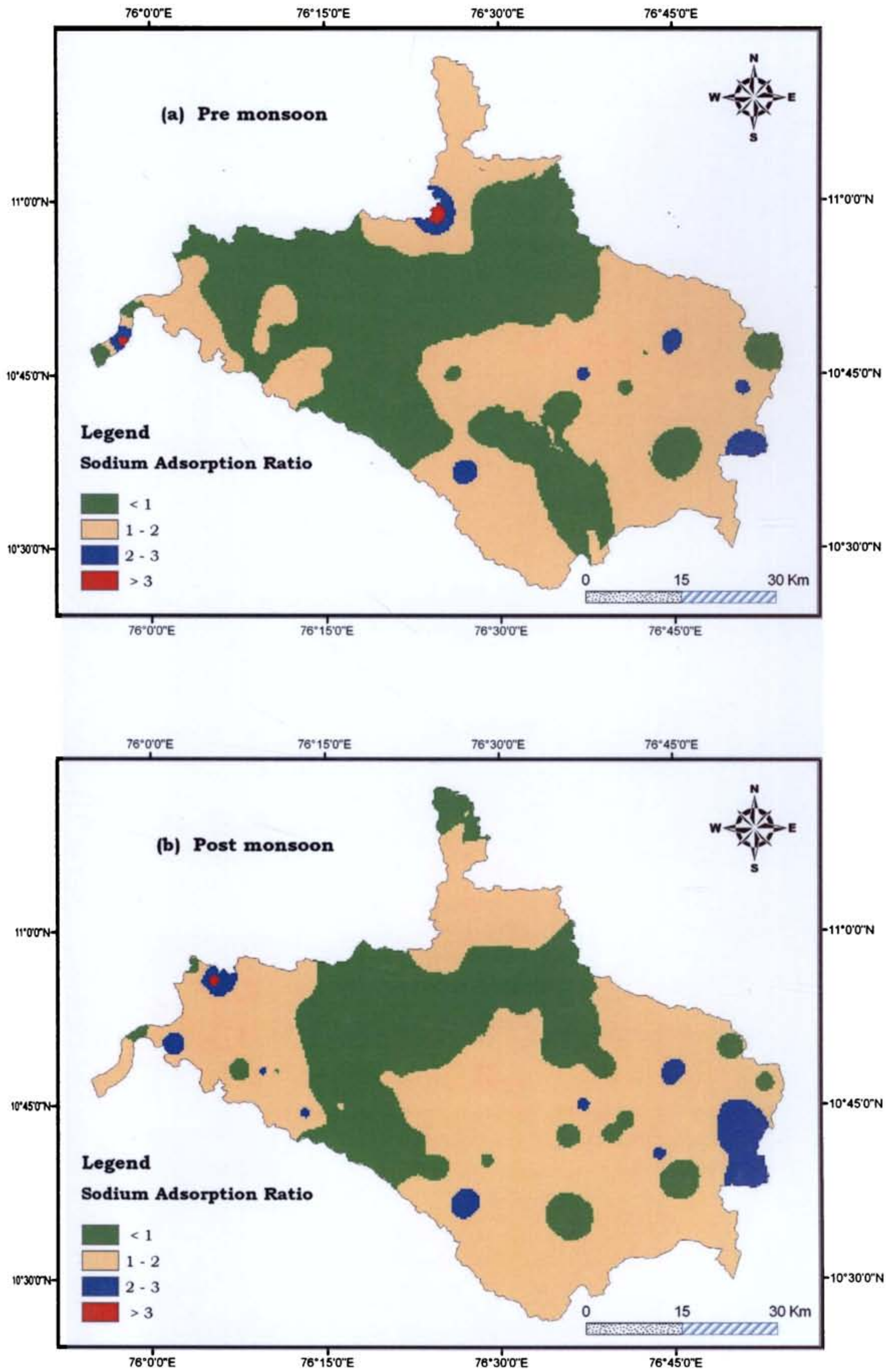
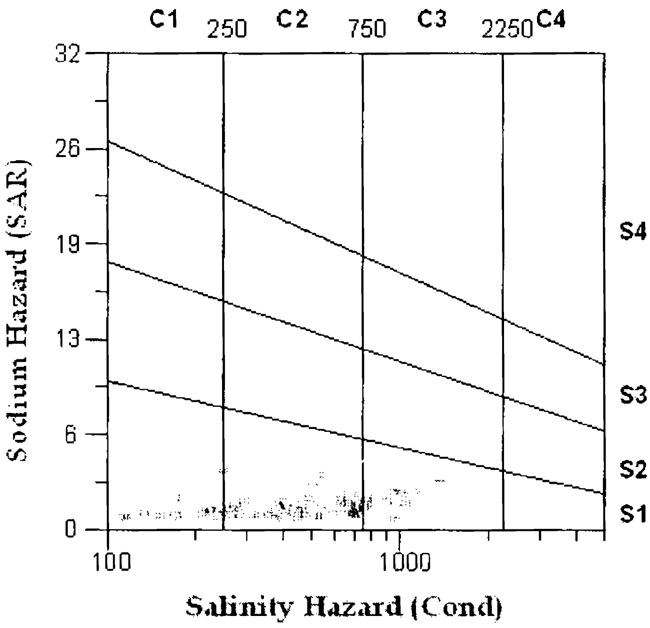


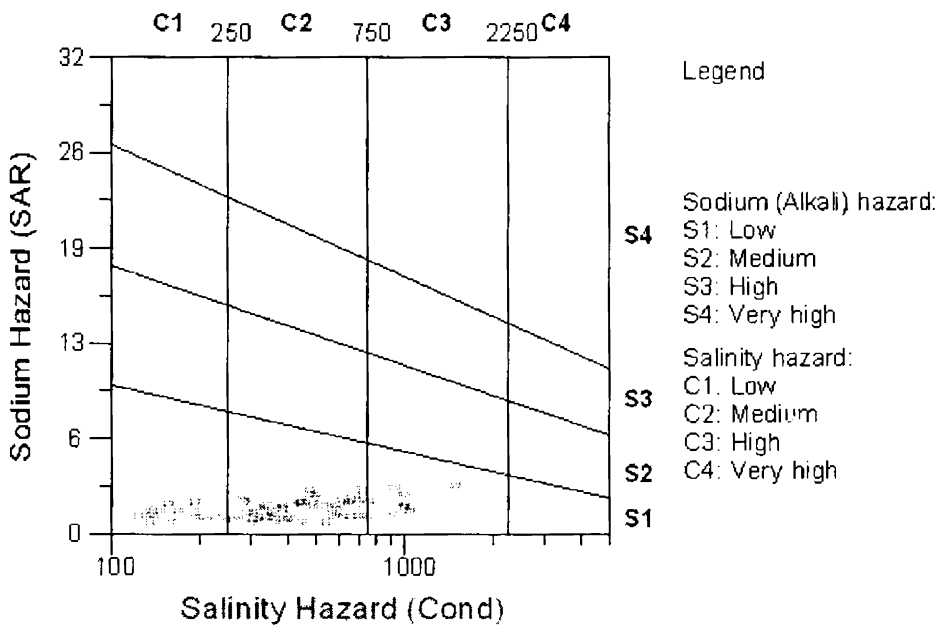
Fig. 4.19 Distribution of SAR in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

USSL Diagram

(a) Pre monsoon



(b) Post monsoon



4.20 Classification of groundwater based on USSL Diagram in the study area
(a) Pre monsoon (b) Post monsoon

On the basis of salinity hazard water have been divided into C1, C2, C3, C4 and C5 types and that of sodium hazard as S1, S2, S3 and S4 water types (Table 4.12). Based on USSL diagram for irrigation quality, the area can be divided into sixteen water classes as C1S1, C2S1, C3S1, C4S1, C5S1, C2S1, C2S2, C2S3, C2S4, C2S5 etc.

Table 4.12 Classification of Groundwater quality of irrigation based on U.S.S.L. diagram

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

Salinity hazard

Salinity hazard is of specific conductance of water (EC). The significance and interpretations of quality ratings based on the USSL diagram can be summarized as follows:

(i) Low salinity water (C1) can be used for irrigation with most crops on most soils. Some leaching is required, but this occurs under normal irrigation practices, except in soils of extremely low permeability.

(ii) Medium salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices of salinity control.

(iii) Medium to high salinity water (C3) is satisfactory for plants having moderate salt tolerance, on soils of moderate permeability with leaching.

(iv) 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 have to be selected.

(v) Very high salinity water (C5) is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soil must be permeable, drainage must be adequate, irrigation water must be in excess to provide considerable leaching and salt tolerant crops should be selected.

Sodium hazard

Sodium hazard is expressed in terms of SAR and classified as follows;

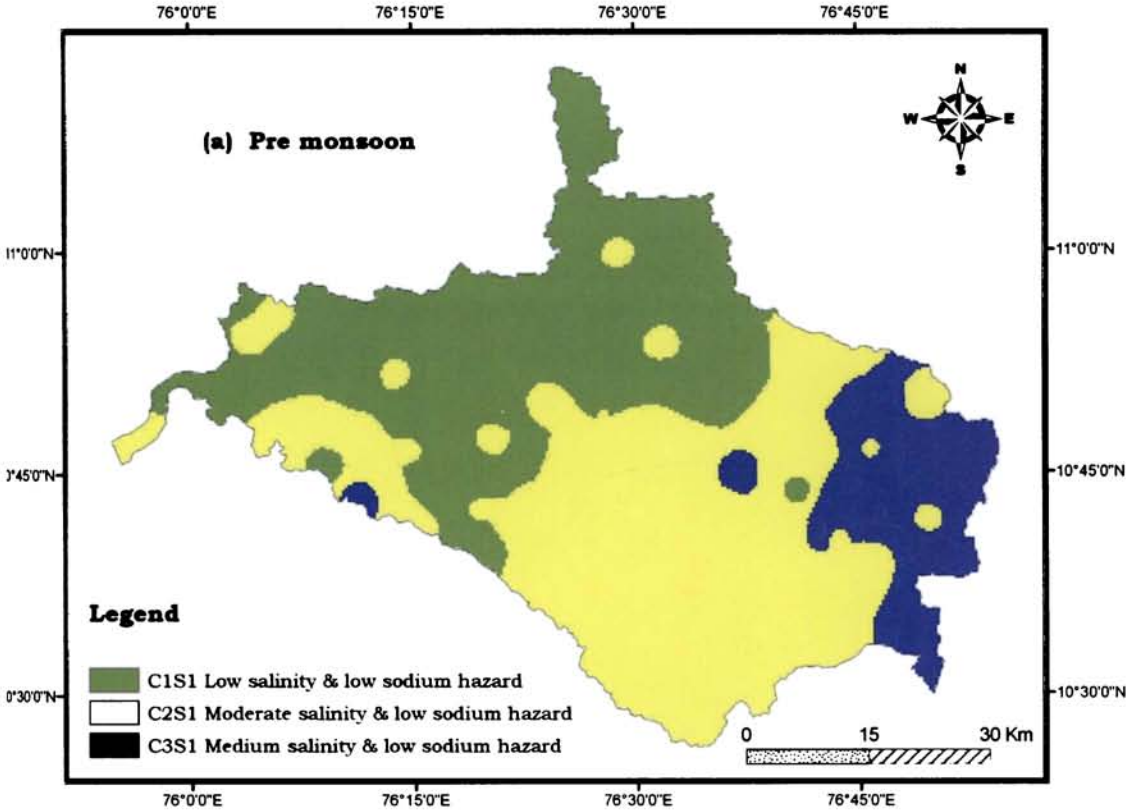
Low sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium sensitive crops, such as stone-fruit trees and avocados may accumulate injurious concentration of sodium.

Medium sodium water (S2) can be used for irrigation in fine-textured soils of high cation exchange capacity, especially under low leaching conditions, unless gypsum is present in the soil, presents appreciable sodium hazard, but may be used on coarse textured or organic soils which have good permeability.

High sodium water (S3), may produce harmful levels of exchangeable sodium in most soils and will require special soil management like good drainage, high leaching and addition of organic matter. Gypsiferous soils may not develop harmful level of exchangeable sodium from such water.

Very high sodium water (S4) is generally unsatisfactory for irrigation purposes, except at low and perhaps medium salinity. Application of gypsum or other amendments may render this water feasible. Application of gypsum also increases the crust conductivity property of the soil as elaborated by Goyal and Jain (1982).

Classification of groundwater based on USSL diagram (Fig. 4.20) of the study area for the pre monsoon shows that 32% of the samples belongs to C1S1 (low salinity hazard and low sodium alkali hazard) class, 57% of the samples fall in the C2 S1 class (moderate salinity hazard and low sodium alkali hazard) and the remaining 11% are in the C3S1 class (medium salinity hazard and low sodium alkali hazard) where as during the post monsoon 28% of the samples falls in the C1S1 class, 61% of the samples are in the C2S1 class and the remaining 11% of the samples belongs to C3S1 class. From the distribution maps of groundwater drawn using USSL diagram for the study area (Fig. 4.21a and 4.21b) it is seen that for both seasons



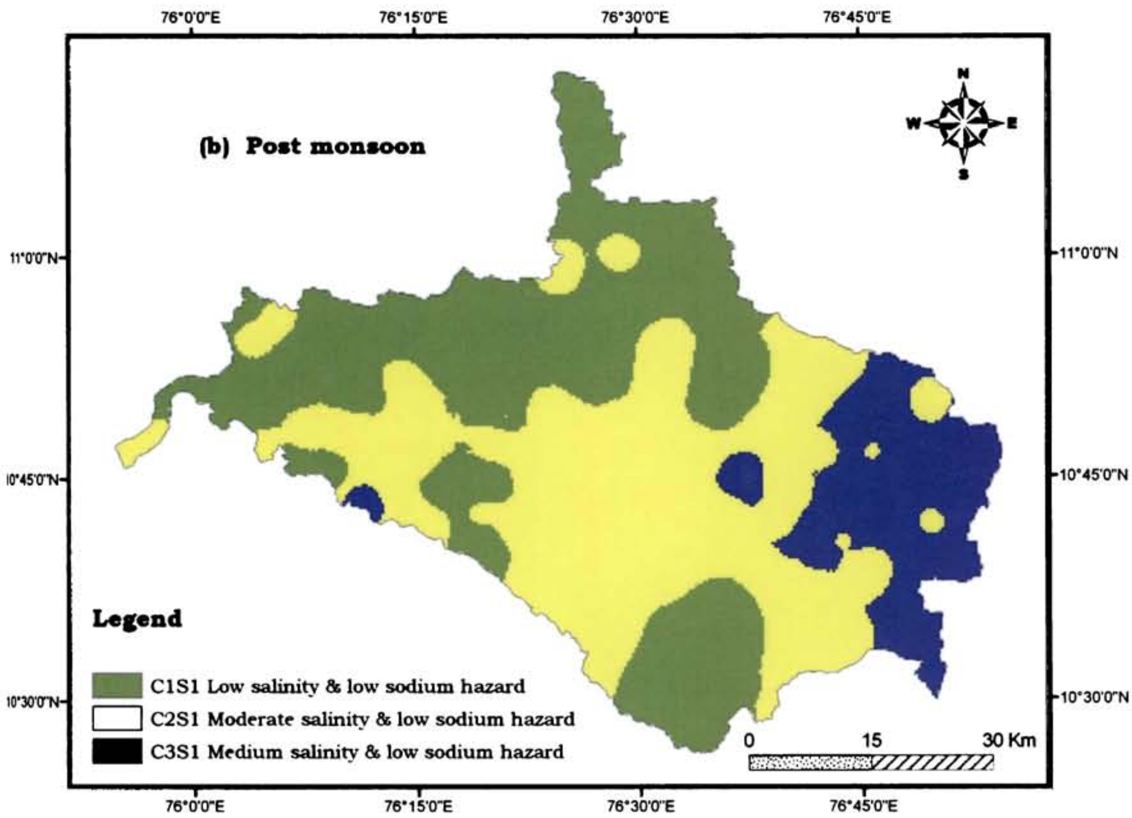


Fig. 4.21 Distribution of groundwater based on USSL diagram in the Bharathapuzha river basin. (a) Pre monsoon (b) Post monsoon

eastern side have medium salinity and a low sodium hazard (C3 S1) whereas north west and southern part of the area it is low salinity and low sodium hazard (C1S1) and that of central part and river mouth is characterised by moderate salinity and low sodium hazard (C2 S1). In general, based on the U.S.S.L diagram (1954) the groundwater of the Bharathapuzha river basin is considered as good for irrigation.

4.4.2g Residual Sodium Carbonate

Eaton (1950) suggested the Residual Sodium Carbonate (RSC) index can be used to evaluate bicarbonate hazard. The hazard caused on soils by excess of carbonate and bicarbonate ions in irrigation water is called bicarbonate hazard. It is due to the increase of sodium in the soil which leads to the formation of soda alkali soils.

RSC is defined as the excess of carbonate and bicarbonate amount over the alkaline earths mainly of calcium and magnesium. When it is present in excess of permissible limits, affects the irrigation adversely (Eaton, 1950 and Richards, 1954). Residual Sodium Carbonate is given by the equation.

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

These units are expressed in meq/l of water. Excessive RSC causes the soil structure to deteriorate, due to the restricted movement of air and water through the soil. Eaton has classified the water for Irrigation into three classes based on RSC values which are given in the Table 4.13.

Table 4.13 Classification of Groundwater based on Residual Sodium Carbonate, Eaton (1950)

RSC (meq/l) Range	**Water class**
<1.25	Excellent
1.25-2.5	Good
>2.5	Unsuitable

The RSC values for the Bharathapuzha river basin ranges from 3.95 meq/l to 0.55 meq/l during pre monsoon (Table 4.9a) where as in the post monsoon it ranges from 3.74 meq/l to 0.99 meq/l (Table 4.9b). The spatial distribution map shows that the RSC values of the basin in both seasons (Fig. 4.22a and 4.22b) falls with in the excellent water class.

4.4.3 Corrosivity Ratio

Ryzner (1944) proposed a ratio to evaluate corrosive tendency of groundwater towards metallic pipes. Badarinath et al. (1984) and Balasubramaniam and Sastry (1987) used this ratio for the analysis of groundwater chemistry to evaluate its effects on metallic pipes during the transport of water from the source to consumer.

Corrosivity ratio (CR) can be calculated by using the formula,

$$\text{Corrosivity Ratio} = \frac{0.028\,Cl + 0.021\,SO4}{0.02\,(HCO3 + CO3)}$$

Where, all values are expressed in mg/l.

The corrosivity ratio could be positive or negative, and the groundwater having corrosivity ratio less than one is safe and non-

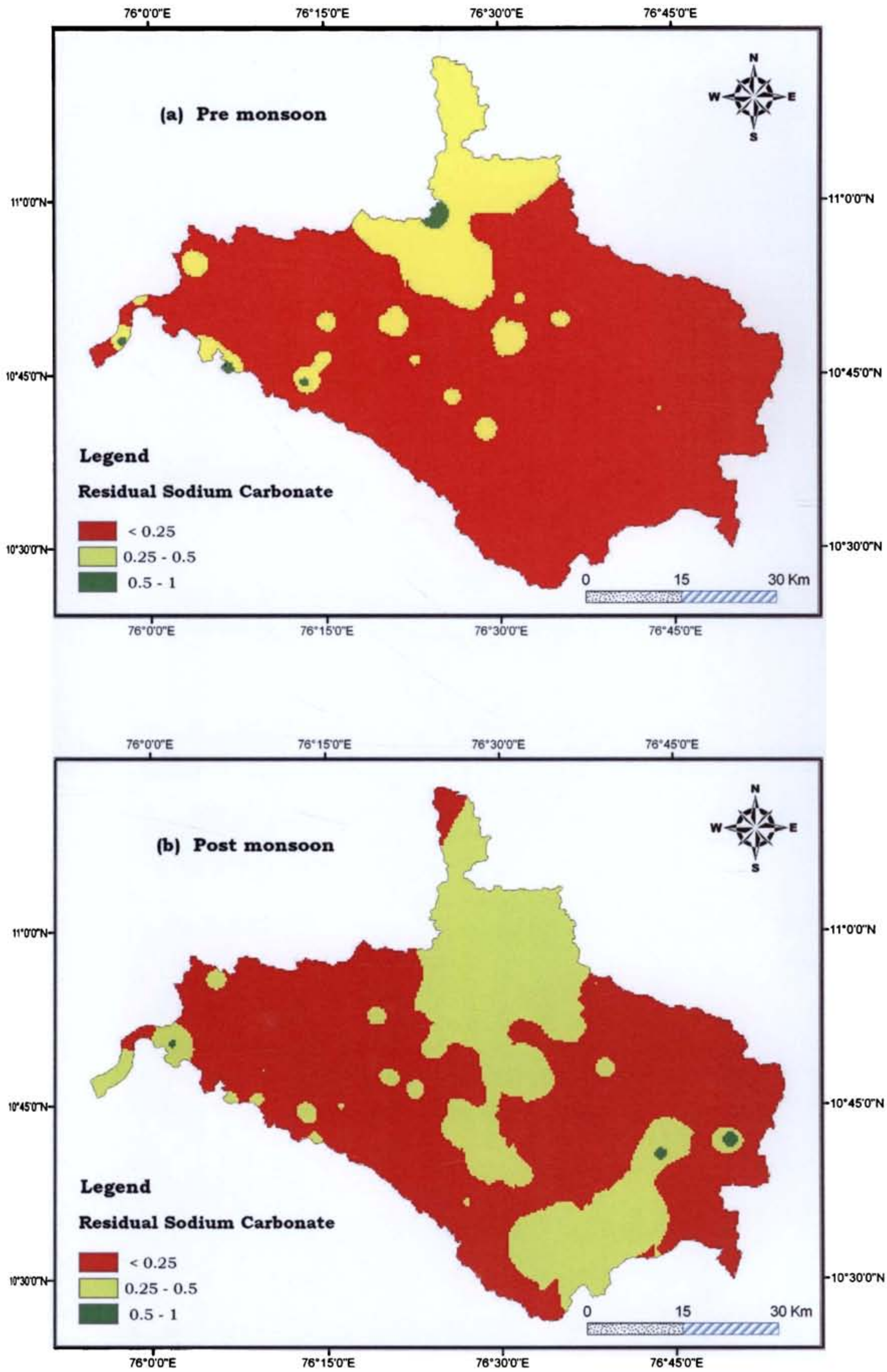


Fig. 4.22 Distribution of RSC in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

corrosive. Water with a corrosivity ratio greater than one cannot be transported to consumer points through metallic pipes.

The corrosivity ratio determined for the groundwater in the study area is given in the Table 4.9a and 4.9b and the spatial distribution of corrosivity ratio drawn for both the seasons shows that (Fig. 4.23a and 4.23b) major portions of the study area are fall in the safe zone where as part in the eastern and western part of the basin is unsafe zone. Poly Vinyl Chloride (PVC) pipes are recommended in the unsafe zone for carrying water instead of metallic pipes.

