AN INTEGRATED STUDY ON THE HOLOCENE AQUIFER AND THE WATER RESOURCE POTENTIAL OF KARAMANA RIVER BASIN, SOUTHERN KERALA, INDIA

Thesis submitted to the

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

In Marine Geology

Under the Faculty of Marine Sciences

By

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December 2014

Dedicated to my Respected Parents

DECLARATION

I hereby declare that the thesis entitled "**An Integrated Study on the Holocene Aquifer and the Water Resources Potential of Karamana River Basin, Southern Kerala, India"** is an authentic record of the research work carried out by me under the supervision and guidance of Prof. Dr. K. Sajan, Professor in charge of Head, Department of Marine Geology and Geophysics under the Faculty of Marine Sciences, Cochin University of Science and Technology and also that no part thereof has been presented for the award of any degree in any University/ Institute.

Kochi- 16 Sakkir S.

06-12-2014

CERTIFICATE

This is to certify that the thesis entitled "**An Integrated Study on the Holocene Aquifer and the Water Resource Potential of Karamana River Basin, Southern Kerala, India"** is an authentic record of research work carried out by Mr. Sakkir S, under my supervision and guidance in partial fulfillment of the requirement of the degree of Doctor of Philosophy in the Department of Marine Geology and Geophysics, Cochin University of Science and Technology, under the Faculty of Marine Sciences and also that no part thereof has been presented for the award of any degree or diploma in any other University / Institute.

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PREFACE

Water constitutes the basic resource for life. Management of coastal aquifers, which are the important sources of freshwater that feed the rapid economic growth of the region is facing increasing challenges. A large portion of the global population inhabits the coastal and adjoining areas leading to a high demand for water both surface and ground water resources of coastal tracts. With increasing population this puts significant stress on water resources of many of the coastal tracts of the world. Several recent studies have indicated that coastal aquifers of Cenozoic age are globally under threat due to several reasons.

Climate change is expected to affect the freshwater resources of coastal aquifers, which in turn will affect half of the global population residing in coastal areas. Sea-level rise will induce landward migration of the freshwater-saltwater transition zone, i.e., seawater or saltwater intrusion, jeopardizing freshwater availability. In order to facilitate the management of fresh coastal groundwater resources, a comprehensive understanding of the SLR-SWI relationship is crucial.

Coastal aquifer of Karamana River Basin and its neighborhood is associated with older Pleistocene and younger Holocene sedimentary successions and the water resources of this region are predominantly used for domestic purposes and to a little extent for irrigation. No reliable long - term data are available regarding neither the quantity of water generated by the aquifer nor the possible changes of quality, except for the period roughly covering the last decade. Relatively dense habitat with significant population increase of the tract may result in overexploitation of water and also deterioration of quality of water over time.

Hence the present study

The Holocene aquifer of the Karamana River Basin (KRB) of the Thiruvananthapuram District, Kerala and its water resources potential form the main theme of the thesis. Emphasis has also been given to the hydrogeochemisty of the water resources and morphmetric analysis of the Karamana River Basin.

The thesis is organized into 5 chapters.

Chapter-I gives a general introduction of the Karamana River Basin which is a 6^{th} order basin and spreads over an area of 703 km^2. The river originates at Chemmunji Mottai Peak (1717 m amsl) and flows down across the highland, midland and lowland zones with two main tributaries Killi Ar and Todai Ar.

Chapter-II deals with the Holocene geology of the KRB. A general picture of the Quaternary succession of the coastal tract of the basin is presented in this chapter. Quaternary sediments of Karamana River Basin are dominantly of coarse sand with occasional silty and clayey intercalations, the latter hardly exceeding 2% of the bulk and devoid of marine fossils indicating their fluvio-lacustrine origin. The radiocarbon analysis elucidates the Holocene succession of the Karajan Basin which commences upward from the middle litho unit and the underlying portion of the Quaternary constituting the Pleistocene succession of the region. The maximum thickness of the Holocene Stratigraphy units of the Karajan Basin is restricted to about 20m. The hydrological properties of the Holocene aquifer of the basin are also elaborated in this chapter. It is concluded that the specific yield of Holocene sediments of Karamana River Basin has been noted to range from 28 percent to 32 percent and its coefficient of storage ranges from 0.028 to 0.032 where as the transmissivity value range from 280 m^2/day to 420 m^2 /day and the coefficient of permeability (hydraulic conductivity) has been noted to be very high (25.5 m/day to 45.0 m/day).

Chapter-III illustrates the salient features of the morphmetric attributes (such as the linear, areal and relief parameters) of Karamana River Basin. Karamana River Basin is dominantly dendritic in the lower reaches expressing its homogeneity of texture and lack of any significant structural control. Linear aspects of the basin and other morphometric characteristics like the total area (a), drainage density (Dd), constant of stream maintenance (C), stream segment frequency or channel frequency (F), drainage area of each order (A1 to A6), average density of each order ($\bar{A}1$ to $\bar{A}6$), area ratio (Ar), form factor (Rf), circularity ratio (Rc), elongation ratio (Re), basin shape factor (s), unit shape factor (Ru), form factor etc are presented in this chapter. Among the various relief features of the Karamana River Basin, basin relief (Rb), relief ratio (Rh), and ruggedness number (Rn) were measured/calculated.

Chapter-IV encompasses the hydrochemistry and the drinking water potential of the basin. It is noted that the groundwater samples collected from urban area of Thiruvananthapuram exhibit notable regional and spatial variation in terms of physical, chemical and biological qualities. There is significant contamination of the Holocene aquifer of Karamana River Basin due to mixing of polluted waters from the canal. The hydrochemical analysis include pH, conductivity, TDS, alkalinity, hardness, chloride, sulphate, nitrate, phosphate, fluoride, sodium, potassium, calcium, magnesium, BOD, COD, total coli form and fecal coliform.

Chapter-V summarizes the salient findings of the study.

The literature perused and cited is given towards the end of the thesis under references.

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CHAPTER I

GENERAL INTRODUCTION

1.1 INTRODUCTION

The most recent of the three periods of the Cenozoic Era, in the Quaternary Period follow the Neogene Period. The Neogene is a geological period starting 23.03+.05 million years ago and ending 2.583 million years ago. This follows the Paleogene Period, as the second period within the Cenozoic Era and is succeeded by the Quaternary period spanning from 2.588 ± 0.05 million years ago to the present. Recently, the sub-commission on Quaternary Stratigraphy (SQS) of International Commission on Stratigraphy (ICS) of IUGS, proposed that the Quaternary be considered as a sub period spanning the past 2.6 myr.

The Quaternary includes two geologic epochs, the earlier Pleistocene and the later Holocene. The name Holocene (recent whole) for the post-glacial epoch of the past ten to twelve thousands years, seems to have been proposed for the first time by Sir Charles Lyell in 1833, and adopted by the International Geological Congress in Bologna, 1885. The name Holocene comes from the Greek words *halos* meaning whole or entire and *kainos* meaning new (entirely recent). Holocene is the name for the most recent interval of Earth history and includes the present day. It is generally regarded as having begun 10,000 radiocarbon years or the last 11,500 calibrated (i.e. calendar) years before present (i.e. 1950). The term 'Recent' as an alternative to Holocene and according to the Sub-commission on Quaternary Stratigraphy since it is invalid, the term should not be used and the sediments accumulating or processes operating at present should be referred to as 'modern' or by similar synonyms.

Paleontologists have defined no faunal stages for Holocene. When subdivision is required the stage of human technological development is taken in to consideration and divisions such as the Mesolithic, Neolithic and Bronze Age, are usually employed. However, the time periods referenced by these terms vary with the emergence of those technologies in different parts of the world; climatically the Holocene is sometimes divided evenly in to the Hypsithermal and Neoglacial periods, the boundary of the two coinciding with the start of the Bronze Age in Europe (Fig. 1.1).

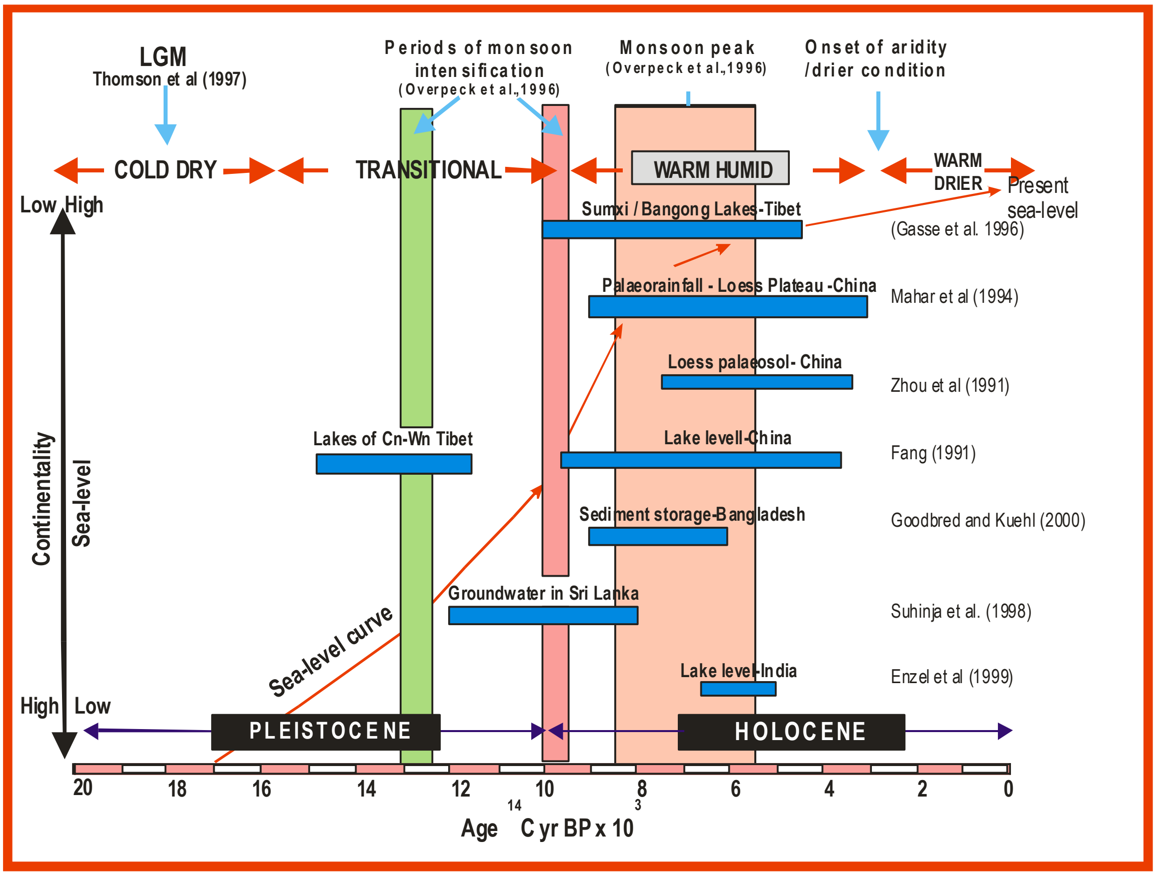


Fig. 1.1 Paleoclimate history of the period between LGM and the present day (after Kale et al., 2004).

The Holocene as already noted, is the latest of many Quaternary intra glacial phases and is the only one to be accorded the status of an epoch. Holocene is also the only unit in the whole of the Phanerozoic (covering the past 542 my) whose base is defined in terms of numbers of years from the present, taken as 10,000 radiocarbon years before 1950. The bases of all other periods, epochs, and ages from the Cambrian onward are defined by or shortly will be defined by- golden spike (Gradestein et al., 2004a and b), in which a suitable section is chosen as a Global Strato type Section (GSS), the “golden spike” being placed at an agreed point within it, giving rise to a Global stratigraphic section and point or GSSP. The base of the Holocene, in line with all other Phanerozoic boundaries, is defined in terms of an ice core in the North

Greenland, at the beginning of an interval at which deuterium values (a proxy for local air temperature) rise. This event has been rapidly followed by a marked decrease in dust levels and an increase in ice layer thickness (ICS, 2006).

1.2 HOLOCENE AQUIFER

A large portion of the global population inhabits the coastal and adjoining areas, leading to a high demand for water, both surface and ground water resources of coastal tracts. With increasing population, this puts significant stress on water resources of many of the coastal tracts of the world. Several recent studies have indicated that coastal aquifers, the majority of which are of Cenozoic age are globally under threat due to several reasons.

The coastal aquifers are often large and have a complex past history with sea water transgression and regression and in many instances these are mirrored in the groundwater chemistry (Jacks and Rajagopalan, 1996; Jacks et al., 2009). Sea level rise due to climate change is expected to adversely affect coastal water resources, in particular, ground water resources. Apart from sea water intrusion there are several other threats like land subsidence (Phien-wej et al., 2006), unscientific land use (Rönnbäck et al., 2003) and not least climate change with a rising sea level (Ericson et al., 2006). Land reclamation has played a significant role in the urban development process in coastal areas in many countries. While reclamation provides valuable land, it also creates various engineering, environmental and ecological problems in coastal areas. The direct impact of land reclamation on coastal engineering, environment and marine ecology is well recognized and widely studied. However, it has not yet been recognized that reclamation may change the regional groundwater regime apart from the change of water level and migration of seawater/groundwater interface. It is shown that it may take tens to over 100 years for groundwater system to approach a new equilibrium once it is disturbed. The degree of the modification of the groundwater system and the time required for the system to approach a new equilibrium depends on the hydraulic conductivity of the fill materials and the reclamation scale. The possible modification of the regional flow system at Penny’s Bay, Hong Kong due to land reclamation had been studied by Jiu Jimmy Jiao, 2009.

Climate change is expected to affect the freshwater resources of coastal aquifers, which in turn will affect half of the global population residing in coastal areas. In particular, sea-level rise will induce landward migration of the freshwater-saltwater transition zone, i.e., seawater (or saltwater) intrusion, jeopardizing freshwater availability. Thus, in order to facilitate the management of fresh coastal groundwater resources, developing a comprehensive understanding of the SLR-SWI relationship is crucial (Watson et al., 2009).

Almost all coastal aquifer systems in India and elsewhere in the world have become targets for saline water intrusion processes. These processes are more pronounced in coastal deltaic areas when compared to inter deltaic regions. Saline water intrusion phenomenon is a complex process and could be seen in a variety of combinations such as (a) fresh water systems underlined by saline water aquifer systems with a hydraulic interface, (b) fresh water systems over lined by saline water aquifer systems and sometimes sandwiched between two saline water bodies with a geological interface (aquicludes and aquitards). The structural frame of saline-freshwater interface therefore becomes very important and basic for all developmental and management concerns.

Admittedly, shoreline is the most rapidly changing landform of the coastal zone. Geomorphic processes continue to modify the shoreline and elements of adjacent coastal landforms. Because of above facts, groundwater in coastal areas has received considerable attention from various sectors of society, including scientific communities. Asia-Pacific is on the verge of water scarcity. Being the production house of the world, many countries of Asia-Pacific are exploiting their natural resources, including the water resources, beyond their carrying capacity. Management of coastal aquifers, which are the important sources of freshwater that feed the rapid economic growth of the region is facing increasing challenges (Ti Le-Huu, 2009)

Water constitutes the basic resource for life. Coastal aquifer of Karamana Basin and its neighborhood is associated with older Pleistocene and younger Holocene sedimentary successions and the water resources of this region are predominantly used for domestic purposes and to a little extent for irrigation. No reliable long term data are available regarding neither the quantity of water generated by the aquifer nor the possible changes of quality, except for the period roughly covering the last decade. Relatively dense habitat with significant population increase of the tract may result in overexploitation of water and also deterioration of quality of water over time.

1.2.1 Holocene of Kerala

The sedimentary basin south of the Narmada Rift Zone of the continental shelf of Western India consists of the Bombay offshore basin in the north and the Kerala-Konkan basin in the south. The Vengrula Arch separates these two offshore basins. The western coast adjoining the Bombay offshore is formed of Deccan Traps while that of the Kerala - Konkan Basin is generally cliffed and exposes Precambrian basement rocks, Deccan traps and laterally discontinuous stretches of Tertiary successions. The coastal Tertiaries are generally thin and of Miocene age.

The portion of the coastal tract of Kerala between Kodungalloor in the north and Kollam in the south is generally plain and displays a curvilinear landward extension of the offshore sedimentary basin Fig.1.2 shows the Land ward extension of the Kerala-Konkan Basin (KKB) with a sediment fill of about 700 m. This constitutes the so called Southern Kerala Sedimentary Basin (SKSB). This has a maximum width of about 35 km at Alappuzha (9^{o} 30″N). This stretch of the coastal plain of Kerala cover an area of over 1000 km^2 and includes Vembanad Lagoon, Kayamkulam Lagoon, seasonal and perennial wetlands of Kuttanad, alluvial fans and mounds, paleo-estuaries, and the characteristic ridge-runnel systems. This region is devoid of any exposures of Tertiary succession. The entire succession of this part of Kerala ranges in age from Early Miocene to Quaternary. Drill hole data show the presence of a pronounced unconformity with a hiatus with a duration extending from Middle Miocene to Early Quaternary.

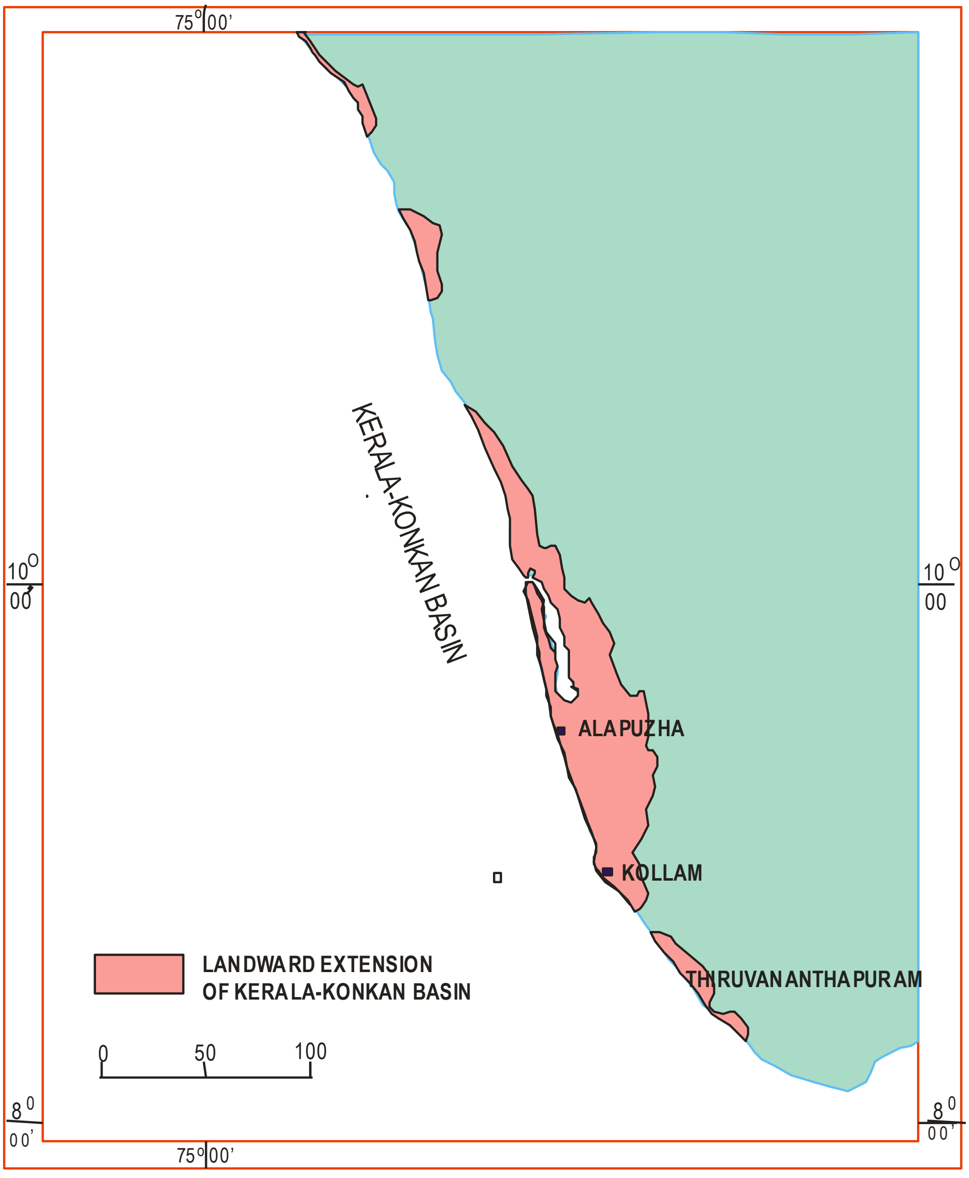


Fig. 1.2 Landward Extension of Kerala-Konkan Basin (KKB).

The eastward onshore extension of the sedimentary succession of the offshore Kerala-Konkan Basin is believed to have developed in response to the stress patterns following the collision of the Indian Plate with the Eurasian Plate during Early Miocene (Aitchison and Davis, 2001).Table1.1 gives the stratigraphic succession of SKSB. The Quaternary sand-clay succession has been given an informal stratigraphic name – the Vembanad Formation (Raha et al., 1983). Some workers recognize and subdivide the lowermost clastic succession below the Quilon Formation (Vaikom Formation) into Alleppy Beds and Vaikom Beds and recent studies indicate that this is not justifiable (Nair et al., 2006). On the basis of evidence of subsurface structure, three blocks can be recognized in the SKSB: (1) A Southern Block (extending from Thirumullavaram in the south to Purakkad in the north), (2) A Central Depression (extending from Purakkad to Chellanam) and (3) A Northern Block (Chellanam to north of Eriyad). These blocks are shown in Fig 1.3. The coastal stretch south of Ashtamudi Lake and extending up to is characterized by pocket beaches, cliffs of Tertiary rocks and crystalline rock promontories. The coastal tract of Thiruvananthapuram district further south, marking the southern limit of Kerala state, in the southwest coast of India, has a total length of 70 km and an area of 361.25 km^2. Beaches, coastal plains, laterite mounds (hills or hillocks), paleo channels, flood plains, beach ridges, beach cliffs, estuaries and lagoons are the coastal landforms observed in this sector. With the exception of rocky promontories (such as the one at Kovalam), a narrow strip of modern day sandy-beach is noticed all along most parts of the shoreline. Parallel beach ridges have been noticed at the southern, central and northern sectors of the coastal tract of Thiruvananthapuram district. Well-developed backshore cliffs at Varkala in the north and cliff lines at Karichal in the south are also recognized. Yet another remarkable feature of this part of the coast is the presence of estuaries and lagoons. The process of formation of coastal landforms, indelibly depict the evolutionary history of this coastal tract.

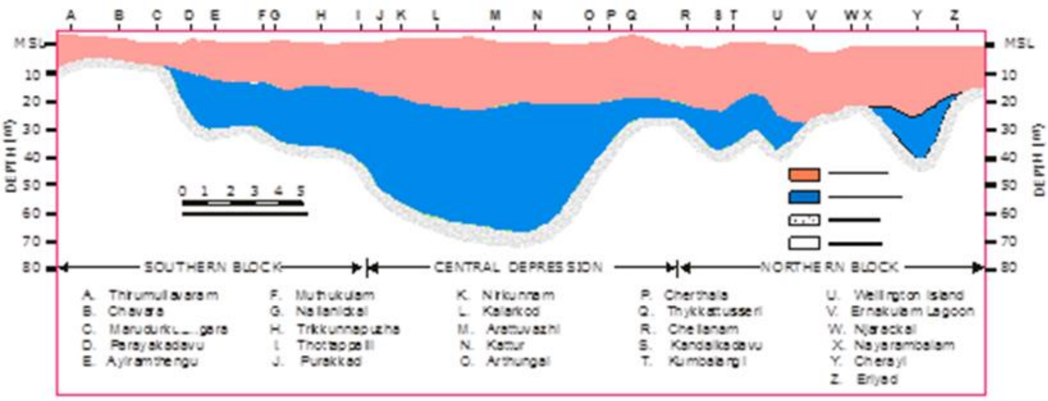


Fig. 1.3 Quaternary stratigraphic units of South Kerala Sedimentary basin (Source: Nair et al., 2006)

Table 1.1 Stratigraphic Succession of South Kerala Sedimentary Basin (SKSB) (Modified and adopted from Najeeb (1999).

Lithostratigraphic units / Rock units	Lithology	Age	Maximum thickness (m)
Vembanad Formation	Sand, clay and peat	Quaternary	80
Laterite	Residual and reworked laterite	Late Miocene –Quaternary	30
Warkalli Formation	Sand, clay and lignite	Middle Miocene	150
Quilon Formation	Calcareous clay and limestone	Early Miocene	130
Vaikom Formation	Pebbly sand , clay and lignite	Early Miocene	300
Basement (mainly khondalites and charnockites)			

Four rivers debouch their waters into the sea in this segment of Kerala coast, Varkala cliff of Tertiary rocks is under severe wave erosion. While indications of severe coastal erosion are found in the neighborhood of the confluence of Ithikara River, signs of accretion (coast parallel estuary, spit and barrier bar formation) are noticed at the confluence of Vamanapuram River. The coastal plain stretching from Vamanapuram River in the north and the Karamana River in the south is relatively broad and displays characteristic ridge and runnel topography, indicating that this portion is a pro grading coast. Aeolian sand deposits of some localities in the neighbourhood of Veli, Thiruvananthapuram airport and Vallakkadavu are considered as localized accumulation of good quality glass sands of commercial value. The northern most sector of the coastal land of Thiruvananthapuram district located up to Muthalapozhi having a total length of about 18 km displays geomorphologic features indicative of coastal erosion. The coastal tract between Mudalapozhi in the north to Vettukad in the south having a length of about 4 km) is undergoing accretion. The shoreline of Karamana River Basin has a nearly uniform trend with minor local variations. This part of the coastline is considered as a 'mixed type', as it exhibits features indicative of submergence and emergence (Nair, 1999). At the northern extremity of the coast in the basin outcrops of crystalline rocks occur near Veli, very close to the coast. The sector between Vettukadin the north and Kovalam in the south exhibit features indicating coastal erosion. Between Chowara in the south and Vizhinjam in the north for a distance of 8 km the coast is characteristically stable, perhaps due to the crystalline nature of cliff or promontory-forming-rocks, which could withstand monsoon-wave-energy and also block the littoral drift. Southwards from this locality, the coastal tract gradually increases in width to about 2 km up to the Karamana River. Further south from Chowara, up to a distance of 12 km, there are marshy pockets, mudflats and a narrow sandbar indicating accretionary coastal environment. The coastal plain north of Veli is broader than its southern side.

A brief review of various geological studies on Kerala coast, having relevance to Quaternary geology, especially the Holocene, is presented in this section. Earlier geologists such as Blanford (1872), Foote (1883), King (1882) and Lake (1890), while describing the geology of the Konkan and Kerala areas have marginally touched on the topics of the morphology and geology of the coast in their reports. These may be considered as the earliest references on coastal tract of Kerala. Subsequent notable contributions are those of Jacob and Sastri (1952), Narayanan (1958), Subramaniam (1964) and Poulose and Narayanaswami (1975). Murthy (1976, 1979) and Suchintan et al., (1987) studied some of the beaches and dune ridges and backwaters of Kerala coast.

Quaternary geological mapping of Kerala by G.S.I commenced as early as 1973. The work was initiated by Sreenivasan and Thirugnanasambandam (1974). KERI published their observations of coastal data in 1974 (KERI, 1971). Later contributions in the field were made by Aditya and Sinha (1976 a & b), Bose et al., (1976), Rao and Datta (1976), Rasheed and Ramachandran (1978), Dasikatchar (1976), Thirugnanasambandam, (1975, 1976 and 1977), Murthy (1976), Nair (1976), Thirugnanasambandam and Nair (1978 and 1979), Nair and Rao (1980) and Nair (1990). Stratigraphic studies made by Raha et al., (1983) focused on the lithostratigraphy of the entire Cenozoic sequence of Kerala.

Nair (1987) prepared an environmental geomorphic atlas of the Kerala coastal zone. Rajendran et al., (1989) published some evidence on Quaternary geology of Kerala and Nair published an outline on quaternary coastal geomorphology of Kerala in 1990. Nair (1999) and Chattopadhyay (2002) made a study on the emergence of central Kerala coastal plain and made geomorphological analysis. Sabu Joseph and Thrivikramji (2002) made a study on the kayals of Kerala coast and their implications to Quaternary sea level changes. Nair et al., (2006) made stratigraphic and palynological appraisal of the Late Quaternary mangrove deposits of the west coast and made pale morphological appraisal and discussed the climate prevailed during Late Quaternary in Kerala. Chattopadhyay (2004) while giving an overview of geomorphology provided some valuable information on the coastal landforms and their geology. Fig.1.4 shows the Quaternary stratigraphic units of South Kerala sedimentary Basin. Ground water occurs in all geological formations from crystalline to Holocene alluvium either in unconfined or semi-confined/confined conditions. Phreatic conditions mainly exist in coastal alluvium and in weathered crystalline formations and are mostly developed by dug wells for domestic or irrigation purposes. Semiconfined/ confined condition exists in deep fractures of crystalline rocks where storage and movement is mainly controlled by interconnected fractures which are developed by deep bore wells.

To understand the impact of urbanization on the groundwater scenario of TUA, Central Ground Water Board (CGWB) has established 21 key wells in various parts of the area and monitoring was carried out monthly since April 2007. Earlier TMC was only considered as urban area. Later while considering the population growth and other facilities in the outskirts of the city, adjoining panchayats were also included. Anticipating the impact of proposed Vizhinjam Container Terminal Project on groundwater regime 5 more monitoring wells have been established recently in Vizhinjam and Kalliyoor panchayats.

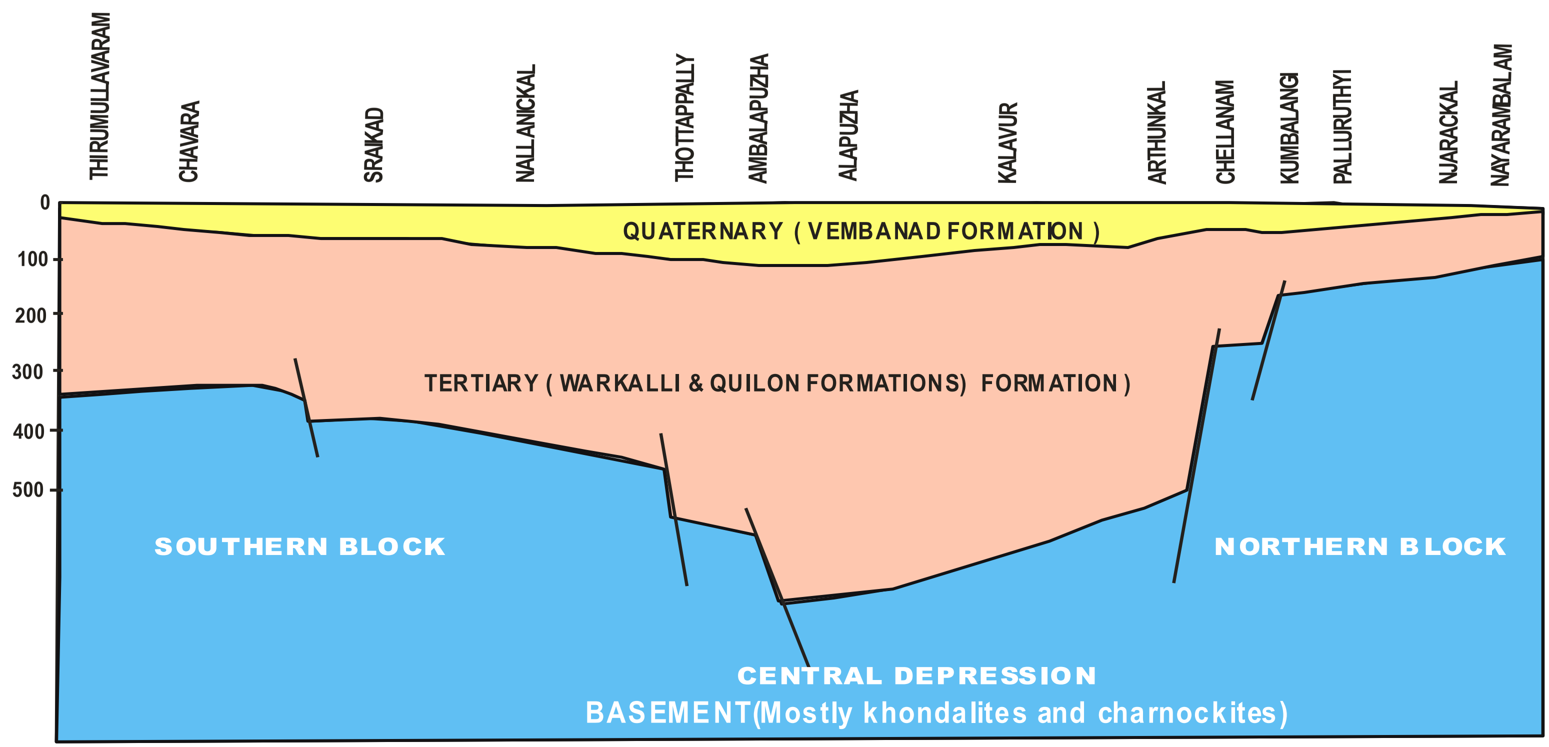


Fig. 1.4. Geological cross section of South Kerala Sedimentary Basin (SKSB) along the coast showing stratigraphy and main structural divisions. (after Nair et al., 2006)

The CGWB has drilled exploratory wells in hard rocks, particularly khondalites and in soft rocks to delineate the aquifer geometry and quality of formation water. The wells drilled in khondalites are in the depth range of 60 - 200 m bgl and the discharge ranges from 12 to 90 lpm. Exploratory drilling revealed the presence of 2 - 3 aquifer groups within the depth range of 200 m (CGWB, 2006). The bore wells tapping NNW, NE, NW lineaments in the district gives better yield. In the sedimentary formations, wells of medium yields have been encountered from the granular zones of Tertiary formations down to maximum depth of 100 m bgl. The Warkallai formation has a limited potential in the Thiruvananthapuram district. The wells drilled in this formation are in the depth range between 32 and 100.5 m bgl and have low discharge (CGWB, 2000). Recent alluvial formation is thinner and the maximum thickness of alluvium is 18 m, which is encountered at Chakkai.