4.5 Hill – Piper Trilinear diagram

Presentation of chemical analysis in graphical form makes understanding of complex groundwater system simpler and quicker. The Piper–Hill diagram (Piper, 1953) is used to infer hydrogeochemical facies. These plots include two triangles, left triangle one for plotting cations (milli equivalent per litre) as a single point on the left triangle and the right triangle for plotting anions (milli equivalent per litre). The cation and anion fields are combined to show a single point in a diamond-shaped field, from which inference is drawn on the basis of hydrogeochemical facies concept (Back and Hanshaw, 1965). The trilinear diagram conveniently reveals similarities and differences among groundwater samples because those with similar qualities will tend to plot together as groups (Todd, 1980). These tri-linear diagrams are useful in bringing out chemical relationships among groundwater samples in more definite terms rather than with other possible plotting

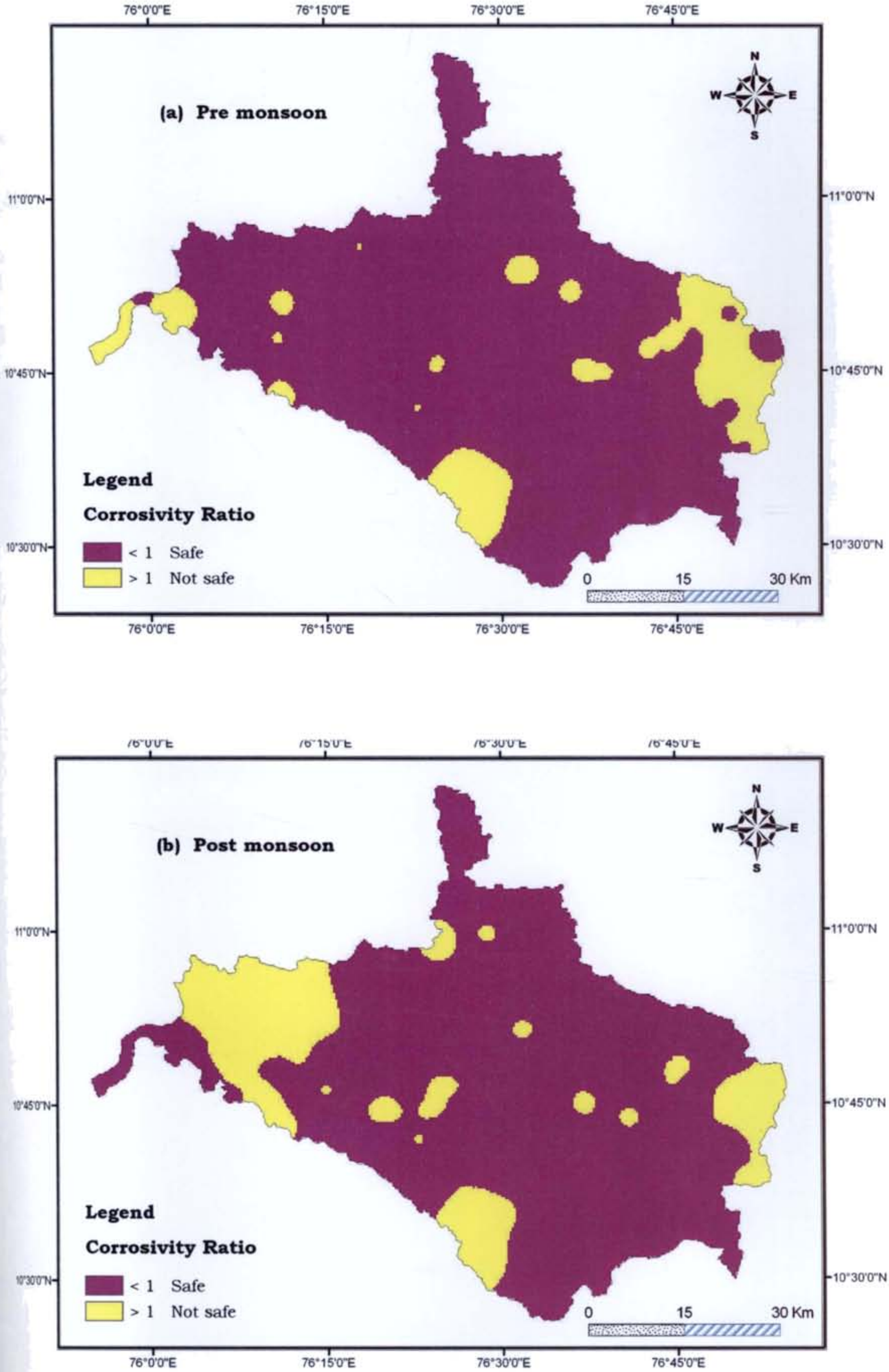
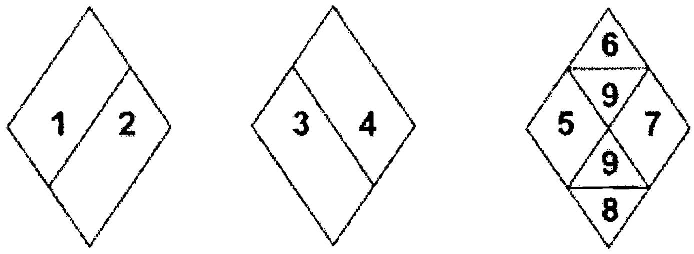


Fig. 4.23 Distribution of Corrosivity Ratio in the Bharathapuzha river basin
(a) Pre monsoon (b) Post monsoon

methods (Walton, 1970). Chemical data of the area are subjected to graphical treatment by plotting them in a Piper (1944) trilinear diagram. Distribution of groundwater samples in different sub divisions of the diamond- shaped field of the Piper diagram reveals that the water samples fall in the sub divisions 1 to 9 (Fig. 4.24).

The trilinear diagram described above is useful for visually describing differences in major ion chemistry in groundwater flow systems. For this purpose Back (1961 and1966), Morgan and Winner (1962) and Seaber (1962) have developed the concept of hydrochemical facies. Facies are identifiable parts of different nature belonging to any genetically related body or system. Thus hydrochemical facies are distinct zones that have cation and anion concentration describable within defined composition categories (Freeze and Cherry, 1979). The facies mapping approach is one way of smoothing chemical data. The limited number of possibilities (facies) for classifying the chemical data effectively eliminates local variability yet preserves broad trends (Domenico and Schwartz, 1990).

Chemical data of the study area is presented by plotting them on a Piper tri-linear diagram for Pre and Post monsoons. These diagrams reveal the analogies, dissimilarities and different types of waters in the study area, which are identified and listed in Table 4.14. The concept of hydrochemical facies was developed in order to understand and identify the water composition indifferent classes (Seaber, 1962 and Back, 1961). Facies are recognizable parts of different characters belonging to



The Hydrochemical facies of groundwater

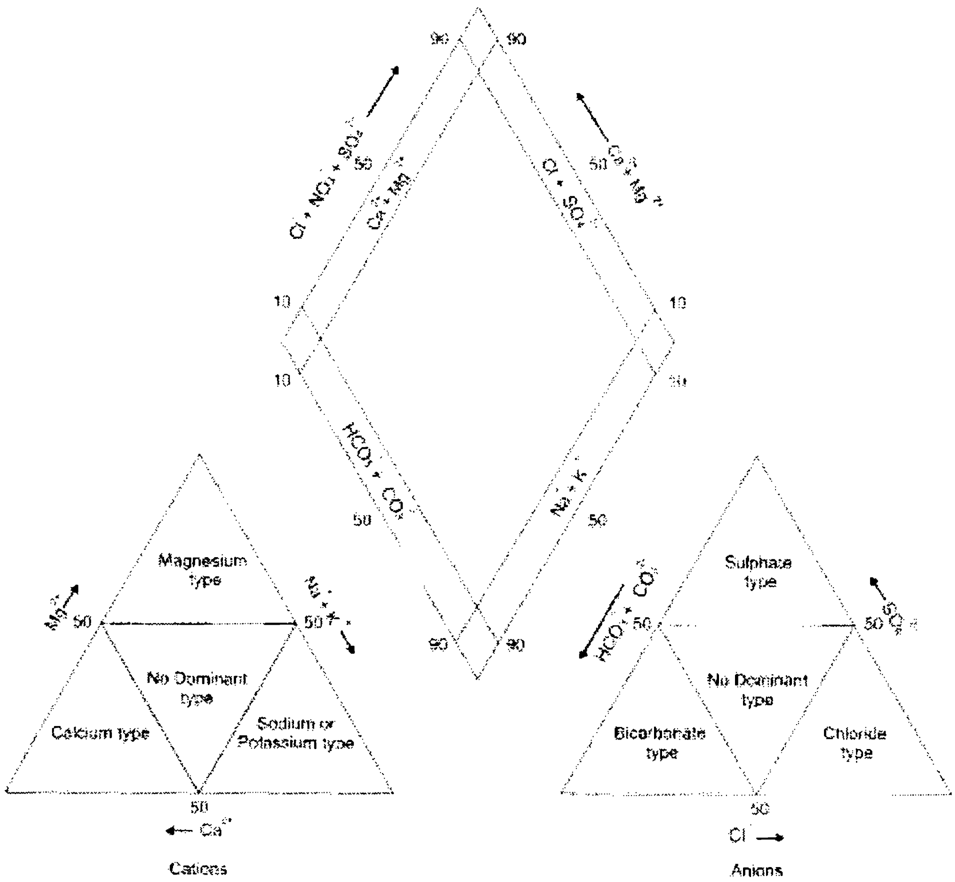


Figure 4. 24 Classification diagram for anion and cation facies in the form of major-ion percentages. Water types are designated according to the domain in which they occur on the diagram segments. (Source : Kumaresan , 2006)

any genetically related system. Hydrochemical facies are distinct zones that possess cation and anion concentration categories. To define a composition class, Back and Hanshaw (1965) have suggested 29 sub divisions in the tri-linear diagram (Figure 4.24). The interpretation of distinct facies from the 0 to 10% and 90 to100% domains on the diamond-shaped cation to anion graph is more helpful than using equal 25% increments.

Piper's trilinear diagram (Fig. 4.25) has been extensively used to understand problems relating to groundwater chemistry (Karanth, 1987). Based on the Piper's trilinear classification the groundwater of the area under investigation is classified and described in the Table 4.14.

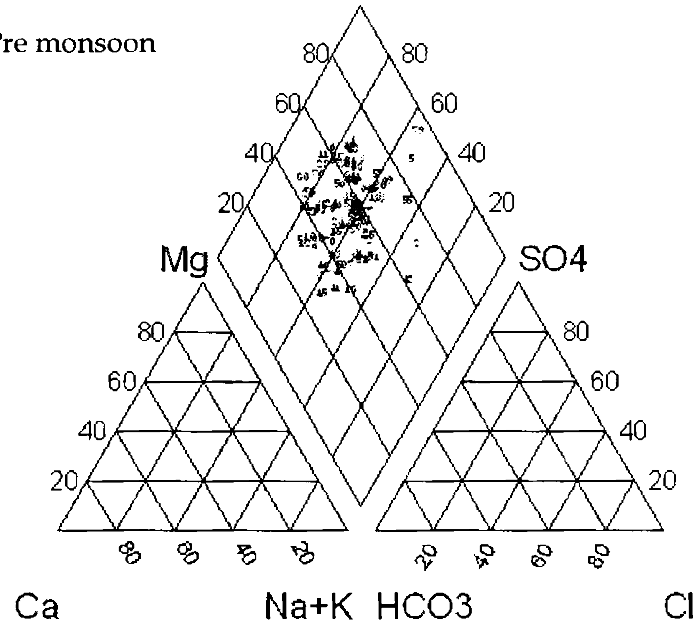
In the study area, the water samples fall in the upper half of the diamond field suggesting that these water samples are primarily alkaline in nature. The Table 4.14 shows that for the pre monsoon (50.63%) and that of Post monsoon (38.27%), carbonate hardness exceeds 50% (sub division number 5 of the diamond shaped field) .So also 45.67% in the pre monsoon and 49.38% in post monsoon represents no cation - anion pair (sub division number 9 of the diamond shaped field). Fourty one water samples (50.65%) in the Pre monsoon and 31 water samples (38.27%) in the post monsoon falls in the

Table 4.14 Suitability of groundwater based on Hill Piper's Trilinear Diagram of the Bharathapuzha river basin. (After Piper, 1944)

Sub division Number of diamond shaped field	Characterization of Sub division of diamond shaped field	No. of samples		Percentage	
		Pre monsoon	Post monsoon	Pre monsoon	Post monsoon
1	Alkaline earths (Ca + Mg) exceed alkalies (Na + K)	-	-	-	-
2	Alkalies exceeds alkaline earths				
3	Weak acids (CO3 + HCO3) exceed strong acids) (SO4 + Cl + F)				
4	Strong Acids exceedweak acids				
5	Carbonate hardness (secondary alkalinity) exceeds50% (chemical properties are dominated by alkaline earths and weak acids)	41	31	50.63	38.27
6	Non-carbonate hardness (secondary salinity) exceeds 50% (chemical properties are dominated by alkaline earths and strong acids)				
7	Carbonate alkali (primary salinity) exceeds 50% (chemical properties are dominated by alkalies and weak acids)	3	10	3.70	12.34
8	Carbonate alkali (primary alkalinity) exceeds 50% (chemical properties aredominated by alkalies and weak acids)				
9	No cation–anion pair exceeds 50%	37	40	45.67	49.38

Hill - Piper Trilinear Diagram

(a) Pre monsoon



(b) Post monsoon

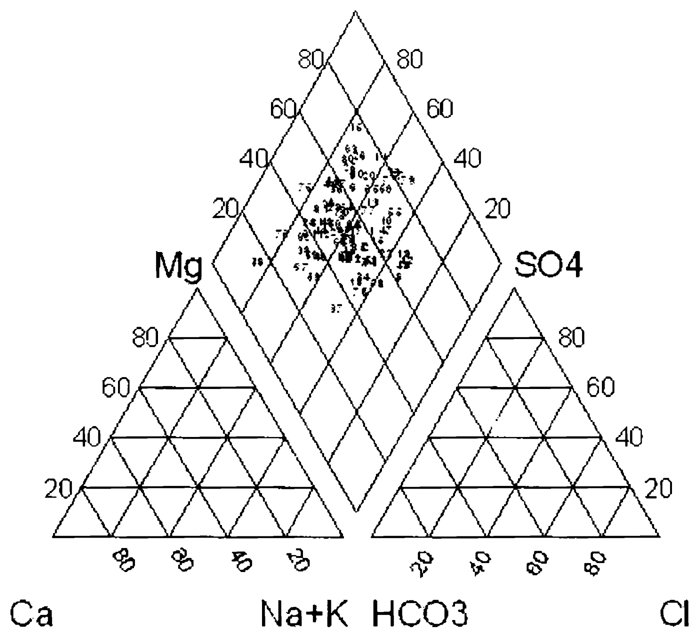


Fig. 4.25 Hill – Piper Trilinear Diagram of groundwater of the study area
(a) Pre monsoon (b) Post monsoon

4.6 STATISTICAL ANALYSIS OF GROUNDWATER CHEMISTRY

Correlation matrix

The correlation matrix of the chemical parameters in the groundwater samples of the Bharathapuzha river basin for Pre and Post monsoons shown in the Table 4.15a and 4.15b. It is inferred from the table that EC has a high significant correlation with Ca, Na, Mg, TDS, Total hardness, Cl in both the seasons. Further EC shows a highly significant correlation with HCO_3 for post monsoon. The above relationship indicates that EC has a major role in controlling the groundwater quality irrespective of the season. Ca also shows a highly significant correlation with TDS, EC and TH in both the seasons. Total iron shows highly significant correlation with HCO_3+CO_3 in pre monsoon due to the leaching of iron from laterites. Sodium has significant correlation with EC, TH, TDS, Ca, and Mg in both seasons. Chlorine shows correlation with EC, TH, TDS, Ca, Mg, and Na in all seasons. Sulphate has significant correlation with EC, TDS, Ca, and Na in both seasons.

Table 4.15a Correlation matrix of the chemical parameters in the groundwater samples in the Bharathapuzha river basin (pre monsoon)

	pH	EC	TH	TDS	ca	mg	Na	K	CO_3 $+HCO_3$	Cl	SO_4	No_3	F	T.Fe
pH	1.00													
EC	0.17	1.00												
TH	0.28	0.71	1.00											
TDS	0.16	0.99	0.71	1.00										
Ca	0.12	0.65	0.71	0.67	1.00									
Mg	0.07	0.75	0.69	0.74	0.47	1.00								
Na	0.19	0.75	0.60	0.74	0.57	0.65	1.00							
K	0.00	0.34	0.26	0.34	0.37	0.20	0.37	1.00						
CO_3+HCO_3	0.45	0.12	0.10	0.12	0.05	0.04	0.08	-0.07	1.00					
Cl	0.05	0.76	0.63	0.75	0.63	0.77	0.85	0.37	0.11	1.00				
SO_4	0.13	0.64	0.56	0.65	0.66	0.55	0.71	0.43	-0.01	0.60	1.00			
NO_3	0.04	0.42	0.37	0.40	0.31	0.44	0.52	0.13	-0.14	0.41	0.51	1.00		
F	0.50	0.29	0.32	0.27	0.28	0.18	0.30	-0.03	0.58	0.25	0.12	-0.07	1.00	
T.Fe	0.30	0.01	-0.04	0.01	-0.07	-0.04	-0.05	-0.07	0.92	0.01	-0.08	-0.14	0.21	1.00

Table 4.15b Correlation matrix of the chemical parameters in the groundwater samples in the Bharathapuzha river basin (post monsoon)

	pH	EC	TH	TDS	ca	mg	Na	K	CO_3 +HCO_3	Cl	SO_4	No_3	F	T.Fe
pH	1.00													
EC	0.14	1.00												
TH	0.27	0.72	1.00											
TDS	0.15	0.99	0.72	1.00										
Ca	0.21	0.60	0.70	0.60	1.00									
Mg	-0.08	0.69	0.67	0.67	0.40	1.00								
Na	0.19	0.73	0.68	0.72	0.56	0.61	1.00							
K	0.17	0.34	0.29	0.33	0.31	0.25	0.25	1.00						
CO_3+HCO_3	0.20	0.69	0.78	0.68	0.82	0.66	0.63	0.38	1.00					
Cl	0.05	0.70	0.63	0.69	0.49	0.76	0.82	0.22	0.47	1.00				
SO_4	0.05	0.53	0.54	0.53	0.52	0.50	0.69	0.34	0.53	0.50	1.00			
NO_3	-0.06	0.36	0.34	0.35	0.26	0.47	0.50	0.06	0.21	0.46	0.50	1.00		
F	0.57	0.26	0.44	0.26	0.29	0.11	0.28	0.08	0.35	0.11	0.12	-0.01	1.00	
T.Fe	0.21	0.08	-0.08	0.08	-0.06	-0.14	0.01	0.32	-0.07	-0.04	-0.02	-0.14	-0.06	1.00

CHAPTER 5

GROUNDWATER RESOURCE MANAGEMENT

5.1 INTRODUCTION

Groundwater represents one of the most important water sources in India and accounts for nearly 400 km^3 of the annual utilisable resource in the country. Indiscriminate development and unscientific management of this resource has led to multiple problems of decline in groundwater level, sea water ingress, in-land salinity, groundwater pollution, land subsidence etc. So groundwater management is as important as surface water management. The purpose of Sustainable Water Management (SWM) is simply to manage our water resources while taking into account the needs of present and future users. The International Hydrological Programme, a UNESCO initiative, noted:

"It is recognized that water problems cannot be solved by quick technical solutions, solutions to water problems require the consideration of cultural, educational, communication and scientific aspects. Given the increasing political recognition of the importance of water, it is in the area of sustainable freshwater management that a major contribution to avoid/solve water-related problems, including future conflicts, can be found."

Proper management is hardly considered until actual fall of water level is noticed. The measures to be adopted in the country to meet the increased water demand in the new millennium would include exploration of deeper aquifers, groundwater recharge, development of aquifers in flood plains, direct use of saline/brackish water, conjunctive use of surface and groundwater in canal command area, creation of groundwater sanctuaries and regulation of groundwater development.

Groundwater continues to serve as a reliable source of water for variety of purposes including industrial and domestic use. The use of high- quality groundwater for irrigation draft all other uses (Burke, 2002). The groundwater and the aquifer that host it are inherently valuable to wide range of human impacts. The development of mechanized pumping has induced widespread depletion of groundwater. This over exploitation of groundwater affects the yield of the surrounding region. The disposal of human and industrial waste and the percolation of pesticides and herbicides have degraded many aquifers beyond economic remediation. Reduction of yield and deterioration in water quality made the need for better management of groundwater. Groundwater has special importance in the development and improvements of agriculture. The river basin can be visualised as a large natural underground reservoir. Urbanisation, drought, agricultural and industrial expansion, unscientific and over exploitation of groundwater, withdrawal etc have imparted serious problems in the groundwater status of the Bharathapuzha river basin, which in turn affect the base flow. It is observed that the available groundwater resources are not properly managed and hence Ground Water Management is the need of the hour.

The construction of minor irrigation tanks, percolation tanks, conjunctive use of surface and groundwater are being adopted to increase groundwater storage, conserving and relocation of groundwater. Many technically feasible groundwater management methods are being adopted to increase groundwater supply by recharging aquifer storage. Advanced water treatment technology, recycling techniques and analytical tools such as groundwater modeling are also being adopted. The present chapter deals with the estimation of water resources of the study area, groundwater potential zones of the Bharathapuzha river basin, suitable sites for artificial recharge and management aspects of the basin. Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrologic cycle (Kumar, 1996).

The groundwater potential of the Bharathapuzha river basin has been worked out and presented in the following sections.

5.2 ESTIMATION OF GROUNDWATER RECHARGE

Recharge to the groundwater systems form a part of the hydrological cycle. There are many methods for computing the groundwater recharge and the following simple methods have been used in this study.

1) Rainfall infiltration method and
2) Hydrodynamic method

Rainfall infiltration method

In the Bharathapuzha river basin, a considerable part of the basin is underlain by hard rocks which are practically impervious. The storage capacity of the rocks is so limited and depends on the degree and depth of weathering as well as fracturing. The calculation of groundwater recharge by using rainfall infiltration method is based on the following formula.

Groundwater recharge = Area x Rainfall infiltration factor x Average annual rainfall

For the Bharathapuzha river basin:-

Area (A)	=	3586 km^2 (less hilly terrain)
Rainfall infiltration factor	=	5.5 % (Karanth, 1994)
Average annual rainfall	=	2650 mm
Groundwater recharge	=	A x RFI x Rainfall
	=	3580 x 0.055 x 2.65
	=	521.79 mm^3
		(after using appropriate units)

The rise in groundwater table levels will be the cumulative effect of contribution from different sources of recharge like atmospheric precipitation, seepages from tank and canals, recharge from groundwater irrigation etc (Subhash Chandra, 1994). Hence it is necessary to monitor the water levels through a network of representative observation wells. Based on this, CBIP (1976) and Adyalkar and Shrihari Rao (1979) suggested the use of Hydrodynamic method for water balance estimation which consider the application of quantitative changes in aquifer behaviour due to either natural recharge or discharge. The computation of recharge is based on the following equation.

Recharge = Area x Average water level fluctuation x Specific yield

For the Bharathapuzha river basin:-

Area	=	3586 km^2 (less hilly terrain)
Average water level fluctuation	=	5.54 m (Table 2.1)
Specific yield	=	0.03 (CGWB)

Recharge	=	Area x Water level fluctuation x Specific yield
	=	3586 x 5.54 x 0.03
	=	595.99 mm^3 (after using appropriate units)

The recharge obtained by this method is more reliable because of the actual measurements in the field and hence this value has been used for water balance studies. Ground Water Resource Estimation Methodology (GWREM) of Ministry of Water Resources, Government of India recommended that 5 % to 10 % of the total annual recharge may be assigned to account for natural discharges like base flow, evapotranspiration etc. The balance will account for the groundwater available for different purposes and it is known as net annual groundwater availability.

Net annual groundwater availability = 90 % of total recharge

= 536.39 mm^3

5.3 GROUNDWATER BALANCE

Groundwater balance of the basin is necessary to determine the future development of groundwater. Based on the values of recharge and draft, the mean available groundwater balance in the basin can be expressed as follows:-

Net annual groundwater availability	=	536.39 M CuM
Total draft of the groundwater	=	337.56 M CuM *(CGWB,2004)
Groundwater balance	=	Net annual groundwater availability – Total draft of the groundwater
	=	536.39 – 337.56
	=	198.83 M CuM
Stage of development of the basin	=	$\left(\frac{\text{Total draft x 100}}{\text{Net availability}}\right)$
	=	$\left(\frac{337.56 \times 100}{536.39}\right)$
	=	62.93%

GWREM (1997) have categorised areas based on the stage of the development as 'safe' (<70 %), 'semi critical' (<70-90 %), 'critical' (90-100 %) and 'over exploited' (>100%). The present study revealed that 62.93 % of the available groundwater is being used and hence the Bharathapuzha river basin can be considered as '*safe areas*'.

5.4 STATIC GROUNDWATER RESERVE

An estimation of static groundwater reserve is desirable for planning the optimum utilization for future development of the groundwater resource of an area. The computation of static groundwater reserve could be done by considering the aquifer thickness and specific yield of the aquifer material. Static groundwater available in the Bharathapuzha river basin is computed considering the details of saturated aquifer thickness, specific yield and area. The equation used is

Static storage of groundwater = Area x saturated aquifer thickness x specific yield

For the Bharathapuzha river basin:-

Area (A)	=	3586 km^2 (less hilly terrain)
Saturated aquifer thickness (SAT)	=	27.32 m
Specific yield (Sy)	=	0.03
Static storage of groundwater	=	A X SAT X Sy
	=	3586 X 27.32 X 0.03
	=	2939.08 M CuM (after using appropriate units)

5.5 DEMARCATION OF GROUNDWATER POTENTIAL ZONES

Groundwater, being a vital resource, needs to be developed with proper understanding about its occurrence in time and space. Groundwater management on scientific lines has become inevitable for sustainability of this vital resource. In the present study, the factors like geomorphology, lineament, drainage, geology, slope, relative relief, transmissivity, storativity, land use and water table fluctuation were taken into consideration for evaluating the groundwater potential of the basin. An effective evaluation of groundwater potential zones can be done in an integrated way.

5.5.1 Preparation of thematic maps

In the present study, geological map has been prepared by using maps of the Geological Survey of India (GSI, 1995) in a scale of 1:5,00,000. Geomorphology, land use and lineament maps were generated from the remote sensing imagery (IRS-P6, LISS-4) at a scale of 1:50,000 and the drainage density, relative relief map and ground slope maps were prepared from the Survey of India (SOI) toposheet (49 N/13, 58 A/4, 58 A/8, 58 B/1, 58 B/2, 58 B/5, 58 B/6, 58 B/9, 58 B/10, 58 B/13 and 58 B/14) in a scale of 1:50,000 by digitising the drainage lines and contours.

Visual Interpretation

It is the traditional method for extracting information on various natural resources. P6 resource satellite image (LISS- 4, 2006 imaging mode) on 1:50,000 scale has been subjected to visual interpretation using certain fundamental photo elements viz., colour, tone, shape, texture, pattern, location and association, shadow aspects and resolution. The details of the IRS LISS 4 satellite data are given below

Path (Dec-Jan 2006)	Row
201	148,149
201	145,146,147
101	140,141,142

The base map has been prepared on 1:50,000 scale using SOI toposheet of the study area by overlying on satellite imagery. With the help of Arc GIS 9.1. Software, lineament, hydro geomorphology and land use maps have been prepared considering the imagery characteristics. From the contour map a Digital Elevation Model (DEM) has been generated and with the help of spatial analyst in Arc Scene software, slope map is prepared as a raster image.

All the doubtful areas in the imagery are identified and checked with the ground truth. Their geographical location and accessibility in the ground is verified with the respective toposheet. Proper ranks and weightages were assigned to each component based on their proximity, favouring the occurrence of groundwater. An index is formulated for all thematic maps based on their ranks and weightages. The final groundwater potential map was prepared based on the overall index (Groundwater prospective index-GWPI) obtained by the integration of all thematic layers selected for the study.

5.5.2 Geomorphology

Geomorphology is the scientific study of landforms for their genetic, dynamic and spatial aspects. Morphological characteristics of an area depend upon the physiochemical nature of lithological units existing therein. Hence the overall geomorphology of an area depends upon the structural evolution of the geological formation and chemistry of litho units. Geomorphology reflects various land forms and structural features. Many of the features are favourable for the occurrence of groundwater and are classified in terms of groundwater potentiality. These units are deciphered from the remote sensing data of the Bharathapuzha river basin and are shown in figure 5.1.

The topographic maps furnish a lot of information about the landforms and drainage patterns of the basin. The geomorphologic units of the basin can be divided into structural hills, residual hills, pediment zones, moderately dissected pediment zones, plateaus, moderately dissected plateaus, less dissected plateaus, braided drainage, channel bars, costal plains, water bodies, reservoir and valley fills. Among these, valley fills and flood plains are rich in groundwater and are very good locations for induced recharge. The evolution of the present landscape is the result of weathering and denudation. Thus the landforms are the result of the action of various endogenic and exogenic forces operating on the earth crust. These elements and their characteristics directly or indirectly affect the hydrological conditions (Reddy, 2004).

Geomorphological mapping of pediments, buried pediments, valley fills and their characterisation is very useful in groundwater investigations. Thus the study of the hydro geomorphology using remote sensing technique has much utility in groundwater studies.

The present study follows the classification of geomorphology by National Remote Sensing Agency (NRSA). Based on the ground truth verification, the geomorphology of the study area has been classified into 13 category with their areal extend (Table 5.1).

Table 5.1 Spatial distribution of various geomorphological units with their areal extent in the Bharathapuzha river basin

Sl No.	**Description**	**Area (Km^2)**
1	Moderately dissected Plateau	1258.38
2	Valley fills	892.04
3	Structural hills	813.96
4	Pediment zones	359.26
5	Less dissected plateau	338.97
6	Moderately dissected pediment zone	310.53
7	Plateau	233.45
8	Residual hills	50.61
9	Water body	47.11
10	Channel bars	42.22
11	Coastal plain	28.79
12	Reservoir	24.53
13	Braided drainage	0.14
Total		4400

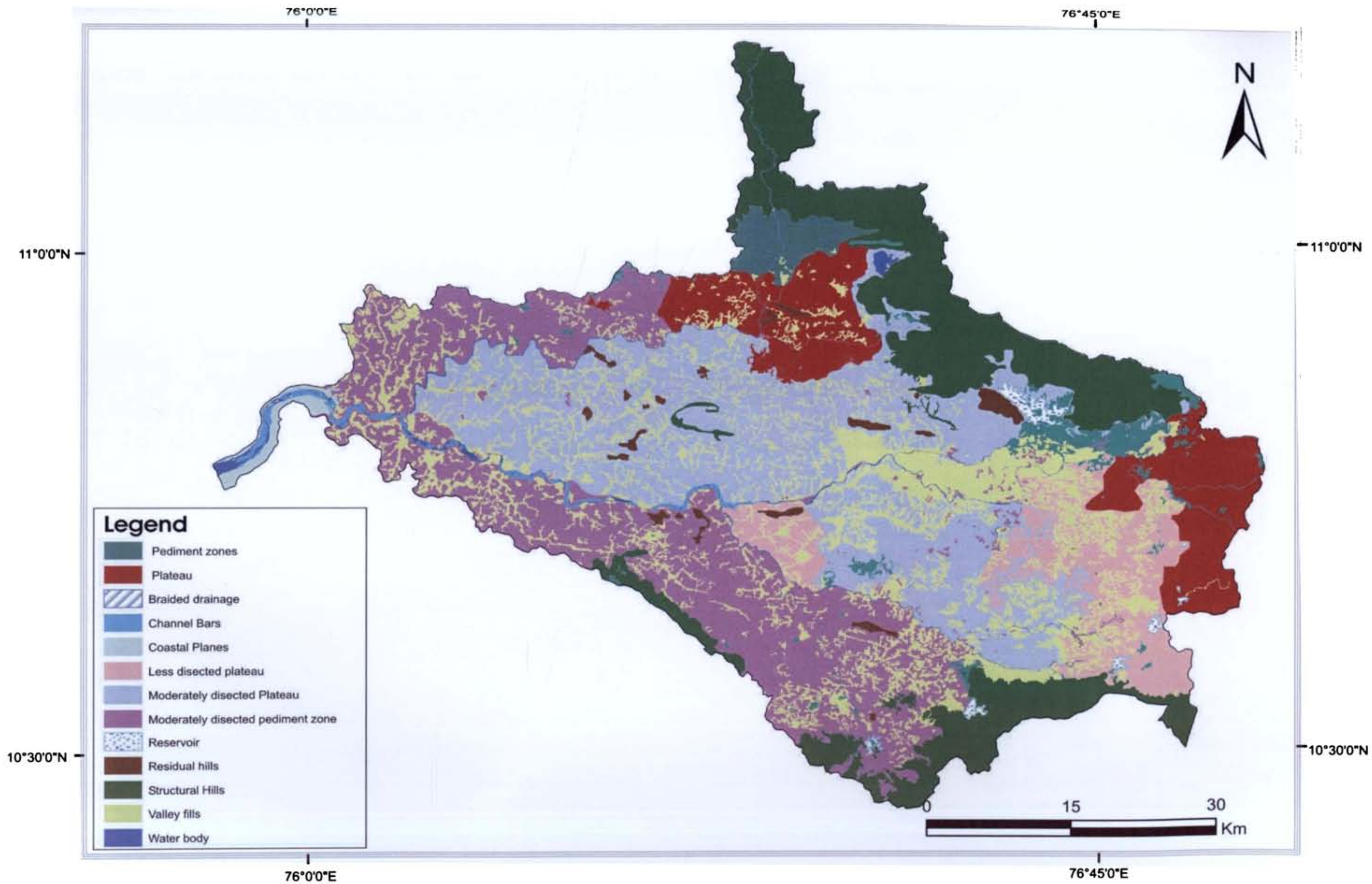


Fig. 5.1 Geomorphology of the Bharathapuzha river basin

• **Structural Hills**

In the study area, along the northern, northeastern and southern regions, the structural hills are significantly seen and along the central part of the basin there is an arch shaped structure . The major rock types on the north and northeast sides are biotite-hornblende gneisses, hornblende-biotite gneisses, charnokite, pink granite, quartzo feldspathic gneisses, hornblende-biotite gneisses with schist, calc granulite with limestone. Charnockite and quartzofeldspathic gneisses are seen in southern region. Structural hills cover an area of 813.96 Km^2 in the study area (Table 5.1). Normally structural hills are considered to be poor source of groundwater. But in the study area the structural hills are marked by several lineament intersections and groundwater extraction through deep bore wells can be possible.

• **Residual hills**

Residual hills are the end products of the process of pediplanation, which reduce the original mountain masses into series of scattered knolls on the Pediplains (Thronbury, 1995). They occur as isolated hills with considerably small aerial extent formed at lower altitudes. They are seen in pediment zone and plateau. The image characteristic feature of these land forms is darker in tone, mostly circular in shape, devoid of any vegetation. Due to steep slopes, most of the rain water drained immediately without much infiltration and hence the groundwater resource is poor in these areas. The central north and extreme eastern part of the river basin is marked for residual hills

- **Pediments**

Pediments are the transition zone between the hills and adjoining plains. They are better developed in semi-arid climate. They have a less soil thickness and low slope. The slope varies from 1^0 to 8^0. On the satellite imageries, these are observed with light photo tones. The pediments are shaped by erosion and transportation. It is a gently sloping smooth surface of erosional bedrock with or without thin cover of detrital materials.

In the study area, pediments are distributed with an aerial extent of 359.26 km^2. In this basin the pediments are found in the northen region (Chullimade and Tenkara). Groundwater prospects in pediments can be considered as normal to poor (Sankar, 2002). But presence of any lineaments or fractures can provide some scope for movement of groundwater and hence potential zones for groundwater exploration.

- **Moderately dissected pediment zones**

These areas are described as nearly flat terrain with gentle slope. In the study area moderately dissected pediment zones are distributed in the north-western and south-western parts of the basin with an aerial extend of 310.53 km^2. Groundwater prospect in this area is described as moderate to good depending up on the thickness of weathered zone.

- **Plateaus**

Plateaus are flat topped residual mountains seen in plains. They are divided into two categories as moderately dissected and less dissected plateau. The plateau is seen in the eastern side and foot hills of Silent Valley. Moderately dissected Plateau occupies the central portion and a part of western region of the basin with an aerial extent of 1258.38 km^2. It covered the major portion of the basin. Less dissected Plateau is seen on Southeastern side of the basin and as a part of southern central region. Dissected nature of the plateau accelerates more run off so it falls under the category of moderate potential zone.

- **Valley fills**

Valley fills are described as the deposition of unconsolidated materials in narrow valleys which are of fluvial sediments, composed of pebbles, sand, silt and clay. These are mostly controlled by fractures/lineaments. It occupies narrow to large patches in the entire study area with an aerial extent of 892.04 km^2. Groundwater prospects are good in these areas. Their yield depends on the thickness of the fill and structure. A large number dug wells, dug-cum-bore wells and bore wells are feasible in these areas. Valley fill areas are observed to be highly potential zones. Auden, 1993; Kumar and Srivatsava, 1991; Singh et al.1993; Pal et al. 1997; Pratap et al. 1997 and Sankar et al.

2001 have carried out hydrogeomorphological and remote sensing investigations revealed that valley fills are excellent areas for groundwater storage. Valley fills regions are highly suitable for construction of water harvesting structures.

- **Coastal terrains**

Coastal terrain areas seen near the coast that is on the western side of the basin exhibit unique characteristics as sluggish drainage, marshy lands, bars, spits etc.

5.5.3 Land Use

Land use classification gives an idea about the level of utilisation of the area. Land uses refer to "man's activity and the various uses which are carried on land" (Clawson & Stewart, 1965). Land use describes how a parcel of land is used for agriculture, settlements or industry, where as land cover refers to materials such as vegetation, rocks, water bodies, which are present on the surface (Anderson et al.1976). Both these terms are related and interchangeable; the term land use is more frequently used.

Land use/land cover mapping is one of the important applications of remote sensing. Land use plays a significant role in the development of groundwater resources. It controls many hydrological processes in the water cycle viz., infiltration, evapotranspiration, surface runoff etc. Surface cover provides roughness to the surface, reduce discharge thereby increase the infiltration. In the forest areas, infiltration will be more and runoff will be less whereas in urban areas rate of infiltration may decrease (Sarkar et al. 2001). Remote sensing provides excellent information with regard to spatial distribution of vegetation type and land use in less time and at low cost in comparison to conventional data (Roy et al. 1973).

Land use classification of the Bharathapuzha river basin has been prepared using the False Colour Composite (FCC) images through visual interpretation based on the classification decoded by National Remote Sensing Agency (NRSA) Fig.5.2. Based on these classification 23 types of land use are recognised in the basin and is given in the Table 5.2

Table 5.2 Spatial distribution of various land use/land cover units with their areal extent of the Bharathapuzha river basin

Sl No	**Description**	**Area (Km^2)**
1	Mixed vegetation	1744.50
2	Paddy	640.76
3	Dense mixed jungle	503.26
4	Land with scrub	380.29
5	Rubber plantations	356.24
6	Open scrub	219.18
7	Waste land with scrub	195.50
8	Waste land without scrub	116.03
9	Water body	53.14
10	Town	49.06
11	Sand deposits	37.93
12	Open mixed jungle	31.37
13	Open jungle with bamboo	22.26
14	Reservoir	22.21
15	Land without scrub	9.01
16	Fairly dense jungle	6.53
17	Mixed jungle	4.09
18	Fairly dense jungle mainly teak	3.62
19	Open jungle	2.27
20	Scrub land	1.55
21	Stony waste	1.05
22	Buildup lands	0.09
23	Ponds	0.06
Total		**4400**

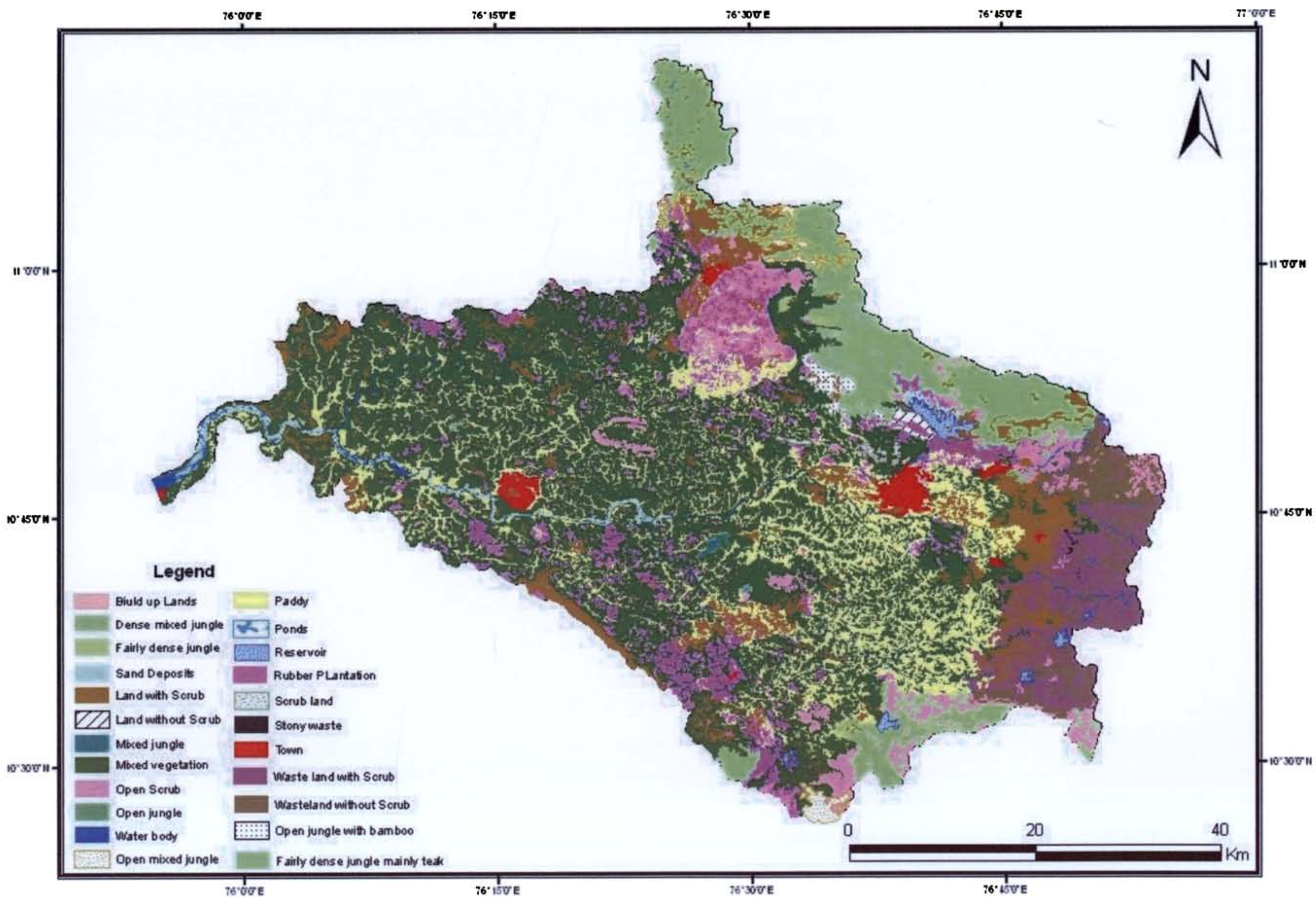


Fig. 5.2 Land use classification of the Bharathapuzha river basin

- **Mixed vegetation**

A major portion of the basin is characterised by mixed vegetation/agricultural land with an aerial extent of 1744.50 km^2. The area includes mixed land uses, for example residential and commercial and residential and slums, which are not distinguishable or separable and no single land use is predominant. It is seen in the valley fills of the river basin.

- **Paddy**

In the land use classification, paddy field occupies the second largest portion of the study area with an aerial extend of 640.76 km^2. It is distributed on the valley region of the study area.

- **Forest area**

These are the area bearing an association predominantly of trees and other vegetation types. They exhibit bright red to dark red in colour in varying sizes with smooth to medium texture.

- Dense/Closed - Canopy is more than 40 %
- Open /degraded- Canopy cover /density range between 10-40 %

In the study area the forest covers the northern, northeastern and a part of southern region with an aerial extend of 573.40 km^2. The forest area are classified as dense mixed jungle, open mixed jungle, open jungle with bamboo, fairly dense jungle, open jungle, fairly dense jungle with teak and mixed jungle.

• **Waste land**

Waste land is described as degraded land which can be brought under vegetative cover with reasonable effort and which is deterioting because of lack of appropriate water and soil. Waste land includes wasteland with scrub and wasteland without scrub with an aerial extends of 311.53 km^2 which is located in the eastern side of the basin. It is due to the influence of arid climatic condition of Tamil Nadu through Palghat gap.

• **Scrub land**

This is land which is generally prone to deterioration due to erosion. Such land occupies topographically high locations, excluding hilly/mountain terrain. They appear in light yellow to brown to greenish blue depending on surface moisture cover and varying in size. Scrub lands are associated with moderate slopes in plains and foot hills and are generally surrounded by agricultural lands. Land without scrub seen along the northeastern segment(Malampuzha region) It is distributed as patches in the entire basin. Open scrubs are similar to scrub land but they possess sparse vegetation or devoid of scrub and have thin soil cover. Open scrubs are seen in the foot hills of the structural hills of the basin.

• **Sand deposits**

Riverine sands are those that are seen as accumulation in the flood plain as sheets, which are the resultant phenomena of river flooding. In the study area, it is prominently seen along the river course from the central part (Ottapalam) to extreme western region with an extent of 37.93 km^2.

- **Water body**

Water body category comprises area with surface water, in the form of ponds, lakes and reservoirs or flowing as streams, rivers, canals etc. These appear as blue to dark blue or cyan in colour depending on the depth of water. In the study area water body covers reservoirs and ponds with a total area of 75.41 km^2.

Artificial lakes created by construction of dams across the river. They appears in light blue to dark blue and possess regular to irregular shapes. They are associated with crop lands, low land, and hills with or without vegetation. Bharathapuzha river basin is one of the most heavily dammed rivers in Kerala, comprising of nine dams of which seven are in Kerala state. The reservoirs have an aerial extend of 22.21 km^2.

5.5.4 Lineaments

Lineaments are large scale linear features, which express itself in terms of topography and an expression of under lying structural features like fault, joint, displacement and abrupt truncation of rocks. They are the underground conduits for groundwater movements. Lineaments in the study area are clearly visible on the remotely sensed data. These are visible due to sudden changes in the vegetation, spectral signatures and drainage.

Satellite imageries are extensively used to delineate lineaments and their analysis for groundwater studies. Lineaments have been delineated through visual interpretation of geocoded satellite imageries. They are represented with their trend directions and varying dimensions.

In the study area, considering the occurrence of groundwater, the lineaments in pediment zone and valley fills are considered to be very significant than along structural hills and residual hills in high drainage density which is high slope area because there could be high run off in these areas. The major lineaments in the study area trends NNW-SSE to NW-SE and E-W (Fig. 5.3). The NNW-SSE lineaments fall in the major tributary (Gayathripuzha) extending 40 km and the E-W lineaments represent the main stream of the Bharathapuzha. There are many small lineaments also trending NW-SE and N-S. Most of the lineaments are the expression of the drainage network.

5.5.5 Lineament density

Lineament density map is a measure of quantitative length of linear feature expressed in grid. Lineament density of an area has a direct influence on groundwater prospectiveness of that area. Areas with high lineament density are good for groundwater development (Haridas et al. 1998). Maximum lineament density is found at the extreme north, south and the central part of the basin where as majority of the basin is marked by the lower lineament density (Fig. 5.4).