The monthly monitoring of depth to water level of 26 key wells reveals that deepest water level is noticed before the onset of south-west monsoon (pre-monsoon) and the shallow well water level during the month of October/November which in turn also depends on the retreating period of North-East monsoon. The depth to water level varies from 1.9 to 19.8 m bgl and 1.56 to 19.88 m bgl during pre-monsoon and post-monsoon respectively (Fig. 4.8). The depth to water level ranges from 0 to 5 m bgl in wells tapping recent alluvium while the depth to water level is more than 10 m bgl particularly in laterite formation. Seasonal fluctuation also indicates that in major portion of TUA, there is rise in water level in the range from 0 to 5 m.

The computation of groundwater resource of urban area is difficult due to large built-up area and other structures, hence the Groundwater resource of the district has been assessed based on Ground Water Resource Estimation Methodology–97, by considering administrative block as the assessment unit by excluding hilly regions and is computed based on the data available as on March 2004. The net groundwater availability of the Thiruvananthapuram (Rural) block is 14.90 MCM whereas the gross ground water draft of the block is 11.23 MCM; hence scope for further groundwater development is possible. The stage of groundwater development in Thiruvananthapuram block is 75.37% (CGWB, 2005 and 2006) and is categorized under safe category indicating the presence of potential aquifer which can be harnessed. In addition to Thiruvananthapuram block, Kazhakuttam and Sreekaryam panchayaths also show lesser development. Hence further ground water development can be taken up safely and more wells can be constructed. The Vengannur panchayat and Vizhinjam Corporation of Athiyanuur block show development of more than 100%. Analysis of trend of water table shows significant decline during pre and post-monsoon, hence both areas are categorized under over-exploited category which requires a restriction in groundwater development. The four panchayaths of Nemom Block show 91.7% of groundwater development and are categorized under semi-critical category and this area requires a control on groundwater development

1.3 MORPHOMETRIC STUDIES IN INDIA

Subramanyan (1974) made a detailed quantitative analysis of the Karawan (a sixth order stream) and Bankri (a fifth-order stream) drainage basins, associated with the Yamuna river system, around Sagar of Madhya Pradesh, using modern morphometric techniques.

Saxena and Vidhyanathan (1988) made a geomorphic study of the Dindi Resevoir Basin for land use planning in Andhra Pradesh. Panda (1982) conducted quantitative analysis of ten small drainage basins. Rajendran (1982) conducted a morphometric study of the Pamba Basin and James and Padmini (1983) made quantitative geomorphologic studies of the Kuttiyadi River Basin of north Kerala. Singh (1992) made morpho metric analysis of some selected drainage basins of South Mirzapur upland, U.P and Singh and Jain (1992) studied the geomorphology of Kolar sub-basin. Singh et al., (2003) made a geomorphologic study of a watershed using remote sensing and GIS techniques. Pandey et al., (2004 & 2007) studied morphological analysis and water shed management using GIS.

The National Institute of Hydrology, Roorkee geomorphologic studies of selected river basins spread over the entire country with the objectives: (1) Estimation of geomorphologic parameters covering linear aspects of stream network, areal aspect and relief aspect of stream system, (2) To study relationships of drainage characteristics with stream flow, (3) To rationalize hydrological models of runoff process. Studies were conducted during the early 1990-2000 of geomorphological characteristics for the following river basins:

(1) Varna Basin up to Samdoti

(2) Krishna Basin

(3) Ghataprabha Basin and Malaprabha Basin

(4) Kolar sub basin,

(5) Hemavathi Basin in Karnataka

(6) Sabarmathi Basin in Gujarat

(7) Tawi Basin up to Jammu, Jammu Kashmir

(8) Bairanullah sub catchment Himachal Pradesh

(9) Narmada Basin up to Manot

(10) Bagmati Basin

(11) Chenab Catchment

(12) Himalaya Rivers

(13) Devak Basin of Ravi Basin

(14) Myntdu River Basin

1.3.1 Drainage Morphometric studies in Kerala

Geomorphological studies have been attempted on different scales for a few river basins of Kerala with variable degrees of success in addition to the studies made by Rajendran (1982) and James and Padmini (1983). Kapali (1976), made an analysis of Attingal River Basin of southern Kerala and Nair (1976) studied the geomorphology of the region from Kasaragod to Manjeswar. Senthiappan and Nair (1976) studied the geomorphology of Cannanore district, while Thampi (1976) investigated the geomorphology of Munnar - Idukki area. The geomorphological aspects of Bharathapuzha river basin was attempted by Tirugnanasambandam (1976). Morphometric and geomorphic aspects of Chalakkudy River Basin has been conducted by Maya (1997) and 'Drainage network stability in Bharathapuzha Basin' has been studied by Vasu et al., (1998). George Abe (1998) made a 'Morphometric analysis of small watersheds in the Western Ghats of Kerala State'. Anitha.et al., (1998) conducted a study on 'Geomorphology of River Basins of Vembanad backwater system and its effect on hydrologic processes'. Relation of Morphometric Properties to runoff in the Meenanathara sub basin of Meenachil River basin of Kerala was the theme of study conducted by Upendran et al., (1999), Padmini et al., (2000) studied 'Water balance study of Meenachil river basin of Kerala, while James et al., (2000), made an Investigation on the hydrology of forest watersheds in the Western Ghats'. Geomorphic development of micro watersheds of Chittar Basin with respect to sinuosity index was the theme of study made by Padmini et al., (2000). Suvarnakumari et al., (2001) studied 'Geomorphic development of micro watersheds of Chittar Basin with respect to sinuosity index'. 'An Integrated Hydrogeological Study of the Muvattupuzha River Basin, Kerala' was the theme of Ph.D thesis of Girish Gopinath (2003) submitted to the Cochin University of Science and Technology. Vijith and Satheesh (2006) conducted a GIS based morphometric analysis of two major upland sub-watersheds of Meenachil River in Kerala while Dinesan and James (2006), made a study on 'Canoli Canal of Calicut City-Potential and threats in urban growth'. Manu and Anirudhan (2008) conducted a study on 'Drainage characteristics of Achankovil River Basin' and Sreedevi et al., (2009) made a 'Morphometric analysis of a watershed of South India using SRTM data and GIS'. 'Groundwater quality and its relationship with land use in Karamana River Basin' was the theme of study made by Binoj Kumar et al., (2010) and Jobin Thomas et al., (2010).

1.4 THE KARAMANA RIVER BASIN – AN OVERVIEW

As a necessary prelude to the present study, the physiographic, geomorphologic, geologic, climatic, pedologic aspects, including vegetation and land use of the Karamana River Basin (KRB) are discussed below.

1.4.1 Geographic setting of Study area

The Fig. 1.5 shows location map of the study area - the Karamana River Basin (KRB) (Lat 8^{o}21' and 8^{o}42'N and Long 76^{o}52' and 77^{o}15' E) falls entirely in the Thiruvananthapuram District, Kerala. The KRB stretches for an area of703 km^{2}which is sandwiched, between the Vamanapuram River basin in the north and the Neyyar River basin in the south; while Thamrabarani river basin of Tamil Nadu in the east. The KRB drains into the Lakshadweep Sea. Thiruvananthapuram city - the state capital and Nedumangad municipality are some among the important population centers in the KRB. Fig. 1.6 shows the taluks falling within the KRB and Table 1.2 and Fig. 1.7 shows the Panchayats that fall either entirely or partly within the Karamana River Basin.

The general shape of the KRB notably deviates from the typical pear or fan shape, and instead it is visibly elongate and has a more or less irregular outline. KRB measures longest along NE – SW for 39 km and the width being 20 km along NNW – SSE. Like majority of west flowing rivers, upper reaches of the KRB rests on the westerly slopes of the southern Western Ghats, i.e., the Sahyadri Range, while the crest of the Western Ghats forms the eastern drainage separating it from the adjacent Thamirabarani basin of Tamil Nadu. The eastern boundary of KRB roughly coincides with the border of Thiruvananthapuram District of Kerala and Thirunelveli District of Tamil Nadu. Fig. 1.8 and Fig. 1.9 show the Digital Elevation Model (DEM) and Digital Terrain Model (DTM) of the Karamana River Basin.

The Agasthyamalai, at the near-extreme southern end of the Western Ghats, straddles on both sides of the state border, i.e, the Kollam and Thiruvananthapuram Districts of Kerala and Tirunelveli and Kanyakumari Districts of Tamil Nadu. The State border is a jagged high ridge running roughly north- south over the hills, which is a renowned habitat for over 2,000 species of herbs and traditionally believed to be the abode of the Vedic sage - Agasthyar, the founder of the Siddha system of indigenous medical practice. Spanning between south of the Aryankavu Pass, a minor mountain pass located at latitude 9°N to the vicinity of the Mahendragiri, near Kanyakumari, the hills rise to elevations in the range of 50 m near sea level to the highest peak in the

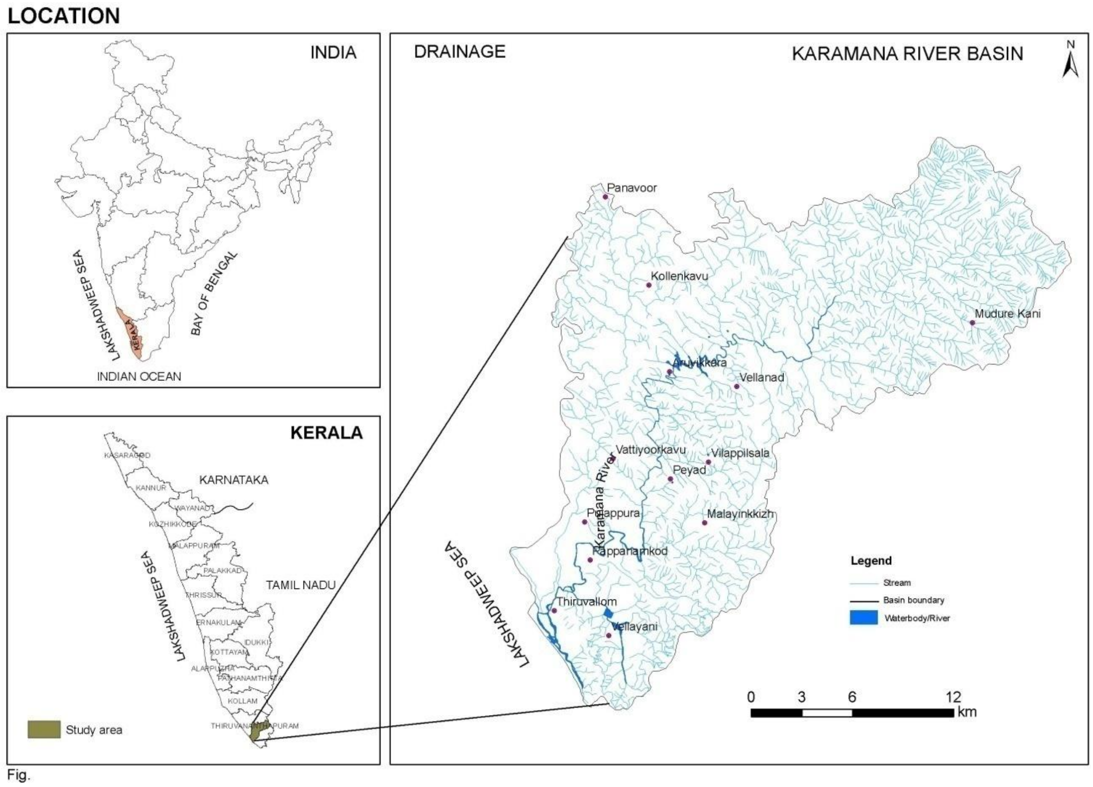


Fig. 1.5 Location map of Study area (Karamana River Basin)

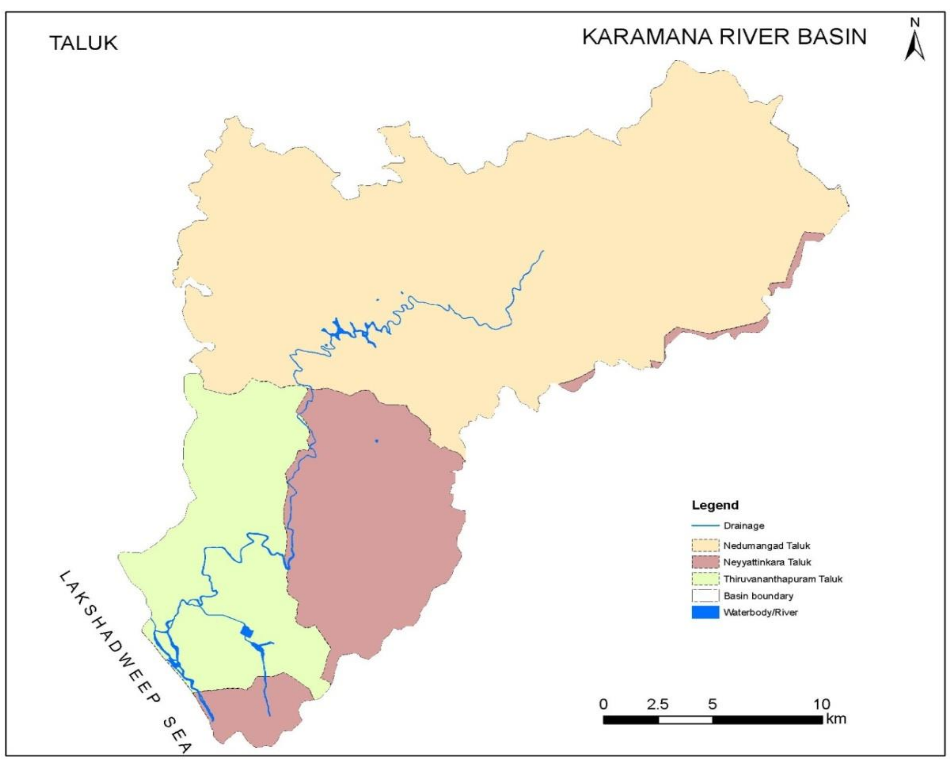


Fig. 1.6 Taluks of Karamana River Basin

Table 1.2 List of Panchayats partly or entirely falling within KRB

Sl.No.	Name of Panchayts	Sl.No.	Name of Panchayts
1	Anad	12	Pullampara
2	Aryanad	13	Sreekaryam
3	Aruvikkara	14	Tholicode,Vellanad
4	Karakulam	15	Vidura
5	Kuttichal	16	Vembayam
6	Kallikkad	17	Vattiyoorkavu,
7	Maranalloor	18	Vilappil
8	Nanniyode	19	Vizhinjam
9	Pallichal	20	Venganoor,
10	Paruthippara	21	Uzhamalackal
11	Panavoor	22	Poovachal

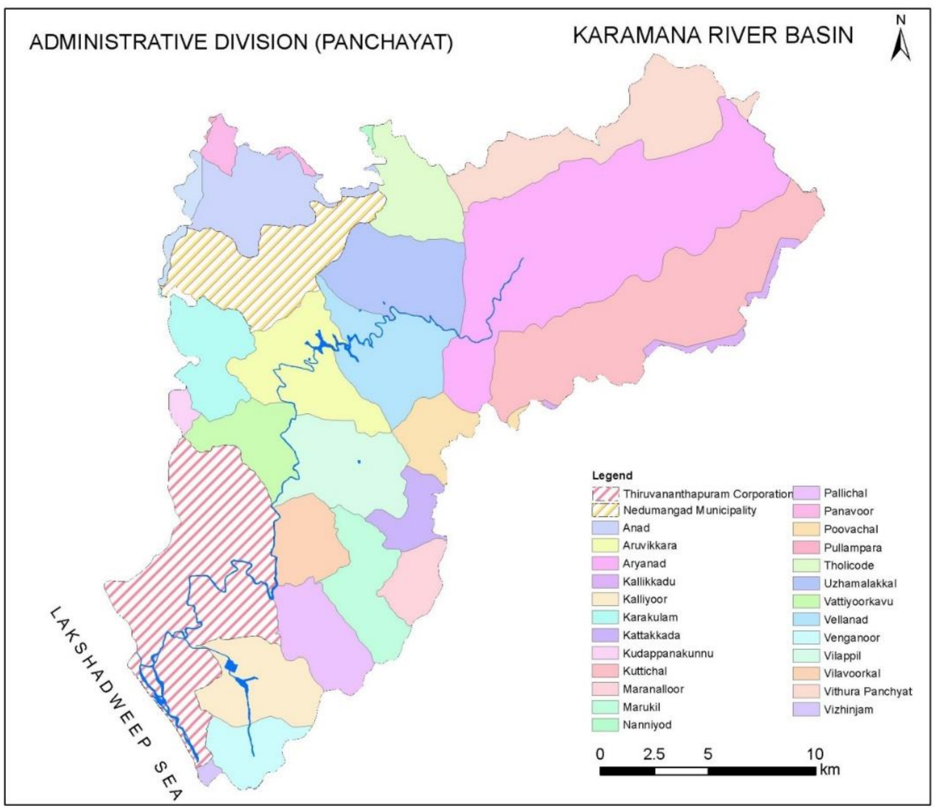


Fig. 1.7 Administrative Divisions (Corporation, Municipality and Panchayaths) of Karamana River Basin

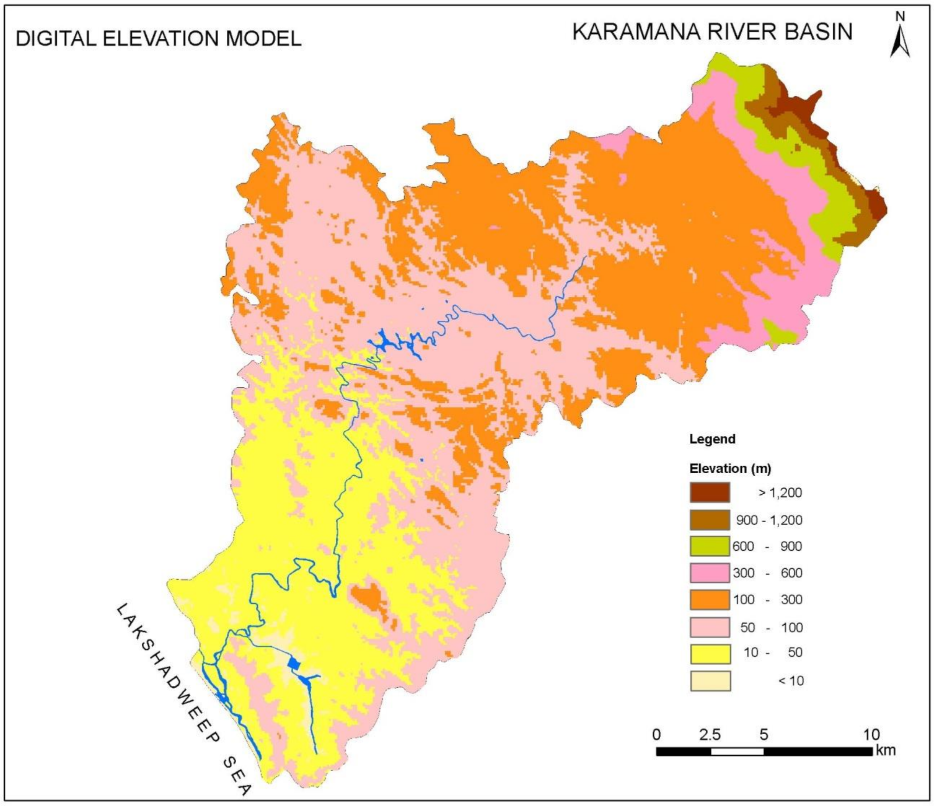


Fig. 1.8 Digital Elevation Model (DEM) of Karamana River Basin

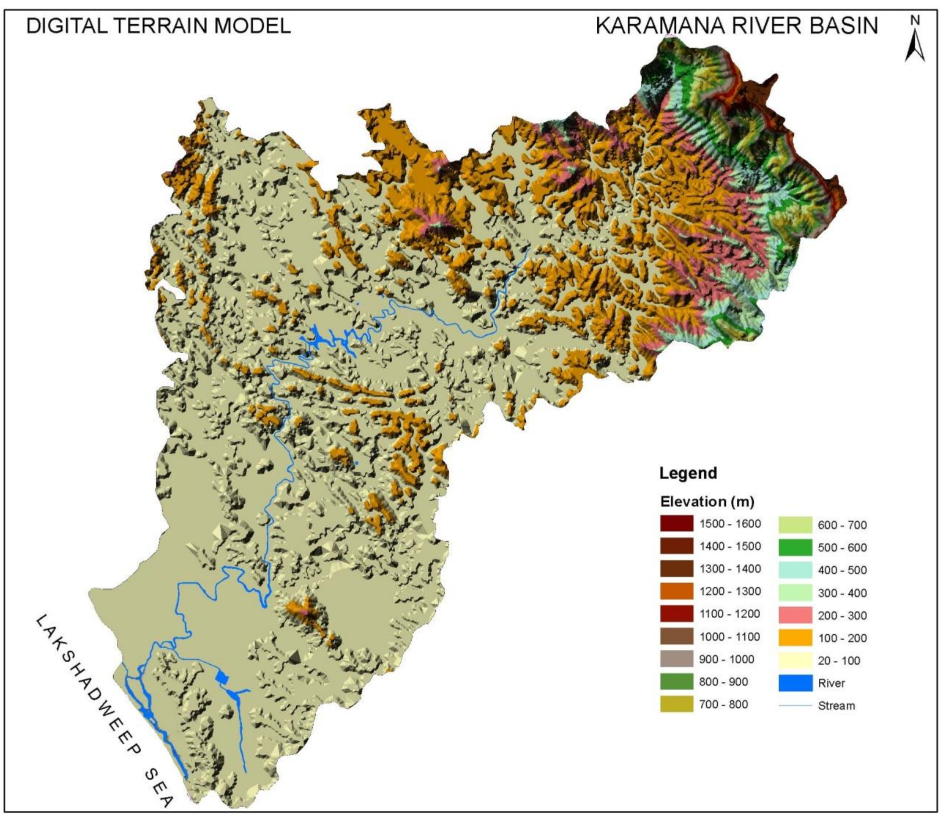


Fig. 1.9 Digital Terrain Model (DTM) of Karamana River Basin

venerated Agasthyamalai of 1,868 m after which this portion of the Western Ghats is named.

There are about 25 peaks with altitudes exceeding 1,600 m average MSL in the Agasthyamalai Hills. The five-peaked mountain Ainthuthalai Pothigai (1,862 m) immediately adjacent to Agasthyamalai, Chemmunji (Cherumunj) Mottai (1717m) and Naga Pothigai (1,600 m). The Ashambu Hills include the eco regions of South Western Ghats moist deciduous forests above 500 meters, South Western Ghats Montana rain forests above 1,000 meters and Shola-Grasslands Complex on peaks above 1,600 meters.

To the west, on the Kerala side, the Agasthyamalai hosts the Neyyar Wildlife Sanctuary (extent: 128 km^2), Peppara Wildlife Sanctuary to an extent of 53 km^2 as well as the Kulathupuzha and Palode Reserve forests in the Nedumangad Taluk, Thiruvananthapuram District has been carved out of portions of the Palode reserve forest, (24km^2) and the Kottoor reserve forest, (29 km^2) of Agastyamala range. Unscathed by human interference and forest fire, it forms an evergreen patch within the KRB. These three protected areas (Neyyar, Peppara and Shendurney Wildlife Sanctuaries) along with the Kulathupuzha and Palode Reserve Forests form an almost contiguous tract of extensive forests in Kerala. The topography is rugged with many perennial mountain streams originating in the tropical rainforests on the upper slopes. Such streams merge to form several important rivers. Vamanapuram Ar, Karamana Ar and Neyyar flowing westerly from these hills across Kerala. The Thamirabarani River and its tributaries (Ramanadhi and Manimuthar) of Tamil Nadu state are significant east flowing perennial rivers rising from Agsthyamalai Hills.

These protected areas in the Agasthyamala Hills comprise the Agasthyamalai Biosphere Reserve (area: 3,500.36 km^2 of which 1,828 km^2 is in Kerala and 1,672.36 km^2 in Tamil Nadu). The Biosphere Reserve now covers parts of Tirunelveli and Kanyakumari Districts in Tamil Nadu and Thiruvananthapuram, Kollam and Pathanamthitta Districts in Kerala (Lat 8 ^{o} 8' and 9^o 10’ N and Long. 76^{o}52' and 77^o 34' E). Agasthyamalai Sub-Cluster, including all of Agasthyamalai Biosphere Reserve is under consideration by the UNESCO World Heritage Committee for inclusion in the list of World Heritage Sites.

1.5 DRAINAGE- THE KARAMANA RIVER (KARAMANA Ar)

The Karamana Ar, named after the suburb of Karamana, in the Thiruvananthapuram city, flows along the eastern edge of the city of Thiruvanananthapuram after rising from the Chemmunji Mottai (1717amsl), north of southern Agastyamalai Hills. It is the most prominent peak among those located along the drainage divide. Another major peak, the Athirumalai (1594 amsl) is another prominent one and forms the source region of Attayar- a major right bank tributary of KRB. Figure 1.10 shows the drainage map of Karamana River Basin (KRB)

In the topographic maps, the upper reaches or the source zone of the major tributaries of the Karamana Ar are mostly confined within a mountainous zone of altitude upward to 500 m. Karamana Ar which flows through 68 km in a westerly direction merges with the Lakshadweep Sea at Panathura (Lat 8º 25' 30"N, Long 76º 57' 38"E), a fishing village north of Kovalam. The Killi Ar, an important tributary, traverses roughly along the northern part of Thiruvananthapuram city, before joining Karamana Ar. This stream rises at Vettamppalli Hills (217 m), about 6 km northwest of Nedumangad Municipal Town, in the village of Panavur in Nedumangad Taluk.

The Karamana Ar, immediately downstream of Thiruvallom (NH-47) Bridge branches into northern and southern channels encircling the Edayarathuruthu - an island with an ox-bow lake before joining the Lakshadweep sea through the Poonthura estuary, which maintains only a seasonal connection in the SW monsoon season. The "heavily" polluted Parvathy Puthen Ar, an intra-coastal water way (man-made canal) joins the north branch of Karamana Ar, at Munnattumukku, near south of Poonthura village. The flow of water on the western side of the island of Edayarathuruthu is blocked due to heavy silting (aided by storm over wash from seaside) at Munnattumukku and accretion of beach sand at Kunnumel. During the high tide, sea water from the estuary surges up to Thiruvallam, through the eastern side of Edayarathuruthu.

Water discharge in the Karamana Ar, is modulated by two dams viz. the older one at Aruvikkara in the downstream and the later one at Peppara further upstream, constructed primarily to store water to meet the drinking water needs of Thiruvananthapuram . Recently supply of drinking water from Aruvikkara reservoir has been extended to the town of Nedumangad.

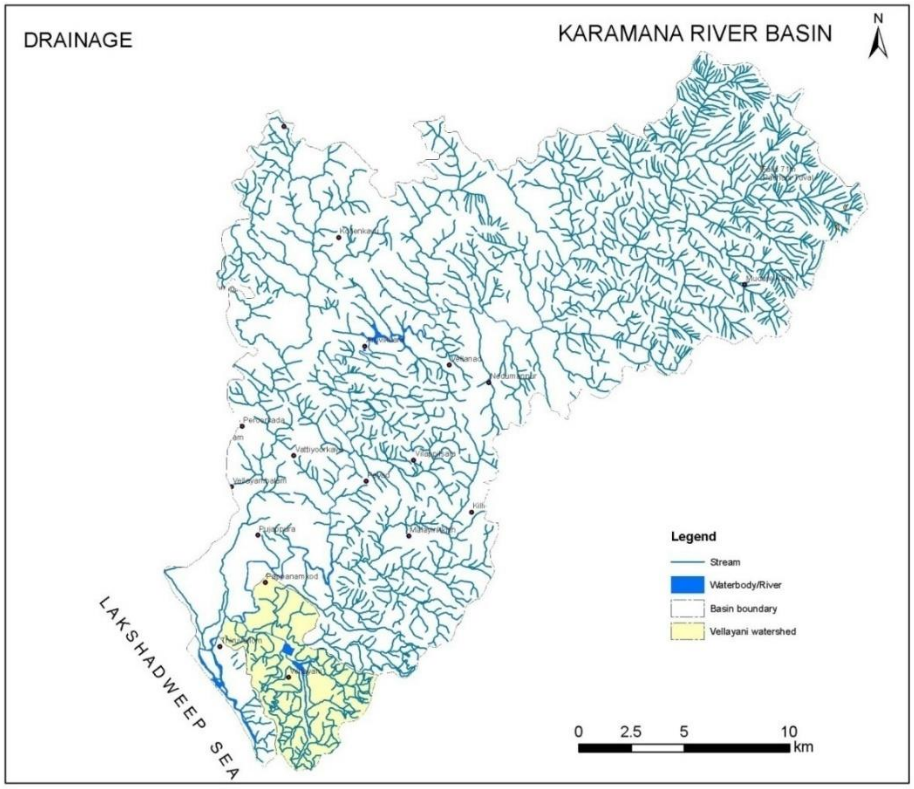


Fig. 1.10 Drainage Map of Karamana River Basin

In Karamana Ar, there is a water fall (drop: 71 m) at Pachani Thuval, about 2 km SW of Chemmunji Mottai. The Vazhapazatti (Vaiyapadi) Ar and the Attayar Ar, two major mountain tributaries of Karamana Ar, both originating from Panditheri Malai (1560 amsl) and Athiru Malai, sub sequently head southward to join the trunk stream in the neighborhood of Peppara Dam. The tributary, Attapuram Thodu, rising from the east of Kalluppara Kunnu (473 amsl) joins the Todai Ar, at about 2 km north of its confluence with the Karamana Ar. Upstream of the Pepparadam site, the main stream receives waters from nine other minor tributaries.

The Peppara dam, within the sanctuary (Water spread at FRL: 5.82 km^2) and across the Karamana Ar was commissioned in 1983 for the augmenting the supply of Aruvikkara reservoir – only source of drinking water supply to the Thiruvananthapuram city and its suburbs. It presents a remarkable diversity in vegetation and forest types, as a result of typical climatic condition prevailing in the region and associated topographic characteristics. Peppara Wildlife Santuary has all typical vegetation types found in tropical areas like tropical moist deciduous forests (29 km^2), tropical evergreen forests (10 km^2), tropical semi-evergreen forests (14 km^2), shoal forests (0.79 km^2), reed breaks (2 km^2), bamboo areas (0.5 km^2), and grasslands (0.2 km^2). A recent study documented 1084 species of flowering plants from this region. (Mohanan et al., 1997). Peppara wildlife sanctuary is a 'gene pool' sanctuary, with a rich variety of flora and fauna over a rugged terrain with running rivulets, rolling hillocks and green meadows. West coast tropical evergreen, southern semi evergreen moist mixed deciduous forests and southern subtropical savannahs are the major forest types of this region (Chandrasekharan,1962 and Champion and Seth, 1968). Most of the surrounding forests were clear-felled and converted to monocultural plantations of eucalyptus, acacia and albizzia.