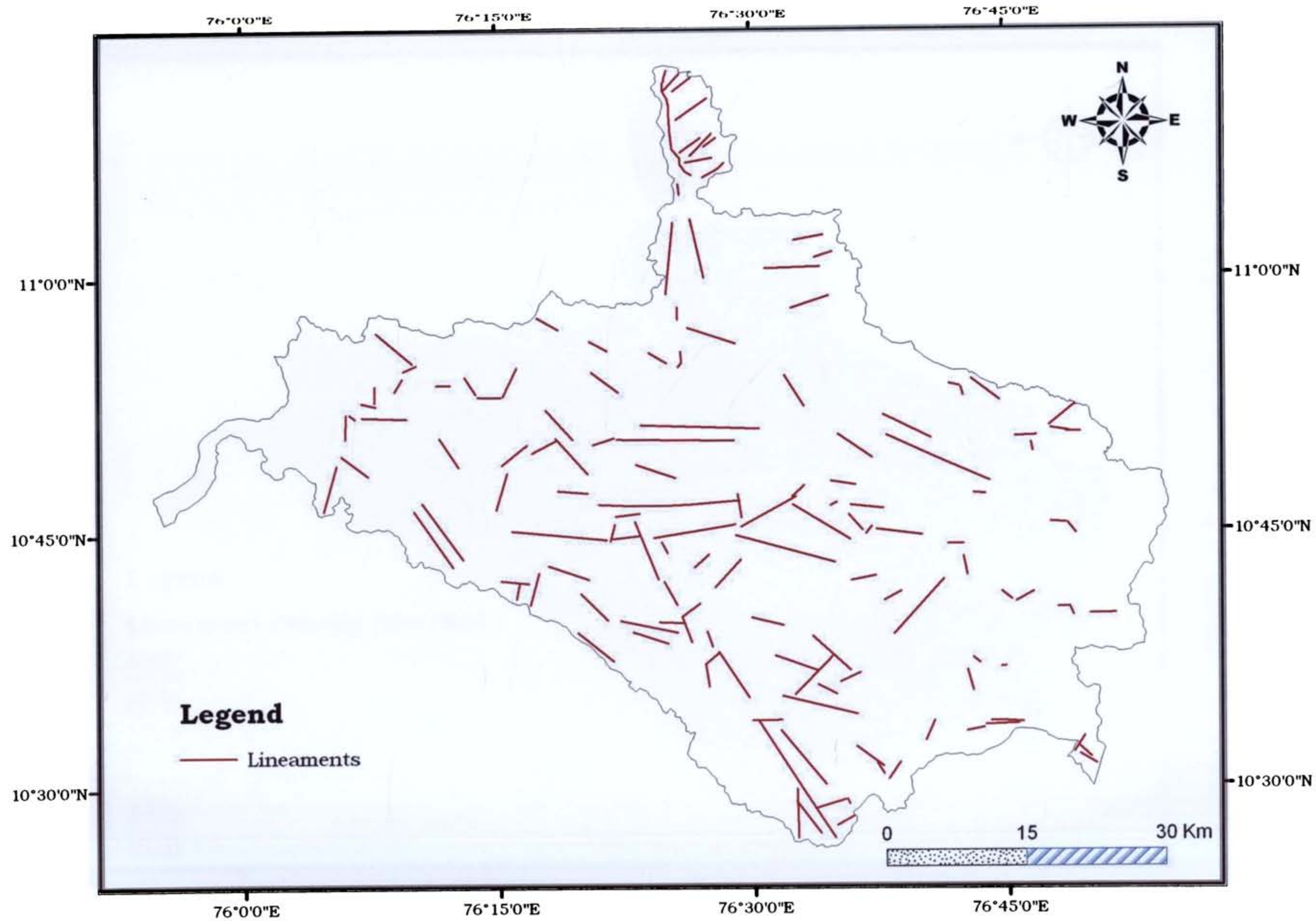


Fig. 5.3 Lineament map of the Bharathapuzha river basin

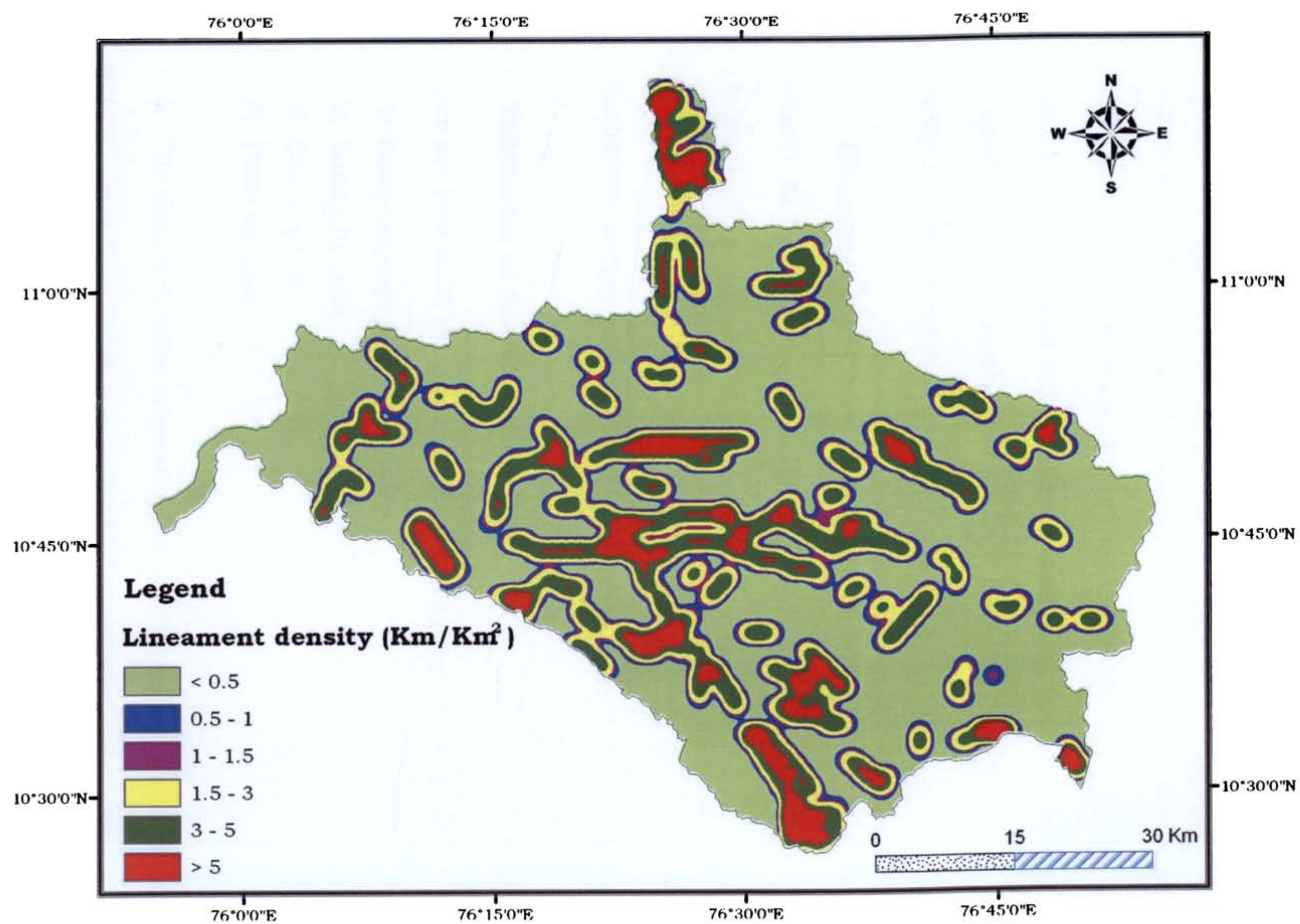


Fig. 5.4 Lineament density map of the Bharathapuzha river basin.

5.5.6 Drainage

The drainage basin is the area drained by a single stream. Drainage pattern of any terrain reflects the characteristics of surface as well as subsurface formations. The Bharathapuzha River is a 6^{th} order streams and exhibits dendritic drainage pattern and has a total length of 209 kms. The Bharathapuzha or the Ponnani River originates from Anamalai hills of Tamil nadu and flows westward through Palghat Gap, by confluence of Gayathripuzha, Chitturpuzha, Kalpathipuzha and Tuthapuzha and it empties into the Arabian Sea at Ponnani (Fig 5.5).

Bharathapuzha follows a northerly course in the first 40 km till Pollachi. At Parali both Kannadipuzha and Kalpathi puzha merge. The Thuthariver merge at Pallipuram and flow as Bharathapuzha and follows a westerly course into the Arabian Sea at Ponnani. When Thuthariver merges with Bharatapuzhapuzha, it thickens in flow.

- **Tributaries of Bharathapuzha River**

There are four main tributaries to Bharathapuzha and they are

1) Gayathripuzha
2) Kannadipuzha
3) Chitturpuzha
4) Thuthapuzha

The Gayathripuzha originates from Anamalai and flows along the NW-SE trending fault valley through Kollengode, Nenmara, Vadakkanchery, Alathur and Pazhayannur before it finally join the main river at Mayannur. This tributary has five sub-tributaries,

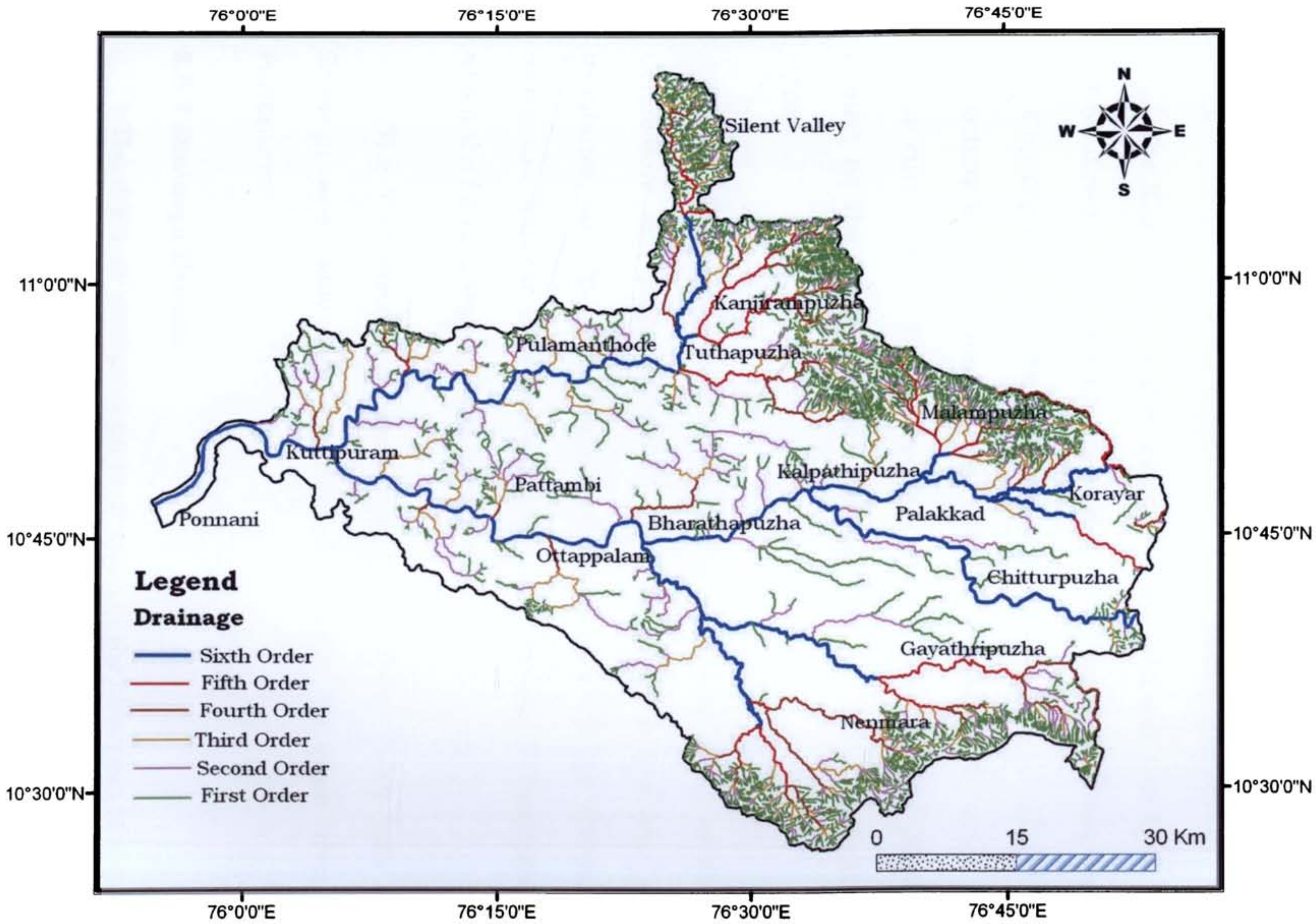


Fig. 5.5 Drainage net work of the Bharathapuzha river basin

namely (i) the Mangalam, in which Mangalam dam is constructed, (ii) the Ailurpuzha on which Pothundy dam is constructed (iii) the Vandazhipuzha (iv) the Meenkara in which Meenkara dam is located and (v) the Chulliar in which Chulliar dam is located.

The Kannadipuzha also originates from Anamalai and flows in a NW-SE direction through Chittur and joins the main river near Parali; The Chitturpuzha irrigation project is located in this tributary. The sub-tributaries of Kannadipuzha are, (i) the Palar on which the Tirumurthy dam of Parambikulam-Aliyar project of Tamil Nadu is located. (ii) The Aliyar, on which the Aliyar dam is located and (iii) the Uppar.

The Chitturpuzha (Kalpathipuzha) originates from south of Coimbatore and flows roughly in an E-W trend. It has four sub-tributaries, namely, (i) the Korayar (ii) the Varattar (iii) the Walayar in which the Walayar dam is constructed and (iv) the Malampuzha in which the famous Malampuzha dam is located.

The Thuthapuzha originates from the Silent Valley hills and flows in a roughly E-W direction and joins the main river at Pallippuram.

5.5.7 Drainage Density

The drainage density is an expression of the closeness of spacing of channels and it provides quantitative measure of length of stream within a square grid of the area expressed in terms of length of channels per unit area (km/km^2). It thus provides the average length of stream channels within different portions of a basin.

Drainage density characterises the run off in the area or the quantum of rain water that could infilterate. Drainage density is significant in the case of artificial recharge because it indirectly indicates the permeabilty and porosity of the terrain. More the drainage density higher would be runoff and lesser the drainage density, higher is the probabiltiy of recharge or potential groundwater zone.

In the present investigation, the drainage density values are calculated after digitisation of the entire drainage pattern. The Bharathapuzha river is characterised by dendritic drainage pattern which is typical of granitic terrain. The highest drainage density is seen at the north, northeast, south and southeastern parts of the basin (Fig. 5.6). Majortiy of the area is marked by low drainage density (< 0.5).

5.5.8 Relative Relief

The relative relief (Fig. 5.7) which is also known as local relief represent the variation of altitude in unit area with respect to its base level (RR=Z-z where Z is the height of highest point and z is the height of the lowest point and RR is the relative relief). This parameter helps to ascertain the amplitude of available relief (Glock, 1932), but does not take into account the dynamic potential of the terrain (Anil Kumar and Pandey, 1982).

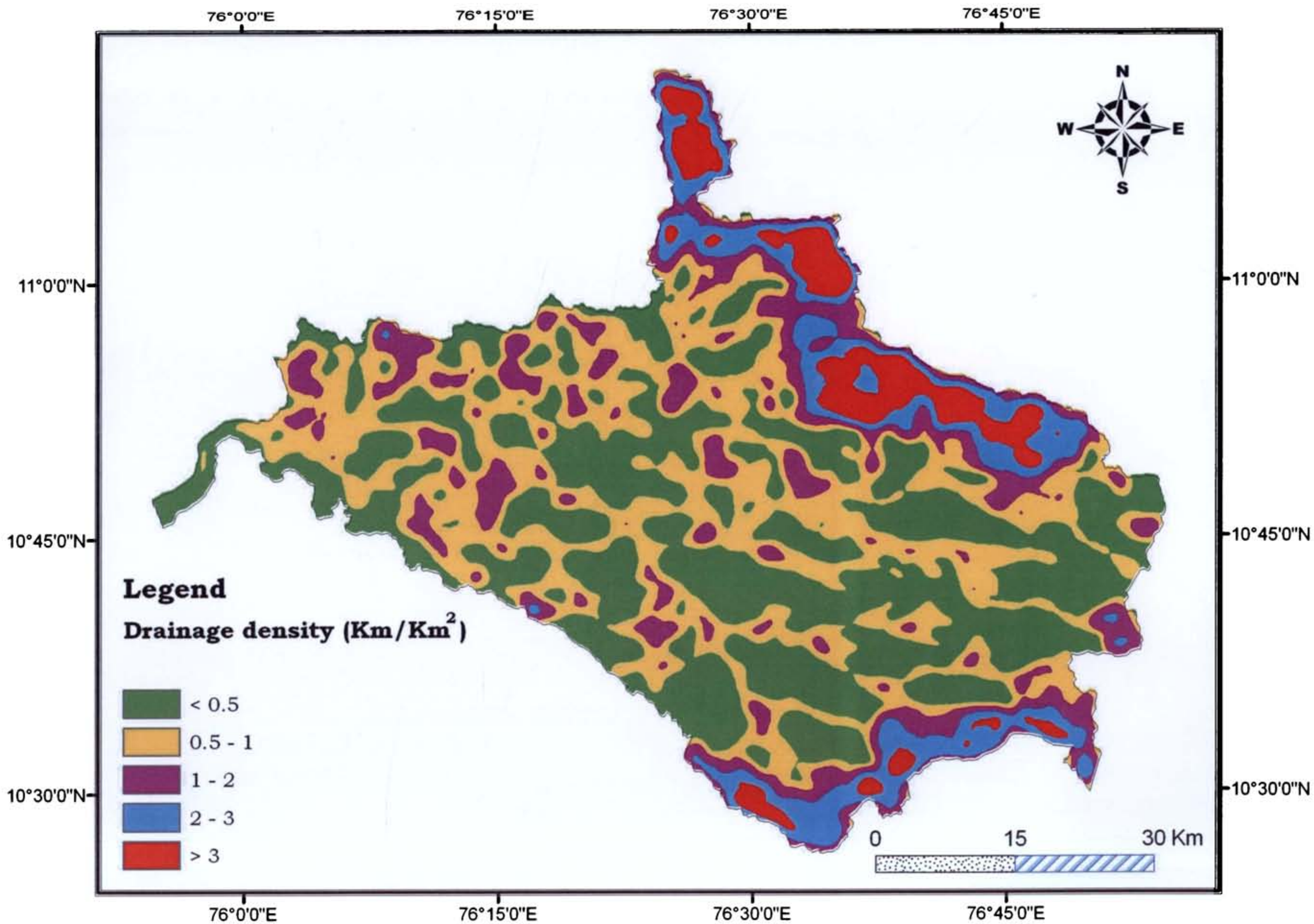


Fig. 5.6 Drainage density map of the Bharathapuzha river basin

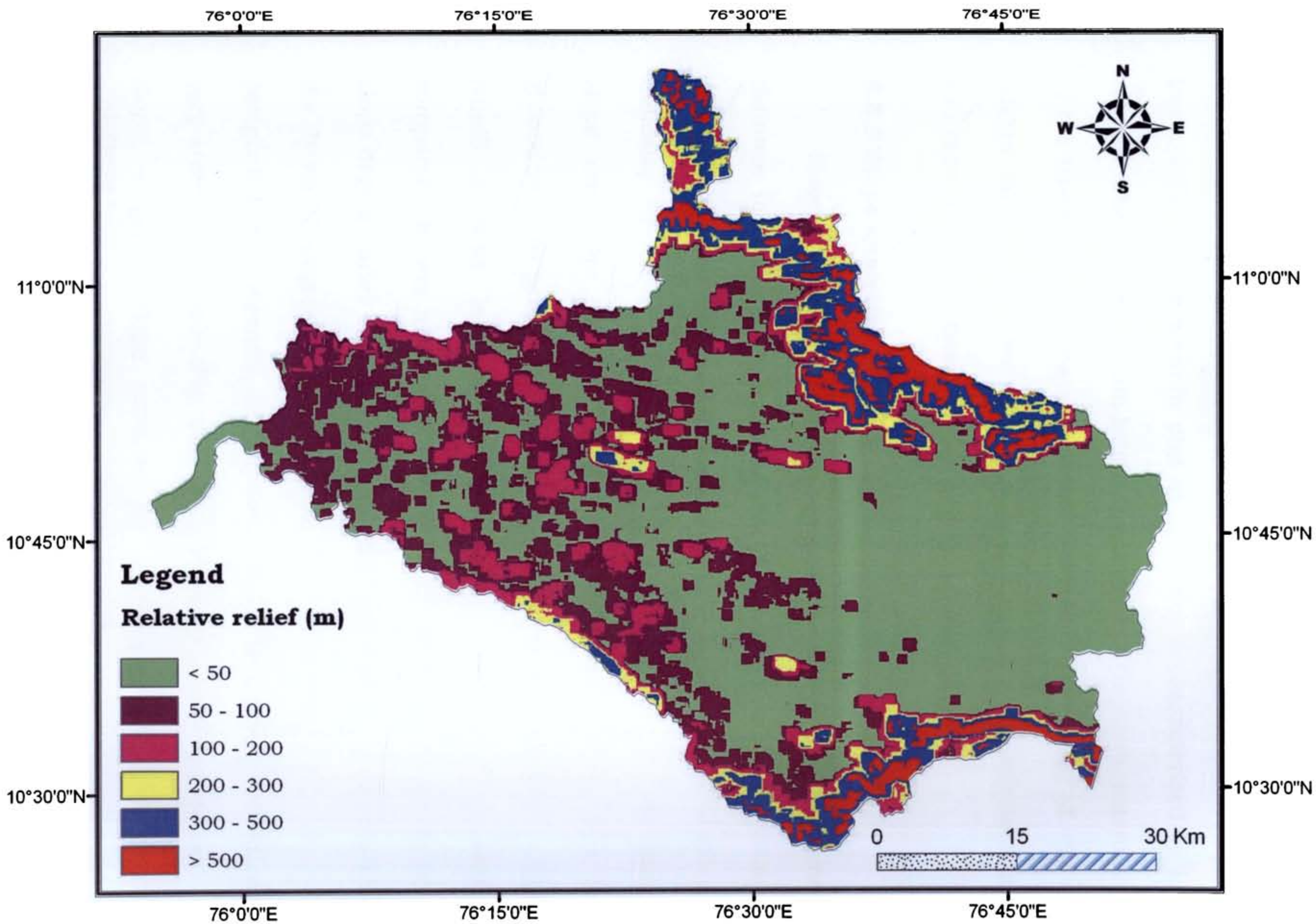


Fig. 5.7 Relative relief of the Bharathapuzha river basin

The basin was divided into grids of 1 km^2 each and the difference in maximum and minimum altitude (relative relief) was obtained for each grid. The relative relief map drawn for the Bharathapuzha river basin indicates the western part of the basin is characterised by low relative relief and maximum height is recorded at the northeastern side of the basin. Most of the study area shows a relative relief of <50 m. Higher values of relative relief is seen at the North, northeastern and southern part of the basin.

5.5.9 Slope analysis

Slope is defined as the loss or gain in altitude/unit horizontal distance in a direction. Slope of any terrain is one of the factors controlling the infiltration of groundwater into subsurface hence an indicator for the suitability for groundwater prospect. In the gentle slope area, the surface runoff is slow allowing more time for groundwater to percolate, where as, high slope areas facilitates high runoff allowing less residence time for rainwater and hence comparatively less infiltration (Prasad et al. 2008). In the study area slope degree varies from 0 to 84 and the entire basin is classified on the basis of degree of slope as <3, 3-5, 5-10, 10-15, 15-35, >35 designated as very gentle, gentle, moderate, moderate-steep, steep, and very steep respectively (Fig. 5.8). As infiltration is inversely related to slope, a gentle slope promote for an appreciable groundwater infiltration. In the study area, majority of the area occupies slope category of 0-5 and is favourable while considering the groundwater

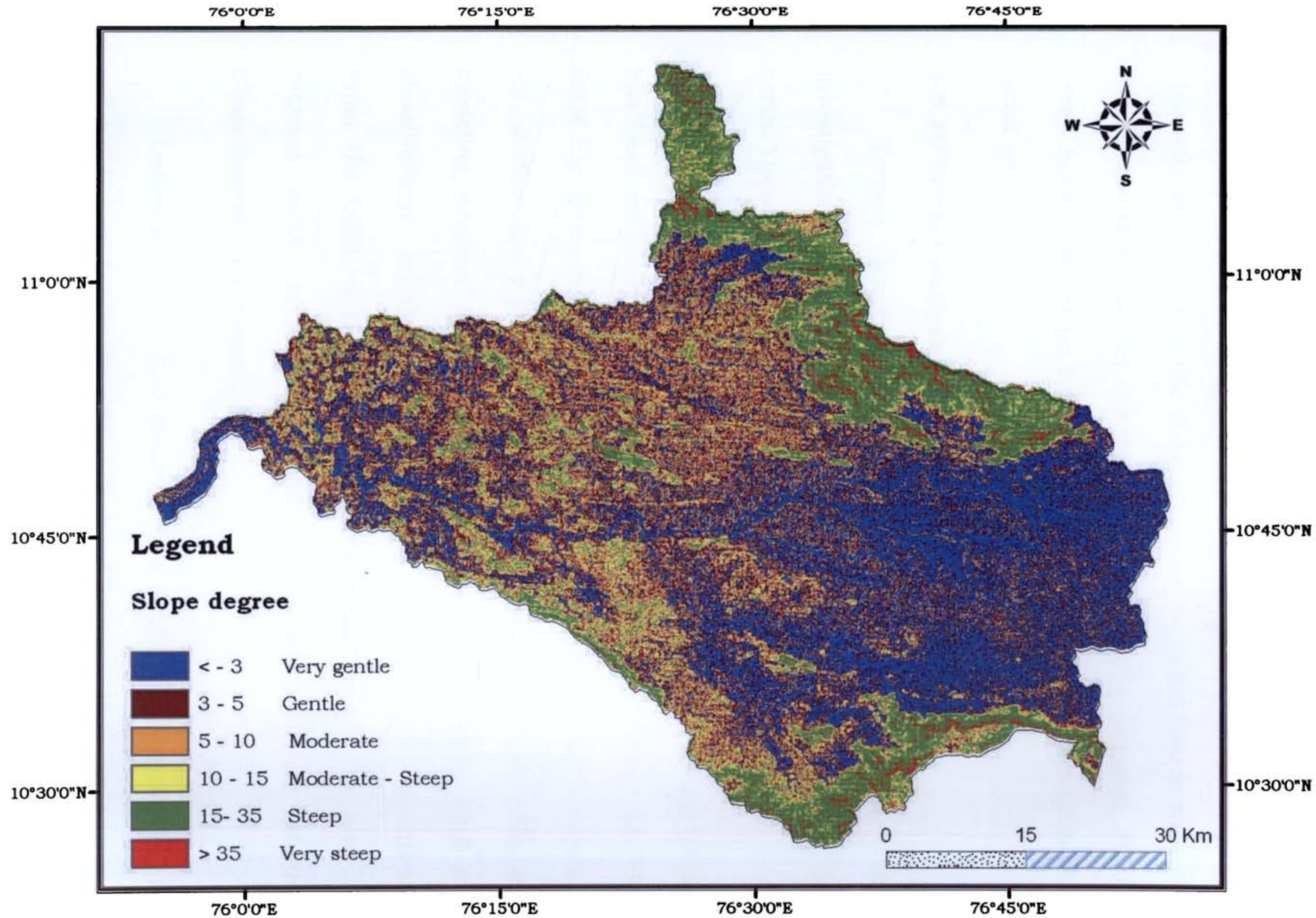


Fig. 5.8 Slope map of the Bharathapuzha river basin

potential. High slope area is marked by the northern, northeastern, southern and south western part of the basin. Central portion is characterised by moderate slope (5-10) while eastern part is characterised by very gentle slope where the Palakkad Gap is situated. Higher the slope, higher the run off and lower the recharge. Hence areas having low slope can be considered as sites for groundwater recharge.

5.5.10 Terrain analysis

Terrain analysis is defined as the representation and investigation of information relating to the physical features of the earth. These surfaces are often referred to as terrain models.

Using the ILWIS GIS package, the Digital Elevation Model (DEM) has been prepared for the Bharathapuzha river basin (Fig. 5.9). The DEM can be used for various common applications of the watershed viz., surface and groundwater hydrological modeling, stream pollution modeling, overland flow modeling, forest resource modeling, land use classification, salinity assessment and cartographic enhancement. From the DEM, it is observed that maximum elevation is seen at extreme north, northeastern and southwestern regions of the Bharathapuzha river basin.

Determination of flow direction is a fundamental parameter in hydrological modeling. Hence Triangulated Irregular Network (TIN) has been drawn for the Bharathapuzha river basin to determine the flow direction and is inferred as towards western region from the north

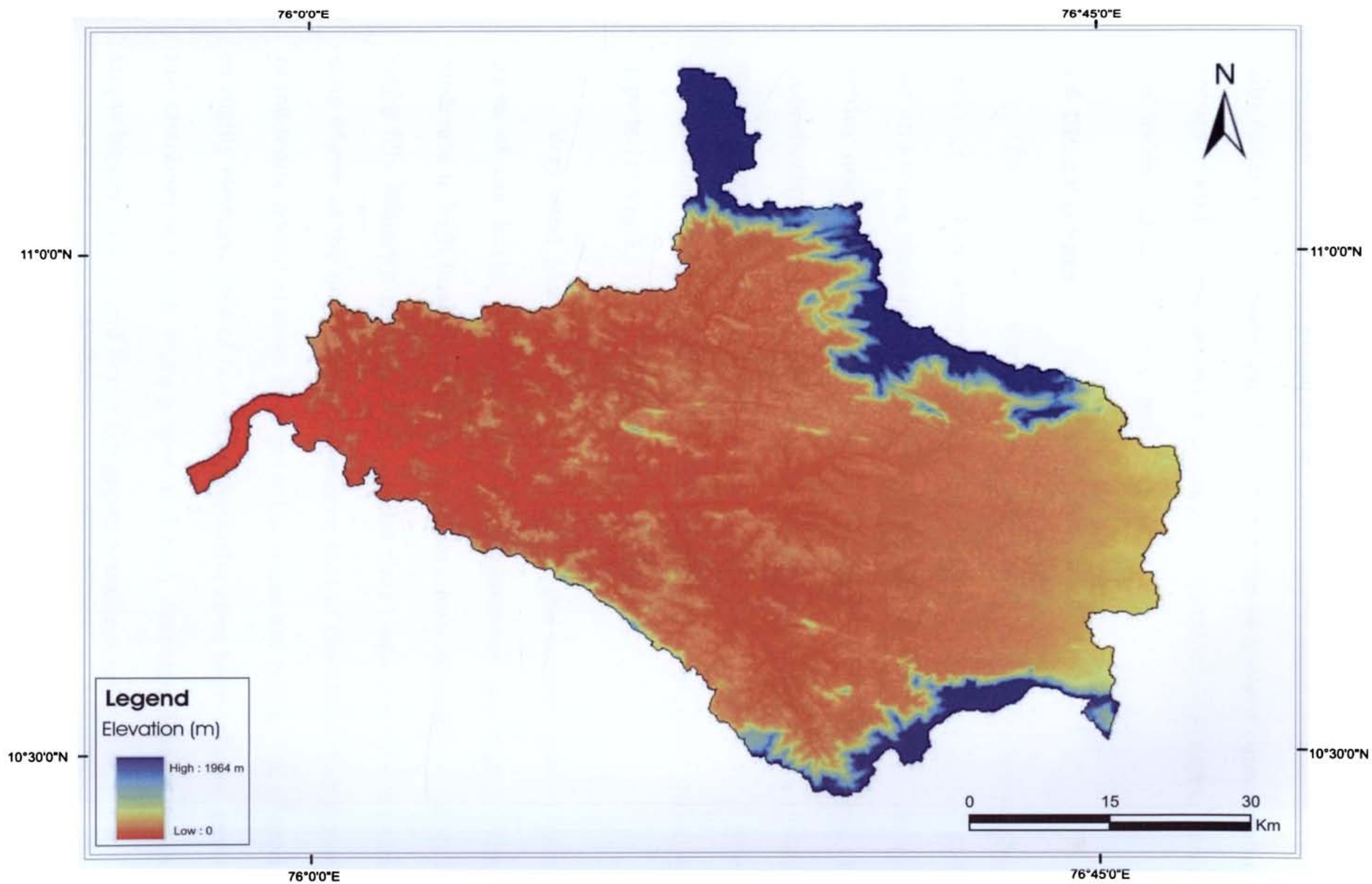


Fig. 5.9 Dem of the Bharathapuzha river basin

eastern and southern side. The confluence is at the centre (Fig 5.10). The various thematic maps are described above have been converted into raster form considering 20 m as cell size to achieve considerable accuracy and is reclassified and assigned suitable weightages, rank and index and is given Table 5.3.

5.6 GIS ANALYSIS

The selected parameters like geomorphology, lineament, drainage, geology, slope, relative relief, transmissivity, storativity, land use and water table fluctuation were integrated on the GIS platform by overlay analysis. The resultant map was divided into four zones of groundwater potential namely, poor potential zones, moderate potential zones, good potential zones and very good potential zones. The groundwater potential map of the Bharathapuzha river basin is depicted in Fig 5.11.

Very good potential zones are seen in the central and western parts of the basin. They are mainly concentrated in areas having moderate to high lineament density, comparatively less slope area and valley fills. Majority of the Bharathapuzha river basin is good potential zone where as the northern and southern part of the basin shows poor to moderate potential zone. Poor potential zones are mainly distributed in highly elevated area of the Bharathapuzha river basin. These areas are characterised with steep slopes and high drainage density which create higher run-off and hence the groundwater potential is very low.

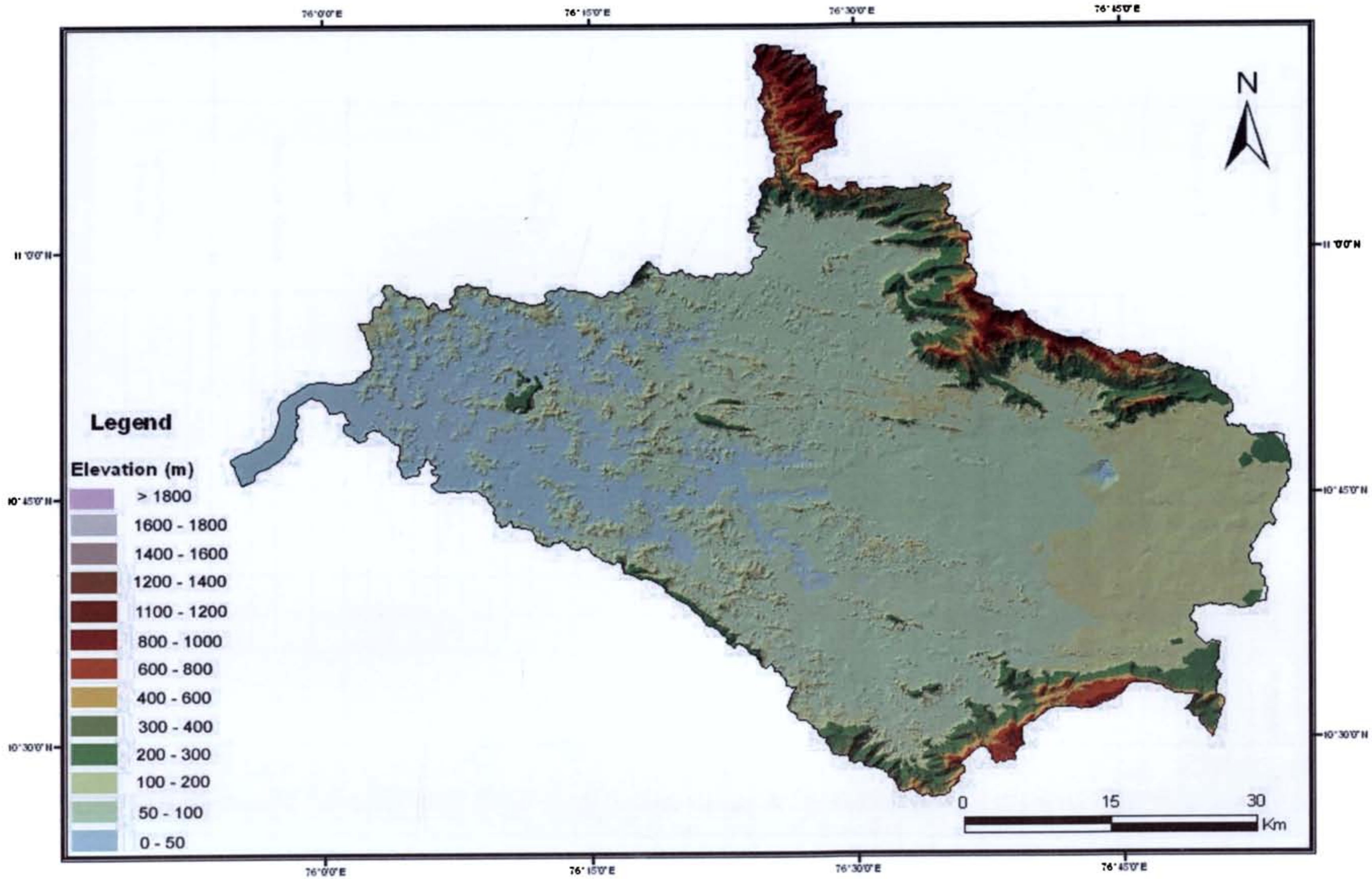


Fig. 5.10 TIN of the Bharathapuzha river basin

Table 5.3 Weightages, rank and index assigned for different groundwater controlling parameters to derive grour Potential zones of the Bharathapuzha river basin

Sl no	Parameter	Class	Rank	Weight	Index
1	Drainage Density	< 1	4	7	28
		1 – 3	3		21
		3 – 4	2		14
		> 4	1		7
2	Slope	< 8	4	9	36
		8- 16	3		27
		16 – 24	2		18
		> 24	1		9
3	Geo morphology	Coastal plain	1	12	12
		Pediment zones	2		24
		Structural hills	2		24
		Residual hills	2		24
		Less disected plateau	3		36
		Moderately disected plateau	3		36
		Channel bars	3		36
		Plateau	3		36
		Moderately dissected pediment zone	4		48
		Valley fills	4		48
4	Geology	Gabro	1	10	10
		Dolerite	1		10
		Charnokite	1		10
		Pink granite	1		10
		Pyroxene and Norite	1		10
		Pyroxene granulite/Charnockite	1		10
		Quartz syenite	1		10
		Hornblende biotite gneiss with schist	2		20
		Quartzofeldspathic gneiss	2		20
		Biotite hornblende	3		30
		Hornblende biotite	3		30
		Hornblende biotite gneiss	3		30
		Coastal alluvium	4		40
5	Relative Relief	<40	4	5	20
		40 - 80	3		15
		80 – 120	2		10
		>120	1		5
6	Lineament Density	<0.5	1	15	15
		0.5-1	2		30
		1-1.5	3		45
		>1.5	4		60
7	Transmissivity	<60	1	12	12
		60-120	2		24
		120-180	3		36

		>180	4		48
8	Storativity	<0.24	1	12	12
		0.24 – 0.27	2		24
		0.27 – 0.29	3		36
		>0.29	4		48
9	Landuse	Rubber plantation	1	8	8
		Stony waste	1		8
		Open jungle	2		16
		Wasteland without scrub	2		16
		Built-up lands	2		16
		Land with scrub	2		16
		Land without scrub	2		16
		Open scrub	2		16
		Fairly dense jungle mainly teak	2		16
		Scrub land	2		16
		Open jungle with bamboo	2		16
		Open mixed jungle	2		16
		Waste land with scrub	3		24
		Fairly dense jungle	3		24
		Mixed vegetation	3		24
		Paddy	3		24
		Mixed jungle	3		24
		Sand deposits	4		32
		Dense mixed jungle	4		32
10	Water table Fluctuation	<2	4	10	40
		2-3	3		30
		3-4	2		20
		>4	1		10

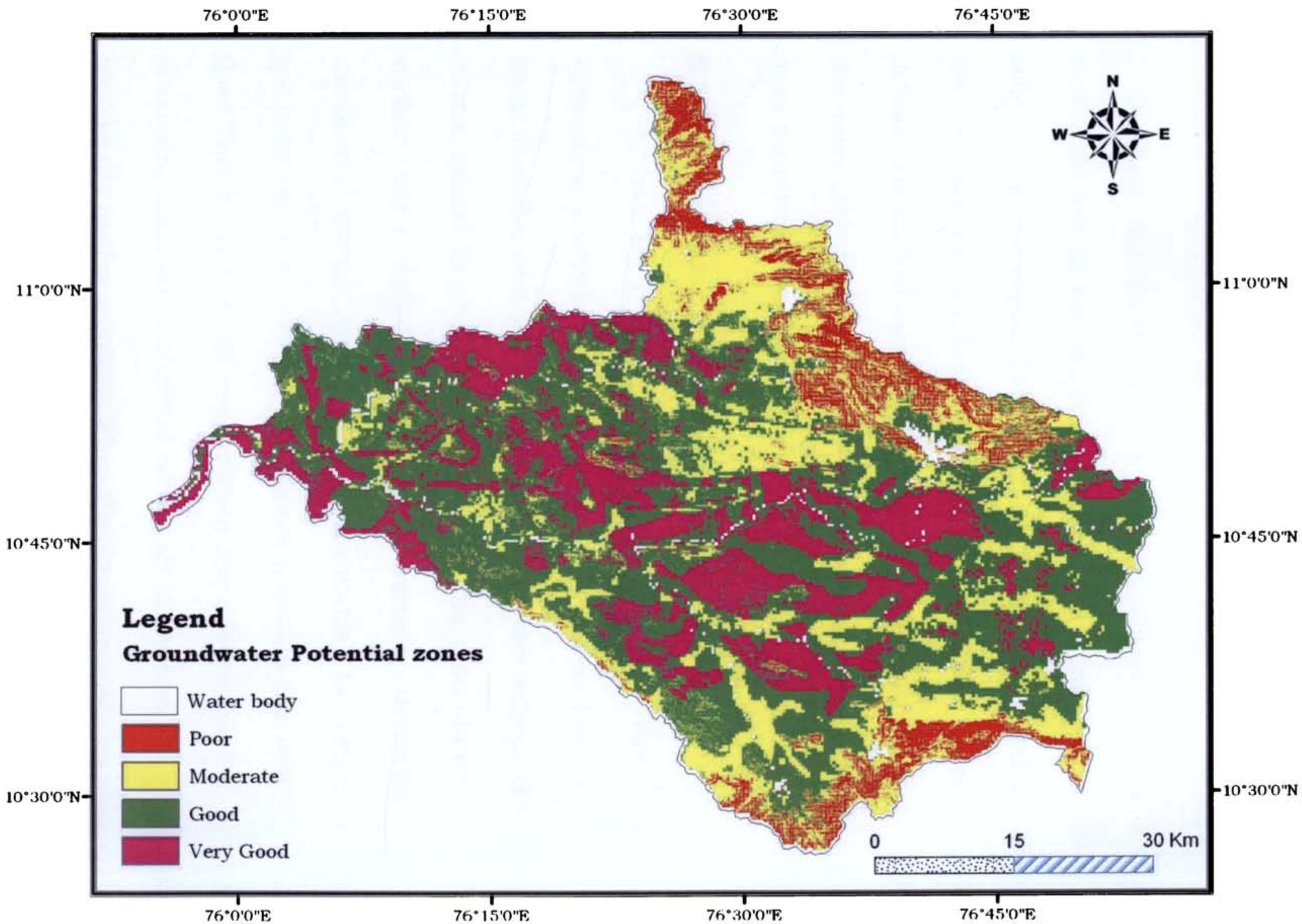


Fig. 5.11 Potential map of the Bharathapuzha river basin

5.7 GROUNDWATER RECHARGE

Groundwater recharge can be defined as the process that replenishes the underground water stock. Natural recharge mechanisms can either be direct, localised or indirect (Simmers, 1997).

There are three types of recharge. Direct recharge refers to replenishment of the groundwater reservoir from precipitation after subtracting interception, runoff and transpiration. Localised recharge results from the ponding of surface water in the absence of well-defined channels of flow whilst indirect recharge refers to percolation to the water table from surface water courses. Each type of mechanism is more prevalent in some climatic conditions than others (Lloyd, 1986).

5.7.1 Groundwater recharge and river management

It has been already pointed out that the river replenishes subsurface aquifers during rainy season when its flow is due to the water available from rains. In the lean or summer season, the river flow is maintained by the contribution from the groundwater. Thus the surface water and groundwater is mutually dependant. Unless conditions within the basin are suitable to retain adequate groundwater, the river channel cannot maintain the needed summer flow. This is true for all rivers. When the existing natural conditions preserving such environmental set up are disturbed, the river courses become dry during summer. When the conditions become more critical, the river becomes dry immediately after the rains and its dry spell increasing with progress of time. To restore the original status of the basin it is necessary to increase the groundwater storage in the entire river basin. This is possible through artificial recharging of groundwater.

5.7.2 Artificial recharge to groundwater

Artificial recharge to groundwater is a process by which the groundwater reservoir is augmented at a rate exceeding that obtained under natural conditions or replenishment. Any man-made scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system. Artificial recharge provides groundwater users an opportunity to increase the amount of water available during periods of high demand, typically summer months.

Wide spectrums of techniques are available to recharge groundwater reservoir. Similar to the variations in hydrogeological framework, the artificial recharge techniques too vary widely. The artificial recharge techniques can be broadly categorised as follows:-

Direct surface techniques which are of Flooding, Basins or percolation tanks, Stream augmentation, Ditch and furrow system, Over irrigation, Direct sub surface techniques are of Injection wells or recharge wells, recharge pits and shafts, dug well recharge, borehole flooding, natural openings, cavity fillings.

Combination surface – sub-surface techniques which is based on basin or percolation tanks with pit shaft or wells, indirect techniques are Induced recharge from surface water source, aquifer modification.

Besides above, the groundwater conservation structures like groundwater dams, sub-surface dykes or locally termed as Bandharas, are quite prevalent to arrest sub-surface flows. Similarly in hard rock areas rock fracturing techniques including sectional blasting of boreholes has been applied to inter-connect the fractures and increase recharge.

The main advantages of artificially recharging the groundwater aquifers are, no large storage structures needed to store water, structures required are small and cost-effective, enhance the dependable yield of wells and hand pumps, negligible losses as compared to losses in surface storages. Improved water quality due to dilution of harmful chemicals/salts. No adverse effects like inundation of large surface areas and loss of crops, no displacement of local population, reduction in cost of energy for lifting water especially where rise in groundwater level is substantial and utilizes the surplus surface runoff which otherwise drains off.

5.8 DEMARCATION OF SUITABLE SITES FOR ARTIFICIAL RECHARGING OF GROUNDWATER IN THE BHARATHAPUZHA RIVER BASIN

Various parameters which are controlling or contributing the groundwater recharge are considered to find out suitable sites for artificial recharging. The selected parameters were available space for recharging, geomorphology, slope, drainage density, geology and storativity. Each theme was subdivided into different sub classes and ranks were assigned to each subclass. The parameters were compared to each other and weightages values were given based on its contribution in a successful recharging programme. An index value was derived from the rank and weightages. The final index values was used to mark out various zones for artificial recharging such as highly suitable, suitable and least suitable (Table 5.4).

5.8.1 Available space for recharging

Available space is one factor which affects the artificial recharging of groundwater. Available space between the ground surface and water table is crucial because it is the storage space for induced recharge. The pore spaces below the water table will be filled with water and no empty space will usually be available below the water table. The available space was found out from the mean yearly depth to water table and divided into four classes and ranks 1 to 4 are assigned (Fig. 5.12). It is evinced from the figure that the available space for recharging is at Walayar which is art extreme eastern part and at Iswaramangalam and Ponnani on the extreme western part of the river basin.

5.8.2 GIS Analysis

Accordingly the suitable sites were found out and given in the Figure 5.13. The entire area is divided into three classes with respect to the scope for artificial recharging of groundwater. The identified three classes are least suitable, suitable and highly suitable.