The topography of the wildlife sanctuary is quite hilly. The region has a warm and humid climate and a dry summer. Daily temperature of the region varies from 35^oC in summer to 16^oC in winter in higher altitude zones. The sanctuary receives an average rainfall around 4,810 mm (Jayson and Christopher, 2008).

The earliest water abstraction structure in KRB, is the Aruvikkara weir, (Lat 8^o 34'N Long. 77^o 01'E) later upgraded to a dam with shutters, across the river later about 25 km downstream from the later built Peppara straight gravity masonry dam. Plate-5 shows a view of the Peppara reservoir.

Another significant left bank tributary joining the Karamana Ar, near the village of Aryanad is the Kottoor Thode rising from the western flank of Chottupara Hill (elevation: 491 amsl). Chittar, yet another significant tributary, flows into the Karamana Ar, at a site 3 km upstream of Aruvikkara Dam. The last one is fed by numerous smaller tributaries, originating from a region spread over Chuliya Malai (elevation: 347 m amsl), Chettikunnu (elevation: 348 m amsl), Manikettanmalai (elevation: 215 m amsl), Pachamalai Reserve Forest and Valiyamalai (elevation: 175 m amsl).

Although numerous smaller tributaries feed into the river downstream of Aruvikara Dam, the Killi Ar is the most significant one.Killi Ar enters Karamana Ar at about 1 km due south of Konchiravila and upstream near Thiruvallum. The Confluence of Karamana Ar and Killi Ar at Thiruvallum is shown in Plate- 9.

CWRDM (1995) estimated the water potential of KRB which is in the order of 836 Mm^3, out of which the utilizable yield is 462 Mm^3. The fresh water discharge required for the Karamana Ar for arresting salinity intrusion has also been estimated as 9.50 Mm^3.

1.6 TOPOGRAPHIC FEATURES OF KARAMANA BASIN

The topographic details of KRB is shown in Fig.1.11 On the basis of physiographic features, three altitudinal zones are identified for the KRB, which are the highland (>75 m amsl), the midland (7.5 m -75 m amsl) and the lowland (<7.5 m amsl). Fig. 1.12 shows the Physiographical features of KRB. The Fig. 1.13 illustrates the major road network of the basin while Table 1.3 gives the area-wise distribution of land in different altitudinal classes. Most of highland comprises reserve and other forest lands. The midland which is moderately rugged and has hills of low altitude and a dominant cover by a layer of primary laterite. The intervening valleys are seen as paddy fields created by terracing the valley fill. The lowland is a strip of land of low relief with beach. The main landforms of the lowland zone are sandy and rocky beaches and sand ridges. The midland with low or moderate slope while the highland is characterized by thick vegetation and NW-SE trending ridges, narrow valleys with steep slopes, rocky cliffs and escarpments and is a highly rugged terrain. The landforms of the KRB basin are products of denudational, fluvial and marine processes.

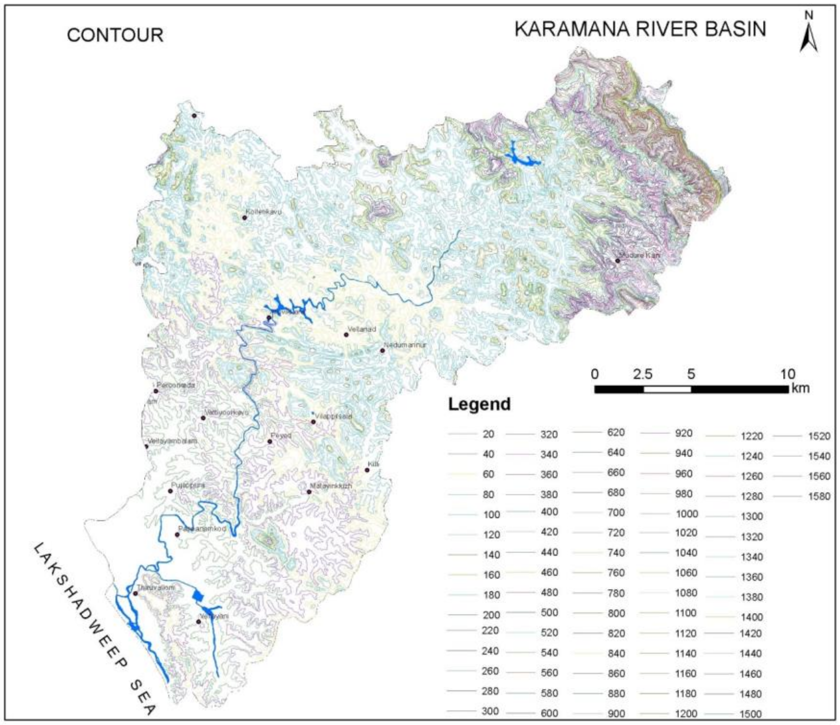


Fig. 1.11 Elevation contour map of Karamana River Basin.

Table 1.3 Area-Altitude Percentage Distribution of KRB

Sl.No	Altitude Range, m	Area,%
1	0 m to 20 m	16.54
2	21 m – 100 m	47.91
3	101 m to 300 m	23.63
4	301 m to 600 m	5.10
5	601 m to 900 m	3.37
6	901 m to 1200 m	2.22
7	1201 m to 1717 m	1.23

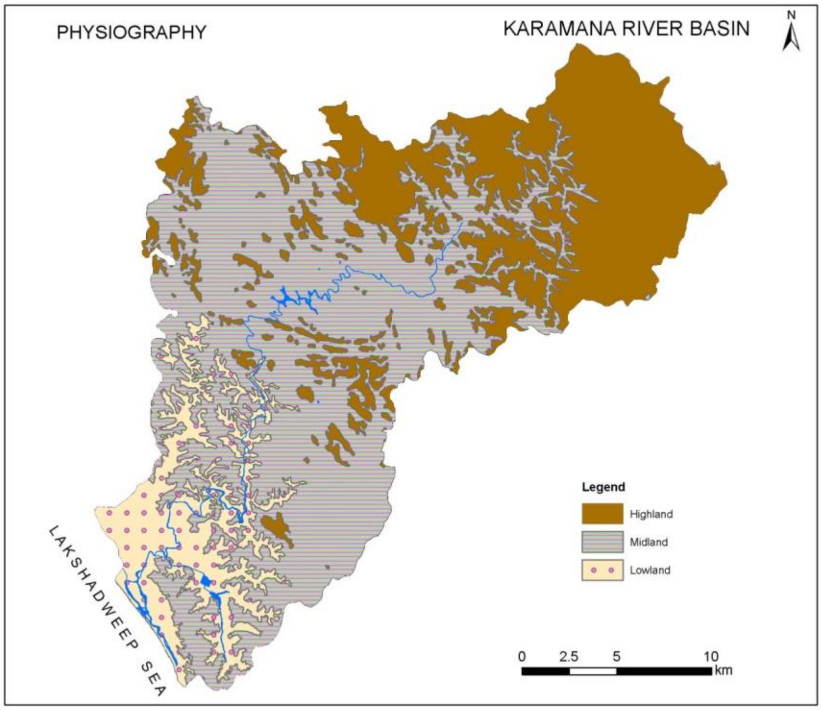


Fig. 1.12 Physiographic units of Karamana River Basin

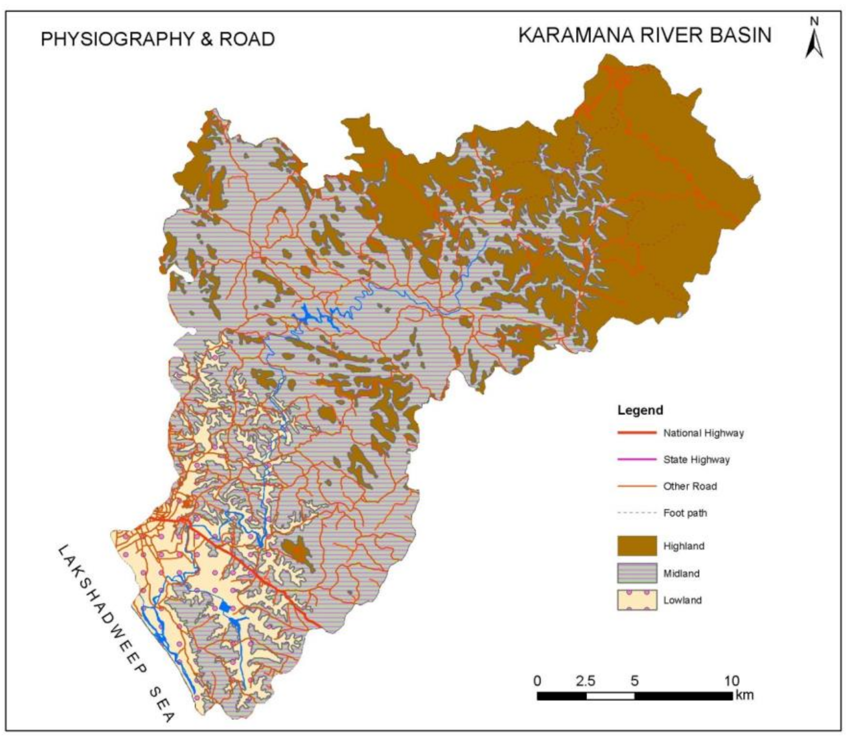


Fig. 1.13 Major accessibility routes of Karamana River Basin

1.7 GEOLOGICAL SETTING OF THE STUDY AREA

The major rock types of Kerala, are grouped into (1) the Precambrian crystalline rocks (2) the Tertiary Formations and (3) the Recent and Subrecent sediments. The Precambrian crystalline rocks comprise charnockites, khondalites, migmatites, gneisses and Dharwar schists.

Charnockites are exposed in all districts; khondalites and gneisses are concentrated in southern part of the state while Dharwar schists are found restricted to the northern parts. These rocks host several intrusive such as layered ultrabasic – basic complexes, ultrabasic rocks, granites, basic intrusive and gabbro-dolerite dykes.

Pegmatites and quartz veins cut across all the older rocks. Tertiary sedimentary sequence is constituted by an older Quilon series of fossiliferous limestone, shell limestone alternating with thick beds of sandy clays, calcareous clays. The younger Warkalli series primarily are clastic rocks made of ferruginous, coarse grained (gritty), cross bedded sandstones, clay stones, variegated clays and marcasite bearing carbonaceous clays with occasional thin beds/ seams of lignite. Recent to Subrecent sediments are chiefly modern and ancient beach sand deposits, lime shell deposits, soils and alluvium.

The KRB falls within the Kerala Khondalite Belt (KKB) in the Trivandrum Block, bounded in the north by the prominent Achenkovil Shear Zone which extends across the southern part of Tamil Nadu and southern Kerala. The Fig. 3.4 represents the aerial extent of Geological units. Area-wise the rocks of the Charnockite- Khondalite Group cover the lion’s share of about 77% of the basin.

The rock units of Tertiary age are exposed on the north facing slope of the ridge between Thiruvallom (The Chitranjali Studio Complex) and Madhu Palam. And at Konchiravila (an isolated patch), Trivandrum, while the Quaternary rock units of Holocene to Pleistocene age, occur scattered in several places, especially along the lowland of KRB, and in valley flats, river terraces, as well as the dominant sediment in the coastal land. The Table 3.10 shows the aerial extent of geological units in sq.km and in percentage.

The major rock types of KRB are: Charnockite-Khondalite assemblage ie., garnetiferous-biotite-sillimanite gneiss with or without graphite (khondalite), garnetiferous biotite gneiss and associated migmatites, charnockites (including pyroxene granulites, either gneissic or massive types) leptynites, calc-silicate rocks, pegmatites and associated quartz veins of variable sizes and minor intrusive of dolerite (dike).

The order of abundance of these rocks are Khondalites, garnetiferous biotite gneiss, charnockites, leptynites and calc-silicate rocks. The calc-silicate rocks occur mostly as thin and minor lenses of "insignificant" size (3 m to 7 m), except at a site 4 km north of Aryanad. The distribution or plan view of the exposures of these rocks implies a south-east trending, plunging antiform, with possible cross-folding.

Pegmatites occur in numerous localities in varying dimensions and seem to be concentrated along linear zones nearly coinciding with the hinge zones of major regional structure. Some of these pegmatites are well-known for their content of semi-precious and precious stones, such as alexandrite and the cat's eye variety of chrysoberyl. Stratigraphic succession of the KRB is given in Table 1.4.

The sub horizontally disposed rock units of the Warkalli Formation are dominantly composed of coarse to medium grained friable sandstones in various shades (deep red, red to light yellow etc.) with frequent intercalations of argillaceous lenses and lamina. These are blanketed on the top by a cap of laterite of varying thickness, mostly covered in turn by alluvium and are found distributed along the lowland zone of the KRB. Further, this laterite differs from the *in situ* type capping the crystalline rocks (Charnockite-Khondalites) by being detrital in nature. Good exposures of Tertiary rocks occur only just beyond the coastal belt of Karamana River Basin, at Karichal in the south and Varkala and Edava in the north where the exposures abound in the coastal cliff sections.

The rocks belonging to the Quaternary age in the KRB is a heterogeneous assemblage composed of alluvium (occupying most of the flood plain and stream terraces), pebble beds, valley- fills of colluvial nature, coastal sands of marine and aeolian origin.

The major lineaments discerned from LANDSAT imageries identified in the Karamana Basin are shown in Fig. 1.14. These are important in the groundwater hydrology of the basin. Studies have shown that bore wells tapping NNW, NE and NW lineaments in KRB generally give high yield of groundwater.

The geology of the region and especially the structure of the rock units, very significantly appear to influence both the geomorphological evolution as well as the geometry of stream courses of the KRB. Obviously, there is a causal relation between the drainage net on the one hand and the structural makeup, such as the joints, shear zones, rock contacts etc. of the Precambrian crystalline basement rocks. On the other hand, this is discernible from the orientation of streams and placement of landform elements in the basin. The geological influence upon the regional variation in the pedological, geomorphological, hydrogeological aspects of the basin is considered separately.

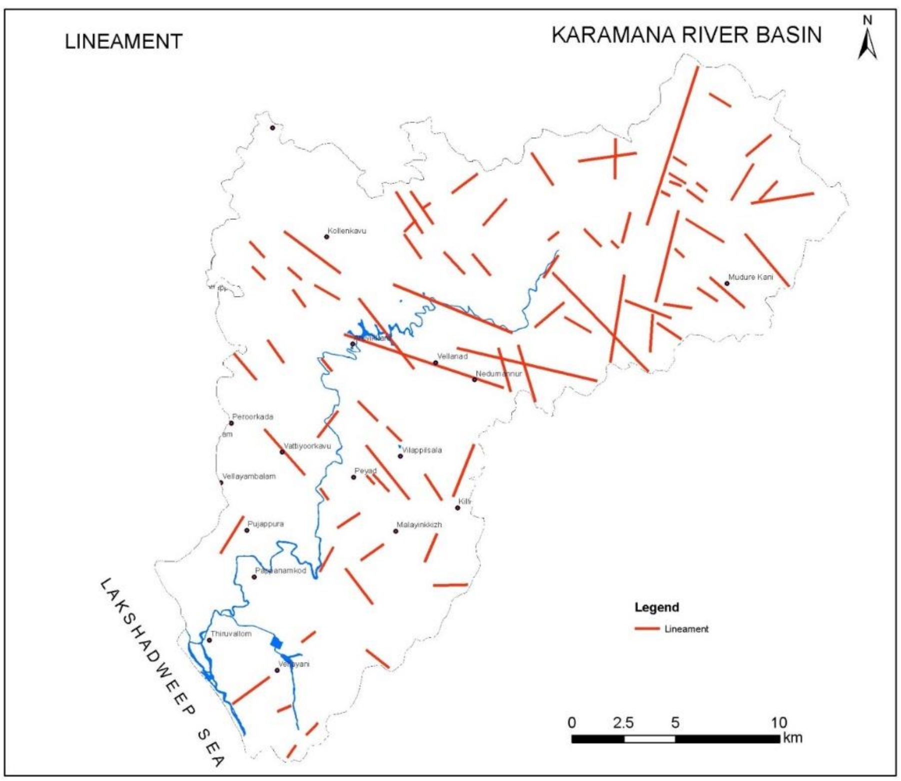


Fig. 1.14 Lineament map of Karamana River Basin

Table 1.4 Stratigraphic Succession of KRB.

Recent to Sub-recent		**Soil and Alluvium Beach and Dune Deposits, Later marine and estuarine formations.**
---unconformity---		
Upper Tertiary (Mio-Pliocene)	**Warkalli Formation**	**Current bedded, friable, variegated sandstone, interbedded with plastic clays and variegated clays, gravel and pebble beds, sedimentary clays and china clays**
---unconformity---		
Precambrian	**Charnockite - Khondalite Group**	**Garneti ferousbiotite gneiss, khondalite, leptynite, charnockite, calc-silicate granulites (together with a minor dyke of dolerite, pegmatites and quartz veins of later age)**

1.8 CLIMATE

The Meteorological Observatory, Thiruvanathapuram, has been operational for more than a century and is currently part of the I M D. It sits outside of the water shed of Killi Ar. As there are no other meterological stations in the KRB, data set of I M D has been used to get a picture of the rain fall and temperature of the KRB. From the data set it is inferred that the mean annual temperature of Karamana River Basin is 27.5^{o} C. The mean monthly temperature varies from 33°C to 26°C, a maximum value of 33^{o}C during the months of March to May and to a minimum of 26˚C during the period from June to November. However, the value of mean daily temperature during the period from March to May reach abnormally high value of 38^{o}C in certain years. As per the records of average of 24 hourly temperature distribution, the mean minimum temperature occurs at 4.51 am, thereafter increasing till it agrees exactly with the mean temperature of the day at 8.16 am and attains its maximum value at 1.34 pm. Afterwards, there is noticeable drop in temperature. Due to lack of data, the spatial variation of temperature across the basin could not be inferred.

The Fig. 1.15 shows the diurnal variation of average pressure, temperature and humidity, based on data collected from Thiruvananthapuram Meteorological Obervatory.

The mean annual rainfall received in the KRB is estimated to be 1753 mm. However, the amount of rainfall varies from coastal belt to the interior. On the scrutiny of monthly distribution of rainfall data, the following three distinct seasons are identified: Hot Season (January to April), SW Monsoon Season (June-September) and NE Monsoon Season (October to December).

SW monsoon rains usually breaks in the basin by mid-May or early June and frequent heavy showers starts from this period and will continue up to the month of September. The major portion of the total rainfall (about 59 %) occurs during this period. However, the monthly distribution of precipitation during this five month period is not uniform. Table 1.5 and 1.6 represent the normal monthly rainfall for the period from 1901 to 1999 and monthly rainfall for the period from 2006 to 2010. The mean rainfall associated with SW monsoon is about 1027 mm. During the period from October to December, KRB receives rainfall associated with the NE monsoon. During this period, it is estimated that nearly 28 percent of the total annual rainfall of the basin occurs. The mean rainfall during this period is about 495 mm. Thus it is only 48 percent of the mean rainfall received during the SW monsoon period. During the period from January to April (hot season) the basin received the remaining 12 percent of the total annual rainfall (2009 mm). Arithmetic average of rainfall in the study area is about 1917.5 mm for the period from 2006 to 2010.

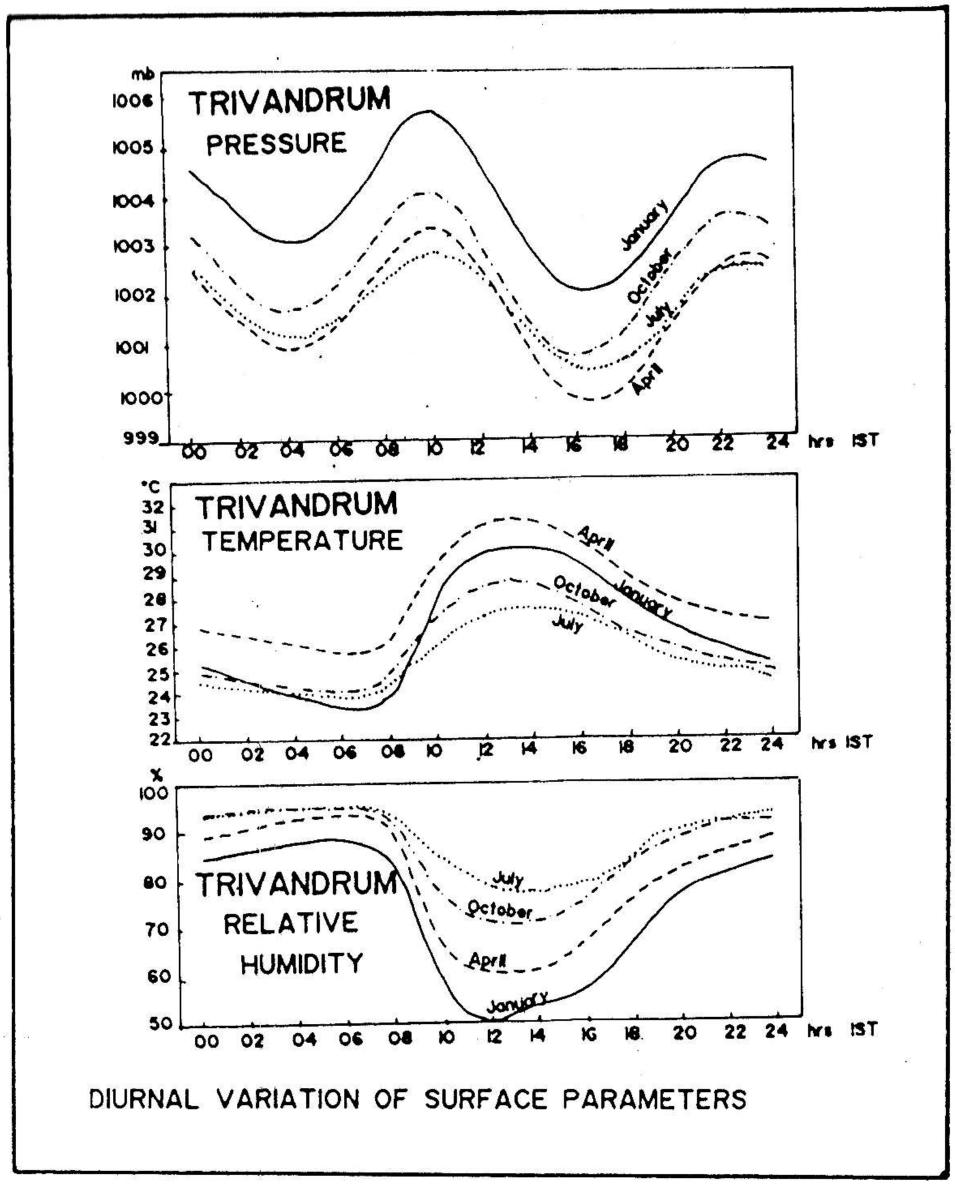


Fig. 1.15 Average variation of Pressure, Temperature and Relative Humidity, Thiruvananthapuram (Source: CGWB, Kerala).

Table 1.5 The Normal Monthly Rainfall (mm) for the period 1901-1999

Montrh	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall	22.6	24.5	39.9	108.2	211.4	350.8	234.7	134.9	148.7	276.1	195.5	73.2	1820.5

Table 1.6 Monthly Rainfall (mm) of Thiruvananthapuram for the period 2006-2010

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2006	18.9	0.0	73.7	81.4	289.7	239.1	190.2	122.6	47.9	521.4	296.7	13.9	1881.o
2007	0.3	1,7	3.7	213.3	167.2	348.7	306.6	177.2	279.1	327.8	213.8	117	2156.6
2008	0.0	24.6	276.0	158.3	89.8	116.3	286.0	180.6	202.6	363.9	195.2	38.2	1931.8
2009	0.0	0.0	60.0	44.6	206.9	183.3	204.2	87.3	183.4	119.4	346.3	42.5	1478.1
2010	108.3	0.0	73.1	109.4	216.7	237.0	234.9	118.7	114.1	414.3	326.0	188.3	2144,1

Rainfall data for the district is the arithmetic average of rainfall stations under the district

(Source: I M D, Thiruvananthapuram)

1.9 SOIL TYPES

The chief soil types of the KRB are red loams, coastal alluvium, riverine alluvium, lateritic and brown hydromorphic soils and loamy soils in the forest. The most predominant soil occurring in the basin is lateritic soil of reddish brown to yellowish red and is mainly confined to the midlands. Brown hydromorphic soils are confined to valley floors as fills in the midland and lowland tracts of the coastal land and these exhibit characters like grey horizon, mottling, streaks, enrichment of organic matter and iron concretions.

Red loamy soils are highly porous, friable and low in organic matter, which is seen only in limited extent in some localities in the southern portions of the basin. The lowland of the basin is dominated by alluvial soils, which can be described texturally as sandy loam or clayey loam. These are found along banks (flood plains) of the Karamana Ar and its major tributaries and is traceable inland into the midland. Alluvial soils, associated with the coastal alluvium occur along the coastal tract. The eastern part of the basin is characterized by loamy soils of the forests which are generally dark reddish brown to black in colour with loam to silty loam texture.

1.10 LANDUSE PATTERN

The percentage of basin area under various categories of use in the KRB is given Table 1.7 and an inspection of this table brings out the following facts.

(1) about 22% of the area is under forests of various types.

(2) Nearly 63% crops is presently under settlements, and some of these may be with homestead farms and tree.

(3) In the KRB only about 11% of the area is paddy field.

(4) Remaining 4% is of other land use practices.

Since the intensity of urbanization is high in the lowland, the percentage of land under cultivation in this tract is on a rapid decline. The increasing urban sprawl of Thiruvananthapuram city through decades and the changes in the various land use practices during 1966 to 2005 is given in Table 1.8. (Balakrishnan and Narayanan, 2008 and Sujith, 2005). During a 40 yr period (1961- 2001), the city extended extent from 44.52 km^2 to 141.74 km^2. For e.g, in 1966, area under paddy was 101 km^2, but it steeply declined to about 8.53 km^2 in 1988, primarily due to reclamation and use as real estate. The same period also saw a rise in the area under roads from 2.79 km^2 to 13.95 km^2 as an indicator of growth and expansion of new human settlements. Expansion of railway and airport also absorbed a decisive chunk of land, adding to the land use change. The landuse change in the Nedumangad Town, in the midland of KRB is presented in Table 1.9.

Table 1.7 Landuse / Landcover percentage of KRB.

Sl.No	Landuse / Landcover Category	Area, %
1	Evergreen forests	1.62
2	Semi-evergreen forests	3.06
3	Moist deciduous forests	6.56
4	Dense jungle with grass lands	0.28
5	Dense mixed jungle	2.80
6	Degraded forests	3.00
7	Reserve forests	1.20
8	Forest plantations (eucalyptus, teak, acacia etc ;)	1.86
9	Tribal settlements	0.24
10	Rubber plantations	1.81
11	Tea plantations	0.25
12	Mixed trees with settlements	40.80
13	Settlements with trees	5.85
14	Settlements	1.70
15	Tree crops	0.43
16	Coconut farms	0.28
17	Coconut with settlements	12.90
18	Paddy fields	11.79
19	Coconut with paddy	0.04
20	Rotation crops	0.35
21	Roads	1.88
22	Water bodies including reservoirs	0.40
23	Rocky outcrops and wastelands.	0.90

Table 1.8 Landuse change of Thiruvananthapuram city, 1966-2005

<table>
<tr><th rowspan="2">Landuse categories</th><th colspan="2">Landuse in 1966</th><th colspan="2">Landuse in 1988</th><th colspan="2">Landuse in 2005</th></tr>
<tr><th>Area in km^2</th><th>%</th><th>Area in km^2</th><th>%</th><th>Area in km^2</th><th>%</th></tr>
<tr><td>Paddy fields/mixed plantation</td><td>10.1</td><td>14.5</td><td>7.20</td><td>9.61</td><td>8.53</td><td>6.05</td></tr>
<tr><td>Restricted area</td><td>1.18</td><td>1.57</td><td>1.30</td><td>1.73</td><td>3.9</td><td>2.76</td></tr>
<tr><td>Commercial area</td><td>2.35</td><td>3.13</td><td>1.0</td><td>1.33</td><td>13.46</td><td>9.55</td></tr>
<tr><td>Public and semi-public area</td><td>4.2</td><td>5.71</td><td>6.63</td><td>8.84</td><td rowspan="2">10.43</td><td rowspan="2">7.40</td></tr>
<tr><td>Parks /open spaces</td><td>0.198</td><td>0.26</td><td>5.82</td><td>7.77</td></tr>
<tr><td>Transport(air, road, railway)</td><td>2.79</td><td>3.72</td><td>5.50</td><td>7.34</td><td>13.95</td><td>49.49</td></tr>
<tr><td>Residential area</td><td>46.2</td><td>61.6</td><td>40.23</td><td>53.75</td><td>69.75</td><td>49.49</td></tr>
<tr><td>Industrial area</td><td>1.51</td><td>2.51</td><td>1.63</td><td>2.18</td><td>9.62</td><td>6.82</td></tr>
<tr><td>Coastal Land (Beach sand)</td><td>0.735</td><td>0.98</td><td>0.9</td><td>0.735</td><td>1.92</td><td></td></tr>
<tr><td>Nondeveloped</td><td>4.5</td><td>6.07</td><td>3.99</td><td>5.32</td><td>-</td><td>-</td></tr>
<tr><td>Natural vegetation</td><td>-</td><td>-</td><td>-</td><td>-</td><td>9.36</td><td>6.64</td></tr>
<tr><td>Water bodies</td><td></td><td></td><td>1.59</td><td>2.13</td><td></td><td></td></tr>
<tr><td>Total</td><td>74.93</td><td>100</td><td>74.89</td><td>100.0</td><td>140.92</td><td>100</td></tr>
</table>

Table 1.9 Current Landuse of Nedumangad Municipality, KRB.

Type of Land use	Area, km^2	Area (%)
Residential	9.032	28.60
Industrial	Nil	Nil
Commercial	0.137	0.42
Public/Semipublic	1.378	4.24
Park / open space	Nil	Nil
Transport	0.626	1.92
Water courses	0.097	0.30
Paddy fields	1.02	3.39
Restricted areas	0.912	2.80
Non-developed region	Nil	Nil
Rocky outcrops	0.551	1.69
Rubber plantation	6.886	21.17
Agricultural land	10.420	32.04
Total	32.52	100

1.11 ENVIRONMENTAL ISSUES

Accelerated rate of deforestation in the higher reaches of KRB as well as the rapid changes of land use, resulting from the increasing spread of urbanization into the interior parts of the basin are modifying the hydrological regime of the basin. The effect is recognizable in the increasing content of finer fraction (silt and clay) in the river load and the lowering of water yield in the catchment, the latter in turn affects the amount of groundwater recharge.

Studies indicate that large-scale deforestation in the Western Ghats and introduction of plantation crops in highlands replacing the natural vegetation has not only brought about a significant reduction of the storage capacity of soil in higher reaches of the basin but also has resulted in increased rate of surface soil erosion in watersheds. This in turn has led to enhancement in annual rate of sedimentation in the river bed and associated reservoirs, and reducing the effective life span. All these changes associated with changing pattern of land use, has adverse impact in stream discharge in summer base flow. Several investigators have pointed out that some perennial rivers and river lets have become seasonal in the last few decades and large scale land use / land cover changes has been recognized as the major cause for this (Govt. of India, 2013).

Sand quarrying in river beds and banks are slaughtering the rivers, as this activity not only leads to bank erosion and lowering of local water table but also create several other environmental problems. Studies in different river basins of Kerala have shown that ground water level in some of the watersheds has gone down by nearly one meter during the last two decades. In the KRB, quarrying operations associated with sand barrowing is not restricted to river bed but in many places sand is being quarried from the river banks damaging the adjoining agricultural properties. Moreover, agricultural practices of cultivation in the riverbanks and also inside the dry riverbeds during non-rainy months (especially in the upper reaches of dam-sites), also add to increased tempo of bank erosion and sedimentation.

Most of the industries are near the thickly populated localities along the riversides. Killi Ar, a major tributary of Karamana River is a victim of serious pollution right downstream from the town of Nedumangad. Several studies have shown that, when this stream reaches Thiruvallum, it is in the most seriously polluted condition. There is total absence of any efficient water treatment system in industries located in the neighbourhood of stream channels and in Nedumangad Municipality, to prevent or reduce pollution and contamination of stream water. Several recent studies indicate that pollution levels of both Karamana Ar and Killi Ar where these flow through the Thiruvananthapuram City are far above permissible limits in many localities.

1.12 MAJOR GROUNDWATER RELATED PROBLEMS OF THE BASIN

The important groundwater related problems in Thiruvananthapuram urban area are:

• Over-exploitation: With the adoption of modern drilling techniques, construction of bore wells has become a common practice to meet domestic as wells as agriculture needs. This increase in tube wells may result in more groundwater draft from potential aquifers.