Table 5.4 Weightage, rank and index assigned for different groundwater controlling parameters to derive suitable sites for artificial recharging

Sl. no.	Parameter	Class	Rank	Weight	Index
1	Drainage Density	< 1	4	15	60
		1 – 3	3		45
		3 – 4	2		30
		> 4	1		15
2	Slope	< 8	4	20	80
		8- 16	3		60
		16 – 24	2		40
		> 24	1		20
3	Geomorphology	Coastal plain	1	10	10
		Pediment zones	2		20
		Structural hills	2		20
		Residual hills	2		20
		Less dissected plateau	3		30
		Moderately dissected plateau	3		30
		Channel bars	3		3
		Plateau	3		30
		Moderately dissected pediment zone	4		40
		Valley fills	4		40
4	Geology	Gabro	1	20	20
		Dolerite	1		20
		Charnokite/Charnockite gneiss	1		20
		Pink granite	1		20
		Pyroxene and Norite	1		20
		Pyroxene granulite/Charnockite	1		20
		Quartz syenite	1		20
		Hornblende biotite gneiss with schist	2		40
		Quartzofeldspathic gneiss	2		40
		Biotite hornblende gneiss	3		60
		Hornblende biotite	3		60
		Hornblende biotite gneiss	3		60
		Coastal alluvium	4		80
5	Available space	1-2	4	15	60
		2-5	3		45
		5-7	2		30
		>7	1		15
6	Storativity	<0.24	1	20	20
		0.24 – 0.27	2		40
		0.27 – 0.29	3		60
		>0.29	4		80

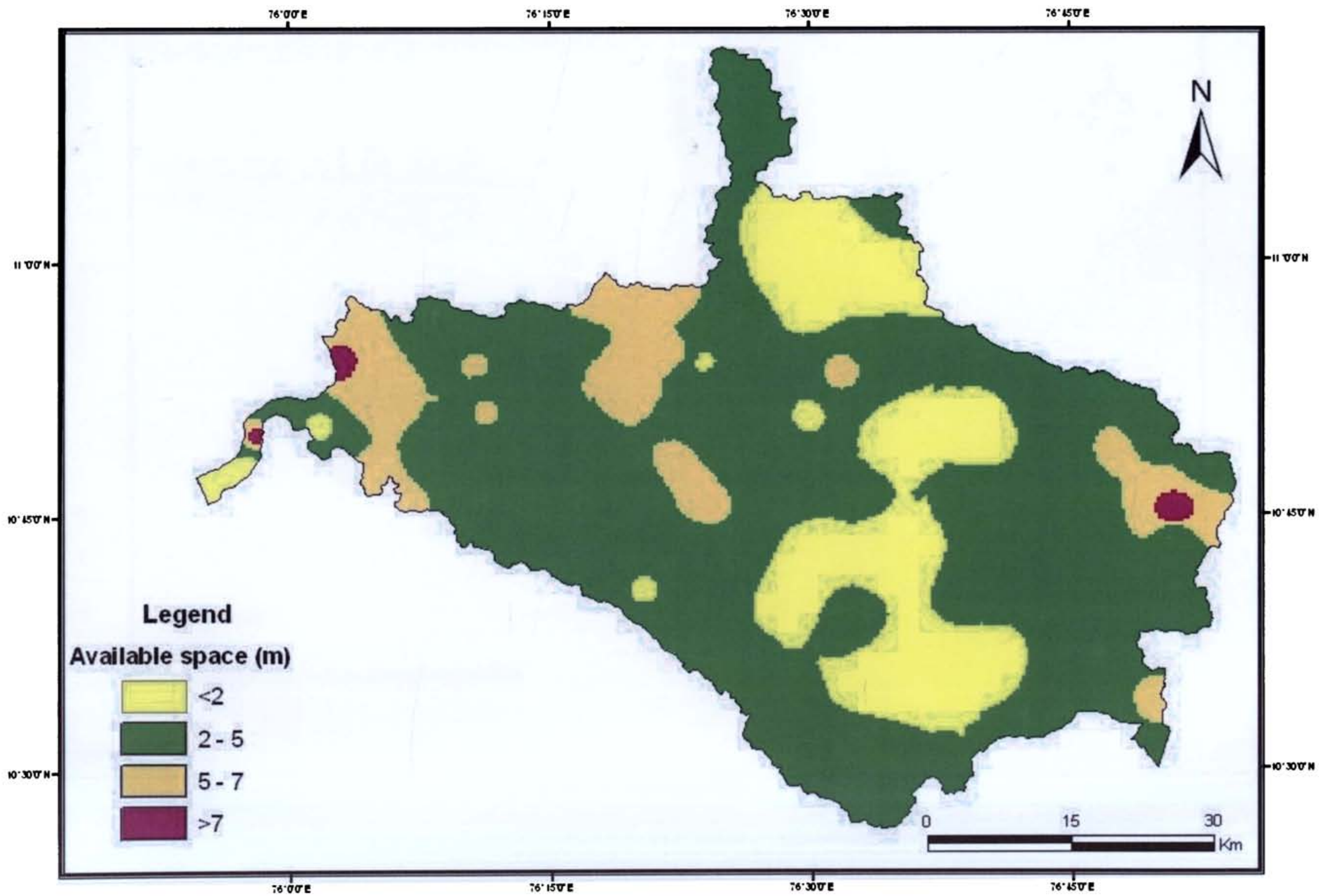


Fig.5.12 Available space for recharging sites of the Bharathapuzha river basin

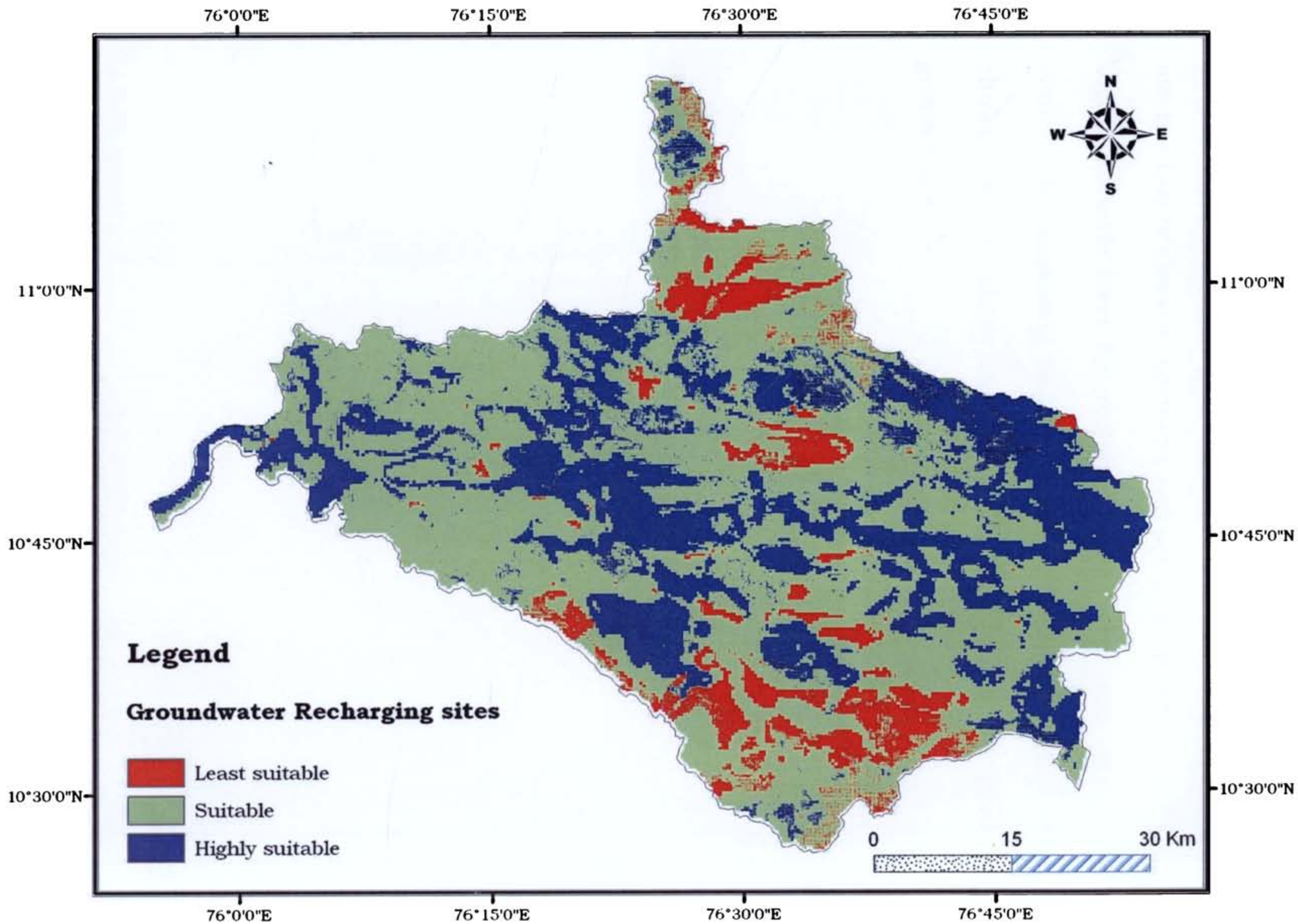


Fig. 5.13 Groundwater recharging sites of the Bharathapuzha river basin

In the Bharathapuzha river basin majority of the area is suitable for artificial recharging of groundwater. The highly suitable artificial recharge areas are seen in the northeastern and central parts of the basin. Slope in this region is comparatively less. Least suitable zones are the highly elevated northern and southern parts of the basin. The highly suitable sites for recharging area are seen along the river course. By comparing suitable sites for recharging map with DEM shows that the highly elevated areas are suitable for recharging of groundwater.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The present study is an integrated approach based on the hydrogeological, geophysical, hydro geochemical parameters to demarcate aquifer potential area and suitable sites for artificial recharge by using GIS and satellite data. The salient finding of the study are accounted below to provide a holistic picture on the groundwater status of Bharathapuzha river basin. Some recommendations for the proper management of the groundwater in the river basin also recommended in this chapter.

Comparison of Geomorphology map with drainage map shows that the geomorphology has a clear control on the drainage net work of the basin. The structural hill area shows a highest drainage network, where as pediment shows lowest drainage network.

From the drainage and lineament map it is concluded that many parts of the major river course follow the lineament. This observation reveals the structurally controlled nature of the Bharathapuzha river.

Surface lineament map on comparing with isoresistivity map at different depths show that many of the underground lineaments recognised through ground resistivity studies have surface expressions as surface lineaments. Such areas are classified as high ground water potential zones.

There are many discontinuous lineament in the Bharathapuzha river basin which can be connected by a straight line. Hence even though they appear as small lineaments in the imagery they could be parts of mega lineaments and sub surface lineaments.

The central portion of the basin shows shallow water level because all the tributaries of the river confluence at the central portion. The zone of shallow water table is seen at the north eastern, southern and western part of the basin, where as deeper water zones are located on the eastern and north western part of the basin.

The north eastern part of the basin shows shallow water table even though this area is marked by steeply sloping structural hills. It is due to the effect of Silent Valley reserve forest, where thick humus acts as a sponge to maintain a constant water level. The eastern side shows a deeper water table due to the influence of Palghat gap. In general the areas having maximum fluctuation are charecterised with deeper water table and vice - versa

Ground water flow directions are generally towards the western portions of the study area. From the northern region water flows towards the central and also water from the eastern and southern side confluences at the centre and move towards western side of the basin.

From the water level data the river basin is divided in to a negative and positive zone separated by a zero line. The negative zone lies at the mid and lower reaches of the basin. In the negative zone area the river attains the wider channel width Negative zone or discharge area covers more than 60% of the study area. A major positive zones lies in the upstream area (north and eastern part of the basin) which are highly elevated. From the study it is observed that the upstream portions are the major recharging areas where as the mid and lower reaches are the discharge zone. The ground water flow direction more or less coincides with grid deviation map suggesting that topography play a considerable role in the ground water recharge and movement.

Water level fluctuation is compared with water table above the mean sea level reveals that areas having maximum fluctuation are characterized with deeper water table which are confined to the eastern part of the basin. While minimum water level fluctuation is confined to shallow water table which is on the western side marked for the presence of alluvium deposits.

On comparing the water level fluctuation map with geological formation, it is found that the charnockite and hornblende biotite gneissic terrain shows a higher water level fluctuation.

Eastern side also shows higher water level fluctuation may attribute to the presence of the rock type in the terrain which is characterized by the charnokite, hornblende biotic gneisses. However this does not hold good for the northern region where lower water level fluctuation has recorded. This is due to the presence of thick humus in to the silent valley bio reserve forest, the thick humus act as a sponge, prevent the free run off, where by enhances infiltration.

Water level fluctuation when compared with the geomorphology of the basin reveals that valley fills, coastal planes and pediment zones have low water level fluctuation and the plateau regions of the eastern side has higher water level fluctuation. Even though southern and northern part of the basin is characterized with structural hills, northern part of the basin shows low water level fluctuation due to the effect of Silent valley bioreserve.

So also the water level fluctuation map is compared with the lineament density map which shows that majority of the high lineament density areas have low water level fluctuation. There is a positive relationship between the water level fluctuation and lineament density.

Comparison of water level fluctuation map with relative relief map shows that majority area of the basin is marked by low relative relief and has a medium water level fluctuation except eastern and north western part of the basin which has high water level fluctuation. In the basin high relative relief area is characterised by medium water level fluctuation except on the northern side of the basin.

The transmissivity value observed through sensitivity analysis method reveals that higher transmissivity values are seen in the western part (discharge area). These are suitable sites for well development. Majority of the storativity values falls with the 0.05 to 0.3° category and thus it clearly support the unconfined nature of the dug wells. The positive correlation of transmissivity and storativity values show good aquifer conditions exists in the present study area.

Analysis of Slichter's specific capacity and radius of the dug well in the study area,it is concluded that the specific capacity is controlled mainly by equatorial radius rather that the lithology of the terrain. Similarly the time taken for the full recovery indicates that majority of the basin shows a negative correlation between time required for full recovery and transmissivity values reflecting the good aquifer condition prevailing in the Bharathapuzha river basin,

Based on Vertical Electrical Sounding analysis the layer thickness and apparent resistivity values reveals that majority of the top soil shows 2 - 4 m thickness, and a maximum thickness of 89.8 m is seen at the central and western region.Most of the second layer has thickness of less than 10m, depth to aquifer basement between 20-40 m and a positive correlation of 2nd layer thickness to depth to aquifer basement.

From the iso-resistivity studies for the 5m and 10m depth shows the presence of low resistivity horizons in the central and western region of the basin, indicating the suitability of open wells. The iso-resistivity at 20m depth reveals that majority of the southern portion of the basin is characterised with low resistivity which extend towards the western part. Hence bore wells or open wells in the southern region of the basin can be productive if it is drilled to more than 20m depth.

Analysis of the groundwater chemistry of the Bharathapuzha river basin with respect to the drinking water standards of the WHO and BIS shows that ionic and non ionic constituents except fluoride and nitrate at small areas in eastern and north eastern and central region are within the permissible limits. So the groundwater of the Bharathapuzha river basin is good for domestic consumption.

From the Wilcox, US salinity laboratory and Hill Piper classification of the ground water in the study area for it suitability for Irrigation / Agricultural uses indicates that the groundwater do not have any salinity, sodium and bicarbonate hazards and hence it is ideal for irrigation / agricultural purpose.

For Ground Water Resource Management (GWRM), groundwater recharge, annual draft, groundwater balance and static groundwater reserve were estimated and the study revealed that the net annual groundwater availability is 536.39 million cubic meter, the stage of development of the basin is 62.93% and static storage of the basin is 2939.08 million cubic meter. Hence the Bharathpuzha river basin is under "Safe areas" in accordance with groundwater resource estimation methodology.

Integrating various hydro geological parameters using geographical information system, it is concluded that the very good potential areas are confined to central and western part, where as poor to moderate potential zones to that of northern and southern part of the Bharathapuzha river basin. So also the central belt along the east-west direction of the study area is suitable for artificial recharging of groundwater.

In short it is gratifying to understand that the Bharathapuzha river basin still retains the qualitative and quantitative potential of the groundwater.

RECOMMENDATIONS

- Traditional farm practices are to be followed in homestead gardens for the rejuvenation of first order streams.
- Practices like rain pits, trenches, ploughing of land, bunding, terrace farming etc. with the positive strategy to retain as much rain water as possible within the plot to irrigate the field and also to maintain the homestead wells. The activities are crucial in the conservation of water within the first order micro-level water sheds areas.
- The public participation in the grass root level is needed for such rejuvenating activities of the river basins.
- Based on the site condition of each river basin different techniques like basin method, stream channel method, ditch and furrow, recharge pit, recharge well, flooding etc. can be chosen to conserve water.
- The subsurface dykes using materials like clay, brick walls etc. are very effective for impounding water in many micro-watersheds during rains for controlled release during summer for maintenance of water table.

- Limited thickness of overburden (2 to 8m) makes subsurface dykes economic and efficient.
- These water bodies can transform river basin even in rain shadow regions by maintaining the water table without alarming fluctuation.

REFERENCES

Abbi, S.D.S., Gupta, D.K. and Sharma, J.K. (1971). A mesoscale study of groundwater fluctuations of Delhi in relation to rainfall, Ind. Jour. Meteol. and Geophy., v. 22, pp. 82-88.

Adayalkar, P.G. and Mani, V.V.S. (1972). An attempt at estimating the transmissibility of trappean aquifers from specific capacity values, Jour. Hydrol., v. 17, pp. 237-241.

Adayalkar, P.G., Nair, K.B. and Doshi, D.S. (1966). Quality deterioration as an evidence of marine transgression along the Lathi-Jaisalmer contact in Jaisalmer district, Rajasthan, Symposium on groundwater studies in arid regions (Sponsored by University of Roorkee and Geological Society of India), pp. 385-397.

Adayalkar, P.G and Shrihar Rao, S. (1979). Hydrodynamic method of assessing groundwater recharge by precipitation in Deccan region - a case study, Jour. Geol. Soc. India, v.20, pp. 134- 137.

Akos Gyulai and Tamas Ormos (1990). A new procedure for the interpretation of VES data: 1.5-D simultaneous inversion method,Jour. Appl. Geophys., v. 41, pp. 1 -17.

Aller, L., Bennet, T., Lehr, J.H. and Pety, R.J. (1987). DRASTICP: a standardised system for evaluating groundwater pollution using hydrogeological settings, United States Environmental Protection Agency, Washington.

Altekar, R. A. (1998). Quality of water for irrigation, Jour. Water works Assoc., pp. 175-177.

Anderson, J.R., Hardy, E.E., Roach, J.T. and Wirmer, R.E. (1976). A land use and land cover classification system for use with remote sensing data, Prof. Paper no.964. US Geol. Surv., Reston Verginia, pp. 28.

Anilkumar and Pandey, R. N. (1982). Quantitative analysis of relief of the Hazaribagh Plateau region. In: Prospectives in Geomorphology, (Eds. H.S. Sharma), Concept publishing co. New Delhi, pp. 235-258.

Anirudhan, S. (1991). Textural and mineralogical variations of sediments of Bharathapuzha river system, unpublished Ph.D thesis, Kerala University.

Anirudhan, S. and Trivikramji, K.P. and Roy Chacko, P.T. (1994). Roles of relief and climate on composition of detriatal and sediments of Bharathapuzha basin, Kerala, Jour. Geol. Soc. India, v. 43, pp. 425-433.

APHA. (1985). Standard Methods for the Analysis of Water and Waste Water (16th edn.), American Public Health Association, Washington. D.C.

Applin, K.R. and Zhao, N. (1989). The kinetics of Fe (II) oxidation and well screen encrustation, Groundwater, v. 27(2), pp. 168-174.

Aravindan, S. (1999). Integrated hydrogeological studies in hard rocks aquifer system of Gadilam river basin, Tamil Nadu, India, unpublished Ph.D thesis, Bharathidasan University.

Ashley, R.P. and Burely, M.J. (1995). Controls on the occurrence of fluoride in the groundwater in the Rift Valley of Ethiopia, Groundwater Quality, 17th special report, (Eds. H. Nash and G.J.H. McCall), Chapman and Hall pub., 17th special report, pp. 45-54.

Auden, J.B. (1993). Vindhyan Sedimentation in the Son Valley, Mirzapur district, Geol. Sur. India, Mem., v. 62 (pt. 2), pp. 141-250.

Back, W. (1961). Techniques for mapping of Hydrochemical facies. U.S Geol. Surv. Prof. Paper 424 –D, pp.380- 382.

Back, W. (1966). Hydrochemical facies and groundwater flow patterns in northern part of Atlantic costal plain. U.S Geol. Surv. Prof. Paper 498-A, 42p.

Back, W. and Hanshaw, B.B. (1965). Chemical Geohydrology, Adv. Hydro Science, v.1, pp. 49-109.

Badarinath, S.D., Raman, V., Gadkari, S.K., Mahaisalkar, V.A. and Deshpande, V.P. (1984). Evaluation of calcium carbonate stability indices for Sabarmati river water, Ind.Water. Ass., v. 16(1), pp. 163-168.

Bagdhan, M. (1976). Application of geophysical methods to specific problems of hydrology in Deccan traps, unpublished Ph.D thesis, Poona University.

Balakrishna, S. and Ramanujachary, K.R. (1979). Resistivity investigations in Deccan trap region, Geophy. Res. Bull., v.16, pp. 31-40.

Balakrishna, S., Ramanujachary, K.R. and Sastry, T.S. (1978). Resistivity surveys in limestone regions, Geophy. Res. Bull., v.16, pp. 97-103.

Balakrishna, S., Subramanyam, K., Gogte, B.S., Sharma, S.V.S. and Venkatanarayana, B. (1984). Groundwater investigations in the

Union Territory of Dadra and Nagar Haveli, Geophy. Res. Bull., v. 21, pp. 347-359.

Balasubramanian, A. (1986). Hydrogeological investigations in the Tambraparani river basin, Tamil Nadu, unpublished Ph.D thesis University of Mysore.

Balasubramanian, A and Sastri, J.C.V. (1987). Studies of the quality of groundwater of Tambraparni river basin, Tamil Nadu, India, Jour. Assoc. Expl. Geophys., v.8, pp. 41-51.

Balasubramanian, A. and Sastri, J.C.V. (1989). Techniques of aquifer parameter evaluation using Pocket Computer. Pro. Ind. workshop on appropriate methods for development and management of groundwater resource in developing countries, NGRI-Oxford IBH publishers, New Delhi, pp. 461- 468.

Balasubramanian, A., Sharma, K.K. and Sastri, J.C.V. (1985). Geoelectrical and hydrogeochemical evaluation of coastal aquifer Tambraparani basin, Tamil Nadu, Geophy. Res. Bull., v. 23 (4), pp. 203- 209.

Balling Jr, R. C. and Cerveny, R. S. (2003). Compilation and Discussion of Trends in Severe Storms in the United States: Popular Perception Climate Reality, Natural Hazards, v. 29, pp. 103–112.

Ballukraya, P.N. (2001). Hydrogeophysical investigations in Namagiripettai area, Namakkal district, Tamil Nadu, Jour. Geol. Soc. India, v. 58, pp. 239-249.

Ballukraya, P.N., Sakthidivel, R. and Baratan, R. (1981). Inadequacies in the techniques of resistivity methods for the location of sites in hard rock areas, Nordic Hydrology, v. 12, pp. 185-192.

Barker, G. R. (1988). Remote sensing: the unheralded component of geographic information systems, Photogram. Engg. Rem. Sens., v. 55 (11), pp. 1619-1627.

Basak, P. and Nazimuddin, M. (1987). Sea water intrusion in coasta unconfined aquifers of the south western Peninsula- A case study Jal Vigyan Sameekha- a Publication of high- level technical committee on hydrology, v. 11 (1), pp. 72-80.

Beeson, S. and Jones, C.R.C. (1988). The combined EM/VES geophysical method for setting bore holes, Groundwater, v. 26 (1), pp. 54-63.

Benergy, S.L. (1969). Geophysical investigation for groundwater near Balsar, Purandhar Taluk, Poona district, Geol. Sur. India, Technical report, Groundwater part-1.

Bhattacharya, P.K. and Patra, H.P. (1968). Direct current geoelectric sounding principles and interpretation, Elsevier, Amsterdam.

Bhattathirippad, (2003). Water Conservation: Sooryamoorthy R and Antony (Eds.), 'Managing Water and Water Users: Experience from Kerala', Maryland: University Press of America.

Bhimashankaram, V.L.S., Murali, S. and Tarkhor, A.G. (1975). Geophysical and hydrological surveys for groundwater in Munsi, Ayakat area, Nalgonda disctrict, A.P., Tech. report no. 4 CEG, OU, Hyd.

Bhimashankaram,V.L.S. (1976). Geophysical and hydrogeological investigations for groundwater in upland tracts of west Godavari district, A.P.

Bhimashankaram, V.L.S. and Gaur, V.K. (1977). Lectures on Exploration Geophysics for Geologists and Engineers, AEG Pub., Osmania Uni. Hyderabad, 449p.

Bindumadhavan, V. (1975). Geoelectrical resistivity method as an effective tool for groundwater exploration in Deccan traps, Proceedings Second World. Con. IWRA, New Delhi, v. 3, pp. 247-257.

BIS (1994). Indian Standard drinking water specification (BIS 10500. 1994)

Biswas, A. B. and Chatterjee, P. K. (1967). On representation of water table by grid deviation method. Bull. Geol. Soc. India, v. 4, pp. 12-14.

Biswas,K.A. (1976). Systems Approach to Water Management. McGraw hill Inc. 429p.

Black, J.H. and Kipp, K.L. (1977). Observation well response time and its effect upon aquifer test results. Jour. Hydrol., v. 34, pp. 297-306.

Boehmer, W.K. (1993). Secondary type aquifers and the value of pumping tests for the evaluation of groundwater potential, in Mem. 24th Congress of IAH, Oslo, pp. 159-68.

Boulton, N.S. and Streltsova, T.D. (1976). The drawdown near an abstraction well of large diameter under non-steady conditions in an unconfined aquifer, Jour. Hydrol., v. 30, pp. 29- 46.