• Pollution: Mainly due to municipal waste and due to waste disposal particularly around Vilappilsala where the waste disposal facility has been established. The *E.Coli* content is very high in groundwater of this area whereas the other constituents are within the desirable limit.

• Water marketing: Mainly seen during summer months, particularly in Vengannur Panchayat and area near to Aakulam Lake, due to heavy withdrawal resulting in decline of water table. Due to lateral spread of urbanization, groundwater is vulnerable both quantitatively and qualitatively and hence it is very necessary to take up artificial recharge schemes in urban areas. The identification of feasible areas for artificial recharge to groundwater was made on the basis of depth and declining trend of water level. Rain water harvesting, conservation of existing water bodies in the neighborhood and recharging of these water bodies with filtered drain water etc. should be considered instead of allowing all run off to drain into the sea or to cause flooding in some part of the city. Artificial recharge and rainwater harvesting are the best suited and most effective methods to augment groundwater resources in the area (CGWB, 2009). Sub surface dams and dykes are the main structures feasible for the artificial recharge of ground water in the upstream portion of Karamana basin. The most feasible structure is the roof top rainwater harvesting technique. Such schemes can arrest the decline in groundwater levels and improve groundwater quality. Recharge pits and trenches are ideal structures for rainwater harvesting in the midland areas of Trivandrum Urban Area. Roof water can be used for recharging the dug wells, bore wells and tube wells. In TUA, a large number of ponds, tanks and other abstraction structures in the area are filled up with silt, clay and hence sufficient recharge is not taking place in the aquifers. Hence restoration of these structures has to be done to induce recharge. Similarly, many quarry ponds are present in and around Vizhinjam, Kovalam and Pothencode areas which can be effectively used for rainwater harvesting structures.

1.12.1 Groundwater development strategy

There is scope for further groundwater development for irrigation in TUA in areas where the stage of development is low. Groundwater development should be coupled with management of rainwater and surface water. The existing water resources and dug wells, ponds and streams should be protected and conserved. Rainwater harvesting and artificial recharge schemes should be taken up on a massive scale. An essential part of management of the resource is the proper spacing of abstraction structures. The spacing between shallow tube wells should be kept 225 m and for deep tube wells the spacing between the well should be kept 800m.

Hydro geologically, the areas have been grouped into hard rock and alluvial areas. Since the water level is very shallow in alluvial aquifer, artificial recharge can be considered only in hard rock areas. The surface spreading techniques such as check dams, gully plugs and nallah bunds are most appropriate for TUA. As per the Master Plan for Artificial Recharge to Groundwater (CGWB, 2002), in Karamana River basin 544 nos of check dams of capacity 0.1 MCM, subsurface dykes of 0.03 MCM (906 nos), gully plugs (1360 nos) of 0.02 MCM and nallah bunding (1360 nos) of 0.02 MCM is feasible. The impact of artificial recharge to ground water shall be created mainly at the downstream side of the recharge structures.

1.13 SUMMARY AND CONCLUSION

The Karamana River Basin is located within Lat 8^{o}21' and 8^{o}42'N and Long 76^{o}52' and 77^{o}15'E, between the Vamanapuram River basin in the north and the Neyyar River basin in the south. This 6th order basin spreads over an area of 703 km^2. The main stream, the Karamana Ar has a length of 68 km. Its main tributaries are Killi Ar and Todai Ar. The basin extends from Chemmunji Mottai Peak (1717 m amsl) across the highland, midland and lowland zones of the Kerala. There are two dams in the basin. Crystalline rocks of Precambrian age and sedimentary rocks of Tertiary and Quaternary age are the rock types exposed in the basin. The mean annual rainfall of the basin is 1753 mm. The chief soil types of KRB are red loams, coastal alluvium, riverine alluvium and lateritic soils. Nearly 63% of the basin is presently under settlements, and some of these may be with homestead farms and tree crops.

CHAPTER II

HOLOCENE AQUIFER SYSTEM OF KARAMANA RIVER BASIN

The geographical extent, stratigraphy, hydrological aspects and pollution status of the Holocene aquifer of the Karamana River Basin are discussed in detail in the present chapter.

2.1 HOLOCENE STRATIGRAPHY OF KARAMANA RIVER BASIN

As already noted in Chapter I, the Kerala State hosts a fairly thick deposit of Holocene sediments in its coastal lowlands, which is characterized by an interlacing network of wetlands. The succession is known to attain maximum thicknesses of 40-60 m at some localities. The coastal plains of Thiruvananthapuram district have a shoreline length of 78 km extending from the Edava Kayal in the north to Kollenkode in the Kerala-Tamil Nadu border. Quaternary succession of the coastal tract of Thiruvananthapuram district, the surface relief of which hardly exceeds 15 m above MSL, comprises unconsolidated sandy sediments with occasional clayey, silty and organic intercalations. This succession occurs above the Tertiary sediments or the associated laterites are separated in most regions by a layer of pebble-enriched horizon. In the Thiruvananthapuram district these sediments are found best developed from Perumathura in the north to Poovar in the south. These comprise sand bars, sandy flats, alluvial accumulations and sediments associated with some standing water bodies and wetlands associated with the ridge-runnel systems. The maximum thickness of Quaternary succession rarely exceeds around 25 m. Extensive human interference in connection with the construction of airport, coastal canal (T.S Canal), Equatorial Rocket Launching Station and associated establishments, Travancore Titanium Factory, National Highway and spreading of settlements associated with urbanization, have caused considerable surface modifications in most part of the coastal tract of the district, obliterating and disturbing most of the macro and meso-scale coastal landforms (swales, beach ridges and sand dunes, marshes, paleo channels etc.) comprising the Quaternary terrain of the district.

Adequate number of borehole data is not available for a detailed description of the Quaternary succession of the Karamana River Basin. However, from the available data collected from various sources (PWD, Central Groundwater Board, and State Groundwater Department) a general picture of the Quaternary succession of the coastal tract of the basin is deduced.

Grain size analysis of surface samples indicates that lithologically, the Quaternary sediments of Karamana River Basin are dominantly coarse sand with occasional silty and clayey intercalations. The quartz grains are mostly angular to sub angular. However, samples collected from deeper levels beyond 5 m from the ground indicate that there is notable reduction in grain size as well as enrichment of silty and organic materials. The silt content of the Holocene sediments has been noted to vary from 5 to 12 %. Further down, the content of organic matter is found to get enriched where dirty, dark green silty and clay horizons occur at depth. The topmost unit of the Quaternary succession of the Karamana River Basin which is more or less lithologically and texturally homogeneous, consisting of coarse sands, varies in maximum thickness from 7.5 m to 13 m. Towards the east (landward) the unit shows thinning and gradually merges with a succession comprising silty sand, slightly brownish soil and laterite. Below this unit a lithounit of 1.5 to 5 m thicker sandy deposits which are texturally different from the former unit occurs. This unit comprises relatively finer sediments with higher organic content imparting greenish brown or brownish green tints. The deeper lying, lithounit, which exceeds in thickness of over 15 m, can be described as yellowish to brownish medium sand with occasional intercalations of clayey layers and laterite pebbles. Further below this, laterites and Tertiary units are recorded in some bore holes in coastal tracts drilled for groundwater. It is worth noting that most portions of all the above lithounits are devoid of marine fossils thereby indicating their fluvio-lacustrine origin of the most part of the succession (Reghunadh et al., 1995). However, fragments of marine shells are reported to have been recovered from drilling sites in the neighborhood of the fort region during the construction of some high rise buildings by private agencies. The dating of sediments of the coastal tract of Thiruvananthapuram

District carried out by the Wadia Institute of Himalayan Geology, Dehra Dun, for the samples collected from nine localities give age ranging from 1800 to 30,000 YBP (CESS Annual Report 2006-2007 p.3). Longhinos (2009) reported that the second lithounit of the coastal tract of Thiruvananthapuram ranges in age from 10,700 years BP to 7230 years BP Hence the Holocene succession of the Karamana River Basin can be considered to commence upward from the middle lithounit and the underlying portion of the Quaternary constituting the Pleistocene succession of the region. Thus the maximum thickness of the Holocene stratigraphic units of the Karamana River Basin being restricted to about 20 m. The radiometric dating carried out at BSIP for the peat samples collected from river beds of Karamana Ar and Killi Ar, Kaimanam on the banks of Karamana River and Thannimoodu Vattakkarkkakam Eala respectively gave the following values.

(1). Peat sample from Kaimanam : 2.52 Ky BP

(2). Peat sample from Thannimoodu : 1.6 Ky BP

These samples thus represent relatively younger Holocene age for the sediment enclosing them.

2.2 HYDROLOGICAL PROPERTIES OF HOLOCENE AQUIFER

As the succession of Holocene sediments of the Karamana River Basin constitutes a heterogeneous body comprising intercalated lithology that vary in their degree of permeability and acts as a water yielding hydrologic unit of regional extent, the term ‘aquifer system’ is more appropriate for it rather than the term ‘aquifer’. As the groundwater in the Holocene sediments is not held under pressure by any overlying impervious layer, the aquifer is not in confined condition.

The term ‘water table condition’ or ‘phreatic aquifer’ is also frequently applied to denote an unconfined aquifer. The term meaning that the upper limit of the aquifer is defined by the water table itself. Since the aquifer is non-artesian, water level of the aquifer is not influenced by fluctuations in atmospheric pressure (barometric efficiency of wells).

Although adequate number of well distributed drillhole data is not available, an isopach map of the Holocene sequence of the Karamana River Basin has been prepared using available drill log data collected from CGWD, GWD and CWRDM (Fig. 2.1). From the map it is identified that the thickest succession of Holocene sediments occur east of Vettukad and Shangumughom. The maximum estimated thickness of Holocene sediments is assumed to be over 16 m east of Shangumughom while it is over 12 m east of Vettukad located about 5 km northwest and is provided in Table 2.1.

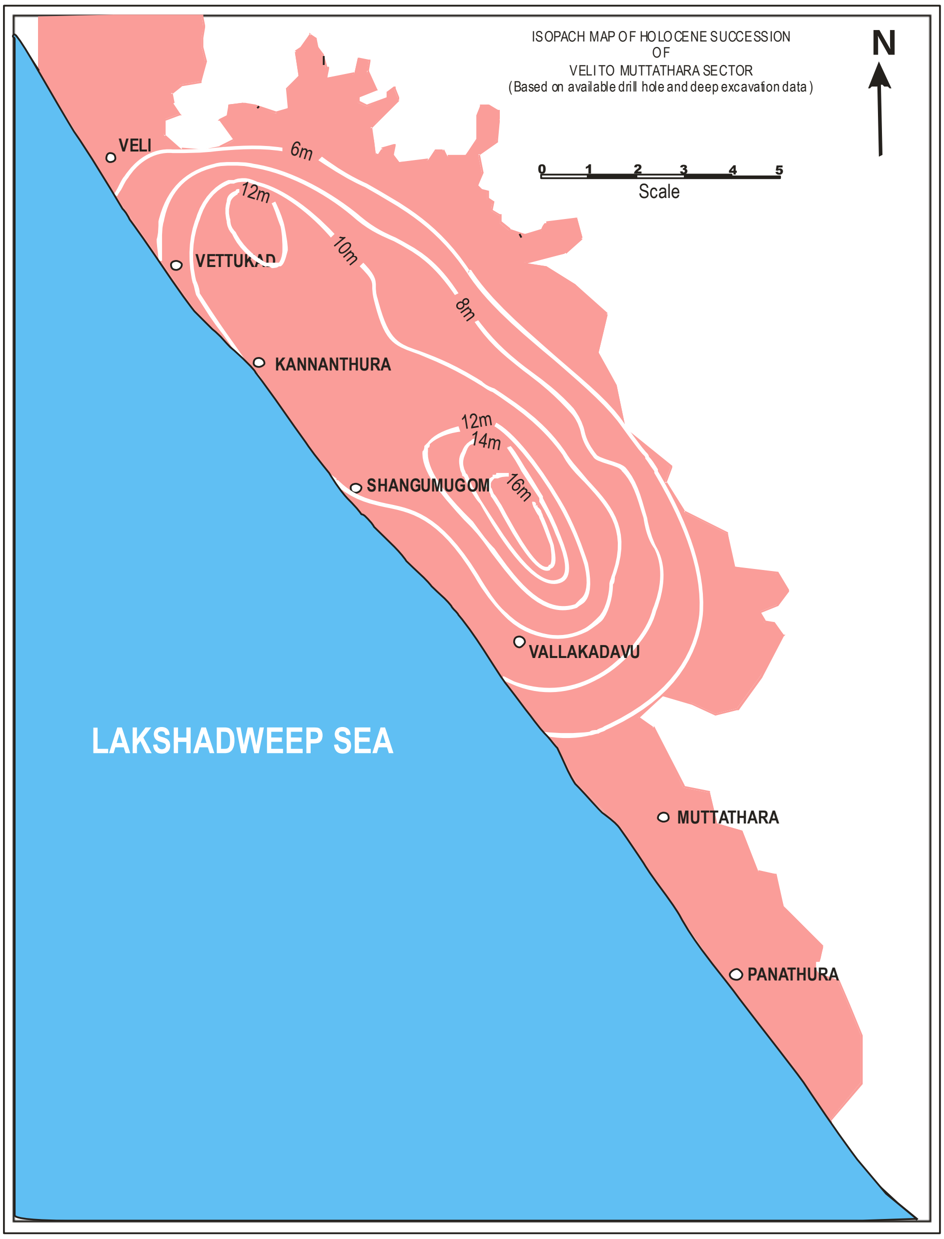


Fig. 2.1 Isopach map of Holocene succession of Karamana River Basin

Table 2.1 Holocene succession of KRB

QUATERNARY	**HOLOCENE**	Lithounit I (7.5 m - 13 m)	Unconsolidated coarse sand
		Lithounit II (1.5 m - 5 m)	Greenish /brownishunconsolidated finer sand with organic matter
	PLEISTOCENE	Lithounit III (over 15 m)	Yellowish to brownish medium sand with occasional intercalations of clayey layers and laterite pebbles.

2.2.1 Fluctuations of water table

Table 2.2 provides the water table fluctuation of the Holocene aquifer from two observation wells maintained by the Central Groundwater Board, for the period from 1985 to 1993. These wells are located at Kochuveli in the north and Poonthura in the south. A scrutiny of the data reveals the fact that the maximum depth of the water table in Holocene aquifer is during the month of April and minimum in November. The rising of the water table in response to the monsoon rains are between 0.2 m to 1.00 m whereas the lowering in hot season are only 0.18 m to 0.82 m.

As there are no recent data available relating water table fluctuations, the water table was measured in 5 observation wells, which are evenly distributed in the Holocene aquifer of the Karamana River Basin. Observations were made during the period of Jan 2010 – December 2011 (Table 2.2). The results are shown in Table 2.3.The data shows that Veli records deepest water level 5.9 m and the Muttathara area shows water level 3.15 m

Table 2.2 Water Table Fluctuation in Holocene Aquifer (Source: CGWB)

Locality	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kochuveli	1985	5.72	NA	NA	5.92	NA	NA	NA	4.81	NA	NA	4.32	NA
	1986	NA	5.07	NA	5.57	NA	NA	NA	4.55	NA	NA	4.75	NA
	1987	5.50	NA	NA	Dry	NA	NA	NA	5.67	NA	NA	3.55	NA
	1988	NA	6.49	NA	NA	NA	NA	NA	3.64	NA	NA	3.77	NA
	1989	4.15	NA	NA	NA	3.00	NA	NA	3.53	NA	NA	3.67	NA
	1990	3.61	NA	NA	NA	3./7 0	NA	NA	3.53	NA	NA	2.63	NA
	1991	3.41	NA	NA	NA	NA	NA	NA	NA	2.39	NA	3.06	NA
	1992	NA	NA	NA	4.10	NA	NA	NA	3.13	NA	NA	3.03	NA
	1993	3.04	NA	NA	3.90	NA	NA	NA	NA	NA	NA	NA	NA
Poonthura	1985	4.32	NA	NA	4.15	NA	NA	NA	4.31	NA	NA	3.02	NA
	1986	NA	4.24	NA	4.15	NA	NA	NA	4.55	NA	NA	3.88	NA
	1987	4.18	NA	NA	4.32	NA	NA	NA	3.90	NA	NA	4.12	NA
	1988	NA	4.34	NA	NA	NA	3.99	NA	4.35	NA	NA	4.25	NA
	1989	4.20	NA	NA	NA	4.28	NA	NA	NA	NA	NA	4.00	NA
	1990	4.13	NA	NA	NA	3.50	NA	NA	4.24	NA	NA	3.30	NA
	1991	NA	NA	NA	3.07	NA	NA	NA	NA	3.38	NA	3.79	NA
	1992	NA	NA	NA	4.01	NA	NA	NA	4.25	NA	NA	3.83	NA
	1993	3.19	NA	NA	3.10	NA	NA	NA	NA	NA	NA	NA	NA

Table 2.3 Water Table Fluctuations in Holocene Aquifer of KRB from March 2008 to February 2009

Locality	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Veli	2008	5.81	NA	5.90	NA	NA	4.72	NA	N.A	NA	4.21	NA	NA
	2009	NA	5.07	NA	5.57	NA	4.78	NA	4.55	NA	NA	4.75	NA
Muttathara	2008	3.30	NA	NA	3.15	NA	NA	NA	3.31	NA	NA	3.02	NA
	2009	NA	NA	3.24	3.21	NA	3.53	NA	NA	3.28	NA	3.88	NA

2.2.2 Grain size analysis

In order to study the hydrogeologic nature of the Holocene aquifer, 42 sediment samples were taken from 20 selected sites H-1 to H-20 as shown in Fig. 2.2, Because of intense anthropogenic interference, the samples close to the upper horizons will not be undisturbed ones and therefore samples were collected using an auger from depths ranging from 50 cm to 75 cm from the ground level. Plate. 8 shows the collection of drill sample from Valiyathura. The samples were subjected to sieve analysis and the results are shown in Table 2.4. The grain size classification and nomenclature of Folk (1965) has been adopted in the present study.

The results of the sieve analysis show that the Holocene sediments north of Vallakadavu are mostly sandy. However, south of Vallakadavu there is an irregular spatial pattern of enrichment of finer fractions. This enrichment may be due to the reworking of sediments due to proximity to the mouth of the Karamana Ar (Fig. 2.3).

Textural maturity is a property that relates to the amount of mechanical energy imparted on transported sediments through the abrasive power of currents and tides. It is observed that certain characteristics such as rounding and sorting of the grains reflect the mechanical energy applied to transport sediment. This sediment will pass through four stages: (1) Immature stage: The sediment contains more than 5% clay and sand grains are poorly sorted and angular. (2) Sub mature stage: The sediment contains less than 5% clay and sand grains are poorly sorted and sub angular to sub rounded (3) Mature stage: The sediment contains little to no clay and sand grains are well sorted but not well rounded and (4) Super mature stage: Sediment contains no clay and sand grains are well sorted and well rounded. Therefore, the bulk of the Holocene sediments of Karamana River Basin can be considered as belonging to sub mature stage of Folk’s scheme of classification (Folk, 1965).

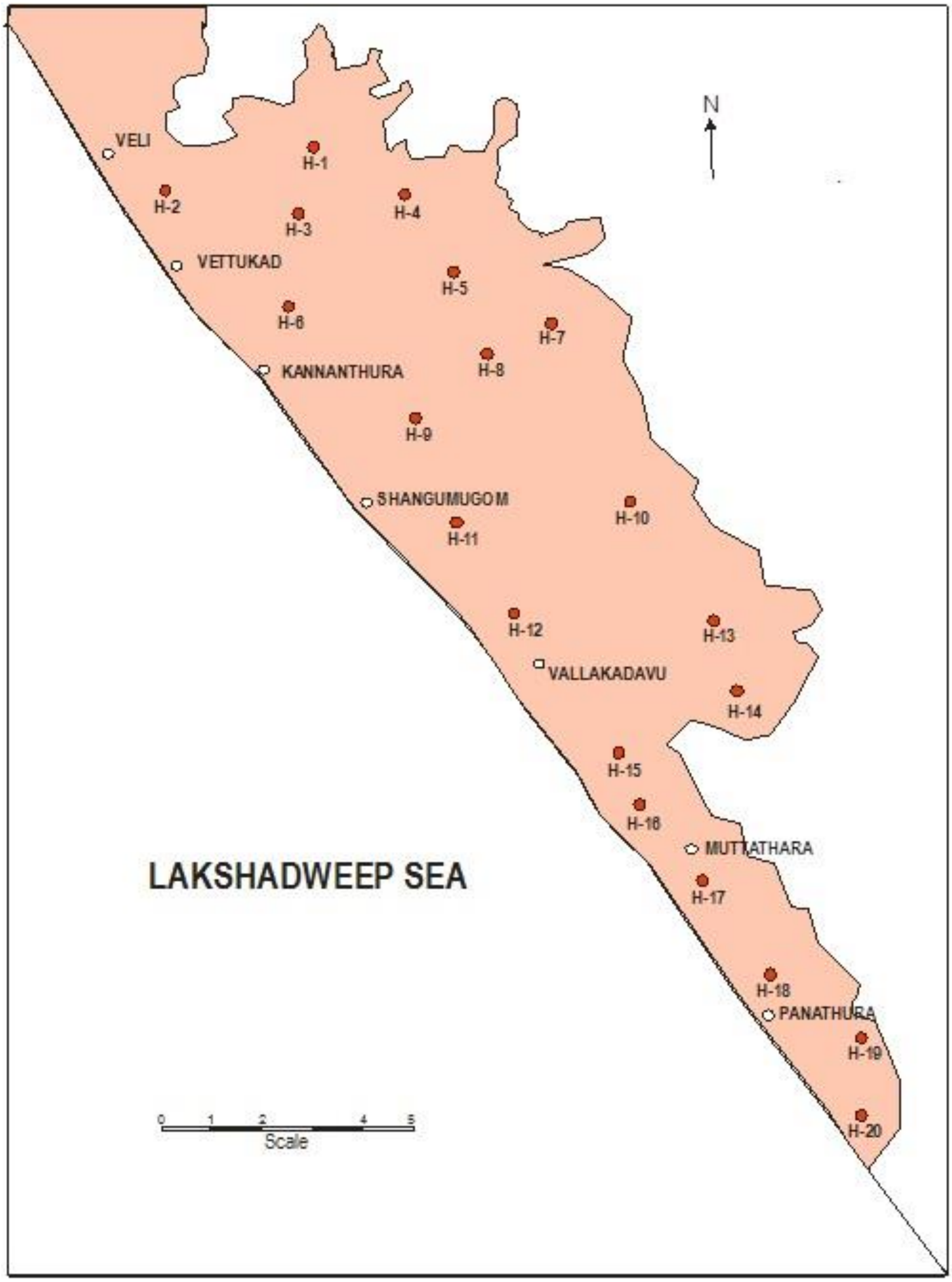


Fig. 2.2 Sampling locations

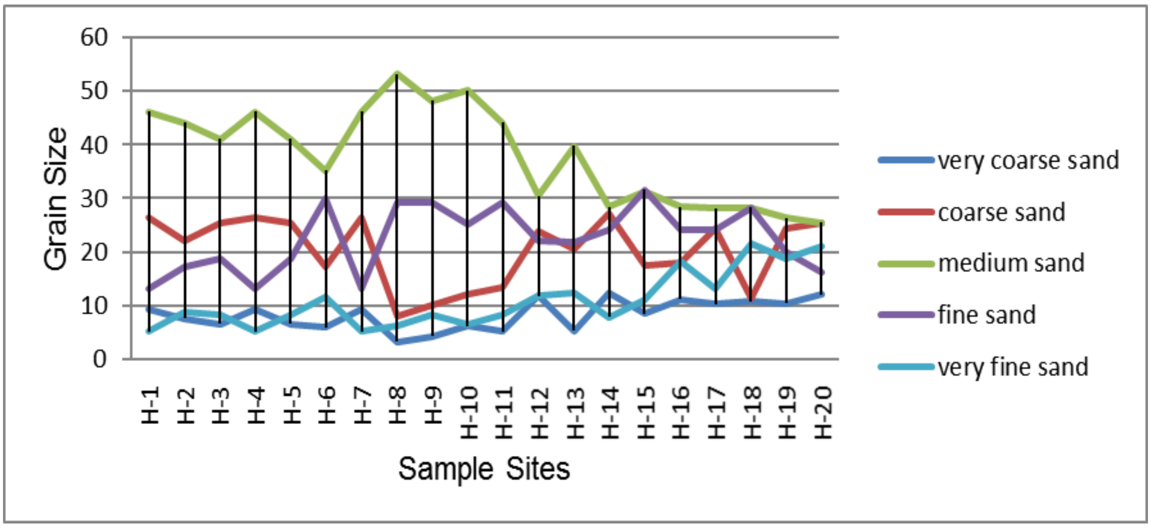


Fig. 2.3 Graphical Representation of sieve analysis data of Holocene sediments

2.2.3 Safe yield

Groundwater, which is a valuable natural resource, is replenished periodically from precipitation through recharge sources. The amount of water that can be withdrawn from an aquifer, without producing any adverse result, is defined as the “safe yield”. The safe yield is thus limited by the rate at which the groundwater is replenished by rain fall. Seasonal fluctuation in safe yield from shallow well supplies is more marked for artesian supplies in confined aquifers. Water withdrawn in excess of safe yield is termed as “overdraft”. Safe yield is exceeded when the extractions over a period are in excess of replenishment of aquifer recharge. The possible adverse effects of overdraft through excessive pumping include lowering of water table which may result in decrease in yield of an individual well and gradual deterioration of groundwater resources. A careful study of the available data (Table 2.2) on long term rise and fall in water level does not indicate any overdraft for the Holocene aquifer of the Karamana River Basin.

2.2.4 Porosity and permeability of Holocene sediments

Porosity of a rock unit is a measure of the voids present and it is expressed as the ratio of pore space, or void volume, divided by the total volume. Void volume is a function of the size, shape and gradation of the rock constituents and their state of packing and cementation. The least compact arrangement of spherical grains is that of a cubical array of spheres (porosity 47.6 percent), whereas the most compact arrangement is that of a rhombohedral array (porosity 26.0 percent). In natural rocks, porosity may be higher than cubical array of spheres due to bridging action between the particles. In general, porosity greater than 20 percent is considered high, a porosity between 5 – 20 percent medium and a porosity less than 5 percent is considered as low. The estimation of porosity for 10 samples, selected at random, for the Holocene sediments of KRB, is given Table 2.5 and 2.5.1 and ranges from 34 to 42 percentages.

Porosity is also a measure of water bearing capacity of sediments, and plays a role in the capability of a medium to transmit water. This capability is expressed by the “hydraulic conductivity” of the sedimentary rock unit. The relationship between porosity and hydraulic conductivity is not a simple one, as several factors other than porosity affect the value of hydraulic conductivity. The size of the effective opening between the grains is far more important than the porosity for the water transmitting capability of a medium. Sands with relatively coarse, rounded or angular grains may have smaller values of porosity than clays and silts having particles with larger specific surface causing high molecular forces between particles and water. In spite of their smaller porosity, sandy materials are more pervious and therefore constitute good aquifers, whereas thick clay successions form aquicludes or at least aquitards.

	SEDIMENT SAMPLES																			
GRAIN SIZE	**H-1**	**H-2**	**H-3**	**H-4**	**H-5**	**H-6**	**H-7**	**H-8**	**H-9**	**H-10**	**H-11**	**H-12**	**H-13**	**H-14**	**H-15**	**H-16**	**H-17**	**H-18**	**H-19**	**H-20**
very coarse sand	9.2	7.6	6.6	9.2	6.6	5.9	9.2	3.2	4.2	6.2	5.1	12	5.3	12	8.4	11	10	11	10	12
coarse sand	26	22	25	26	25	17	26	8.1	10	12	13	24	21	27	17	18	24	11	24	25
medium sand	46	44	41	46	41	35	46	53	48	50	44	30	40	28	31	28	28	28	26	25
fine sand	13	17	19	13	19	30	13	29	29	25	29	22	22	24	32	24	24	28	20	16
very fine sand	5.1	8.9	8.2	5.1	8.2	12	5.1	6.3	8.3	6.4	8.3	12	12	7.8	11	18	13	22	19	21

Table 2.4 Sieve analysis data of Holocene sediment samples of KRB

Table 2.5 Range of hydrological parameters in the study area

Parameters	Range	
	Lower Limit	Upper Limit
Porosity (percentage)	34	42
Specific Yield (percentage)	28	32
Storage Coefficient (m/day)	0.028	0.032
Coefficient of Permeability (m/day)	25.5	45
Transmissivity ((m^2/day)	280	420

Table 2.5.1 Porosity of sediment samples

Porosity of Holocene Sediments of Karamana River Basin	
Sample	**Porosity (%)**
H-1	**34**
H-3	**41**
H-5	**36**
H-7	**38**
H-9	**40**
H-11	**38**
H-13	**42**
H-15	**38**
H-18	**37**
H-20	**41**
Mean value of porosity	**38.5**

2.2.5 Specific yield

The specific yield of any rock unit is the quantity of water released from it by force of gravity and is defined as the ratio of the volume of water drained to the total volume of the rock unit. It is also termed as 'effective porosity' and is mathematically expressed as:

$$S_y = W_g / V.$$

Where S_y denotes specific yield, W_g is the volume of water drained, V is the total volume of the rock unit. Fig. 2.4 similarly, specific retention is defined as the ratio of the volume occupied by the retained water to the total volume of rock unit and is expressed as

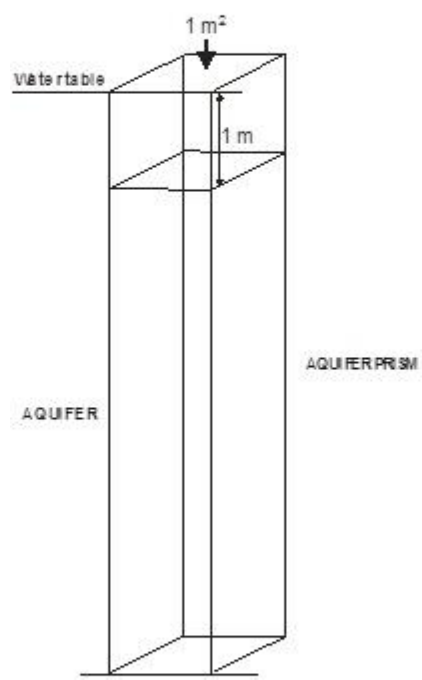


Fig. 2.4 Diagrammatic representation of Coefficient of Storage and Specific yield

$$S_r = W_r / V$$

Where S_r denotes specific retention and W_r is the volume of retained water. Total porosity is expressed as the sum of specific yield and specific retention, or

$$n = Sy + Sr$$

where n denotes the porosity of the rock. In unconfined aquifers, water discharged by a pumped well is derived from storage through (1) gravity drainage (2) compaction of the aquifer and (3) expansion of water itself as pressure on the groundwater is reduced. However, the gravity drainage is not immediate, particularly in the case of finer-grained sediments. The yield of water from an aquifer storage is rarely instantaneous and does not occur simultaneously with the decline of head; the aquifer therefore, exhibits the phenomenon of delayed yield depending on their drain ability characteristics. The specific yield of Holocene sediments of Karamana River Basin has been noted to range from 28 percent to 32 percent (Table 2.5.1)

2.2.6 Coefficient of permeability

The permeability or hydraulic conductivity of porous rock materials is indicative of the ease which water can flow through it. Coefficient of permeability is expressed as:

$$K = \frac{Q / A}{(h_1 - h_2) / L}$$

In the case of coherent sediments and cemented sediments, the method employed for the determination of coefficient of permeability consists of measuring the quantity of water flowing through the rock sample (generally in the form of cores) under known head in given time. This method is not suitable for loose sands and unconsolidated materials (such as the Holocene sediments of Karamana River Basin) whose undisturbed samples are difficult to obtain. Large variation in permeability may occur if disturbed samples are used in the determination of coefficient of permeability, because of the consequent change in porosity and packing arrangement subsequent to placing it in the perimeter. Moreover, Holocene aquifer is stratified and may have different permeability in both horizontal and vertical directions within the succession (hydrologic anisotropy). Presence of thin interstratified layers of silt and clay may influence the overall permeability values of the aquifer to considerable extent. Therefore, laboratory determination of permeability is not dependable in the case of Holocene sediments. In view of the various factors discussed above, the determination of coefficient of permeability of Holocene aquifer has been estimated on the basis of field tests

The coefficient of permeability (hydraulic conductivity) of the Holocene aquifer has been noted to be very high ranging from 25.5 m/day to 45.0 m/day (Table 2.5.1). The reported yield of the filter points and shallow tube wells tapping the potential aquifer zones in the Holocene aquifer ranges from 510 to 850 lpm.