Boutt, D.F., Hyndman, D.W., Pijanowski, B.C. and Long, D.T. (2001). Identifying potential land use- derived solute sources to stream base flow using groundwater models and GIS, Groundwater, v. 39, no.1, pp. 24- 34.

Bowder, L.W. and Pruit, E.L. (1975). Manual of remote sensing Vol.II, Interpretation and application, Amer. Soc. Photogrammetric Engineering, v. 30, pp. 630-635.

Boyer, R.E. and Mague, J.E. (1964). Comparison of mapped rock fractures and air photo linear features, Photogrammetric Engg., v. 30, pp. 630- 635.

Bradbury, K.R. and Rothschild, E.R. (1985). A Computerised technique for estimating the hydraulic conductivity of aquifers from specific capacity data, Groundwater, v. 23 (2), pp. 240-246.

Brakeman, C.E. and Fernandaz, C.A. (1973). Application of ERTS imagery to geologic mapping, Proceedings, First Pan Amer. Symp. of Remote Sensing, pp.40-52.

Burjia, J. S. and Romani, S. (2003). Indian Jour. Pub. Adm., v. XLIX, pp. 301-307.

Butt, M.A. and Mc Elwee, C.D. (1985). Aquifer parameter evaluation from variable rate pumping test using convolution and sensitivity analysis, Groundwater. v. 23, pp. 212-219.

Canter, L.W. (1985). Methods for the assessment of groundwater pollution potential. In. Groundwater quality (Eds. C.H. Ward, W. Giger and P.L. Mc Corty). John wiley, Newyork, pp. 270-306.

CBIP, (1976). Manual on groundwater and tube wells, Govt. India, New Delhi, 411p.

CESS, (1984). Resource atlas of Kerala, Centre for Earth Science Studies, Thiruvananthapuram, Kerala.

CESS, (1997). Bharathapuzha and its problems, Centre for Earth Science Studies, Thiruvananthapuram, Kerala.

CGWB (2003). A study on seawater ingress in the coastal aquifers in parts of Alleppey and Ernakulam districts, Kerala, Technical report, Central Groundwater Board, AAP 2000-2001, 29p.

CGWB (2004). Groundwater Year Book, Trivandrum: Ministry of Water Resources, Central Groundwater Board, Kerala Region.

Chabdler, R.l. and Whorter, D.B.M. (1975). Upconing of the salt water-fresh water interface beneath a pumping well, Groundwater, v.13 (4), pp. 354 - 359.

Chandra, P.C. and Athavale, R.N. (1979). Close gridresistivity survey for demarcating the aquifer encounter in bore well at Koyyur in lower Mane basin, Technical report No.GH-11-GP-7, Hyderabad.16p.

Chandrasekharan, H. (1988). Geo-electrical investigations for groundwater in Thar desert-some case studies, Transactions of the ISDT Part II, pp. 155-168.

Changyuan Tang, (1989). Evolution process of groundwater quality in Dejma Upland, Science Report, Institute of Geoscience, University of Tsukuba, Section A, v.10, pp. 59- 85.

Clawson, M. and Stewart (1965). Land use information committee on landuse statistics, resources for future, John Hopkins Press, Boltmore, USA, 212p.

Cobb, P.M., McElwee, C.D. and Butt, M.A. (1982). An automated numerical evaluation of leaky aquifer pumping test data; an application of sensitivity analysis, (Kansas Geol. Surv.), Groundwater, v. 6, pp. 55.

Cooper, H.H. and Jacob, C.E. (1946). A generalized graphical method for evaluating formation constants and summarising well field history. Amer. Geophy. Union Trans., v. 27, pp. 526- 534.

CPHEEO. (1997). Manual on water supply and treatment Akalank publication, New Delhi, Central public Health and Environment, Engineering Organisation, pp.8-9.

Daly, D., Lloyd, J.W., Misstear, D.R. and Daly, E.D. (1980). Fault control of groundwater flow and hydrochemistry in the aquifer system of the Castlecomer plateau, Ireland, Jour. Engg. Geol., v. 13, pp. 167- 175.

Davis, S.N. and De Wiest, (1960). Hydrogeology, John Wiley Inc., New York, 463p.

Davis, S.N. and Turk, L.J. (1964). Optimum depth of wells in crystalline rocks. Groundwater, v. 2, pp. 6-11.

deStadelhofen, C.M. (1994). Anwendung Geophysikalisher Methoden in der Hydrogeologie. Springer Verlag. Berlin.

Domenico, P.A. and Khanadali, S.D. (1983). Physical and chemical hydrogeology, John Wiley and Sons, New York, 824p.

Domenico, P.A. and Schwartz, F. W. (1990). Physical and chemical hydrogeology, John Wiley& Sons, Inc., New York.

Domonkos, P. (2003), Recent Precipitation Trends in Hungary in the Context of Larger Scale Climatic Changes, Natural Hazards, v.29, pp. 255–271.

Driscoll, F.G. (Eds). (1986). Groundwater and Wells, Johnson Division, St.Paul, Minnesota, 1089p.

Drury, S.A. (1987). Image interpretation in geology. Allen and Unwin, London, 243p.

Dumble, J.P. and Cullen, K. T. (1983). The application of a microcomputer in the analysis of pumping test data in confined aquifers, Groundwater, v. 21, pp. 79-83.

Eagon, H.B. and Johe, D.E. (1972). Practical solutions for pumping tests in carbonate rock aquifers, Groundwater, v.10, pp. 6-13.

Eaton, E.M. (1950). Significance of carbonate in irrigation water, Soil Science, v. 69, pp. 123-133.

Edmunds, W.M. (1994). Groundwater chemistry and development, Groundwater quality. (Eds. Nash, H. and McCall, G.J.H. Chapman and Hall).

El-Kadi, A.I., Oloufa, A.A., Eltahan, A.A. and Malik, H.U. (1994). Use of a geographic information system in site- specific groundwater modelling, Groundwater, v. 32 (4), pp. 617-625.

Erhan Sener, Aysen Davraz and Mehmet Ozcelik (2005). An integration of GIS and remote sensing in groundwater investigations: A case study in Burdur, Turkey, v.13, pp. 826–834.

Fauchereau, N., Trzaska, M., Rouault, M. and Richard, Y. (2003). Rainfall Variability and Changes in Southern Africa during the 20th Century in the Global Warming Context, Natural Hazards, v.29, pp.139–154.

Freeze, R.A. and Cherry, J.A. (1979). Groundwater, Prentice-Hall, Inc., New Jersey, 604p.

Galin, D.L. (1979). Use of longitudinal conductance in vertical electrical sounding induced potential method for solving hydrogeologic problems, Vestrik Moskovskogo Universiteta, Geologiya, v. 34, pp. 74-100.

Ganesh Raj, K. (1994). Major lineaments in Karnataka and their significance, In: Geo Karnataka, (Eds. B. M. Ravindra and N. Ranganathan), KAGA, Bangalore, pp. 303-313.

Gilkcson, R.H. and Wright, K.C. (1983). The application of surface electrical and shallow geothermic methods in monitoring network design. Groundwater monitoring RCV, v. 3 (3), pp. 30-42.

Girish Gopinath (2003). An integrated hydrogeological study of the Muvattupuzha river basin, Kerala, India, unpublished Ph.D thesis, Cochin University of Science and Technology.

Girish Kumar, M., Agarwal Agand, Rameshwar Bali, A. K. (2008). Delineation of potential sites for water harvesting structures using remote sensing and GIS, Jour. Indian Soc. Rem. Sens. v.36, no. 4, pp. 323-334

Glock,W.S. (1932). Available relief as a factor of control in the profile of a landform, Jour, Geol., v. 40, pp. 74-83.

Golditch, S. S. (1938). A study in rock weathering, The Journal of Geology, v.46, pp.17.

Goldschmidt, V.M. (1958). Geochemistry, Oxford University press, Amen house, London, ECA, (Eds. Alex Muir), 730p.

Goyal, R.S. and Jain, B.l. (1982). Use of Gypsum modifying crustal conductive conditions in saline water irrigated soils, Indian Soc. Soil Sci.,v.30(4), pp.447-454.

Goyal, S., Bharawaj, R.S. and Jugran, D.K. (1999). Multicritiria analysis using GIS for groundwater resource evaluation in Rawesen and Pilli watershed, U.P. Proceedings Map India 99, New Delhi, India

Gregg, D.O. (1996). Analysis of groundwater fluctuations caused by ocean tides in Glynn country, Georgia, Groundwater, v. 4 (3), pp. 24-32.

GREM (1997). Ground Water Resources Estimation Methodology, Ministry of Water Resource, Govt. of India.

Gupta, I.C. (1987). The scope of utilising saline groundwater for supplemental irrigation in arid and semi arid zones. In dry land Agriculture in India, (Eds. Mohammed Shafi and Mehdi Raza), Rawat Pub., Jaipur, pp. 124- 134.

Gupta, R.P. (1991). Remote Sensing in Geology, Springer-Verlag, Berlin, 356p.

Gustafsson, P. (1993). SPOT satellite data for exploration of fractured aquifers in a semi-arid area in southern Botswana. Mem. of the 24th Congress of International Association of Hydrogeologist, Oslo, pp. 562- 575.

GWREM, (1997). Groundwater resource estimation methodology – Ministry of water resources, Government of India, New Delhi, 105p.

Halliday, S.L and Wolfe, M.L. (1991). Assessing the groundwater pollution potential from nitrogen fertilizer using geographic information system. Bull. Water Resources, v.27 (2), pp. 237-245.

Haridas, V.R., Aravindan S. and Girish Gopinath (1998). Remote sensing and its applications for ground water favorable area identification, Quat. Jour. GARC, v.6, pp.18–22.

Hem, J.D. (1959). Study and interpretation of the chemical characteristics of natural water. US.Geol. Surv., 1935-C, pp. 17.

Henriet, J.P. (1975). Direct interpretation of the Dar Zarrouk Parameters in groundwater survey, Geophy., v. 24, pp. 344-353.

Henriksen, H. (1995). Relation between topography and well yield in boreholes in crystalline rocks, Sognag Fjordane, Norway. Groundwater, v. 33 (4), pp. 635-43.

Howe, R.H. (1956). Application of air photo interpretation in the locating of groundwater, Jour. Am. Water Works Assoc., v .48, pp.1380-1390.

IPCC, (2008). Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210p.

ISI (1983). Indian Standard methods of Sampling and Test (Physical and Chemical) methods for water used in industry, 122p.

Jain, C.K., Dayaram and Bhatia, K.K.S. (1996). Evaluation of groundwater quality in district Harwar, Indian J. Environ Prot., v. 16, pp. 730-737.

Jaiswal, R.K., Mukherjee, S., Krishnamurthy, J. and Saxsena, R. (2003). Role of remote sensing and GIS techniques for generation of groundwater prospect zones toward rural developments- An approach, Intern. Journ. Rem. Sens., v. 24, no.5, pp. 993- 1008.

James, C.J, (2003). Managing Water and Water Users: Experience from Kerala, 'Water Management' in Sooryamoorthy R and Antony ((Eds.), 'Maryland: University Press of America.

Johnston, C.D. (1987). Distribution of environmental chloride in relation to subsurface hydrology. Jour. Hydrol., v. 94, pp. 67-88.

Junge, C.E and Wrby, R.T. (1958). The concentration of chloride, sodium, potassium, calcium and sulphate in rainwater over the United States. Jour. Meteorol., v.15, pp. 417- 25.

Kaehler, C.A. and Hsieh, P.A. (1994). Hydraulic properties of fractured rock aquifers, Lee Valley, San Diego Country, California. US. Geol. Surv. Water Supply, v. 2394, 64p.

Kahya, E. and Demirel, M. C. (2009). Grouping of stream flow characteristics in Portugal, Earth Science Research jour. (in press).

Kalkoff, S.J. (1993). Using geomorphic information systems to determine the relation between stream quality and geology of the Roberts Creek watershed, Clayton country, Lowa Water resources Bull. American Water Resource Association, v. 19(6), pp. 989-996.

Karanjac, J. (1975). Breif note on testing the possibility of defining optimum yield of dug wells of large diameter, Groundwater, 13: 4p

Karanth, K.R (1994). Groundwater Assessment, Development and Management,Tata McGraw-Hill publishing Company Ltd,New Delhi.

Karanth, K.R. (1985). Groundwater recharges evaluation in hard rocks, Seminar vol. on research and development programme for water resources in Karnataka, KSCST-I.I.Sc, Bangalore, pp. C3-1 to C3-18.

Karanth, K.R. (1987). Groundwater assessment, development and management, Tata Mc Graw-Hill, New Delhi, 720p.

Keller, G.V. and Frisehknecht, F.C. (1966). Electrical methods in geophysical prospecting, Pergamon Press, New York.

Kelley, W.P. (1940). Permissible Composition and concentration of irrigation waters, Proc. American Society of Civil Engineering, v. 66, 607p.

Kelley, W.P. (1951). Alkali Soils–Their Formation Properties and Reclamation, Reinold Pub. Corp., New York.

Kelly, G.P. and Kemp, R.G (1974 & 1990). The corrosion of the groundwater pumping equipment, Australian water resources council project, 72p.

Khurshid, S., Zaheeruddin and Basheer, A. (1998). Pollution assessment and water quality status in parts Cochin, Indian .Jour. Environmental Prot. v. 18, pp. 46-249.

Klein, M. and Kaser. (1963). A statistical analysis of groundwater levels in twenty selected observation wells in Ohio, Tech-Rept. 5, Ohio Dept. Natural Resource, Div. of water, Columbus, 124p.

Knopman, D.S and Hollyday, E.F. (1993). Variation in specific capacity in fractured rocks, Pennsylvania, Groundwater, v. 31(1), pp.135-145.

Kresic, N. (1997). Quantitative solutions in hydrogeology and groundwater modeling, Lewis Publishers, New York, p. 461.

Krishnamurty, J.N., Venkadesa, K., Jayaraman, V. and Manivel, M. (1996). An approach to demarcate groundwater potential zones through remote sensing and geographical information system, Intern.Journ. Rem. sens., v. 17, no. 10, pp. 1867- 1884.

Kruseman, G.P. and de Ridder, N.A. (1970). Analyses and evaluation of pumping test data, Int. Inst. for land reclamation and improvement, Bull. 11, Wageringen, 200p.

Krupanidhi, K.V.J.R., Venkataraman, S., Mathuria, D.P. and Murthy, K.N. (1973). Studies of specific capacities of wells in hard rocks and alluvial formations of Mysore state, Int. Nat. Symp. Proc. Development of Groundwater resources, Madras, India, v. 1, pp. 61-74.

Kruseman, G.P. and de Ridder, N.A. (1990). Analyses and evaluation of pumping test data, 2nd edn, Int. Inst. for land reclamation and improvement, Publ. 47, Wageringen, 377 p.

Kumar,C.P. (1996). Assessment of groundwater potential.proc. natl. Sem. small watershed development, Indian Association of Hydrologist, Calcutta, pp. 1-23.

Kumar, A. and Srivatsava, S.K. (1991). Geomorphological units, their geohydrological characteristics and vertical electrical sounding response near Munger, Bihar, Jour. Ind. Soc. Rem. Sens, v. 19 (3), pp. 205- 212.

Kumaresan, M and Riyazuddin, P. (2006). Major ion chemistry of environmental samples around sub-urban of Chennai city. Curr. Sci., 1668 v.91, pp. 12.

Laluraj, C.M., G. Gopinath and P.K. Dinesh Kumar (2005). Groundwater chemistry of shallow aquifers in the coastal zones of Cochin, India App. ecology and envir. res., v. 3, no.1 pp. 133-139.

Langmuir, D. (1997). Aqueous environmental chemistry, Prentice-Hall, Inc, New Jersey, 600p.

Lattman, L.H. and Parizek, R.R. (1964). Relationship between fracture traces and occurrence of groundwater in carbonate rocks, Jour. Hydrol., v. 2, pp. 73-91.

LeGrand, H.E. (1967). Groundwater of Piedmont and Blue Ridge Provinces of and Southeastern States, US Geol .Surv .Circular, v. 238, pp.11.

Lehr,J.H., Gass, T.E., Petty John, W.A. and De Marre, J. (1980). Domestic water treatment, mc Graw- Hill book Co. New York.

Levns, R.L., Williams, R.E. and Rushton, D.R. (1994). Hydrogeologic role of geologic structures. Part 2 analytical models, Jour. Hydrol., v. 156, pp. 245-263.

Limaye, D.G. (1973). Discussion on studies of specific capacity of wells in hard rocks and alluvial formations of Mysore state by

Krupandidhi et. al., Proc. Int. nat. Sym. on Groundwater resources., Madras, India, v. 4, pp. 2-87.

Lloyd, J.W. (1976). Hydrochemistry and groundwater flow patterns in the vicinity of Straford- Upon-Avon, Qly. Jour. Engg. Geol., v. 9, pp. 315-326.

Lloyd (1986). A review of aridity and groundwater, Hydrol. Proc. V.1, pp. 63-78

Lloyd,J.W. and Heathcote, J.A. (1985). Natural inorganic hydrochemistry in relation to groundwater –An Introduction, Clarendon Press Oxford 296p.

Lobo Ferreira e Catarina Diamantino, J.P. (2008). Groundwater artificial recharge based on alternative sources of water: Advanced integrated technologies and management, unpublished PhD Thesis, University of Gottingen.

Mall, R. K., Akhilesh Gupta, Ranjeet Singh, Singh, R. S. and Rathore, L. S., (2006). Water resources and climate change: An Indian perspective. Curr. Sci., v. 90, no.12, pp. 1610-1624.

Mani, K.A.S. (1989). Hydrogeological studies in parts of Bukaleru watershed, Nalgonda district, A.P, India, unpublished Ph.D thesis, Osmania University, Hyderabad.

Manivel, M and Aravindan, S. (1997). Groundwater pollution and around Sempattu area, Tiruchirappalli, Tamil Nadu, The geography teachers, India, v. 4 (2), pp. 22-23.

Mark. W. Rosegrant., Ximing Cal and Sarah, A. Cline (2002). Global water outlook to 2025: Averting an impending crisis, Food policy report, International water management Institute, 322p.

Mathai John, (2003). Diverse Water Problems in Kerala: An Overview in Managing Water and Water Users: Experience from Kerala, Sooryamoorthy, R. and Antony (Eds.), Maryland: University Press of America.

Matthess, G. (1982). The properties of Groundwater, John Wiley, New York, 406p.

Matthess, G. and Pekdeger, A. (1981). Concepts of a survival and transport model of pathogenic bacteria and virus in groundwater. Proc. Int. Sym. on quality of groundwater, Amsterdam,pp. 119-159

McElwee, C.D. (1980). Theis parameter evaluation from pumping tests by sensitivity analysis, Groundwater, v. 18 (1), pp. 56 – 60.

McFarlane, M.J., Chiloton, P.J. and Lews, M.A. (1992). Geomorphological controls on borehole yields: a statistical study in an area of basement rocks in central Malawi , Hydrogeology of crystalline basement aquifers in Africa, Geol.Soc .Spl. Pub. no.66, pp. 131 –54.

Millot,G. (1964). Geology des argiles mason (Eds. Paris), 499p. (English edition Oxford IBH, 450p).

Milly, P. C. D., Wetherald, R. T., Dunne, K. A. and Delworth, T.L., (2002). Increasing risk of great floods in a changing climate, Nature, v. 415, 514–517.

Mollard, J.D. (1988). The role of photo-interpretation in finding groundwater resources in Western Canada, Proceedings 2nd seminar on Air-photo interpretation in the development of Canada, pp. 57-75.

Moony, H.L. (1980). Handbook of Engineering Geophysics, Electrical Resistivity, bison Instrument, Minneapolis, Minn., v.2.

Mooney, H.L.and Wetzel, W.M. (1956). The potentials of a point electrode and apparent resistivity curves for 2-3-4 layered earth, University of Minnesota, 145p.

Mondal, N.C. and Singh, V.S. (2004). A new approach to delineate the groundwater recharge zone in hard rock terrain, Curr. Sci., v. 87, no. 5, pp. 658-662.

Moore, G.K. and Duestsch, M. (1975). ERTS- Earth Resource Technology Satellite imagery for groundwater investigations, Groundwater, v. 13 (2), pp. 214-226.

Morgan, C.O. and Winner (Jr), M. D., (1962). Hydrochemical facies in the 400 foot and 600 foot sands of the Baton Rouge area, Louisiana. US. Geol. Surv. Prof. Paper 450-B, pp. B 120-121.

Mukhopadhyay, A. (1985). Automated derivation of parameters in a non-leaky confined aquifer with transient flow. Groundwater, v. 23 (6), pp. 806-811.

Murthy, K.S.R. (2000). Groundwater potential in a semi arid region of Andhra Pradesh: A geographical information system approach. Int. Jour. Rem. Sens., v. 21, no. 9, pp. 1867- 1884.

Narasimhan, T.N. (1965). On testing open wells, India, Geohydrology, v. l, pp. 101-105.

Narasimhan, T.N. (1968). A ratio method as a substitute for curve matching procedure for solving certain types of problems, Curr. Sci., pp. 37.

Narayana Rao, T. V. (1972). Crystalline rock hydrology, Groundwater dept., Tamil Nadu State, India.

Narendra Babu, K, Padmalal, D, Sreeja, R and Sreebha, S (2003). Water quality variation of Bharathapuzha River, South West coast of India; Problems and solutions, Proceedings of the International conference on water and environment (WE-2003).

National Academy of Sciences. (1977). Drinking water and health, Federal Register, 43 (132), pp.35764

National Environment Policy (2004), Ministry of Environment and Forests, Govt of India, 38p.

Nautiyal, M.S. and Gopalappa, V. (1980). Yield characteristics of open wells in crystalline rocks of Chikkahagari basin, Karnataka, Jour. Ind. Assoc. Hydrol, v. 4, pp. 10-12.

Neuman, S.P. (1975). Analysis of pumping test data from anisotropy unconfined aquifers considering delayed gravity response, Wat. Reso. Res., v. 11 (2), pp. 329-342.

Nightingale, H.I. and Binachi, W.C. (1980). Well-water quality changes correlated with well pumping time and aquifer parameters-Fresno, California, Groundwater, v.18 (3), pp. 274-280.

Oreelana, E and Mooney, H.M. (1966). Master curves and tables for vertical electrical soundings overlayered structures, Interciencia, Madrid.

Ottle, C. Maggar, D.V. and Griward, G. (1989). Remote sensing application to hydrological modelling, Jour.Hydrol., v. 105, pp. 369-384.

Padmalal, D. and Serlathan, P. (1993). Heavy metal content in suspended particulates and bed sediments of a tropical perennial river and estuary, Central Kerala, India, Jour. Geol. Soc. India, v. 42, pp. 349-355.

Pal, D.K., Khare, M.K., Rao, G.S., Jugran, D.K and Roy, A.K. (1997). Demarcation of groundwater potential zones using remote sensing and GIS techniques: A case study of Bala valley in parts of Yamunanagar and Sirmaur districts, Remote Sensing for Natural Resources, ISRS-NNRMS publication, pp.395-402.

Palacky, G.J., Ritsema I.L. and deJong, S.J. (1981). Electromagnetic prospecting for groundwater in Precambrian terrains in the Republic of Upper Volta (Burkino Faso). Geophysical Prospecting, v. 29, pp. 932-955.

Paliwal, B.S. and Khilnani, M. (2001). Electrical resistivity data to assess aquifer parameters for better interpretations of hydrogeology: A study of the Nagaur region Rajasthan, (Eds. Bhu. H and Agrawal). Proc. of the National Seminar on groundwater resources, Dept. of geology, MLS University, Udayapur, pp. 48-67.

Papadopulos, I.S. and Cooper, H.H. Jr. (1967). Drawdown in a well of large diameter. Wat. Res., v. 3, pp. 241- 244.

Park, J.E. and Park, K. (1980). Text book of preventive and social medicine, Bharadidas Bhanet, Jobalpur.

Patangay, N.S. (1977). Application of surface geophysical methods for groundwater prospecting: Lectures on Exploration Geophysics for geologists and engineers (Eds. Bhimashankaram, V.L.S. and Gaur, V.K., pub. AEG, Hyderabad), pp. 375-404.