2.2.7 Storage coefficient (Storativity)

Coefficient of storage or storativity of an aquifer, usually denoted by the letter S, is defined as the volume of water released or taken into storage by it per unit surface of aquifer per unit decline or rise of head. For unconfined aquifers (water table condition) the storage coefficient for unit thickness of aquifer is equal to the specific yield provided gravity drainage is complete. The value of coefficient of storage for the Holocene aquifer of Karamana River Basin therefore ranges from 0.028 m/day to 0.032 m/day (Table 2.5.1).

Aquifer parameters for the Holocene aquifers and the lateritic terrain of the study area are determined. The Table 2.6 shows the representative values of aquifer parameters, for Panvoor in the lateritic terrain while Valiyathura, and Vallakkadave in the coastal aquifer (Holocene). Panvoor, Arryanadu and Vithura are in laterite terrain and all show the same value so among the three, panvoor is taken as sample from laterite.

2.2.8 Transmissivity *'T'*

The coefficient of transmissivity of an aquifer, usually designated by the letter "*T*", characterizes the capacity of an aquifer to transmit water through its entire thickness and is equal to the product of the coefficient of permeability "*K*" (or hydraulic conductivity) of the aquifer material and the saturated thickness "*h*" of the aquifer. Aquifer characteristics are fully defined by its storage coefficient "*S*" and coefficient of transmissivity "*T*". These are therefore, designated as aquifer or formation constants or parameters and are determined by pumping tests. Transmissivity value of Holocene aquifer of Karamana River Basin has been estimated to range from 280 m^2/day to 420 m^2 /day (Table 2.5.1).

Table 2.6 Representative aquifer parameters of Holocene (Pump test data)

Location	Aquifer type	Coefficient of permeability(K) (m/day)	Transmissivity (T) m^2/day	Storativity (s)
Valiayathura	Coastal alluvium	45	407	0.02
Vallakadavu	do	49	395	0.02
Panavoor	Laterite terrain	27	310	0.03

2.3 GROUNDWATER QUALITY OF HOLOCENE AQUIFER

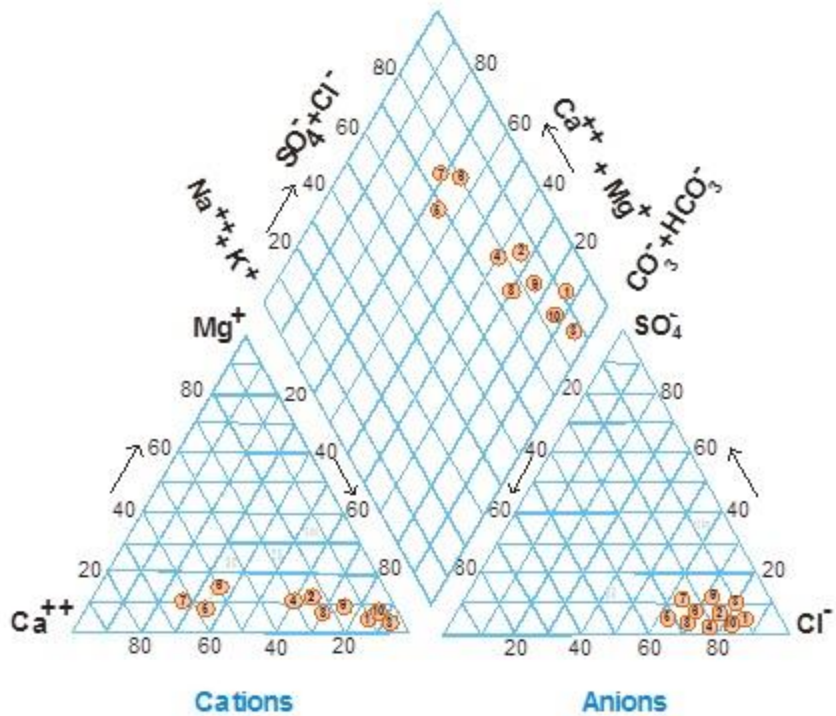
2.3.1 Materials and methods

The various Physico-chemical parameters that determines the quality of Holocene aquifer of Karamana River Basin were analysed following the standard procedures detailed in American Public Health Association (APHA-2005).

2.3.2 Hydrochemistry of Holocene aquifer

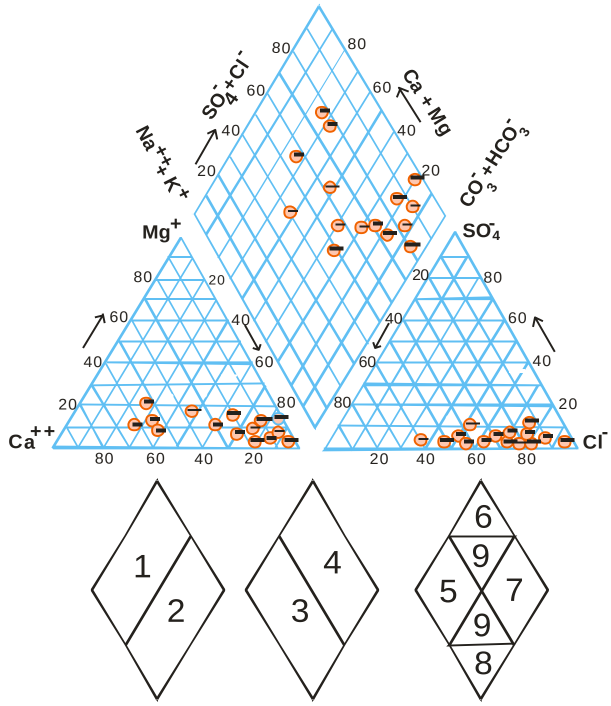
Since water is a universal solvent, groundwater carries minerals in solution. Even though present in small quantities it determines the suitability for various purposes. The quantity and composition of the dissolved minerals in natural water depend upon the type of rock material with which it has been in contact or through which it passes and the duration of its contact with these rock materials. Quality of groundwater may vary from place to place and from stratum to stratum, it also varies from season to season. The requirement of quality of water for various purposes such as for drinking water, industrial water and irrigation water vary widely. Knowledge of chemical quality of groundwater is important since the presence of certain chemical constituents may make the groundwater unfit for domestic, industrial or irrigation use. The determination of suitability of groundwater would therefore involve a description of the occurrence of the various constituents and their relation to the use to which water would be put in. In this section an attempt has been made for the evaluation of the quality of groundwater associated with Holocene aquifer of Karamana River Basin.

Piper Trilinear diagram (Piper, 1944) which brings out the chemical relationships of major anions and cations, which is very useful in categorizing the water use. Therefore, the evaluation of the analytical results has been made by plotting the concentrations of major cations and anions in a Trilinear Piper diagram Fig. 2.5. A careful study of Fig. 2.6 indicate that the groundwater samples of the Holocene aquifer of Karamana River Basin fall in subdivision numbers 1, 2, 3 , 4, 5 , 7 and 9 of Piper diagram (Purushotam et al., 2011). The various Physical parameters that accounts for the acceptability of the water in the Karamana River Basin namely dug well, Tube well, Pond and stream are given in the annexures A1, A2, A3, A4 and chemical aspects for the same water bodies in the monsoon period in annexures B1A, B2A, B3A, B4A along with Post monsoon period in annexures B1B, B2B, B3B and B4B respectively.



The numbers represent the water samples

Fig. 2.5 Piper diagram showing the hydrochemistry of Holocene Aquifer of the Karamana River Basin



Subdivision Number	Characteristics of corresponding subdivision
1	Alkaline earths (Ca +Mg) exceeds alkalies (Na+K)
2	Alkalies exceeds alkaline earths
3	Weak acids (CO_3 + HCO_3) exceeds strong acids(SO_2 +Cl +F)
4	Strong acids exceed weak acids
5	Carbonate hardness (secondary alakalinity) exceeds 50% ie, chemical properties of groundwater are dominated by alkaline earths and weak acids.
6	Non-carbonate hardness (secondary salinity) exceeds 50% ie, chemical properties of groundwater are dominated by alkalies and strong acids.
7	Non-carbonate alkali (primary) exceeds 50% , ie, chemical properties of groundwater are dominated by alkalies and weak acids.
8	Carbonate alkali (primary alkalininity) exceeds 50% ie, chemical properties are dominated by alkalies and weak acids.
9	No one cation-anion exceeds 50%.

Fig. 2.6 Characterization of Groundwater on the basis of Piper diagram

2.3.3 Quality assessment

The data obtained by chemical analyses are evaluated in terms of its suitability for drinking and general domestic use, irrigation and industrial use.

(1) Suitability for drinking and general domestic use:

Depending on the impact of concentration of various ions in water on human health, various standards have been laid down by different agencies. These standards are useful for deciding the suitability of water for drinking and domestic use. In India, the drinking water standards have been proposed by Bureau of Indian Standards (BIS) and the Indian Council of Medical Research (ICMR) in addition to that of the World Health Organization (WHO).

The hydrochemical parameters of water of the Holocene aquifer of Karamana River Basin is compared with the prescribed specifications of WHO (1993) and Bureau of Indian Standards (BIS) (IS-10500 of 1991), and ICMR. Table 2.7 shows that most of the groundwater of the Holocene aquifer is suitable for drinking and general domestic uses, with few exceptions, as most parameters are within the permissible limits. In the case of pH, no lower limit has been prescribed by Indian Standards whereas WHO sets it as 6.5. Although pH of groundwater of Holocene aquifer of Karamana River Basin is below the maximum permissible limit (ie, 8.5) some samples give pH value below 6.5 the value for the lowest permissible limit. In the case of EC the range of values noted in the water samples of Holocene aquifer exceeds both the lower and upper limits set by WHO (1993). In the case of TDS of water samples, the range similarly exceeds both the WHO (1993) and Indian Standards: 1S 10500 (1991). The Water Quality Standards as set by the Union Health Ministry is shown in Table 2.8 and from the Table 2.8 a, among the anion and cation concentrations of the samples, those of Ca, Mg, Na, HCO_3 and Cl exceeds the permissible limits.

Table 2.7 Chemical Parameters of Holocene Aquifer of KRB and WHO and Indian Standards for Drinking Water

Parameters	Range Noticed in 10 Holocene aquifer of KRB	WHO (1993)	**B**IS- (IS10500 - 91)		**ICMR**	
			Desirable limit	Maximum permissible limit in the absence of alternate source	Desirable limit	Maximum permissible limit
1	***2***	***3***	***4***	***5***	***6***	***7***
pH	4-63-8.56	6.5-8.5	No relaxation	8.5	7.0-8.5	6.5-9.2
EC	248-5340	400-2000	-	-		
TDS (mg/L)	146-4260	500-1000	500	2000	500	1500-3000
Ca (mg/L)	36.8 - 478	100-200	75	200	75	200
Mg (mg/L)	8.12-196.1	30-50	30	100	50	-
Na (mg/L)	148-3120	10-12	-	-		
K (mg/L)	2.46 -7.46	20-175	-	-		
HCO_3(mg/L)	14.88-396	10-12	300	600		
SO_4(mg/L)	0.78-16.4	25-250	200	400	200	400
Cl (mg/L)	54.6- 963	25-600	250	1000	200	1000
NO_3(mg/L)	0.1-0.91	25-600-	45	100	20	100
F (mg/L)	*Not determined*	-	1.0	1.5	1	1.5

Units : mg/l, except EC (μS cm^{-1}) and pH

Table 2.8a. Water Quality Standards (Physical) by the Union Health Ministry

Physical standards			
Sl.No	Characteristics	Acceptable	Cause for Rejection
i)	Turbidity (units of J.T.U scale)	2.5	10
ii)	Colour (units on platinum-cobalt scale)	5.0	25
iii)	Taste and odour	Unobjectionable	Unobjectionable

Table 2.8b. The Water Quality Standards (Chemical) by the Union Health Ministry

Chemical Standards			
Sl.No	**Characteristics**	**Acceptable**	**Cause for Rejection**
i)	**pH**	**7.0-8.5**	**6.5-9.2**
ii)	**Total dissolved solids(mg/l)**	**500**	**1500**
iii)	**Total hardness(as $CaCO_3$) (mg/l)**	**200**	**600**
iv)	**Chlorides (as Cl) (mg/l)**	**200**	**1000**
v)	**Sulphates (as SO4) (mg/l)**	**200**	**400**
vi)	**Fluorides (as F) (mg/l)**	**1.0**	**1.5**
vii)	**Nitrates (as NO3) (mg/l)**	**45**	**45**
viii)	**Calcium (as Ca) (mg/l)**	**75**	**200**
ix)	**Magnesium (as Mg) (mg/l)**		**150**
x)	**Iron (as Fe) (mg/l)**	**0.1**	**1.0**
xi)	**Manganese (as Mn) (mg/l)**	**0.05**	**0.5**
xii)	**Copper (as Cu) (mg/l)**	**0.05**	**1.5**
xiii)	**Zinc (as Zn) (mg/l)**	**5.0**	**15.0**
xiv)	**Phenolic compounds (as Phenol) (mg/l)**	**0.001**	**0.002**
xv)	**Anionic detergents (as MBAS) (mg/l)**	**0.2**	**1.0**
xvi)	**Mineral oil (mg/l)**	**0.01**	**0.3**
xvii)	**Arsenic (as As) (mg/l)**	**0.05**	**0.05**
xviii)	**Cadmium (as Cd) (mg/l)**	**0.1**	**0.01**
xix)	**Chromium (as Cr) (mg/l)**	**0.05**	**0.05**
xx)	**Cyanides (as CN) (mg/l)**	**0.05**	**0.05**
xxi)	**Lead (as Pb) (mg/l)**	**0.1**	**0.1**
xxii)	**Selenium (as Se)(mg/l)**	**0.01**	**0.01**
xxiii)	**Mercury (total as Hg)(mg/l)**	**0.001**	**0.001**
xxiv)	**Polynuclear aromatic hydrocarbons (PAH) (µg/l)**	**0.2**	**0.2**
xxv)	**Gross alpha activity(pCi/l)**		
xxvi)	**Gross beta activity (pCi/l)**		
	Bacteriological Standards		
ii)	**Water in the distribution system shall satisfy these three criteria** **1. E.coli count in 100 ml of any sample should be zero.** **2. Coliform organisms not more than 10 per 100 ml shall be present in any sample** **Coliform organisms should not be detected in 100 ml of any two consecutive samples or more than 50 % of the samples collected for the year.**		

(Adopted from Geohydrogy-Draft Approach Paper GSI October 2010)

(2) Suitability for irrigation and livestock

Electrical conductivity (EC) and concentration of Na are two very important factors in the quality assessment of water for irrigation purposes. The salts present in the water, apart from influencing plant growth, also affect soil structure, permeability and aeration, which indirectly affect plant growth. In irrigation waters, the total concentration of soluble salts can be expressed as low (EC = < 250 μS cm^{-1}), medium (EC = < 250 – 750 μS cm^{-1}), high (EC = <750 – 2250 μS cm^{-1}) and very high (EC = < 2250 – 5000 μS cm^{-1}) in terms of salinity classes (Richards, 1954). As the values of groundwater samples of Holocene aquifer of Karamana River Basin vary from 248 μS cm^{-1} to 5340μS cm^{-1} (Table 2.10), it can be stated that the quality of water in terms of salinity vary from very low to very high from locality to locality. Sodium or alkali hazard of natural water is determined by the absolute and relative concentration of cations and is expressed in terms of sodium adsorption ratio (SAR). SAR is the proportion of sodium (Na) ions compared to the concentration of calcium (Ca) plus magnesium (Mg) and it can be estimated by the following formula:

$$SAR = \frac{Na}{\sqrt{Ca + Mg / 2}}$$

Or

$$SAR = [Na^+] / \{[Ca^{2+}] + [Mg^{2+}]) / 2\}$$

Table 2.9 Range of hydro chemical parameter of Holocene aquifer

Parameter	*Minimum*	*Maximum*	**Parameter**	*Minimum*	*Maximum*
pH	4.63	7.56	**Mg^{2+}**	8.12	196.1
EC	248	6340	**HCO_3^-**	14.88	396
Salinity	264	3008	**Cl^-**	54.6	963
Hardness	98	1640	**NO_3^-**	0.11	0.91
TDS	146	4260	**NO_2^-**	0.002	0.342
Na+	148	6120	**SO_4-**	0.78	16.4
K+	7.40	246	**PO_4^-**	0.09	1.89
Ca^{2+}	36.8	478			

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

When water used for irrigation is high in Na and low in Ca, the cation exchange complex may become saturated with Na and destroy the soil structure caused by the dispersion of clay particles. The calculated value of SAR of the groundwater samples of Holocene aquifer of Karamana River Basin indicated that the water samples are suitable for agriculture

(*3) Suitability for industrial use*

Saturation index (SI) of minerals is the factor that is taken into account to assess water for any industrial use (Rhoades and Bernstein, 1971). Higher values of SI indicate the possibility of precipitation and restricts the safe use of water for industrial purposes, particularly in electrical power stations and boiler houses. The high TDS, hardness and sulphate concentrations in some samples make them unsuitable for textile, paper and allied industries.

2.3.4 Influence of Parvathy Puthenar on Holocene aquifer

Parvathy Puthenar is a manmade canal that runs through the west coast of the Thiruvananthapuram District almost entirely over the Holocene sediments. The canal is named after Rani Parvathi Bai who was reigning Queen of Travancore during the time it was created. “Puthenar” in Malayalam means ‘new river”. It was constructed primarily for inland navigation connecting the Travancore capital to Kadinamkulam, Vamanapuram River and finally to Kochi. This canal also has access to the king’s boat landing place, Vallakadavu. The canal stars from Kadinamkulam Lake in the north and flow southeast, parallel to the coast of Thiruvananthapuram. It is connected to the sea at two localities, i.e Veli in the north and through Karamana Ar in the south. As noted earlier, intervening bar, or sand bar forms near the estuarine mouth by littoral drift of sand during the SW monsoon. High volume of river discharge during this period permits flow of water into the sea. At all other times visible tidal effects are negligible in the river and associated aquatic bodies and discharge from the Parvathy Puthenar remains in the river water for a very long time. This is compounded by solid waste disposal in the canal, blocking the free flow of water.

The canal forms a portion of the T-S Canal (Trivandrum-Shornoor Canal). The canal was recently declared a part of the West Coast Canal which forms the National Waterway 3 (NW-III). During earlier days, its water was very clear and fresh than any river or man-made canal in the state. At that time Travancore was the only hygienic, clean city in India. But today the canal is highly polluted and most portions are not navigable due to pollution and growth of weeds. Fig.2.7 shows the location map of Parvathy Puthenar, Asia’s first Man made Canal.

Parvathy Puthenar passes through thickly populated areas of the city, such as Poonthura, Vallakadavu, Valiyathura and Chackai and joins Karamana River at Moonnattumukku. Presently most part of the sewage (about 50 mld) from the Thiruvananthapuram Municipal Corporation (area: 141.74 km^2) reaches the only sewage disposal, in the form of sewage farm located at Valiyathura. Piped sewerage system, currently serves only 30 percent of the area of the municipal corporation, the core of the city area. In other parts of the city, where facility of sewage system is not provided, sewage disposal methods from households include septic tanks, borehole latrines and community toilets. The quantity of sewage from the city is conveyed through a system of sewage network, aided by pumping stations reaches a stilling chamber located at Muttatharai, from where it flows by gravity to the sewage farm, crossing Parvathy Puthenar. The sewage farm, located merely at 2 m above MSL, established in 1945, was originally designed for a capacity of 8 mld. However, it presently receives 6 times sewage than its carrying capacity. Subsurface drainage in the sewage farm area has been designed to allow surface water to percolate through the top soil and drain towards the southwestern (coastal) edge of the farm, where it is intercepted by deep channels and redirected inland into the Parvathy Puthenar. As the design is now 65 years old, since its construction, the pattern of water flow might have drastically modified today. The soil of the farm has lost its porosity under the unmitigated load of sewage and lack of periodic maintenance leading to a condition of stagnation of raw sewage for prolonged period which in turn leads to septicity.

Fig. 2.8 shows interconnections between groundwater and surface water in terms of effluent and influent surface water bodies. Fig. 2.9 schematically depicts the contamination zones of a shallow aquifer under a waste site. The hydrological setting of the Holocene aquifer of the Karamana River Basin in the adjoining regions of Parvathy Puthenar, especially in the neighborhood of sewage disposal system is as shown in the Fig 2.7 and Plate 6 shows the Garbage filling in Parvathy Puthenar.

Profuse growth of species of algae, such as *Anabaena*, *Lyngbya* and *Microcystis* is a characteristic feature of the sewage discharge zone. Not any kind of aquatic organisms, including fishes, are found in the canal and it is probably because of the reduced level of dissolved oxygen in canal water. The Holocene sediments of the sewage farm area reaches a depth of about 15 m and it is probably underlain by a thin layer of older (Pleistocene) sediments and laterite. There is a thin uppermost layer of sandy-silt in the farm and neighboring areas which at places shows local transition to clay loam. It seems that these are products of deposition of suspended solids brought by waste water during times of heavy rain when considerable amounts of storm water also accompany it.

Studies at Sewage Treatment Plant (STP) for Thiruvananthapuram City also indicate that the soil in the locality is “highly contaminated, with salt accumulation, high nitrogen profile, acid trend, and heavy metal contamination (Cu, Zn, Pb, Hg and Cr). People are not using Dug or bore well water due to the high content of heavy metals at the STP site and other areas. Their findings are shown in Table 2 10. Occasionally, sewage spills over and reaches adjacent peripheral areas including the Parvathy Puthenar. Stagnation of waste water in the site is a potential source of contamination of the Holocene aquifer of the region. With increased quantity of water to be made available to yet another section of the urban population through another project and extension of sewage network under the proposed project (estimated to be 107 mld), the situation is likely to be a very serious nature. Initially the designers of the farm considered the waters of the Parvathy Puthenar theoretically as dilution water to reduce the concentration of sewage before it is applied to the sewage farm. However, today, the waters of Parvathy Puthenar is extremely polluted from direct runoff and uncollected domestic waste from parts of the city directed to the canal via Thekkenkkara canal and the drain from pumping station from Eanchackal and it is clear that the dilution mechanism is not currently effective, as originally planned, as the contamination level of effluent water entering the sewage farm as irrigation water has always been higher than the design expectations. Moreover, the partially treated sewage being directed back into the Parvathy Puthenar has further raised the pollution level of the canal. The Table 2.11 shows the water quality of Parvathy Puthenar 2012, Table 2.12 reveals the water quality of Parvathy Puthenar at STP outlet point in 2012 whereas The Table 2.13

summarises the pollution level (surface water at STP in 2012) of the Parvathy Puthenar and The analytical result of inlet and outlet sewage water shows high content of BOD, COD, pH, E.coli, Suspended solids, NH_4, Nitrates and Phosphates (P) than the permissible limits during 2012 (Table 2.14). The characteristics of groundwater samples in and around sewage farm area, (Sewage Treatment Plant) is summarized in Table 2.15. The high value of BOD and fecal coli form in Karamana River at Moonattukadavu observed is 8.9 mg/l, 1789 MPN/100 ml respectively.

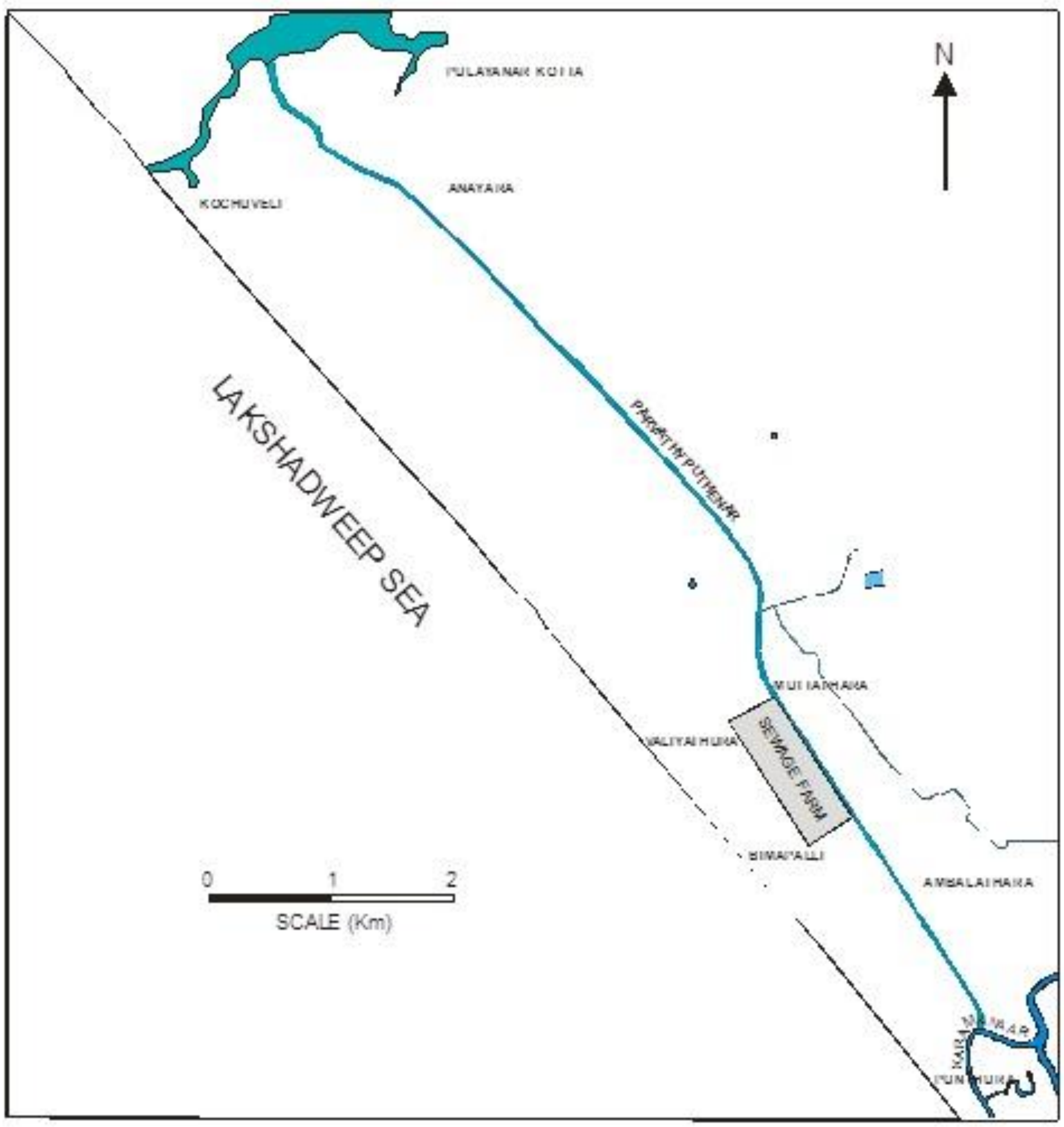


Fig. 2.7 Map showing locations of Parvathy Puthenar

Underground water is subjected to pollution connected with human activity, originating from agriculture, farming and settlements .Pollution can manifest itself as follows:

a) Increased concentrations of ions commonly appearing in groundwater, eg.: NO_3^-, NO_2^-, PO_4^{3-}, K^+, Na^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, SO_4^{2-}, Cl^-;
b) Appearance of man-made organic substances (pesticides and products of their degradation);
c) Increased mineral matter, conductivity, solid residue, and water hardness and
d) Increased oxidation rate, BOD and bacterial contamination.

All pollutants while being dispersed in the ground undergo alterations. The following factors influence the potential threat of pollutants:

a) Presence and thickness of impermeable layers above aquifers;
b) Thickness and type of soil cover;
c) Depth of aquifers, and
d) Self-purification processes of infiltrating water.

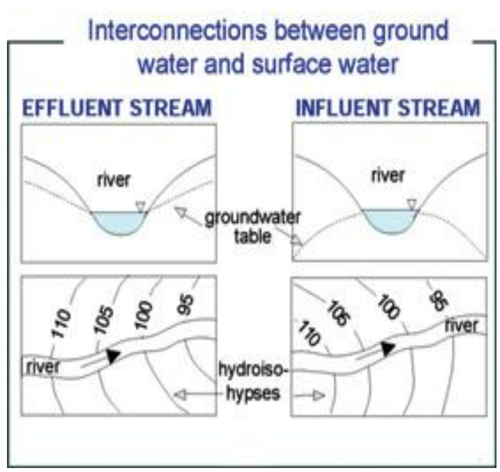


Fig. 2.8 Schematic diagram showing interconnection between groundwater and surface water

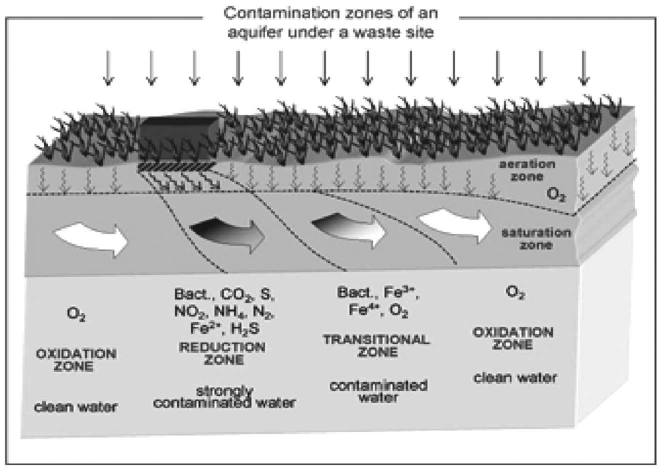


Fig. 2.9 Contamination zones of an aquifer under waste site

Table 2.10 Heavy Metals in groundwater samples near STP Site, Muttathara

on of the Sewage Farm	Cu	Zn	Pb	Hb	Cr	Cd	Ni	Mn	Fe
Subsurface	0.02	0.22	ND	ND	ND	ND	ND	0.07	0.30
East (6m)	ND	0.23	0.01	ND	ND	0.01	ND	ND	0.38
East (30 m)	ND	0.14	ND	ND	0.01	ND	0,01	ND	0.32
East (75 m)	0.01	0.35	ND	0.01	ND	ND	ND	0.63	0.36
North	ND	0.17	ND	ND	ND	0.01	ND	0.02	0.24
North-east	0.01	0.16	ND	ND	ND	ND	ND	0.01	0.28
South west	ND	0.19	0.01	0.01	,01	ND	0.01	0.02	0.30
Anayara	ND	0.18	ND	ND	ND	0.01	ND	0.11	0.36

ND: Not detectable; Concentration in ppm

Table 2.11 Water quality of Parvathy Puthenar at STP site inlet point

Petha Colour	Odour	TSS (ppm)	TDS (ppm)	BOD (ppm)	COD (ppm)	pH	E-coli	NH_4 (ppm)	NO_3 (ppm)	Phenol (ppm)	Phosphate (ppm)
Grey/green	Faint	61.3	627.0	10.0	22.5	7.2	980	1.1	3.2	0.01	0.6
Thiruvallom do	faint	62.4	678	12	27.2	8.6	996	1.2	39	.00	0.8
Dark/green Near the Vellakkadave	Faint	69.3	703	11.4	28.2	7.6	897.5	1.4	41	.02	.04

Table 2.12 Water quality of Parvathy Puthenar at STP site outlet point

Colour	Odour	TSS (ppm)	TDS (ppm)	BOD (ppm)	COD (ppm)	pH	E-coli	NH_4 (ppm)	NO_3 (ppm)	Phenol (ppm)	Phosphate (ppm)
Grey	Smell	53.3	224.0	20.0	32.2	7.2	350	1.7	2.6	0.025	1.1

Table 2.13 Surface Water Quality at STP site

Location	Colour	Odour	TSS (ppm)	TDS (ppm)	BOD (ppm)	COD (ppm)	pH	E-coli	NH_4 (ppm)	NO_3 (ppm)	Phenol (ppm)	Phosphate (ppm)
At inlet	Grey/black	foul	277.7	484.4	220	380	7.3	710	28.7	3.9	0.17	2.8
North section	Blackish	Foul	550.0	256.0	180	320	7.1	400	13.4	8.4	0.15	1.8
West section	Blackish	foul	2,206.6	288.0	200	320	7.3	450	21.1	3.2	0.14	2.1
South section	Blackish	foul		370.4	180	280	7.2	610	27.1	8.7	0.15	1.8

Table 2.14 Analysis of sewage water at STP

Sl.No.	Determinant	Unit	Sewage coming into the farm(Inlet)	Sewage coming out the farm (outlet)
1	BOD	mg/l	182	154
2	COD	mg/l	400	464
3	pH		6.03	6.2
4	E-coli	number	896	993
5	Suspended solids	mg/l	270	318
6	NH_4	ppm	30.4	48.2
7	Nitrates	mg/l	BDL	BDL
8	Phosphates as P	mg/l	1.56	1.72

Table 2.15 Characteristics of Groundwater in and around Sewage Farm Muttathara

Location	Colour	Odour	TSS (ppm)	TDS (ppm)	DOD (ppm)	COD (ppm)	pH	E.coli	NH_4-N (ppm)	NO_3-N (ppm)	T.A.(ppm)	Phenol (ppm)	Phosphate (ppm)
Subsurface	Slight yellow	Slight smell	13.2	422.4	18.0	37.5	7.0	660.0	4.1	12.7	112.0	0.013	0.50
Manacaud	Yellow	Slight smell	96.5	275.2	12.5	25.020.0	7.2	430.0	6.7	9.1	98.0	0.013	0.40
East (30 m)	Slight yellow	Slight smell	1.0	332.8	8.0	15.0	7.1	520.0	7.9	12.3	90.0	0.012	0.30
East (75 m)	Almost clear	Slight smell	70.3	108.8	6.5	14.5	7.2	170.0	0.6	4.0	88.0	0.013	0.25
Kamals.	Slight yellow	Slight smell	47.4	179.2	7.0	17.0	7.3	280.0	1.1	6.4	86.0	0.013	0.30
Northeat	Slight yellow	Slight smell	15.0	332.0	6.8	16.14	7.1	520.0	0.6	7.5	156.0	0.012	0.40
Bengdesh	Slight red	Slight smell	28.6	403.0	6.5	12.0	7.1	630.0	0.4	7.2	88.0	0.012	0.40
East Fort	Almost clear	-	18.2	140.8	4.8		7.1	220.0	0.3	2.7	52.0	0.002	0.20

2.4 RESULTS AND DISCUSSION

The geographical extent, stratigraphy, hydro chemical and pollution status of the Holocene aquifer forming a portion of the Karamana River Basin are discussed in detail. Although adequate number of borehole data is not available for a detailed description of the Quaternary succession of the Karamana River Basin, on the basis of the data collected from various sources (PWD, Central Groundwater Board, State Groundwater Department) a general picture of the Quaternary succession of the coastal tract of the basin is presented here. Quaternary sediments of Karamana River Basin are dominantly coarse sandy with occasional silty and clayey intercalations, the latter hardly exceeding 2 percent of the bulk. Most portions of all the above lithounits are devoid of marine fossils indicating a fluvio-lacustrine origin for most part of the succession. The dating of sediments of the coastal tract of Thiruvananthapuram district from samples collected from nine localities gave age ranging from 1800 to 30,000 YBP and radiocarbon dating by a recent study indicates that the second lithounit of the coastal tract of Thiruvananthapuram ranges in age from 10,700 YBP to 7230 YBP. Hence the Holocene succession of the Karamana River Basin can be considered to commence upward from the middle lithounit and the underlying portion of the Quaternary constituting the Pleistocene succession of the region. The maximum thickness of the Holocene stratigraphic units of the Karamana River Basin is restricted to about 20m. Radiometric dating of peat samples collected from river beds of Karamana Ar and Killi Ar from Kaimanam and Thannimoodu by Birbal Sahni Institute of Paleobotany gave values of 2.52 KY BP and 1.6 KY BP respectively thereby indicating a relatively younger Holocene age for the sediment enclosing them.