Patangay, N.S. and Murali, S. (1984). Geophysical Surveys to locate groundwater prospecting –lectures on Exploration Geophysics for geologist and engineers (Eds. Bhimasankaram, V.L.S and Gaur, V.K., Pub. AEG, Hyderabad), pp. 375- 404.

Paul, A.C. and Pillai,K.C. (1978). Pollution profile of a river, Water, Air and Soil Pollution, v .10, pp. 133-146.

Paul, A.C. and Pillai,K.C. (1983). Trace metals in a tropical environment-Distribution. Water, Air and Soil Pollution, v .19, pp. 63-73.

Perumal, A. (1990). Hydromorphological investigation in parts of Athur Valley, Tamil Nadu, India, using remote sensing data, unpublished Ph.D thesis, University of Roorkee.

Philip, G. and Singhal, B.B. (1991). Importance of geomorphology for hydrogeological study in hard rock terrain – An example from Bihar plateau through remote sensing, Indian Jour. Earth Sci., v. 19 (4), pp. 177 – 188.

Piper, A.M. (1944). A graphic procedure in the geochemical interpretation of water analysis. Amer. Geophys. Union trans., v. 25, pp. 914-923.

Prasad, R.K, Mondal, N.C and Singh, V.S (2008). Evaluation of groundwater resource potential using GIS in Kurmapalli Water of Andhra Pradesh,Jour.Geol. Soc.India., v. 71, pp. 661-669.

Pratap, K., Ravindran, K.V., Prabakaran, B. and Jeganathan, C. (1997). Groundwater investigation in Dala-Renukoot area. Sone Valley, Sonbhadra dist., UP; Remote Sensing for Natural Resources, ISRS & NNRMS Publ., pp. 403-411.

Pratap, K., Ravindran, K.V. and Prabakaran, B. (2000). Groundwater prospect zoning using remote sensing and geographical information system: A case study in Dala- Renukoot area, Sonbhadra district, Uttarpradesh, Jour. Ind. Soc. Rem. Sens., v. 28 (4), pp. 249-263.

Raghunath, H.M. (1987). Geochemical surveys and water quality. Groundwater, Wiley Eastern Limited, New Delhi, pp. 343- 347.

Rai. S.N. (2003). Groundwater pollution in India. An overview, Proceeding of the international conference on water and environment.

Rajagopalan, P.T., Abhram, S. and Prabha Sanker, P.N. (1983). Pumping tests and analysis of test data from open wells in the coastal tract of Trivandrum Dist. Rrp. GW/R-92/83, Groundwater Division, CWDRM, Calicut.

Rajendran, S., Karthikeyan, P. and Serlathan, P. (1996). Heavy mineral and geochemical studies of Lower Bharathapuzha sediments, Kerala, Jour. Geol. Soc. India, v. 48, pp. 319-324.

Rajendran, S., Ajeeb, P. & Thompson, L. (2002): Implications of rainwater harvesting in the coastal aquifer – A case study.

Proceedings of the international conference on water resources and management in arid regions, March 2002, Kuwait, pp. 135–143.

Rajesh Reghunath, Sreedhara Murthy, T.R. and Raghavan, B.R. (1999). Aquifer parameter evaluvation of Nethravathi river basin, Karnataka state, India, Jour. App. Hydrology, v. 12 (1), pp. 46-51.

Rajesh Reghunath, Sreedhara Murthy, T.R. and Raghavan, B.R. (2001). Spatial distribution of pH, EC and total dissolved solids of Nethravathi river basin, Karnataka state, India, Pollution Research, v. 20 (3), pp. 413 – 418.

Rajesh Reghunath, Biju Sekhar, S., Nithin, R. and Binoj Kumar, R.B. (2009). Demarcation of groundwater prospective zones in a degraded region of Western Ghats: A GIS based approach, Nat. Envr. and Poll. Tech., v.8, pp. 347-350.

Raju, T.S. and Raghava Rao, K.V. (1967). New approach to the analysis of pump test data of an open well, Sym. Ground and Lake water resources of India, Hyderabad.

Ramanujachary, K.R. and Balakrishna, S. (1985). Resistivity investigations in different geological terrains, Groundwater News, pp. 1-14.

Ramasamy, S.M. and Bakliwal, P.C. (1983). Groundwater targeting of banded gneissic complex, Rajasthan through remote sensing, Proc. Nat. Sym. on Rem. Sens.in Development and Management of Water Resources, SAC, India, pp. 277 –285.

Ravi, P.S. and Mishra, D. (1993). Identification of groundwater prospective zones using remote sensing and geoelectrical methods in and around Saidanagar area, Dokor block, Jalaun District, UP, Jour. Ind. Soc. Rem. Sens., v. 21, no. 4, pp. 217-227.

Ray, R.G. (1960). Aerial photographs in geologic interpretation and mapping,U.S. Geol. Surv. Prof. Paper, v.373, pp. 227.

Raymahashay, B.C. (1996). Geochemistry for hydrologists, Allied Publishers Ltd. New Delhi, 190p.

Rayner, F.A. (1980). Pumping test analysis with a handheld calculator. Groundwater, v. 18 (6), pp. 562- 568.

Reddy, D.P. (2004). Integrated hydrogeological investigations in the Amarja Nala watershed, Gulbarga district, Karnataka state, India, unpublished thesis, Karnatak University, Dharwad.

Richards, L.A. (1954). Diagnosis and improvement of Saline and alkali soils,USDA hand book 60, 160 P.

Richards, C.J., Roaza, H. and Roaza, R.M. (1993). Integrating geographic information systems and model flow for groundwater resources assessments, Water Res. Bull. American Water Resources Association, v.29 (5), pp. 847-853.

Rijikswaterstaat. (1975). Standard graphs for resistivity prospecting. Published by the European Assosiation of Exploration Geophysicists. Netherlands.

Roaza, H., Roaza, R,M. and Wagner, J. R. (1993). Integrating geographic information systems in groundwater applications using numerical modelling techniques. Water Res. Bull. American Water Resources Association, v. 29 (6), pp. 981-988.

Robinson, T.W. (1939). Earth-tides shown by fluctuation of water levels in wells in New Mexico and Lowa, Trans. Amer. Geophysical Union, v. 20, pp. 656-666.

Roy, A.K and Raina, B.N. (1973). Hydrogeological studies of Kotepally catmint in Hyderabad, AP, based on areal photographs, Int. sym. develop. Group resources, v. 1, pp. 13-27.

Ruston, K.R. and Singh, V.S. (1983). Drawdowns in large diameter wells due to decreasing abstraction rates. Groundwater, v. 21 (6), pp. 670- 677.

Ryzner, J.W. (1944). A new index for determining the amount of calcium carbonate scale formed by water, Jour. American Water Works Association, v. 36, pp. 473-486.

Sabins, Jr .F.F. (1987). Remote Sensing Principle and Interpretation, 2nd edn, Freeman, San Francisco, 449p.

Saha, D. (2007). The aquifer system and evaluation of its hydraulic parameters in part of South Ganga Plain, Bihar, Jour. Geol. soc. India v. 69, pp. 1031-1041.

Saha, A.K. and Chakravarthy, S.K. (1963). A quantitative petrological study of the Bahalda road Gralodiorite, Mayurbhunj, Jour. Deccan Geol. Soc., v. 3, pp. 50-59.

Sakthimurugan, S. (1995). Hydrogeological studies and simulation of contaminant migration in and around Dindigul, Anna district, Tamil nadu, unpublished Ph.D thesis, Manonmaniam Sundaranar (M.S.) University, Tirunelveli, 214p.

Sakthimurugan, S. and Balasubramanian, A. (1991). Resistivity measurement over granular porous media saturate with fresh and salt water, Regional Sem. Groundwater Development problems in Southern Kerala, pp. 43- 53.

Saleem, Z.A. (1970). A computer method for pumping test analysis, Groundwater, v. 8 (5), pp. 21-24.

Sammel, E.A. (1974). Aquifer tests in large diameter wells in India, Groundwater, v. 12, pp. 265-272.

Sankar, K. (2002). Evaluation of groundwater potential zones using remote sensing data in Upper Vaigai river basin, Tamil Nadu, India, Jour. Indian Soc. Rem. Sens., v. 30 (3), pp. 119-129.

Sankar, J.G., Jagannadha, R.M., Prakasa, B.S. and Jurgan, D.K. (2001). Hyrogeomorphology and remote sensing applications for groundwater exploration in Agnigundala mineralised belt, Andhra Pradesh, India, Jour. Indian Soc. Rem. Sens., v. 29 (3), pp. 165-174.

Sankaranarayana, V.N., Udaya Varma, P.,Balachandran, K.K., Pylee, A. and Joseph, T.(1986). Estuarine characteristics of the lower reaches of the river Periyar (cochin backwaters), Indian Jour. Mar. Sci., v.15, pp.166-170.

Saraf, A.K. and Choudhary, P.R. (1998). Integrated remote sensing and GIS for groundwater exploration and identification of artificial recharge sites, Int. Jour. Rem. Sens., v. 19, no.10, pp. 1825-1841.

Sarkar, B.C., Deota, B.S, Raju, P.L. Nand Jugran, D.K. (2001). A geographic information system approach to evaluation of groundwater potentiality of Shamri microwatershed in the Shimla taluk, Himachal Pradesh, India, Jour. Indian Soc. Rem. Sens., v. 29 (3), pp. 151-164.

Sarma, J.V.V. and Sarma, N.K. (1982). Geomorphometric studies of Upper Sarada river basin, Proc. Sem. hydrological investigations during the last 25 years in India, pp. 217-224.

Sarma, R.K. and Sharma, T.K. (1987). Groundwater and tube well irrigation: Hydrology and water resources, Dhanpet Rai and Sons, New Delhi.

Sastri, J.C.V., Marilingiah, P. and Narasimha Prasad, N.B. (1983). Dug well performance in hard rock areas of Hunsur taluk, Mysore Disrict, Karnataka, Jour. Assoc. Expl. Geol., v. 4, pp. 39-43.

Sathiyamoorthy, K. and Banerjee, B. (1985). Resistivity surveys locating brine pockets in the Little Rann of Kutch, Gujarat, Jour. Assoc. Explo. Geol., v. 5 (3), pp. 8 - 14.

Sawyer, C.N. and McCarty, P.L. (1967). Chemistry for sanitary engineers. 2nd edn., McGraw-Hill, New York, 518p.

Schneider, R. (1961). Correlation of groundwater levels and air-temperatures in the winter and springs in Minnesota, U.S.Geol. Surv. Water Supply, v.1539-D, pp.14.

Seaber, P.R. (1962). Cation Hydrochemical facies of groundwater in the English Town formation, New Jersy, U.S. Geol. Surv. Prof. Paper 450-b. pp. B124 -B126.

Sekhar, M., Kumar, S.M. and Sridharan, K. (1993). A leaky aquifer model for hard rock aquifers, in Memoir. 24th congress of IAH, Oslo Part 1, pp. 338-348.

Selim Reza, A.H.M., JanHoogendoorn, Zhou, Y. and Jan Nonner (2008). Statistical Analysis and interpretation of water quality data of the Vitens well fields. Jour. Geol. soc. India, v. 71, pp. 513-526.

Setzer, J. (1966). Hydrologic significance of tectonic fractures detectable on air photos, Groundwater, v. 4, pp. 526-534.

Shahid, S. and Nath, S.K. (2001). GIS integrating of remote sensing and electrical sounding data of hydrogeological exploration. Jour. Spatial Hydrol., v. 2, no. 1, pp. 1-12.

Shahid, S., Nath, S.K. and Roy, J. (2000). Groundwater potential modelling in a soft rock area using GIS, lnt. Jour. rem. Sens., v. 21, no. 9, pp. 1919- 1924.

Sheila, B.B. and Banks, D. (Eds) (1993). Hydrogeology of hard rocks, Memoir. 24th congress of International Association of Hydrologist, Oslo, Norway.

Siegal, B.S. and Abrams, M.J. (1976). Geologic mapping using Landsat data, Photogramm. Engg. Rem. Sens., v. 42, pp. 325-337.

Simmers,I.(1997). Estimation of natural groundwater recharge, Reidel, Boston, 510p.

Singh, A.K. and Prakash, S.R. (2002). An integrated approach of Remote sensing, geophysics and GIS to evaluation of groundwater potentiality of Ojhala subwatershed, Mirzapur.

Singh, L.M., Roy, P.K., Roy, A.K. and Anand, R. (1993). Application of remote sensing geographic information systems in hydrogeologic investigation of Imphal Valley (Manipur). Proc. on remote sensing application for resource management with special emphasis on NE region, Guwahati, pp. 143-147.

Singh, S.N. and Mesh, A.J. (1982). Groundwater conditions along coastal areas of Saurashtra with special reference to the problem of salinity in Mangrol-Kodinar area, First National seminar on Quaternary environment: Recent researches in Geology, (Eds. Mesh S.S) Hindustani Publishing Corp. India, v. 9, pp. 61-74.

Singhal, B.B.S. (1973). Some observations on the occurrence, utilisation and management of groundwater in the Deccan trap areas of central Maharashtra, India, Proc. Int. Nat. Sym. Development of groundwater resources, Madras, India, v.3, pp. 75-81.

Singhal, B.B.S.and Gupta, R.P. (1999). Applied Hydrogeology of fractured rocks, Kulwer Academic Publishers, Netherlands, 400p.

Singhal, D.C. (1984). An integrated approach for groundwater investigation in hard rock areas. A case study, International workshop on rural hydrogeology and hydraulics in fissured basement area, pp. 87- 93.

Sivaganam, N and Kumaraswamy, K. (1983). Groundwater quality in Vaippar basin, South India, The Indian Geographical Jour., v. 58 (2), pp. 127-140.

Slichter, C.S. (1906). The under flow in Arkansas valley in Western Kansas, US. Geol. Surv. water supply, v.153, 61p.

Sreedhar Ganapura , G.T., Vijaya Kumar, I.V., Murali Krishna , Ercan Kahya and Cüneyd Demirel, M. (2009). Mapping of groundwater potential zones in the Musi basin using remote sensing data and GIS. Adv. Eng. Software, v.40 (7), pp. 506-518.

Sridharan, K., Mohan Kumar, M.S. and Sekhar, M. (1995). Groundwater flow and storage in hard rocks aquifers, Proc. workshop on artificial recharge of groundwater in granite terrain, CGWB, pp. 86-107.

Sridharan, K., Sekhar, M. and Kumar, S.M. (1990). Analysis of aquifer water table aquitard system. Jour. Hydrol., v.114, pp. 175-189.

Srinivasa Rao, Y. and Jugran, K.D. (2003). Delineation of groundwater potential zones of groundwater quality suitable for domestic purposes using remote sensing and GIS, Hydrogeological Sci. Jour., v.48, no. 5, pp. 821-833.

Sooryamoorthy, R. and Antony Palakkal, (Eds.) (2003). 'Managing Water and Water Users: Experience from Kerala' Maryland: University Press of America.

State Planning Board, (2003). Report on working Group on Drinking Water: Formulation of tenth Five Year Plan 2002-2007, Trivandrum: Government of Kerala.

Stewart, M.T., Michael Layton and Theodorc Linazec, (1983). Application of resistivity surveys to regional hydrogeologic reconnaissance. Groundwater, v.21 (1), pp.42-48.

Streltsova, T.D. (1974). Drawdown in compressible unconfined aquifer, Jour. Hydraulic engineering., v. 100 (HY 8), pp. 1601- 1616.

Stuyfzand, P.J. (1988). A new Hydrochemical classification of water types, principles and applications to the coastal dunes aquifer systems of Netherlands. Proc.9th salt water intrusion meeting, Delft University of Technology, pp. 641-655.

Stuyfzand, P.T. (1989). A new Hydrochemical classification of water types with examples of application. AHS, v. 184, pp. 89-98.

Subba Rao, N. (2008). Factors controlling the salinity in groundwater in parts of Guntur district, Andhra Pradesh, India. Environmental Monitoring and Assessment. v. 138, no. 1-3, pp. 327-341.

Subba Rao, N., Chakradhar G.K.J. and Srinivas V. (2001). Identification of groundwater potential zones using remote sensing techniques in and around Guntur Town, Andhra Pradesh, India, Jour. Indian Soc. Rem. Sens., v. 29 (1& 2), pp. 69-78.

Subhash Chandra, K.C. (1994). Occurrence of groundwater and aquifer characteristics of hard rock in Karnataka. Geo Karnataka, (Eds. B.M. Ravindra and N.Ranganathan). KAGA, Bangalore, pp. 337-359.

Subramanian, S. (1994). Hydrogeological studies of the coastal aquifers of Tiruchendur, Tamil Nadu, unpublished Ph.D. thesis, Manonmaniam Sundaranar (M.S) University, Tirunelveli, 308p.

Subramanyan, A. (1975). Specific capacity of wells in hard rocks -A study, Sym. Hydrology, Roorkee, v. 8, pp. 16- 49.

Sudhakar M.Rao, and P. Mamatha (2004). Water quality in sustainable water management, Curr. Sci., v. 87, no. 7, pp. 942-945.

Summers, W.K. (1972). Specific capacity of wells in crystalline rocks. Groundwater, v. 10 (6), pp. 37- 47.

Suresh, T.S., Naganna, C and Srinivas, G. (1991). Study of water quality for agricultural use in the Hemavathy River (Karnataka), Hydrol.Jour., v.14, pp. 247-254.

Taylor, G.C. and Oza, M.M. (1984). Geology and Groundwater of the Dudhai area, Eastern Kutch (India), Geol. Surv. Ind. Bull., Ser. B (5), pp. 35-75.

Taylor, R.G. and Howard, K.W.F. (1994). Groundwater quality in rural Uganda: hydrochemical consideration for the development of aquifers within the basement complex of Africa Groundwater Quality, 17th special report, (Eds. H. Nash and G.J.H. McCall), Chapman and Hall pub., pp. 31-43.

Teeuw, R.M. (1995). Groundwater exploration using remote sensing and a low cost geographical information system, Hydrogeology Jour., v.3, pp. 21-30.

Telford, W.M., Geldart, L.P., Sheriff, R.E. and Keys, D.A. (1990). Applied Geophysics, Cambridge University press, 770p.

Theis, C. V. (1935). The relation between the lowering of the piezometric surface and the rate and the duration of discharge of well using groundwater storage Am. Geophy. Union Trans., v. 16, pp. 519- 524.

Thillaigovindarajan, S. (1980). Practical utilization of remote sensing for groundwater resources evaluation case studies from Southern Tamil nadu, Proc. Sem. J.S.P.I. and R.S., pp. 123 – 127.

Thirugnanasambandam, S. (1980). Geomorphological studies of Bharathapuzha basin in Kuttipuram and Pattambi areas, Kerala, Bull.Oil and Natural Gas Corporation, v.17, no.1.

Thiruvengadachari, S. (1978). Remote sensing application in water resource surveys, Jour. Inst. Engs. India, v. 58 (4), pp. 165-167.

Thornbury, W.D. (1955). Principles of geomorphology, widely toppan, New York.

Tickell, S.J. (1994). Dry land salinity hazard map – The northern territory of Australia, Darwin, Power and Water Authority, Report 54/94D, 43p.

Todd, D.K. (1980). Groundwater Hydrology 2nd edn. John Wiley New York, 535p.

Trilochan Dass (1972). Determination of transmissibility and storage coefficient in shallow open wells in hard rock terrain, Paper presented at Sem. on problems in ground development, Madras.

Usha, K., Ramaswamy, S.M and Subramanyam, S.P. (1989). Fracture pattern modelling for groundwater targeting in hard rock terrain- A study idea by remote sensing techniques, pp. 319-328.

USEPA, (1971). Water quality criteria, United States Environmental Protection Agency, EPTA, R, 3/73-033, Washington D.C.

U.S. Salinity Laboratory (1954). Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agri. Hand book, 160pp.

UNESCO, (1979). Water in crystalline rocks SC-77/WS/71, UNESCO, Paris, 344p.

UNESCO/IAHS, (1967). Proceedings Dubrovnik symposium on hydrogeology of fractured rocks, v. 1 & 2, UNESCO, Louvain, Belgium.

Venugopal, T.N. (1998). Hydrogeological investigation in the Arkavathi river basin – A tributary of Cauvery River, Karnataka, unpublished Ph.D thesis, Mysore University, 224p.

Verma, R.K., Rao, M.K. and Rao, C.V. (1980). Resistivity investigation for groundwater in Metamorphic areas near Dhanbad, India, Groundwater, v.18 (1), pp. 46- 55.

Veron, Rene (2000). 'Sustainability and New Kerala Model' in Govindan Parayil, Kerala Development Experience, Reflections of sustainability and Replicability. Zed books

Vijith.H, (2007). Groundwater potential in the hard rock terrain of the Western Ghats; Case study from Kottayam district, Kerala using Resourcesat (IRS-P6) data and GIS techniques, Jour. Indian Soc. Rem. Sen, v.35, no. 2

Viswanathiah, M.N., Sastri, J.C.V. and Ramegowda, B. (1978). Specific capacity of wells in some hard rocks of Karnataka, Jour. Geol. Soc. India, v.19, pp. 426 -430.

Walton, W.C. (1962). Selected analytical methods of well and aquifer evaluation, Illinois State Water Sur. Bull., v. 49, 31p.

Walton, W.C. (1970). Comprehensive analysis of water table aquifer test data, Groundwater, v. 16, pp. 311- 317.

Walton, W.C. (1970). Groundwater resource evaluation, Mc. Graw - Hill book co., New York, 664p.

Wesslen, A., Gustafson, G. and Marippu, P. (1977). Groundwater and storage in rock caverns, pumping tests as an investigation method, Proceedings 1st Int .Sym. Rock store, Stockholm, pp. 359-366.

White, A.F., Benson, S.M., Yee, A.W., Woiienberg, H.A. and Flexser, S. (1991). Groundwater contamination at Kesterson reservoir, California- geochemical parameters influencing selenium mobility, Water Resource Res., v. 27, pp. 1085-1098.

WHO (1984). Guide lines for drinking water quality,v.1 Recommendations, Geneva.

Wilcox, C.V. (1948). The quality of water for irrigation use, U.S. Department of Agriculture tech. Bull. 962, Washington D.C., 40p.

Wilcox, L.V. (1955). Classification and use of Irrigation waters, U.S. Department of Agriculture circle, Washington, 969p.

Wodeyar, B.K. and Sreenivasan, G. (1996). Occurrence of Fluoride in the groundwaters and its impacts in Peddavankahalla basin, Bellary district, Karnataka-a preliminary study, Curr. Sci., v. 70, no 1, pp. 71-73.

Woolley, (1982). Depth yield relationships of bores in fractured rocks in New South Wales, in AWRC Conference on Groundwater in fractured rock, Conference Ser. no. 5, Canberra, Australia pp. 283 –292.

Worthington, P.F. (1977). Geophysical investigation of groundwater resources in Kalahari Basin, Geophysics, v. 42 (4), pp. 838- 849.

Worthington, P.F. (1977). Influence of matrix conduction upon hydrogeophysical relationships in arenaceous aquifers, Wat. Resour. Res., v. 13, pp. 87-92.

Wright, E.P. and Burgess, W.G. (Eds) (1992). The Hydrogeology of crystalline basement aquifers in Africa, Geol. Soc. Spl. Pub. no. 66, The Geological Society , London , 264p.

Yeh, H.D. (1987). Theis solution by non-linear least squares and finite difference Newton's method. Groundwater, v. 25, pp. 710-115.

Zaporozec, A. (1972). Graphical interpretation of water quality data. Groundwater, v. 10 (2), pp. 32-43.

Zadankush, N.T. (1974). Analysis of shallow hard rock well pumping and recovery test data, Groundwater, v.12, pp. 310-317.

Zambre, M.K and Thigale, S.S (1980). Geophysical investigation for groundwater in Sholapur district, Maharastra, Proc.3rd Ind. Cong. Poona. pp. 435-443.

Zeizel, A.J., Walton, W.C., Sasman, R.T and Pricket, T.A. (1962). Groundwater resource of Du Page Country, Illinois, Illinois state water surv. Co- operative Groundwater Project 2.

Zohdy, A.A.R. (1969). The Schlumberger and equilateral soundings in groundwater investigations near El Paso, Texas, Geophysics, v.34, pp. 713-728.

Zohdy, A.A.R., Eaton, G.P. and Mabey, D.R. (1974). Application of surface Geophysics to groundwater investigations, U.S.Geo.Surv., chapter1, 116p.