The chapter also deals with the hydrological properties of the Holocene aquifer of the basin. An isopach map Fig. 2.1 of the Holocene sequence of the Karamana River Basin has been prepared using available drill log data collected from various sources which showed that the thickest succession of Holocene sediments occur east of Vettukad and Shangumughom. Data is available relating the water table fluctuation of the Holocene aquifer from two observation wells maintained by the Central Groundwater Board, for the period from 1985 to 1993 and it revealed the fact that the maximum depth of the water table in Holocene aquifer is during the month of April and minimum in November. The rising of the water table in response to the monsoon rains is between 0.2 m to 1.00 m whereas the lowering in hot season is only 0.18 m to 0.82 m. In order to study the hydrogeologic nature of the Holocene aquifer, sediment samples were taken from 20 sites and they were subjected to sieve analysis. The results of the sieve analysis show that the Holocene sediments north of Vallakadavu are mostly sandy. However, south of Vallakadavu there is an irregular spatial pattern of enrichment of the proportion of finer fractions in Holocene sediments and this is attributed to reworking of sediments due to proximity to the mouth of the Karamana Ar.

The long term rise and fall in water level does not indicate any indication of overdraft from the Holocene aquifer of the Karamana River Basin. The specific yield of Holocene sediments of Karamana River Basin has been noted to range from 28 percent to 32 percent and the study also showed that the coefficient of storage for the Holocene aquifer of Karamana ranges from 0.028 to 0.032 whereas the transmissivity value range from 280 m^2/day to 420 m^2/day. The coefficient of permeability (hydraulic conductivity) of the Holocene aquifer has been noted to be very high ranging from 25.5 m/day to 45.0 m/day. The reported yield of the filter point wells and shallow tube wells tapping the potential aquifer zones in the Holocene aquifer ranges from 510 to 850 lpm. Some heavy metals such as Cu, Zn, Pb, Cr, Cd, Ni, Mn and Fe are also observed in groundwater near the STP site, Muttathara.

The chapter concludes with hydrochemistry of Holocene aquifer. The parameters analysed for the water samples are pH, conductivity, TDS, alkalinity, hardness, chloride, sulphate, nitrate, phosphate, fluoride, sodium, potassium, calcium , magnesium, BOD, COD, total E coli form. The results are plotted in a Piper Trilinear diagram and evaluated for the quality. The hydro chemical quality of the subsurface water resource of the Holocene aquifer of the basin has also been assessed. In terms of drinking water, most of the aquifer water are not suitable for drinking or for general domestic use, but can use for irrigation. It is not even ideal for livestock and industries, as being against the water quality standards set by the Union Health Ministry.

Finally the chapter reflects the influence of Parvathy Puthenar's waters, a man-made canal on Holocene aquifer. The study showed that that there is significant contamination of the Holocene aquifer of Karamana River Basin due to mixing of polluted waters from the canal and STP.

CHAPTER III

MORPHOMETRIC ANALYSIS OF KARAMANA RIVER BASIN (KRB)

Drainage basins are areas of the earth's surface occupied by a surface stream or lentic water body together with all of the tributary streams, surface and subsurface water flows. Geomorphologic features of the basins are important factors in predicting flood patterns, estimation of sediment yield and prediction of water availability and quality.

According to Clarke (1966), morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms. The morphometric analysis of a stream basin is carried out through the measurement of linear, areal and relief aspects of the basin and slope contribution.

3.1 DATA BASE AND METHODOLOGY

Geomorphic properties (measurement and estimation) of drainage basins can be quantified by one of the two basic approaches. (1) Using topographic maps or (2) Adopting any suitable computer programme using Geographic Information System (GIS).

The present study of the morphometric attributes of the Karamana River Basin (KRB) has been carried out using the Survey of India topographic sheets of (scale1: 50,000) Nos. 58 H/2, 58 D/14, 58 D/15 and 58 H/3), following standard techniques. A number of field checks were also done to ascertain whether any significant changes have taken place in drainage network subsequent to the date of revision of topographic maps. The drainage density and drainage frequency of different regions of the basin have been determined for the entire basin by overlaying cells of 4 cm^2 followed by sampling each cell.

In the process of delineation of drainage basin on topographic map, special attention was given so that the drainage divide (border of the basin) coincides with all locations at which surface runoff splits flow into and away from the basin. For all the land enclosed by the drainage divide, precipitation drains by gravity into the stream or water body within the basin. The line representing the divide was drawn perpendicular to each of the contour lines it crosses. On flat areas, along contour lines the divide was marked along half the area between streams of adjacent basins. The Fig. 3.1 shows the adjacent rivers such as Vamanapuram basin on the left side and the Neyyar Basin on the right side of Karamana River Basin.

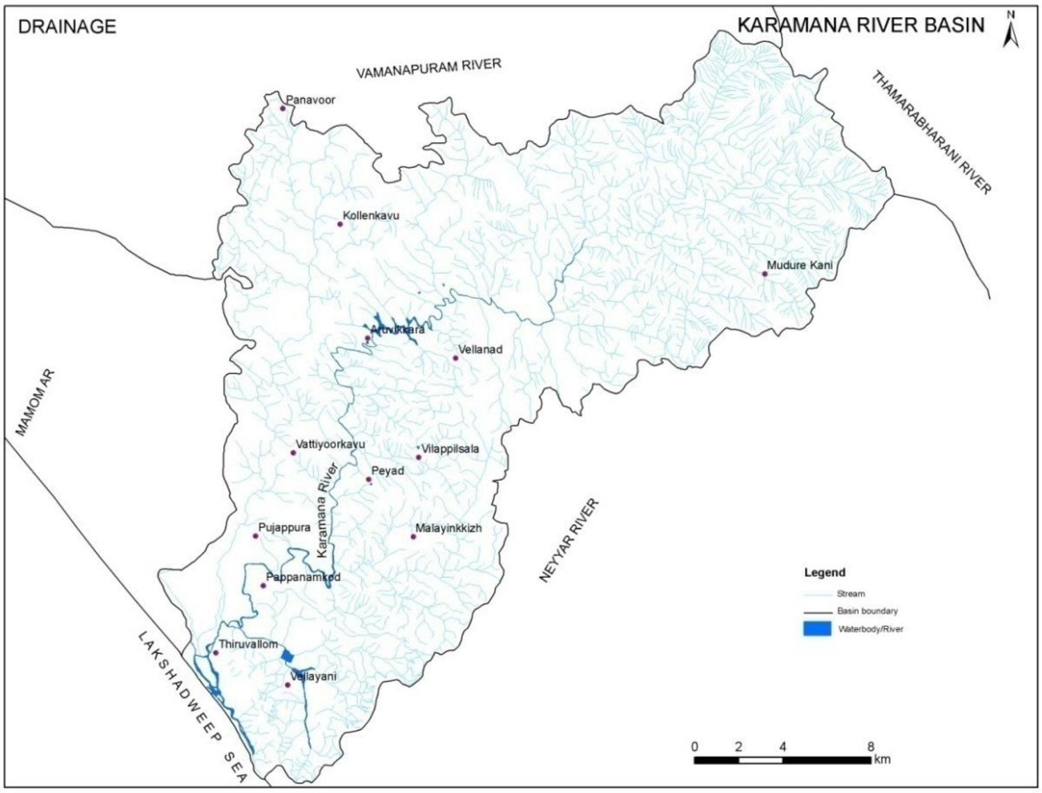


Fig. 3.1 Karamana and adjacent river basins

After a ten-dot-per square centimeter transparent overlay placed over the drainage basin demarcated in the topographic sheet, the total number of dots falling within the basin divide and one half of the number of dots falling on the divide line were estimated. Using appropriate conversion factor, the area of the basin in square kilometers has been estimated by multiplying the total number of dots counted by the conversion factor. The precision of this method of measurement of drainage area can be improved by increasing the grid density of the transparent overlay. After drawing the drainage divide on the map and estimation of drainage area, geomorphic/ morphometric parameters of the basin are determined. For the measurement of lengths of streams and stream segments a rot meter was used as a measuring tool. The frequency distribution analysis of the basin area was carried out.

For the detailed study of the morphometric attributes (such as the linear, areal and relief parameters of the basin), the basin has been delineated into sub-basins. The linear aspects of the basin were studied using the methods of Horton (1945), Strahler (1953) and Chorley (1957), the areal aspects using those of Schumm (1956); Strahler (1956; 1958); Chorley (1957), Miller (1953) and Horton (1932) and relief aspects employing the techniques of Horton (1945), Melton (1957), Schumm (1954) and Strahler (1952 a & b). For further calculation of the area, both square–grid method as well as planimetric method has been employed.

Survey of India topographical maps (1:50,000) and Shuttle Radar Topographic Mission (SRTM) with a pixel size of 90 m were used for the preparation of various thematic layers and estimation of various morphometric parameters with the help of software Arc GIS 10 and ERDAS IMAGINE 2011. Karamana River Basin is divided into seven sub watersheds which also digitized from topographic map. The sub watersheds were designated as SW I to SW VII. Computation of basin parameters required for morphometric analysis, ordering, lengths, area etc. were estimated using GIS (Geographical Information System) technique, which were later used to calculate other parameters. The Digital Elevation Model or DEM derived from the SRTM data reveals that the eastern region of the area under investigation is highly undulating.

3.2 DRAINAGE PATTERN

A drainage map is a plan of all streams or river systems in a drainage basin. It presents some characteristics of drainage basins through drainage pattern and drainage texture. It is often possible to deduce the geology of the basin, the strike and dip of rock units, existence of faults and other information about geological structures from drainage patterns. On the other hand, drainage texture reflects climate, permeability of rocks, vegetation and relief ratio. Howard (1967) related drainage patterns to geological information and recognized dendritic, parallel, rectangular, trellis, radial and annular patterns. If the gradient of the land surface is very gentle, a systematic stream pattern may not be created. In more mountainous zones, where the sub basins are confined to elongated valleys, palmate and pinnate dendritic channel patterns develop where a number of shorter tributaries connect to a larger stream or river that flows along the axis of the valley.

The influence of bedrock lithology is particularly evident in drainage basins that cut across rock units of different erosional resistance, such as in areas of synclines and anticlines. In such basins the stream flow will be focused along less resistant rock units, occasionally cutting through intervening resistant rock units to link adjoining channel systems and a so called trellis drainage pattern develops. The KRB is dominantly a khondalitic suite of rocks with garnetiferous-quartzo-feldspathic gneisses with a few isolated patches of charnockites. The channel pattern of the basin, in general reflects structural features of the rock types rather than lithologic inhomogeneities. The general course of Karamana Ar follows the dominant strike direction of NW-SE foliation. Changes of river course and channel orientations are generally controlled by prominent fracture zones and major joint directions. Drainage pattern noted in KRB is dominantly dendritic in the lower reaches which is expressed by homogeneity of texture and is indicative of lack of any significant structural control (Fig. 3.2). Here the drainage pattern is characterized by tree-like or fen-like pattern, with branches that intersect primarily at acute angles. In the upper reaches of the basin the pattern is semi dendritic. In the higher reaches of the basin, the tributaries as well as their associated subsidiary channels exhibit sub-parallel patterns. The majority of small branching streams join each other usually at acute angles. There are also localized indications of trellis pattern within the reach from Vellayakadavu in the north to Cheelanthivattom in the south.

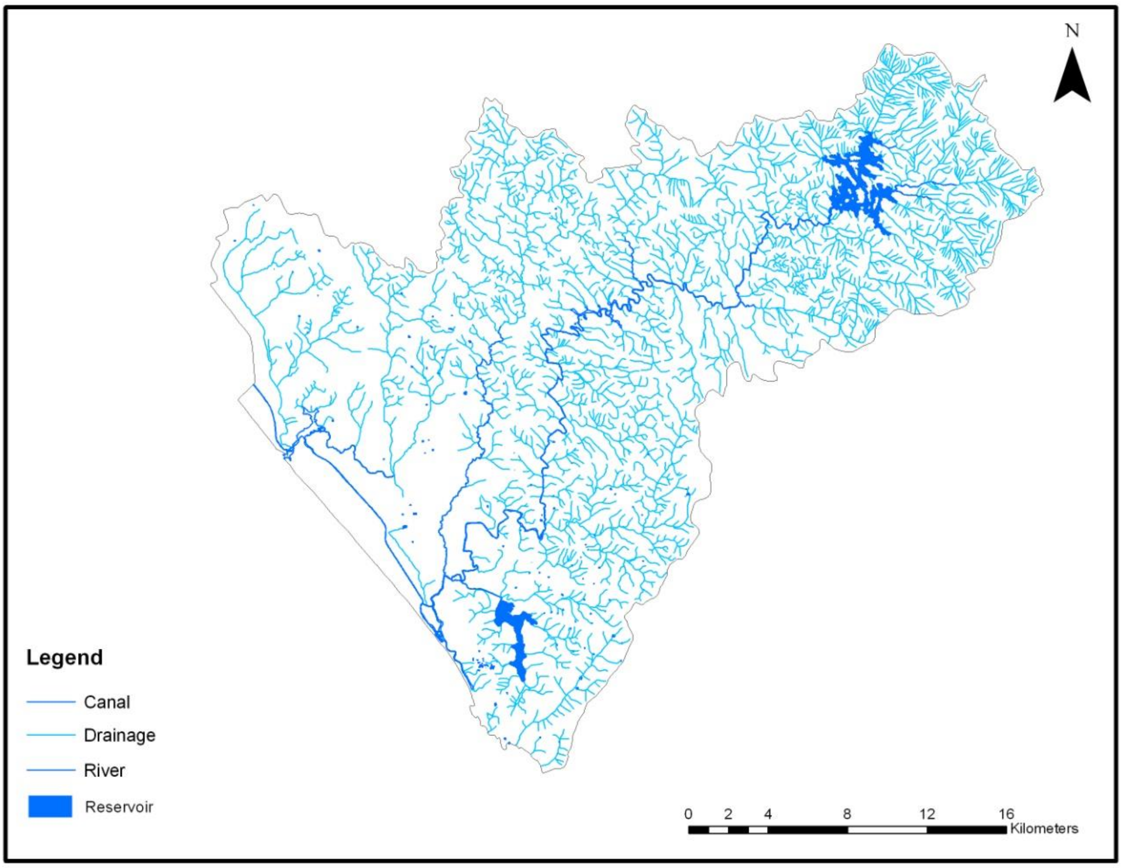


Fig. 3.2 Drainage map of Karamana River Basin

Chief tributaries of Karamana River, the Killi Ar, Chit Ar exhibit trellis pattern indicative of structural control in drainage Moreover, all these tributaries join the main river at very high angles. The remarkably close drainage network and presence of geomorphological indications of stream piracy of tributaries through relief reduction are indicative of the fact that the basin of Karamana River is in the stage of between maximum extension and abstraction- in the evolutionary scheme proposed by Glock (1931 and 1932) commencing from the stage of initiation to that of abstraction, passing through the stages of elongation, elaboration and maximum extension of the stream network. Although not strictly true, with reference to the Davisian geomorphic cycle (Davis,1909) the basin can be viewed as one that has reached more or less the mature stage of stream development.

3.3 LINEAR ASPECTS OF KARAMANA BASIN

Linear aspects of quantitative geomorphology are presented in this section. The symbols adopted for the various linear morphometric parameters and their definitions are presented in Table 3.1.

Table 3.1 Symbols adopted for the linear morphometric parameters

Item	Parameter	Symbol	Definition
1	Basin Perimeter	Lp	Length measured along the basin boundary
2	Length of Main Stream	Lu	Length measured along the longest water course from the outlet to upper limit of basin boundary
3	Basin Length or Valley Length	Lb	Straight line distance between outlet (mouth) of the basin and a point on the drainage divide nearest to the source of the main channel..
4	Number of streams in each order	N1	Total number of streams of 1st order
		N2	Total number of streams of 2nd order
		N3	Total number of streams of 3rd order
		N4	Total number of streams of 4th order
		N5	Total number of streams of 5th order
		N6	Total number of streams of 6th order
		N7	Total number of streams of 7th order
5	Total Stream Length of all orders	Lw	Lu1+Lu2+Lu3+Lu4+Lu5+Lu6
6	Mean Stream Length of each order	Lsm1	Total length of streams of 1st order / Total number of streams of 1st order
		Lsm2	Total length of streams of 2nd order / Total number of streams of 2ndt order
		Lsm3	Total length of streams of 3rd order / Total number of streams of 3rdt order
		Lsm4	Total length of streams of 4th order / Total number of streams of 4th order
		Lsm5	Total length of streams of 5th order / Total number of streams of 5th order
		Lsm6	Total length of streams of 6th order / Total number of streams of 6th order
7	Total number of streams of all orders	Nw	N1+N2+N3+N4+N5+N6
8	Wandering Ratio (Smart and Surkan, 1967)	Rw	Mainstream length / Basin length
9	Fineness Ratio (Melton, 1957)	Rf	Stream lengths / Length of the basin perimeter
10	Bifurcation Ratio (Horton, 1945)	Rb	Ratio of number of streams of lower order w to the number of streams of order w + 1
11	Mean Bifurcation Ratio	Rb_{mean}	Mean value of bifurcation ratios
12	Stream Length Ratio (Horton , 1945)	RL	Ratio of mean stream segment of order *u* to mean stream segment length of order *u* - 1
13	Length of overland Flow (Horton, 1945)	Lg	Half the reciprocal of drainage density.

3.3.1 Stream order

In drainage basin analysis, the first step is stream ordering. The order of a given stream segment is its location in the stream network within the basin. Out of the main four systems of ordering of streams that are available Gravelius (1914), Horton (1945), Strahler (1952 a) and Sheidegger (1970). Strahler's system, a modified Hortonian scheme has gained immense popularity due to its simplicity and hence this is used in the present study of KRB. In this system, the smallest fingertip tributaries are designated as order 1, receiving flow directly from flow on ground surface, i.e. sheet flow and rill flow. When two 1st orders join, a channel segment of order 2 is formed, joining two 2nd orders give rise to 3rd order channel segment and so on (Table 3.2). The trunk stream through which all discharge of water and sediments of the basin pass through is therefore, the stream segment of highest order. Order of a catchment is labeled after the highest order of the stream draining the basin to a bay, coastal plain lake or the ocean. Higher the stream order, the fewer the number of streams at that order and the longer the stream length. In addition, the amount of water drained by a stream increases with stream order. As stream order increases from order *n* to order *n* + 1, there are usually three to four times as much area (Allan, 1995).

Table 3.2 Morphometric parameters of KRB

Sub-watersheds		SW-I	SW-II	SW-III	SW-IV	SW-V	SW-VI	SW-VII	Basin
Total stream length of order u in km	1	91.03	120.45	110.63	47.28	32.79	40.22	468.85	911.46
	2	21.54	30.27	41.87	20.10	11.95	24.94	153.32	303.47
	3	10.35	27.65	19.51	10.35	14.64	10.14	102.70	193.48
	4	6.77	8.10	11.74	16.62	7.97	3.95	36.31	83.48
	5	4.26	3.53	28.20			2.84		38.78
	6							75.91	75.91
	∑Lu	**133.95**	**190.00**	**211.95**	**94.35**	**67.35**	**82.09**	**837.09**	**1606.60**
Mean stream length in km (Lu/Nu)	1	0.60	0.53	0.47	0.72	0.75	0.52	0.52	0.54
	2	0.55	0.54	0.62	1.44	1.09	1.08	0.69	0.70
	3	1.15	2.51	1.15	2.59	4.88	2.54	2.05	1.97
	4	2.26	2.70	2.94	16.62	7.97	1.98	2.59	2.98
	5	4.26	3.53	28.20			2.84		9.70
	6							75.91	**75.91**
	∑Lsm	**8.82**	**9.81**	**33.37**	**21.36**	**14.68**	**8.95**	**81.77**	**91.80**
Stream length ratio (RL)	2/1	0.24	0.25	0.38	0.43	0.36	0.62	0.33	0.33
	3/2	0.48	0.91	0.47	0.51	1.23	0.41	0.67	0.64
	4/3	0.65	0.29	0.60	1.61	0.54	0.39	0.35	0.43
	5/4	0.63	0.44	2.40			0.72		0.46
	6/5								1.96
Number of streams (Nu) of different stream order (u)	1	152	228	233	66	44	78	894	1695
	2	39	56	68	14	11	23	223	434
	3	9	11	17	4	3	4	50	98
	4	3	3	4	1	1	2	14	28
	5	1	1	1			1		4
	6							1	1
	∑Nu	**204**	**299**	**323**	**85**	**59**	**108**	**1182**	**2260**
Bifurcation ratio (Rb)	1/2	3.9	4.1	3.4	4.7	4.0	3.4	4.0	3.9
	2/3	4.3	5.1	4.0	3.5	3.7	5.8	4.5	4.4
	3/4	3.0	3.7	4.3	4.0	3.0	2.0	3.6	3.5
	4/5	3.0	3.0	4.0			2.0		7.0
	5/6								4.0
	mean	**3.6**	**4.0**	**3.9**	**4.1**	**3.6**	**3.3**	**4.0**	4.6

3.3.2 Basin Perimeter (Lp)

The length measured along the basin boundary gives the value of perimeter of the drainage basin (Lp). The measurement of the length of the boundary of KRB gave a value of 164.90 km (Table 3.3).

Table 3.3 Different areal parameters of KRB

Parameters	**SW-I**	**SW-II**	**SW-III**	**SW-IV**	**SW-V**	**SW-VI**	**SW-VII**	**Basin**
Area (A) km^2	34.96	53.02	95.45	68.11	59.09	39.90	351.91	702.44
Perimeter (P) km	29.55	38.46	63.50	41.54	38.36	30.31	163.19	164.90
Basin length (Lb) (km)	8.88	10.23	23.99	11.18	12.87	9.18	29.95	40.20
Drainage Density (D)	3.83	3.58	2.22	1.39	1.14	2.06	2.38	2.29
StreamFrequency (Fs)	5.84	5.64	3.38	1.25	1.00	2.71	3.36	3.22
Drainage Texture (T)	22.36	20.21	7.51	1.73	1.14	5.57	7.99	7.36
Form Factor (Ff)	0.44	0.51	0.17	0.54	0.36	0.47	0.39	0.43
Circularity Ratio (Rc)	0.50	0.45	0.30	0.50	0.50	0.55	0.17	0.32
Elongation Ratio (Re)	0.75	0.80	0.46	0.83	0.67	0.78	0.71	0.74
Basin Shape (Bs)	0.25	0.19	0.25	0.16	0.22	0.23	0.09	0.06
Length of Overland Flow (Lo)	0.13	0.14	0.23	0.36	0.44	0.24	0.21	0.22
Constant of Channel Maintenance(C)	0.26	0.28	0.45	0.72	0.88	0.49	0.42	0.44
Compactness coefficient (Cc)	0.24	0.20	0.19	0.17	0.18	0.21	0.13	0.07

3.3.3 Stream Length (Lu)

Stream length is one of the most significant features of any river basin by revealing surface runoff characteristics of the streams. Streams of relatively smaller lengths are characteristics of areas with steeper slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The number of streams of various orders in the basin is counted and their lengths from mouth to drainage divide are measured from the topographic maps of the basin.

The length (L) of a drainage basin is the second important watershed characteristic of interest. Watershed length is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide. Since the channel does not extend to the basin divide, it is necessary to extend a line from the end of the channel to the basin divide following a path where the greatest volume of water would travel. The straight line distance from the outlet point on the watershed divide is not usually used to compute 'L' because the travel distance of floodwaters is conceptually the length of interest. Thus, the length is measured along the principal flow path. Since it will be used for hydrologic calculations, this length is more appropriately labeled as the hydrologic length. While the drainage area and length are both measures of watershed size, they may reflect different aspects of size. The drainage area is used to indicate the potential for rainfall to provide a volume of water. The length is usually used in computing a time parameter which is a measure of the travel time of water through a watershed.

3.3.4 Basin Length or Valley Length (Lb)

Straight line distance between outlet (mouth) of the basin and a point on the drainage divide nearest to the source of the main channel is termed as basin length or valley length. It is used in the calculation of the shape of drainage basins. The basin length of the KRB has been estimated as 40.20 km (Table 3.3).

3.3.5 Number of streams in each order or Stream Number

The order wise total number of stream segments is known as the stream number and is estimated by taking their count. Horton's law of stream number states that the number of stream segments of each order forms an inverse geometric sequence when plotted against order, and for most drainage networks the corresponding graphs show a linear relationship, with small deviation from a straight line. In the present study also. The number of the streams decreases as the stream order increases (Table 3.2). The graphical representation of KRB data on semi-logarithmic paper where number of streams is plotted against the log scale while the stream order is in the arithmetic scale. The graph with its linearity or straight line follows the Horton's law. This means that the number of streams usually decreases in geometric progression with increase in stream order.

3.3.6 Mean stream length of each order

From Table 3.2, it is observed that the mean stream length increases with increasing stream order. According to Horton's law, the mean lengths of the streams of each order in a river basin increases with the order in direct proportion and approximates a direct geometric series. As per the suggestion of Strahler (1956), the logarithmic plot of the streams length versus stream order showed approximate linear pattern. Deviation from a true straight line can be attributed mostly to variation in lithology of rocks of the region. The graph plotted for stream order versus mean lengths of stream order indicates the 'law of stream length' of Horton, by the straight line regression.

3.3.7 Total Number of Streams of all orders (Nw)

The total number of streams of all orders of KRB is given in Table.3.2.

3.3.8 Wandering Ratio (Rw)

It is the ratio between the main stream length along the course to the straight line distance between the two extremes, outlet and farthest point in basin boundary. While this factor broadly indicates the amount of deviation of main stream from straight line path, it does not necessarily explain the meandering tendency.

3.3.9 Fitness ratio (Rf)

The ratio between the stream length and the length of the basin perimeter is called fineness ratio (Melton, 1957).

3.3.10 Bifurcation Ratio (Rb)

By relating the number of streams of one order to the number of streams in the next lower order, bifurcation ratios are obtained. Bifurcation ratio is defined as the ratio of the number of channel segments of a given order to the number of segments of the next higher order (Schumm, 1956). This ratio exhibits only a small range of variation from region to region or for different environment. Strahler (1964) demonstrated that bifurcation ratios characteristically range between 3.0 and 5.0, for basins in which the geological structures do not significantly influence the drainage pattern (Table 3.2).

3.3.11 Mean bifurcation ratio ($Rb_{(mean)}$)

From the bifurcation ratios, the mean bifurcation ratios were computed. Using Strahler's method (Strahler, 1953) weighted mean bifurcation ratios were also calculated. An elongate basin with a high ratio should result in a hydrograph with a low but extended peak flow while a round basin with a low ratio would yield a sharp peak in the hydrograph (Strahler, 1964).

A plot of Log N*u* versus *u* will approximately yield a straight line with negative slope. The magnitude of this slope will be the logarithm of Rb.

3.3.12 Stream Length Ratio (RL)

It is the ratio of the mean length of segments of order '*u*' to mean length of segments of the next lower order $L_{(u-1)}$. Horton stipulated that stream length ratios (RL) tends to be constant throughout the successive order of a drainage basin. The value of stream length ratios normally falls between 1.5 and 3.5 in natural drainage networks. However, in the present study this general rule is not complied with Table 3.2

3.3.13 Length of Overload Flow (Lo)

The length of overland flow is defined as the length of the longest drainage path that water takes before it get concentrated (Horton, 1945). The length of (Lg) approximately equals to half the reciprocal of the drainage density-‘Dd’ (Horton, 1945). This factor relates inversely to the average slope of the channel and is synonymous with the length of sheet flow.

3.4 AREAL ASPECTS OF KARAMANA BASIN

The area of a drainage basin is an important parameter like the length of the stream draining it. And so all the areas of various drainage basins of higher orders were plan metrically measured and from these values, the mean area of the basins of each order were computed. Then taking pairs of stream orders, the area ratios were obtained between the mean area of the basins of one order and that of the next lower order. From these area ratios, an ordinary mean area ratio and weighted mean area ratios were calculated.

The symbols adopted for the various areal morphometric parameters and definitions are given in Table 3.4

3.4.1 Total drainage area (a)

Drainage area, i.e., the area between the drainage divides enclosing a river basin, is an important hydrological indicator as it dictates both the runoff and sediment yield. It is measured, after projecting the land surface on a horizontal plane. Table 3.3 gives the distribution of drainage areas associated with the fourth, fifth and sixth order streams of the KRB. The measured value of total area of KRB is 702 km^2. The mean of basin area increases directly with increasing magnitude of stream orders, according to the ‘law of drainage basins.

3.4.2 Drainage density (Dd)

In addition to the mathematical relationships found in stream ordering, various aspects of drainage network were also found to be quantifiable. One such relationship is drainage density which expresses the closeness of spacing of channels in a drainage basin. Horton (1945) defined drainage density as the ratio of total channel segment lengths of all orders within a basin to the area of the basin projected to horizontal.

Table 3.4 Areal morphometric parameters, symbols and definitions

Sl.No.	Parameter	Symbol	Definition
1	Total Drainage Area	A	Basin area
2	Drainage Density	Dd	Total length of all streams / Basin area
3	Constant of Stream Maintenance (Schumm, 1956)	C	Inverse of drainage density
4	Stream Segment Frequency (Horton, 1945)	F	Number of stream segments per unit basin area.
5	Drainage area of each order	A1	Total discharge area of 1st order
		A2	Total discharge area of 2nd order
		A3	Total discharge area of 3rd order
		A4	Total discharge area of 4th order
		A5	Total discharge area of 5th order
		A6	Total discharge area of 6th order
6	Average drainage area of each order	Ā1	Total discharge area of 1st order streams / Total number of streams of 1st order
		Ā 2	Total discharge area of 2nd order streams / Total number of streams of 2nd order
		Ā 3	Total discharge area of 3rd order streams / Total number of streams of 3rd order
		Ā 4	Total discharge area of 4th order streams / Total number of streams of 4th order
		Ā 5	Total discharge area of 5th order streams / Total number of streams of 5th order
		Ā 6	Total discharge area of 6th order streams / Total number of streams of 6th order
7	Area ratio (Schumm, 1954)	Ar	Ratio of mean drainage area of basin of order *n* to *n-1*
8	Form Factor (Horton, 1932)	Rf	Basin area / (Basin length) ^{2}
9	Circularity Ratio (Miller, 1953)	Rc	Basin area / Area of circle having circumference equal to the basin perimeter.
10	Elongation Ratio (Schumm, 1956)	Re	Diameter of a circle having the same area as the basin / Basin length.
11	Basin Shape Factor	Rs	Main stream length / Diameter of a circle having the same area as the basin.
12	Unit Shape Factor (Smart and Surkan , 1967)	Ru	Basin length / (Basin area) ^{½}
13	Compactness Coefficient (Strahler, 1964)	Cc	Basin perimeter / Perimeter of the circle having the same area as the basin area

Slope gradient and relative relief are the main morphological factors controlling drainage density. Strahler (1964) noted that low Dd occurs where basin relief is low, while high Dd is favored where basin relief is high. The measurement of Dd provides a hydrologist or geomorphologist with a useful numerical measure of landscape dissection, texture and runoff potential of a basin. On a highly permeable landscape, with small potential for runoff, drainage densities are sometimes less than 1 km / km^2. On highly dissected surfaces, densities of over 500 km / km^2 are often reported. Closer investigations of the processes responsible for Dd variation has disclosed that a number of factors collectively influence drainage density. Drainage density characterizes textural measure independent of basin size and considered to be a function of climate, topography, soil infiltration capacity, vegetation and geology. Coarse drainage density is likely to appear in areas of permeable rocks and low rainfall intensity. On the other hand, fine drainage density develops in badlands because of impermeable rocks, thin vegetation cover and heavy rainfall. A drainage basin in humid region often shows medium drainage density. Drainage density provides a quantitative measure of the average length of stream channel for the whole basin. It has been observed from the drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant or highly permeable subsoil material, under dense vegetative cover, and where relief is low. High drainage density is associated with weak or impermeable subsurface material, sparse vegetation and mountainous relief.

Low drainage density leads to coarse drainage texture, while high drainage density leads to fine drainage texture (Strahler, 1964). The type of rocks also affects the drainage density of a region. Generally lower values of Dd tend to occur in granite, gneiss and schist regions. Drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin (Horton 1932). While this parameter is the result of interacting factors controlling the runoff, it is by itself a powerful factor controlling the discharge of water and sediment of from the watershed. This parameter is higher in Sub-watersheds of higher relief. Drainage density of the Sub-watersheds varies between 1.14

for SW V and 3.83 for SW I respectively (Table 3.3). Drainage density gives an idea about the physical properties of the underlying rocks in the study area.

3.4.3 Constant of channel maintenance (C)

Schumm (1956) introduced the concept of constant of stream maintenance and defined the term as inverse of drainage density. It depends on the lithology, permeability, climatic regime, vegetation cover and relief as well as duration of erosion. Generally, C values of a basin, increase with permeability of the rocks of that basin and vice-versa (Shubha 2009 and Pakmode et al., 2003). The area required to sustain 1 km of stream is higher for basin SW I (0.26 km^2/km) among all the seven sub-watersheds. Table 3.3 lists the calculated values of C for KRB with a total of 0.44.

3.4.4 Stream frequency or channel frequency (Fs)

Stream frequency or channel frequency (Fs) is the total number of stream segments of all orders per unit area (Horton, 1932 and 1945). The occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall and soil permeability. Stream frequency is 5.84 for SW I and is the highest among all the sub-watersheds. Drainage density and stream frequency certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin (Imran et al., 2011). It is noted that the values of Fs streams of KRB range from 1.00 to 5.84 (Table 3.3). As the drainage density values of the sub-basins exhibit a positive correlation with the stream frequency, there is a corresponding increase in stream population with increasing drainage density.

3.4.5 Drainage area of each order

Basin wise distribution of drainage areas associated with different stream orders of KRB is given in Table 3.5. It is customary to list the sub basins in the hierarchy into right and left bank sets.

Table 3.5 Basin-wise distribution of Drainage Area of KRB

Basin (Order)	Drainage Area (km^2)
Third Order	95.45
Fourth Order	68.11
Fifth Order	59.09
Sixth Order	39.90
Seventh Order	351.91

3.4.6 Average drainage density of each order

Average drainage area of n^{th} order stream is defined as the total drainage area of n^{th} order stream divided by the total number of streams of that order. The average drainage density of KRB is depicted in the Table 3.3.

3.4.7 Area ratio (Ar)

Schumm (1954) defined this term as the ratio of mean drainage area of basin of order n to mean drainage area of basin of order n-1.

3.4.8 Basin configuration

Every drainage basin has a unique shape. Shape of a drainage basin contributes to the speed with which the runoff reaches the basin. Basin shape is an element that can be expressed in terms of several factors. In this study, for determining the shape of the drainage basin, a quantitative study of them was made using the dimensionless ratios, such as form factor (Rf), circularity ratio (Rc) etc.

3.4.8.1 Form factor (F or Rf)

Horton (1932) proposed the form factor in order to express the shape (outline form) of a drainage basin quantitatively and defined it as the ratio of the basin area to the square of the basin length. This factor indicates the flow intensity of a basin of a defined area (Horton 1945). In its inverted form it was used in unit hydrograph applications by the U.S Army Corps of Engineers. The form factor values should be always less than 0.7854 (the value corresponding to a perfectly circular basin). The smaller the value of the form factor, the more elongate the basin will be. Basins with high form factors experience larger peak flows of shorter duration, whereas elongated basins with low form factors (Table 3.3).

3.4.8.2 Circularity ratio (R_c)

After Horton advocated the form factor, other ways of expressing the shape of a drainage basin were proposed. Two examples are the circularity ratio (Miller, 1953) and the elongation ratio (Schumm, 1956).

Miller (1953) defined the dimensionless circularity ratio (Rc) as the ratio of the basin area to the area of a circle having circumference equal to the perimeter of the basin. $Rc = A / A_O$ where A_0 is the area of the circle having a perimeter equal to the perimeter of the basin. The circularity ratio (Rc) of our study area KRB is 0.32 (Table 3.3). The values of circularity ratio approaches one (1), as the shape of the basin approaches the form of a circle. Miller found the values consistently in the range of 0.45 to 0.50 for the first and second order basins in regions of homogeneous shale's and dolomites and varying from 0.17 to 0.5 in regions where rocks units dip moderately.

3.4.8.3 Elongation ratio (R_e)

Elongation ratio of drainage basins is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1956). Obviously, for a circular basin the value tends to be unity. The elongation ratio is equal to one for a circular basin and approaches zero for a straight line. The elongation ratio ranges between 0.6 and 1.0 over wide variety of climatic and geologic types. It is considered a very significant index in the analysis of shape of drainage basins to give an idea about the hydrologic character of the basin. Values near to 1.0 are typical of regions of very low relief (Strahler, 1964), whereas values of the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes. Round shaped drainage basins experience greater flood magnitude than elongated ones because flows from multiple tributaries converge more quickly in the former case. Fig. 3.3 compares the discharge hydrographs of two basins with very different shapes.

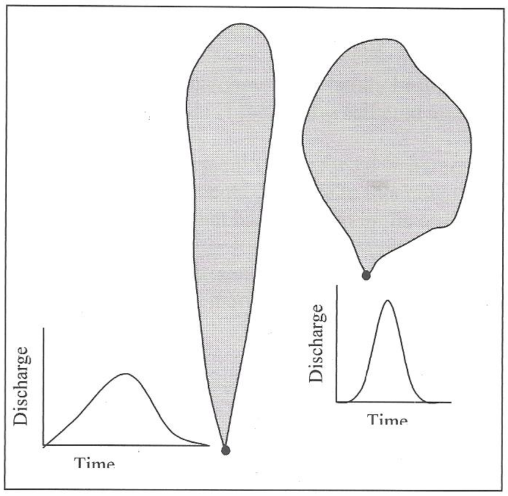


Fig. 3.3 Discharge hydrographs of basins with different shapes

The more elongated basin has a dampened response, compared to the 'flashier' hydrograph of the circular basin. This pattern results because of the first basin has a much broader distribution of flow path lengths, and therefore a wide range of travel times.

The lag-time or the time for concentration of stream flow from the tributaries to the main stream channel is less in oval and circular basins than that in elongated (elliptical) or narrow basins. As the basin areas of fourth order streams increase, the shape of the basin tends to approach more and more elongate. Values near to 1.0 are typical of regions of very low relief (Strahler, 1964).

3.4.8.4 Basin shape factor (Rs)

This parameter has been defined as the ratio of main stream length (L) to the diameter (D) of an equivalent circle ie.one having the same area as the basin. Table 3.3 lists the values of basin shape factors.

3.4.8.5 Unity shape factor (Ru)

It is one of the important concepts of geomorphology which is related to the relative spacing of drainage lines in any specific locality. Smart and Surkan (1967) used the unity shape factor to be defined as the ratio of the basin length (L) to the square root of basin area (A). In general, drainage lines will be numerous over impermeable areas than those in permeable areas.

3.4.8.6 Drainage texture and texture ratio (T or Rt)

Quantitative expression of drainage texture is so difficult that qualitative expressions, such as coarse, medium and fine, are generally used. Drainage texture contains two different concepts viz: density and frequency. Drainage frequency is derived by dividing the number of streams by the area of the drainage basin. Although two drainage basins may show similar drainage density, their drainage frequencies are not necessarily comparable. Texture ratio (T), an important factor in drainage morphometric analysis, is defined as the total number of stream segments of all orders per area of the drainage basin (Horton, 1945).The drainage texture (T) depends on climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development (Smith, 1950). Smith (1950) proposed a scheme of classification of drainage texture (T) (Table 3.6)

Table 3.6 Classification of Drainage texture (Smith, 1950)

Range	Texture
For 4.0 and below	Coarse
From 4.0 to 10.0	Intermediate
Above 10.0	Fine
Above 15.0	Ultrafine (eg: Badland topography)

According to Horton (1945), infiltration capacity is the single important factor influencing drainage texture in any region. The latter includes both the drainage density as well as stream frequency.

The values of drainage texture of the KRB vary from 3.312 to 8.35 in different regions. Smith (1950) has proposed a classification scheme of drainage texture, in which five different categories have been suggested Table 3.7. The variation of drainage texture is generally attributable to the spatial variation of geological, pedagogical and related features.

Table 3.7 Classification of Drainage Texture

Sl.No.	Range of Drainage Texture	Category
1	< 2.0	Very coarse
2	2.0 – 4.0	Coarse
3	4.0 – 6.0	Moderate
4	6.0 - 8.0	Fine
5	> 8.0	Very fine

The drainage texture less than 4 indicates coarse, 4 to 10 is intermediate, greater than 10 is fine and greater than 15 is ultrafine (Smith, 1950). SW I and II are ultrafine textured, SW IV and V with its drainage density and frequency exhibit a texture of coarse category, the rest all sub-watersheds are of intermediate texture.

3.5 RELIEF ASPECTS OF KARAMANA RIVER BASIN

The Table 3.8 lists the basin relief parameters.

Table 3. 8 Basin Relief Parameters

Sl.No.	Parameter	Symbol	Definition
1	Basin relief (Schumm, 1956)	Rb	Altitude difference between highest point and outlet in the basin.
2	Relief Ratio (Schumm, 1956)	Rh	Basin relief (Rb) / Distance between the highest point and outlet in the basin (BL).
3	Relative Relief (Melton, 1957)	R_{hp}	Basin relief(Rb) / Basin perimeter(Lp)
4	Ruggedness Number (Melton, 1957; Strahler, 1958)	Rn	Product of basin relief and drainage density

3.5.1 Basin relief (Rb)

Basin relief is defined as the difference in elevation between the highest and the lowest points in the basin. It controls the gradient of the stream and therefore influences flood pattern and amount of sediment that can be transported. Hadley and Schumm (1961) showed that sediment load increases exponentially with basin relief. Basin relief determines slope and run-off and sediment transport. Low value of basin relief indicates low run-off, low sediment transport and spreading of water basin. High relief tends to enhance the flood peaks of the drainage system. The Basin relief of KRB ranges from 81m to 1504 (Table 3.9).

Table 3.9 Karamana River Basin relief parameters

Parameters	SW-I	SW-II	SW-III	SW-IV	SW-V	SW-VI	SW-VII	Basin
H	99	105	15	11	7	16	0	0
H	1358	1609	254	168	116	97	682	1609
Basin relief (ΔH) (in metres)	1259	1504	239	157	109	81	682	1609
Relative Relief (ΔH/P)	0.043	0.039	0.004	0.004	0.003	0.003	0.004	0.010
Relief Ratio (ΔH/L max)	0.14	0.15	0.01	0.01	0.01	0.01	0.02	0.04
Ruggedness (N= (ΔH)*D)	4.82	5.39	0.53	0.22	0.12	0.17	1.62	3.68

3.5.2 Relief ratio (Rh)

The relief ratio, is the ratio of the maximum basin relief (H) to the catchment's longest horizontal straight distance measured in a direction parallel to that of the principal water course. Schumm (1956) explained that taking vertical and horizontal distances as legs of a right angle triangle, relief ratio is equal to the tangent of the lower acute angle and is identical with the tangent of the angle of slope of the hypotenuous with respect to the horizontal. The relief ratio of the master stream as well as those of the individual stream channels of the basin also can be determined and in both cases more intense flooding is associated with catchment of higher relief ratio. This ratio controls the overall steepness of drainage basins or gradient of associated streams and therefore influences the intensity of flood and amount of sediment that can be transported by the basin. It can be observed that the Rh values increases with decrease in drainage area of the basins and the size of a given drainage basin. It measures the general steepness of a drainage basin and an index of surface flow and intensity of dissection processes.The Rh value of the sub-watersheds ranges from 0.01 to 0.15 and that of the Karamana River basin is 0.04 (Table 3.9). The high Rh value indicates hilly region and low value is the characteristic of valley and pedeplain (Sreedevi, 2009). The Relief ratio is high for sub-watersheds falling in high land tracts. Rr is lowest for SW III, IV, V and VI (0.01) reflecting its low gradient.

3.5.3 Ruggedness Index (Rn)

Taking into account of both slope steepness and length, a dimensionless ruggedness number has been used by Melton (1957) and Strahler (1958). It is defined as the product of relief (H) and drainage density (Dd) (both in same units), ie. Rn = H x Dd. It is an indication of efficiency for peak discharge of the basin and indicates structural complexity of the terrain (Ozdemir and Bird 2009). High values are expected on mountainous region with high rainfall (Ritter et al., 1995). The Rn values are high for sub-watersheds SW I and II (4.82 and 5.39). The different Ruggedness values for Karamana River Basins are deciphered in Table 3.9.

3.6 BASIC PARAMETERS

Karamana River exhibits dominance of trellis patterns in the upper reaches and with dendritic patterns in the mid land region with the low relief parts of the basin. In SW VII the drainage is dominated by the main trunk of river and this sub-watershed is the biggest among all and the number of streams is more than in any other sub-watersheds. Amongst the sub basins, SW I and II are of higher relief and gradients. Basin length, which is the maximum length of the basin parallel to the main trunk measured from mouth to origin, is about 40 km. Of this, about 11 km falls within an elevation of 80 m.

3.6.1 Stream Order (u) and Stream number (Nu)

Karamana is a sixth order basin with seven sub-watersheds of 5^{th} order (Strahler, 1964). Stream order provides information about topography, runoff and drainage network. The number of streams is higher in those of higher relief and slope. The total number of stream segments in the basin are 2260 (Table 3.2).

3.6.2 Stream Length (Lu) and Mean Stream Length (Lsm)

Stream length (Lu) reveals the surface run off of a stream. Generally total length of stream segments is highest in first order watersheds and decreases with increase of stream order. The variations in gradient, topography and lithology influence the stream length. The total stream length is minimum (67.35 km) in the SW V and maximum (837 km) in the SW VII. The total stream length of Karamana amounts to about 1607 km (Table 3.2). The mean stream length (Lsm) is a function of drainage network components and the nature of basin surfaces (Strahler 1964). The Lsm is related to surface flow discharge and erosional stage of the basin. Low Lsm translates to high surface flow.

3.7 DERIVED PARAMETERS

Derived parameters generated from basic parameters for this study are Stream Length Ratio (RL), Bifurcation Ratio (Rb), Drainage Density (Dd), Stream Frequency (Fs), Drainage Texture (T), Constant of Channel Maintenance (C), Length of Overland Flow (Lo), Basin Relief (R), Relief Ratio (Rr), Gradient Ratio (Gr), Ruggedness number (Rn) and Digital Elevation Model (DEM)

3.7.1 Stream Length Ratio (RL)

Length ratio (RL) is defined as the ratio of mean length of streams of an order to that of next lower order. It is reported that RL is influenced by variations in slope and topographic conditions, surface flow discharge and erosional stage of the basin (Sreedevi et al., 2005). The stream length ratio ranges from 0.24 to 1.91 for the sub-watersheds in the Karamana River Basin. For the whole of Karamana basin the RL is ranging from 0.33 to 1.96 (Table 3.2).

3.7.2 Length of Overland Flow (Lo)

Length of Overland Flow is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. Lo signifies hydrological and physiographical development of the drainage basin (Horton, 1945). The length of overland flow approximately equals to half of reciprocal of drainage density. The value of Lo ranges from 0.13 to 0.36 (Table 3.3).

3.7.3 Compactness coefficient (Cc)

Compactness Coefficient of a watershed is the ratio of perimeter of watershed to the circumference of a circle with area equivalent to that of the watershed. The compactness coefficient is independent of the size of the watershed and depends only on the slope. The computed value of the Cc for the whole basin is 0.07 (Table 3.3).

3.8 REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

Remote sensing is the science and art of obtaining information about an object, area or phenomenon through analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation (Lillesand et al., 2008) as well as it is an excellent tool for understanding the “perplexing” problems of groundwater exploration. Remote sensing data due to its synoptic and repetitive nature are most suitable for studies like short and long term areal changes in land use, preparation of various thematic maps, health status of vegetation, delineating groundwater potential zones etc. Likewise, Geographic Information System (GIS), with its capability to handle large quantity of spatial and non-spatial data is an admirable tool to analyse and integrate data generated by remote sensing method. Space or airborne sensors usually record the electromagnetic radiation that travel with the speed of light ($3x10^8$ m/s) from the source, through the atmosphere, to the sensor. Thus changes in the properties and the amount of electromagnetic radiation recorded by the satellite’s sensor become the basis for extracting or studying the characteristics of the target.

Satellite remote sensing data is not only cost effective, reliable and timely but also meets the essential requirements of data in the Geographical Information System (GIS) domain, which are current, sufficiently accurate, comprehensive and available to a uniform standard. Remote sensing data in conjunction with necessary field investigations will effectively help to identify the groundwater potential zones and facilitate better data analysis and interpretation (Jasmine and Mallikarjuna, 2011). Remote sensing provides multi-spectral, multi-temporal and multi-sensor data of the earth's surface (Chowdhary et al., 2003).

Regular updating of data is an essential element in carrying out any kind of planning activity such as watershed management, surface water budgeting, landuse mapping, etc. The collection of these data through conventional means is not efficient and sufficient enough for modern day planning requirements. Thus satellite remote sensing data provide a means of locating, mapping and monitoring water resources, changes in morphology of rivers, landuse pattern and health status of vegetation etc. The remote sensing data, which are primarily in digital format, are processed further and hard copy images are generated. The use of satellite remote sensing data in conjunction with GIS provides an opportunity to acquire, update and monitor the changes in a timely manner with a reasonable degree of accuracy. Integration of the information on the controlling parameters is best achieved through GIS, which is an effective tool for storage, management and retrieval of spatial and non-spatial data as well as for integration and analysis of this information for meaningful solutions. In this chapter the application of remote sensing and GIS in groundwater exploration of the Karamana River Basin has been taken up. The technique of integration of remote sensing and GIS has proved to be extremely useful for groundwater studies (Sankar, 2002).

3.8.1 Materials and Methods.

The main objective of this work is to use GIS and Remote sensing technique for delineating the groundwater prospect zone with an area of 702.44km$^{2.}$

The unprecedented SRTM database combines global scope and high accuracy, so it offers many opportunities to extend present hydrologic studies to nearly the entire world (Julia et al., 2007). Currently, the Shuttle Radar Topographic Mission 90 m resolution (SRM) provides one of the most complete, highest resolutions, digital elevation model of the Earth. It is an ideal-set for precise terrain analysis and topographic characterization in terms of nature of altimetric distribution, relief aspects, pattern of lineament and surface slope, topographic profiles and their visualization, correlation between geology and topography, hypsometric attributes and finally the hierarchy of terrain sub unit (Priyank and Ashis, 2010). IRS P6 (LISS III) data were utilized for generating the geomorphology and land use/ land cover map using ERDAS Imagine 9.1 software. The thematic maps like geomorphology, drainage map, drainage density map, density map and geology map were prepared using the data obtained from satellite images, secondary sources and Survey of India topographic sheets (1;50,000 scale) using Arc GIS 9.2. The flow chart Fig. 3.12 clearly illustrates the methodology for demarcating the groundwater prospect zone,

3.8.2 GEOGRAPHICAL INFORMATION SYSTEM (GIS)

A Geographic Information System (GIS) is a computer system for capturing, storing, querying, analyzing and displaying geographic data.

3.8.2.1 Components of GIS

GIS can be divided into five components.

- Computer system: Computer system includes the computer and the operating system to run GIS.
- GIS Software: Includes the programme and the user interface for driving the hardware.
- Brainware: Refers to the purpose and objectives, and provides the reason and justification for using GIS.
- Infrastructure: Refers to the necessary physical, organizational, administrative and cultural environments for GIS operations. The infrastructure includes requisite skills, data standards and general organizational patterns.
- People.

The ability of GIS is to handle and process geographically referenced data which distinguishes it from any other information system. Geographically referenced data describe both the location and characteristics of spatial features on the earth’s surface (Chang, 2006).

3.8.2.2 Data representation in GIS

GIS data represents real world objects (roads, landuse, elevation) digitally. It stores two types of data: spatial data and non spatial data (attribute data).

Spatial data

Spatial data relate to geometry of spatial features. To represent spatial features, GIS uses two basic data models:

a. Vector data model: A co-ordinate based data model that represents geographic features such as points, lines, and polygons. Each point feature is represented as a single co-ordinate pair, while line and polygon features are represented as ordered lists of vertices.

b. Raster data model: A raster consists of a matrix of cells (or pixels) organized into rows and columns (or a grid), where each cell contains a value representing information, such as temperature. Rasters are digital aerial photographs, imagery from satellites, digital pictures, or even scanned maps. Data stored in a raster format represents real-world phenomena, such as:

- Thematic data (also known as discrete), representing features such as land-use or soils data.
- Continuous data, representing phenomena such as temperature, elevation or spectral data such as satellite images and aerial photographs.
- Pictures, such as scanned maps or drawings and photographs of buildings.

Non Spatial / Attribute data

Attribute data describes the characteristics of spatial features.

3.8.2.3 Data input

The data input component converts data from their existing form into one that can be used by the GIS. Geo-referenced data are commonly provided as paper maps, tables of attributes, electronic files of maps and associated attributes data, air photos, and even satellite imagery. The data input procedure can be as straight forward as a file conversion from one electronic format to another, or it can be complex. Data input is typically the major bottleneck in the implementation of a GIS hardware and software.

3.8.2.4 Data analysis and out put

Data analysis is the key for extracting meaningful information from database. The various possible manipulation and analysis operations on GIS are: overlaying different thematic layers, computing areas, proximity/corridor analysis, arithmetic and logical operations, scale changes, vector to raster conversions, etc. Systematic presentation of data is essential for effective utilization and retrieval of information. This can be done by providing large symbol set, colour/ pattern fills, different line types, etc. Data may be presented as maps, tables, figures, graphs and charts. One of the greatest advantages of using remote sensing data for hydrological investigations and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful analysis, prediction and validation (Sarma and Saraf, 2002). The remote sensing system remains as a powerful tool for the collection of classified spatial data and the GIS acts as a powerful tool for the management and analysis of spatial data. Most of the GIS utility maps as their primary source of spatial data and remote sensing systems produce such spatial data in the form of maps. The interpreter generally utilizes these complex maps for visual search and retrieval but when the same data are digitised, GIS is the best for their integration. For finding out groundwater potential zones, GIS can play a vital role for demarcation of various zones. In this study the remote sensing and GIS have been applied

a) For the preparation of various thematic maps and land use pattern

b) To delineate the groundwater potential zone of Kuttiyai River Basin.

3.8.3 Description of Thematic Maps

3.8.3.1 Geology

The lithology of the study area is dominated by Khondalite gneiss (77%) and all along the coast the fluvial coastal sediments are seen and adjacent to coastal sediments the Warkali Formation (12.3%) is present. The major distinct geomorphic units in the area are namely lower plateau lateritic and valley flats. The coastal belt with alluvial and beach deposit underlain by laterite, yields abundant of water. Thick laterite layers are porous and slightly permeable, so the layers can function as aquifers. Fig.3.4 represents the geological units of the Karamana River Basin. Their aerial extent in sq. km and in percentage are presented in Table 3.10.

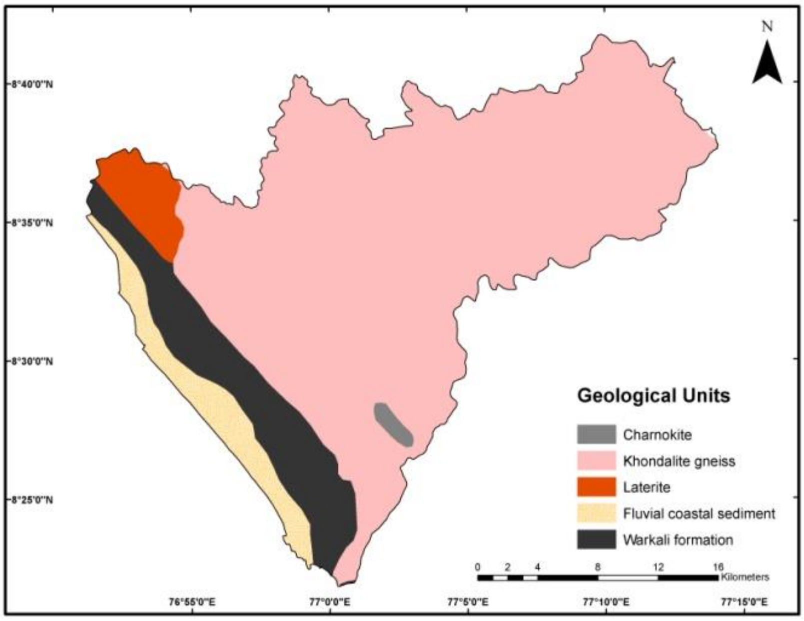


Fig. 3.4 Geological units of Karamana River Basin

Table 3.10 Aerial Extent of Geological units of KRB

Geological units	**Area in sq. km**	**Area in Percentage**
Charnokite	3.635	0.52
Fluvial coastal Sediment	43.69	6.22
Khondalite Gneiss	542.21	77.19
Laterite	26.6	3.79
Warkali formation	86.3	12.29
Total	**702.44**	**100**

3.8.3.2 Geomorphology

The geomorphological units identified in the basin in the ascending order of their groundwater prospects are: Lower plateau Lateritic units, Valley fills, Flood plain, Channel bar, Beach and swale complex are found in Karamana River Basin that are characterized by various lineament intersections. Geomorphological units are given with more weightage for demarcating potential zone for groundwater. 64 % of the area is covered with lower plateau lateritic type and 11 % of the river basin towards the eastern and north-eastern area is covered with denudational hills. The Fig. 3.5 and Table 3.11 shows geomorphological units and their aerial extent in Karamana River Basin.

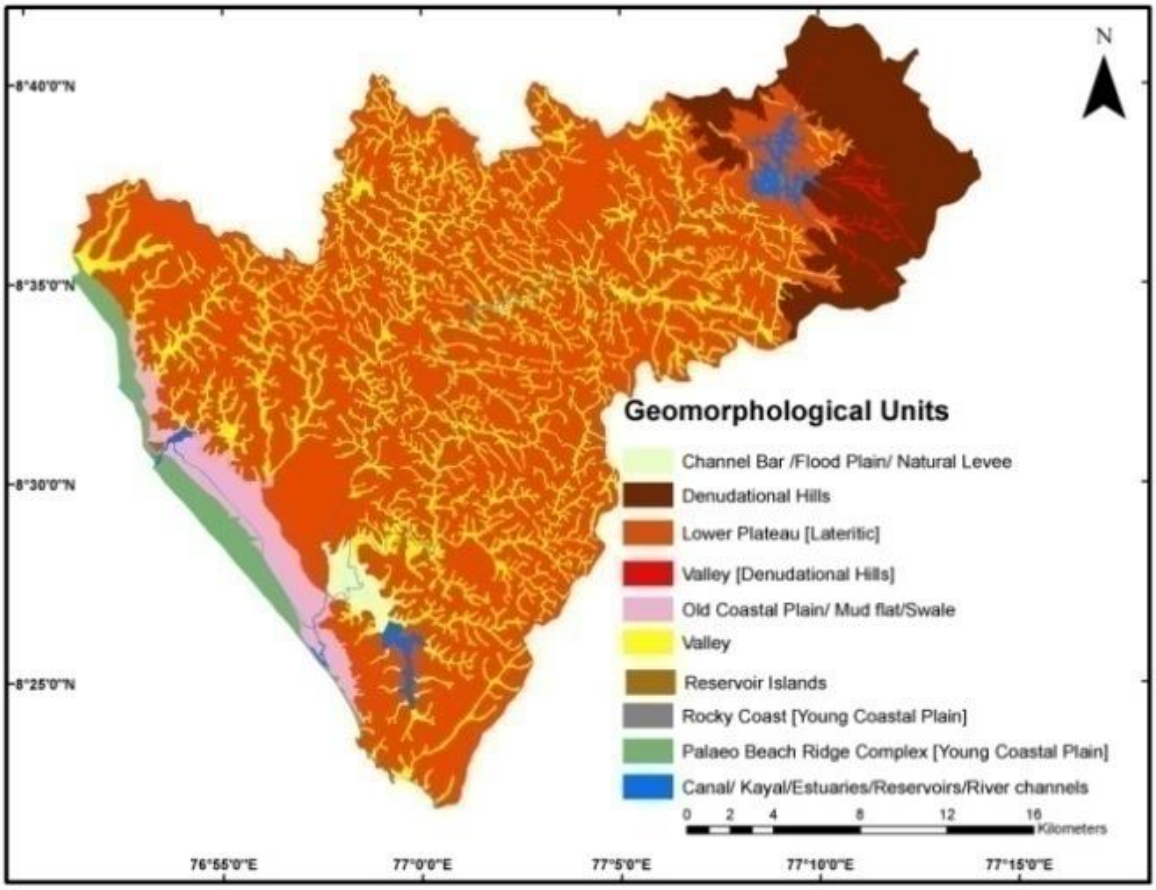


Fig. 3.5 Geomorphological units of Karamana River Basin

Table 3.11 Aerial Extent of Geomorphological units of KRB

Geomorphological units	Area in sq. km	Area in Percentage
Denudational Hills	77.92	11.093
Beach [Young Coastal Plain]	0.93	0.132
Young Coastal Plain	6.74	0.960
Valley	106.49	15.160
Rocky Coast [Young Coastal Plain]	0.16	0.023
Swale [Old Coastal Plain]	0.07	0.010
Water Body Mask	7.4	1.053
Old Coastal Plain	25.94	3.693
Flood Plain	5.47	0.779
Channel Bar [Flood Plain]	0.07	0.010
Natural Levee [Flood Plain]	1.03	0.147
Older Mud Flat [Old Coastal Plain]	1.69	0.241
Palaeo Beach Ridge Complex [Young Coastal Plain]	13.28	1.891
Lower Plateau [Lateritic]	447.26	63.672
Kayals/Estuaries	0.64	0.091
River Channel	3.26	0.464
Canal	0.43	0.061
Valley [Denudational Hills]	3.01	0.429
Reservoir Islands	0.37	0.053
Swale [Young Coastal Plain]	0.28	0.040
Total	**702.44**	**100**

3.8.4 Digital Elevation and Slope map

The Digital Elevation Model (DEM) derived from the SRTM 90 m resolution reveals that the eastern region of the area under investigation is highly undulating. The higher elevation of 1610 m above mean sea level is associated with denudational hills in the eastern region (Sarkar et al., 2001).

have evaluated groundwater potentiality of Shamri micro watershed in Himachal Pradesh using remote sensing and Geographic Information System and found that lineaments and slope play a key role in the groundwater occurrence. DEM (Fig. 3.6) and slope map of the area generated from SRTM data also used for the study.

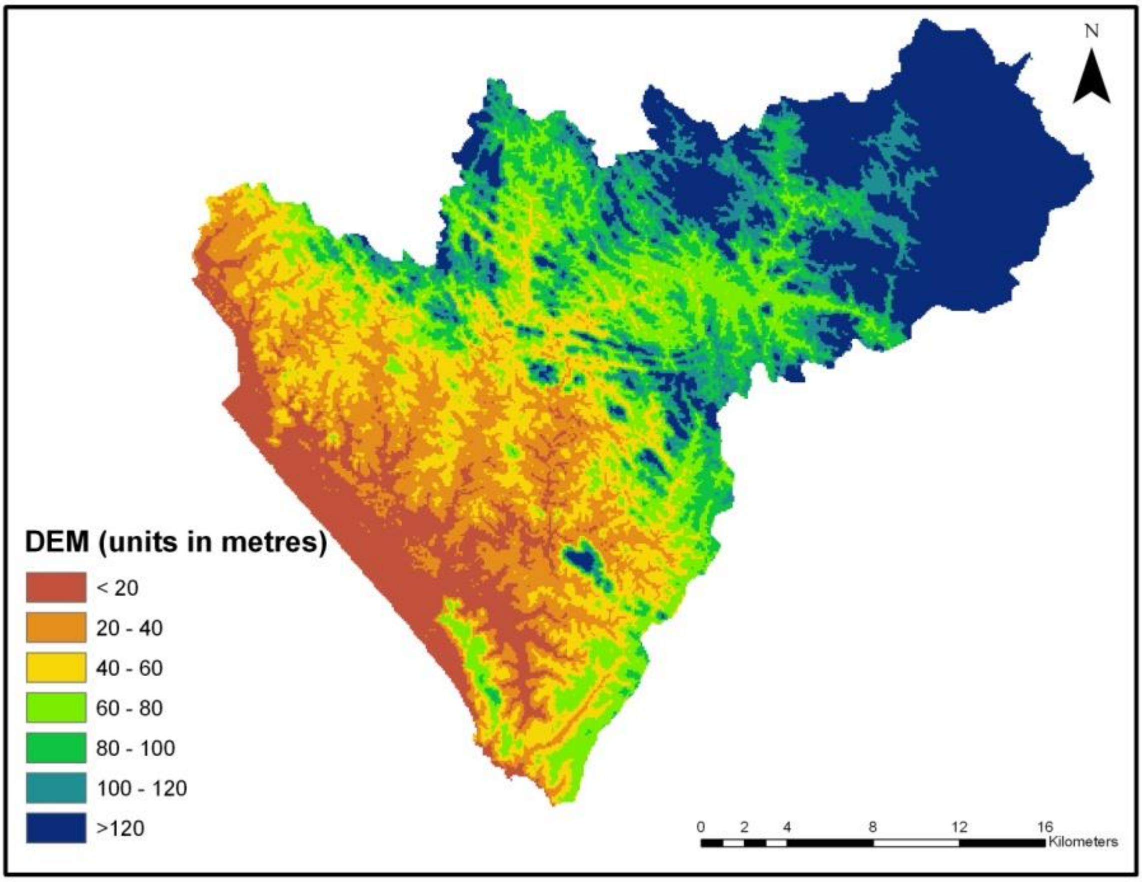


Fig. 3.6 DEM of Karamana River Basin

Shuttle Radar Topography Mission (SRTM) is a joint project between The National Geospatial Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA). The objective of this project is to produce digital topographic data for 80 % of the earth's land surface (all land areas between 60^0 north and 56^0 south latitude) with data points located every 1-arc second (~ 30m) on a latitude/longitude grid. The absolute vertical accuracy of the elevation data will be 16 m. This radar system will gather data that will result in the most accurate and complete topographic map of the earth's surface that has ever been assembled (Lillesand et al., 2008). SRTM made use of a technique called Radar Interferometry. In Radar Interferometry two radar images are taken from slightly different locations. Differences between these images allow for the calculation of surface elevation. To get two radar images taken from different locations the SRTM hardware consisted of one radar antenna in the shuttle payload bay and a second radar antenna attached to the end of a mast extended 60m out from the shuttle. The SRTM obtained elevation data on a near global scale to generate the most complete high resolution digital topographic data base of the earth. SRTM consisted of a specially modified radar system that flew onboard the space shuttle endeaour during an 11- day mission in February 2000. There are three resolution outputs available including 1 km and 90 m for entire world and 30 m for the US (http://srtm.usgs.gov/).

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, whereas, 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 there is general increase in the slope percentage towards north-eastern part of the basin (Fig. 3.7). In the preparation of groundwater prospecting map least weightage is given to steep dip (>20%) whereas more weightage is given to gentle slope (0 – 5%) as slope plays a significant role in infiltration verses runoff. Table 3.12 shows the aerial extent of slope classes in Karamana River Basin.

Table 3.12 Aerial Extent of Slope classes of KRB

Slope (in %)	Area in sq. km	Area in Percentage
0 - 5	273.76	38.97
5 -20	351.22	50.0
> 20	77.46	11.03
Total	702.44	100

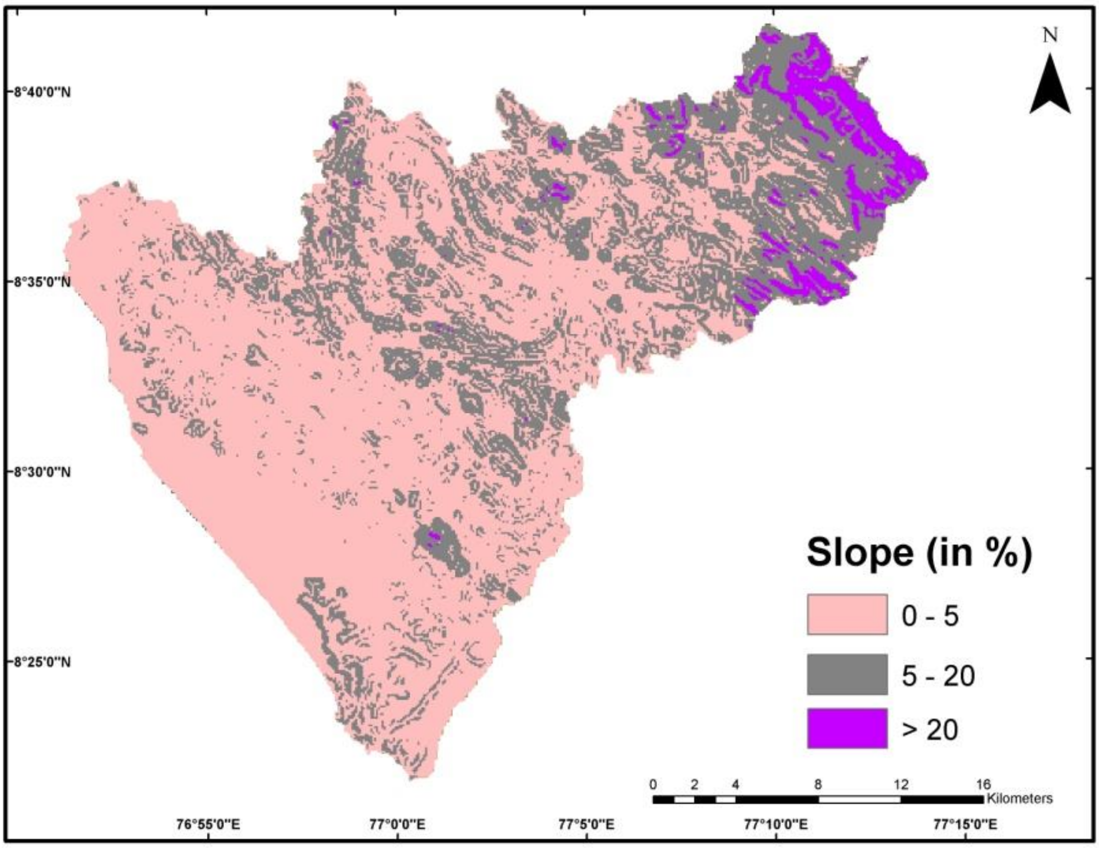


Fig.3.7 Slope map of Karamana River Basin

3.8.5 Land Use and / Land Cover Map

One of the parameters that influence the occurrence of sub-surface groundwater occurrence is the present condition of land cover and land use of the area. Land use describes how a parcel of land is used for agriculture, settlements or industry, whereas land cover refers to the material such as vegetation, rocks or water bodies, which are present on the surface (Anderson et al., 1976). For instance the rate of infiltration is directly proportional to the crown density of forest cover i.e., if the surface is covered by dense forest, the infiltration will be more and the runoff will be less. Due to urbanisation, the rate of infiltration may decrease (Sarkar et al., 2001). The land use /land cover map shows that there is rapid growth in urbanization in all directions around the Thiruvananthapuram City. The upper reaches of Karamana River Basin is covered with dense forest and as coming towards the west direction the major type of landuse is mixed crop with coconut. Table 3.13 and Fig. 3.8 shows land use/ land cover of Karamana River Basin.

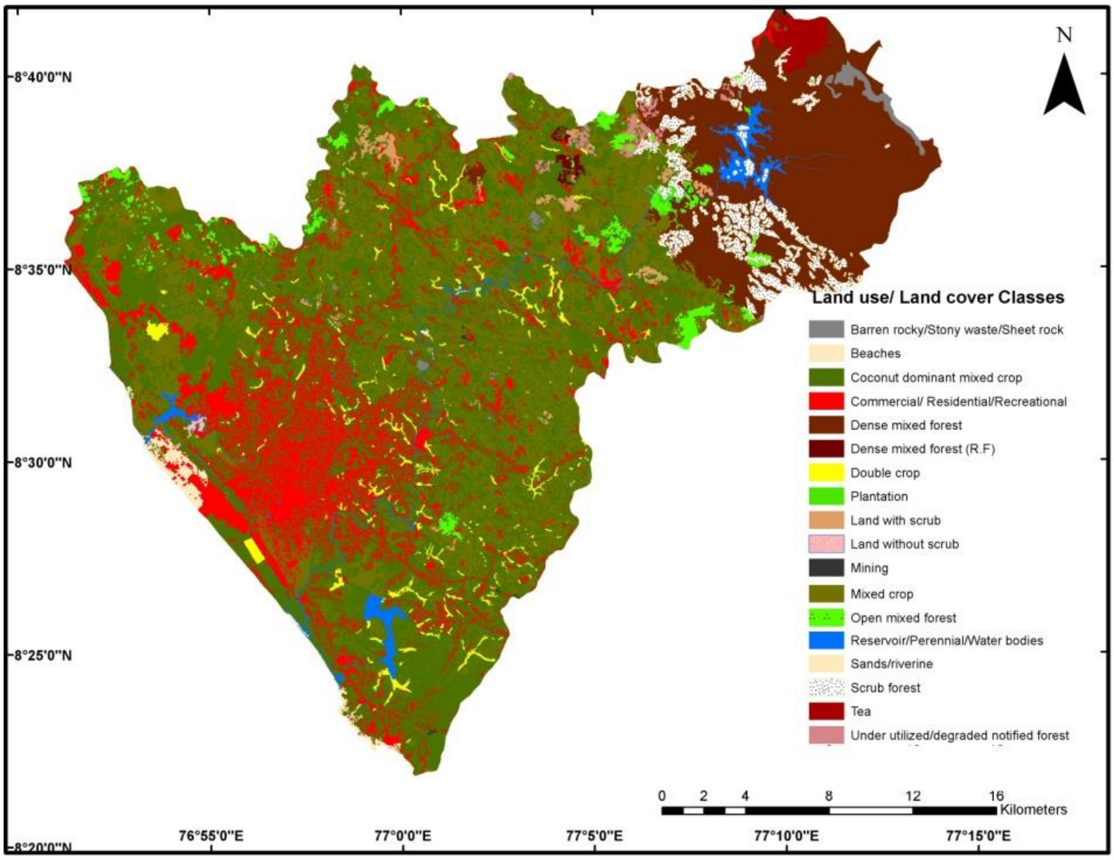


Fig. 3.8 Land use/ land cover of Karamana River Basin

Table 3.13 Aerial Extent of Land use/ Land Cover classes in KRB

Landuse/Land cover Classes	**Area in sq. km**	**Area in Percentage**
Banana	1.2	0.171
Barren Rocky land/ Stony Water/Sheet rock	3.55	0.505
Coastal sand	6.79	0.967
Coconut	12.38	1.762
Commercial	27.32	3.889
Dense	99.78	14.205
Double crop	8.31	1.183
Eucalyptus	0.98	0.140
Land with scrub	5.42	0.772
Land without Scrub	0.47	0.067
Mining	0.26	0.037
Mixed Built up land	44.18	6.290
Mixed crop	398.12	56.677
Open	0.05	0.007
Perennial	4.24	0.604
Reclaimed -Perennial	20.63	2.937
Reclaimed -Seasonal	4.09	0.582
Residential	31.28	4.453
Rubber	1.18	0.168
Rubber (RF)	0.24	0.034
Sand/ Riverine	0.09	0.013
Scrub Forest	16.5	2.349
Tea	5.19	0.739
Underutilized/degraded notified	3.39	0.483
Water bodies/ Reservoir	6.8	0.968
Total	**702.44**	**100**

3.8.6 Drainage Network Map

The Karamana Basin is a sixth order basin with trellis pattern in the upper reaches and dendritic drainage pattern in the mid land region. The stream order has been computed based on the method of Strahler (1964). Stream order provides information about topography, runoff and drainage network. Higher number of streams is developed in areas of impermeable lithology and higher slopes. The drainage map of Karamana River Basin is as shown in Fig. 3.9. Basin length, which is the maximum length of the basin parallel to the main trunk measured from mouth to origin, is about 40.2 km. Of this, about 11 km falls within an elevation of 80 m. Stream order provides information about topography, runoff and drainage network. In the different sub basins of Karamana, the number of streams is higher in those of higher relief and slope. The total number of stream segments in the basin account to 2260.

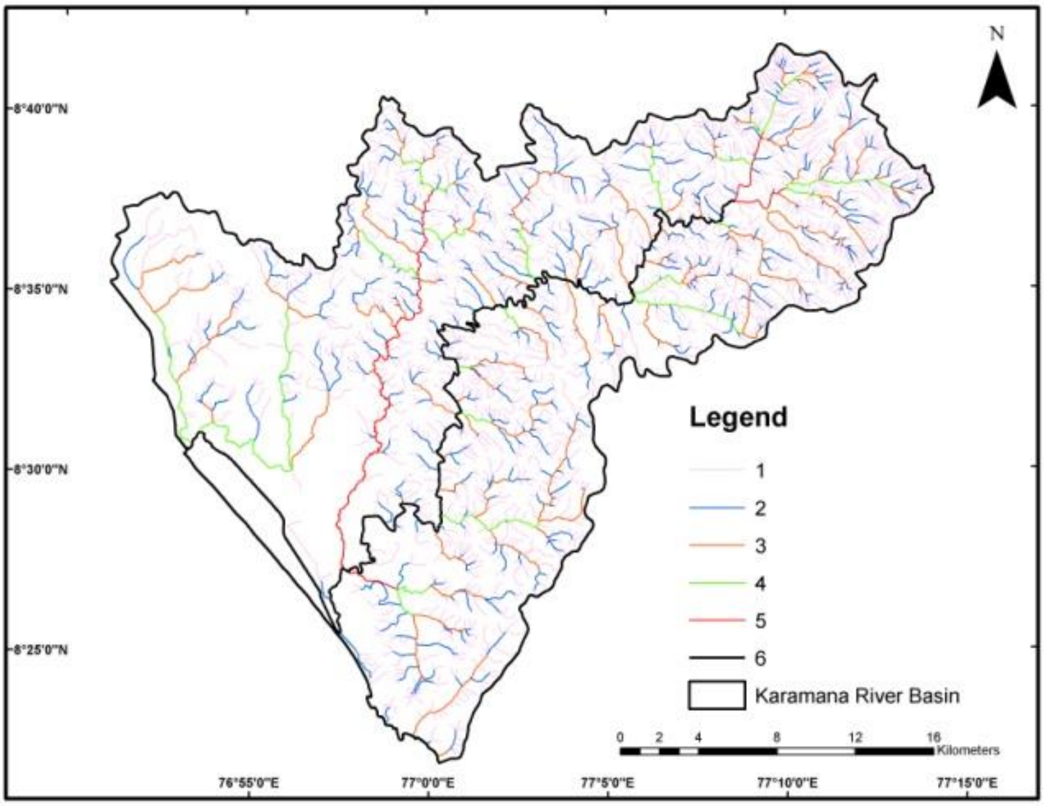


Fig. 3.9 Drainage network of Karamana River Basin

3.8.7 Drainage Density Map

Drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. Areas having high density are not suitable for groundwater development because of the greater surface run off. In the present study the extreme upstream part of the basin showing high Drainage density (0.9 – 4.53 km/ km^2). Low values of Drain density occur for basins in areas with highly permeable sub soil and thick vegetation cover. Fig. 3.10 shows Drainage density map of Karamana River Basin.

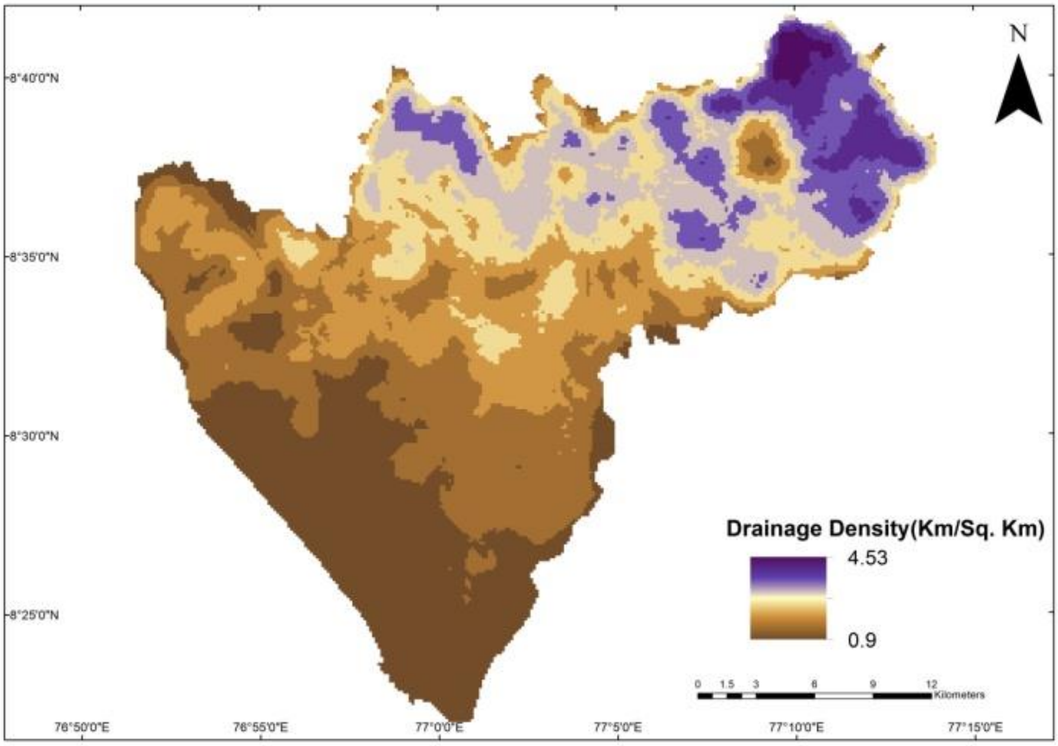


Fig. 3.10 Drainage density map of Karamana River Basin

3.8.8 Development of groundwater prospect zone

The indiscriminate use of this vital natural resource is creating groundwater mining problem in various parts of world hence, the groundwater resource should be evaluated thoroughly, carefully and reliably to meet the ever growing needs (Todd, 2005). The final integrated map was generated by applying the weighted sum analysis of Spatial Analyst tool in ArcGIS 9.1 software and this technique provides a better method for combining multiple thematic maps like by applying a common measurement scale of values to each raster, weighting each according to its importance and adding them together to create an integrated map (Girish, 2003). The final integrated map as generated by applying the weighted sum analysis in ArcGIS. The weightages are assigned as per the rank and weight given below in Table 3.14. This technique provides a method for combining multiple thematic maps by applying a common measurement scale of values to each raster, weighting each according to its importance and adding them together to create an integrated map.

Table 3.14 Weightage, rank and score assigned for different groundwater controlling Parameters

Geomorphology (weight-4)		
Geomorphological units	Rank	score
Denudational Hills	1	4
Beach [Young Coastal Plain]	4	16
Young Coastal Plain	4	16
Valley	3	12
Rocky Coast [Young Coastal Plain]	1	4
Swale [Old Coastal Plain]	2	8
Water Body Mask	4	16
Old Coastal Plain	4	16
Flood Plain	3	12
Channel Bar [Flood Plain]	3	12
Natural Levee [Flood Plain]	3	12
Older Mud Flat [Old Coastal Plain]	4	16
Palaeo Beach Ridge Complex [Young Coastal Plain]	1	4
Lower Plateau [Lateritic]	3	12
Kayals/Estuaries	4	16
River Channel	4	16
Canal	4	16
Valley [Denudational Hills]	1	4
Reservoir Islands	3	12
Swale [Young Coastal Plain]	3	12

Landuse/land cover (weight-1.5)		
Class	Rank	Score
Banana	3	4.5
Barren Rocky land/ Stony Water/Sheet rock	1	1.5
Coastal sand	4	6
Coconut	3	4.5
Commercial	1	1.5
Dense	1	1.5
Double crop	3	4.5
Eucalyptus	1	1.5
Land with scrub	1	1.5
Land without Scrub	1	1.5
Mining	1	1.5
Mixed Built up land	1	1.5
Mixed crop	2	3
Open	1	1.5
Perennial	4	6
Reclaimed –Perennial	4	6
Reclaimed –Seasonal	3	4.5
Residential	1	1.5
Rubber	1	1.5
Rubber (RF)	1	1.5
Sand/ Riverine	4	6
Scrub Forest	1	1.5
Tea	1	1.5
Underutilized/degraded notified	1	1.5
Water bodies/ Reservoir	4	6
Slope (weight-2.5)		
Slope (in %)	Rank	Score
0 to 5	4	6
5 to15	2	3
> 20	1	1.5

Geology(weight-1)		
Geological units	Rank	Score
Charnokite	1	1
Fluvial coastal Sediment	4	4
Khondalite Gneiss	1	1
Laterite	3	3
Warkali formation	2	2
Drainage density(weight-1)		
Drainage density	Rank	Score
0.9 - 1.8075	4	4
1.8075 - 2.715	2	2
2.715 - 3.6225	2	2
3.6225-4.53	1	1

In the present study the weighted sum analysis has been carried out by giving rank to individual parameters and weights to individual themes, according to their degree of prospect. Each theme was assigned a weightage depending on its influence on the movement and storage of groundwater and each unit in every theme map is assigned a knowledge based ranking depending on its significance to groundwater occurrence. The potential zones in the river basin is categorized as very good, good, moderate and poor depending on their characteristics to hold groundwater. Fig. 3.11 shows the Groundwater Prospect Zone Map of Karamana River Basin.

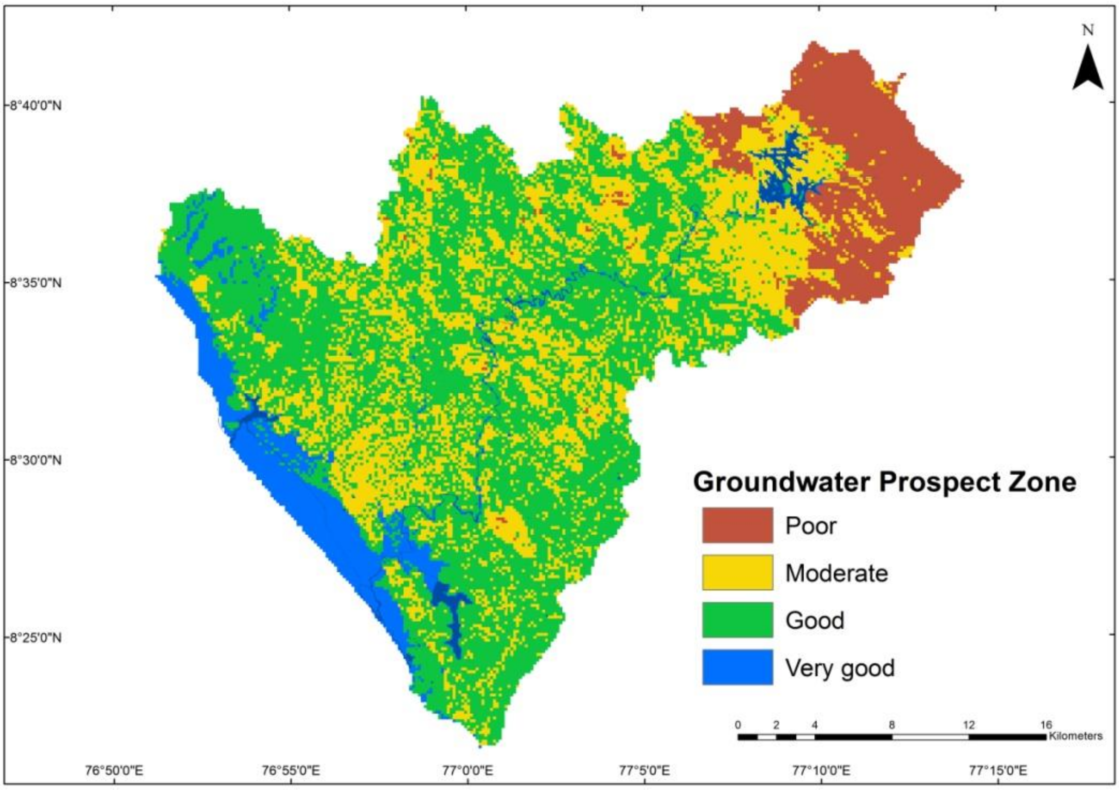


Fig. 3.11 Groundwater Prospect Zones in Karamana River Basin

A stretch of land along the coastal belt, the region near to Vellayani Lake and reservoir towards the north-eastern part of the study area are coming under the zone designated as very good (10.8 % of the basin area). But the upstream premises to the reservoir having Denudational hills (slope greater than 20 %) and with high drainage density is categorised under poor prospect zone. The extreme north-east and south-east part of the basin area is deficient in groundwater availability, i.e., 8 % of the basin area is coming under the zone poor. 31% of the basin area is having a significant quantity of groundwater resource, thus the area is designated as good zone. As the area near to coastal belt is urbanized, this has accounted over abstraction of groundwater has impounded a negative impact to the quality and quantity of groundwater in the shallow aquifers. About 50 % of the study area is showing a moderate prospect in holding groundwater. Innovative technique like remote sensing and GIS have an immense role for the preparation of groundwater prospective zone mapping, for the sustainable development and more realistic data for the decision making policy. This potential map would provide first-hand information to local authorities and planners about the area suitable for pinpointing the exploration of prospective wells and quality of the groundwater. The flow chart given below clearly illustrates the methodology for demarcating the groundwater zone.

3.9 RESULTS AND DISCUSSION

The morphometric parameters were classified under as (1) Basic Parameters and (2) Derived parameters. Salient features of the morphometric attributes such as areal and relief parameters of the basin of Karamana River as determined are discussed below. The drainage pattern observed for Karamana River Basin is dominantly dendritic in the lower reaches which is expressed by homogeneity of texture and is indicative of lack of any significant structural control.

Horton (1945) and Schumm (1956) observed that stream numbers, stream length and total lengths are related to stream orders in a geometric series. Considerable correlation are shown in the relations of stream numbers (r=0.79), mean stream lengths (r=0.72) and total stream lengths (r=0.82) with stream orders. The significant relationship of stream length and stream number with stream order indicates uniformity of the geological setting, area and no large fluctuations of relief and slope. The slight dip in correlation between mean stream lengths and stream order is due to the disproportionate length of the sole sixth order channel in the Karamana Basin (SW VII).

The fundamental characters of drainage basin (size, length, relief etc.) are used to interpret for the various fluvial processes. Among the three sub watersheds in the high relief areas, SWI &SW II show maximum values for drainage density, relief and slope and lowest values for length of overland flow and constant of channel maintenance. They belong to the category of ultra-fine drainage texture. This is aided by the occurrence of the resistant charnockitic terrain and thick vegetation of the area. The bifurcation ratios falling between 3 and 5 are generally attributed to considerable structural control.

However, SWI and II though ultrafine textured, has significantly low drainage densities (3.83 and 3.58) when compared to their stream frequencies. Mean stream length of SWI and II are lower than other sub watersheds for all orders. This deviation might be due to this change in slope and topographic elevations. The highest value for Fs as exhibited by SWI and II is likely due to the occurrence of closely spaced minor fractures/lineaments. This could, at least partially account for its very fine textured nature. The trend and disposition of Western Ghats, where these sub basins fall is controlled by different sets of fracture zones (Soman, 2002). It is reported that the extent, shape, boundary and layout of the sub basins of some river systems originating in Western Ghats are defined by these fracture zones (Nair et al., 2014). This is very evident in the trellis to rectangular patterns of SW I and II all along their lengths. Apparently, lineaments have a strong role in the genesis and characters of these sub basins. The sub basin is evidently not in complete equilibrium with the different components of environments and the drainage has not completely filled the basin (Ritter et al., 1995).

SW VII carries the sixth order channel and encompasses about 50% of the total basin area. It envelopes a wide range of elevation and slope, from the high lands right to the sea level. From figures (Fig. 3.9 and 3.10) it is seen that the drainage frequency and density is high in the elevated parts which gradually become low toward the coast. The high occurrence of lineaments and steep gradients may account for this trend. The influence of slope and elevation on texture is seen in SW IV, V and VI which fall exclusively in the coastal stretch with lowest slope gradients. These have the coarsest texture with wide spacing of stream channels. This is reflected in their low stream densities and frequencies, resulting in their very coarse texture. Lo and C values are proportionally high. An interesting observation is the high texture value (5.57) exhibited by SW VI compare SW IV and V in spite of the low relief (88 m) of the former. The lithology of the southern part of the Karamana River Basin is dominated by crystalline khondalite rocks, while toward the northern part thick blanket of laterite characterize the landscape. Resistant rocks like khondalite nature give rise to more surface flow and consequent high drainage density. Laterite is reputed to encourage percolation of groundwater, diminishing the surface drainage. SW III exhibits intermediate values in relief, texture and ruggedness to those of SW IV and V and rest of the sub basins.

Ruggedness number is another vital index of dissection and run-off and the resultant erosion of a basin. The ruggedness number too follows the trend in texture exhibiting high values for SWI (4.82) and SW II (5.39). Thus these sub watersheds tend to have high runoff, high erosion potential and sediment load, low base flow and infiltration and high capacity for surface water storage. This would result in considerable potential for flood with higher peak flows (Schumm 1963 and Strahler 1957). SWI and SWII are heavily forested since the humid climate and the heavy seasonal rainfall of the region support lush vegetation that encourages permeability and consequently subdues surface runoff (Ritter 1995). Moreover, as mentioned above the resistant charnockitic terrain of Western Ghats that forms the high relief part of the basin is expected to result in high drainage density. However, the effect of dense vegetation in the basins is counteracted by the substantial relief, slope, stream density and frequency values in SW I and II. SWI, though of lower relief and slope, has high runoff (as evidenced by its fine texture), a likely reflection of its significant fracture/lineament control. The strong stream frequency and the influence of structure would be fully revealed only by more detailed field and remote sensing studies.

The Karamana River as a whole is characterized by gentle slope (0.04) and high relief (1609 m.). The basin has intermediate texture (7.36/km), moderate drainage density (2.29 km/km^2), frequency (3.22/ km^2), low constant of channel maintenance (0.44 km^2/km) and length of overland flow (0.22 km). Values for drainage density and constant of channel maintenance suggest that river basin has moderate run off, low erosion potential and sediment load, high groundwater storage and base flow. Intermediate drainage texture and moderate ruggedness values point to the subdued flood potential of Karamana River Basin.

Morphometric analysis of Karamana River Basin reveals it to be a 6th order basin with 2260 streams with total stream length of about 1606 km). The number of first order streams is 1695 and area of basin is 702 km^2. Out of seven sub watersheds, the smallest sub basins possesses highest values for relief and slope. SW VI is of lowest gradient (0.001) and relief (81 m). This basin and SW IV and V fall mostly in coastal stretch with gentle slopes (0.001).

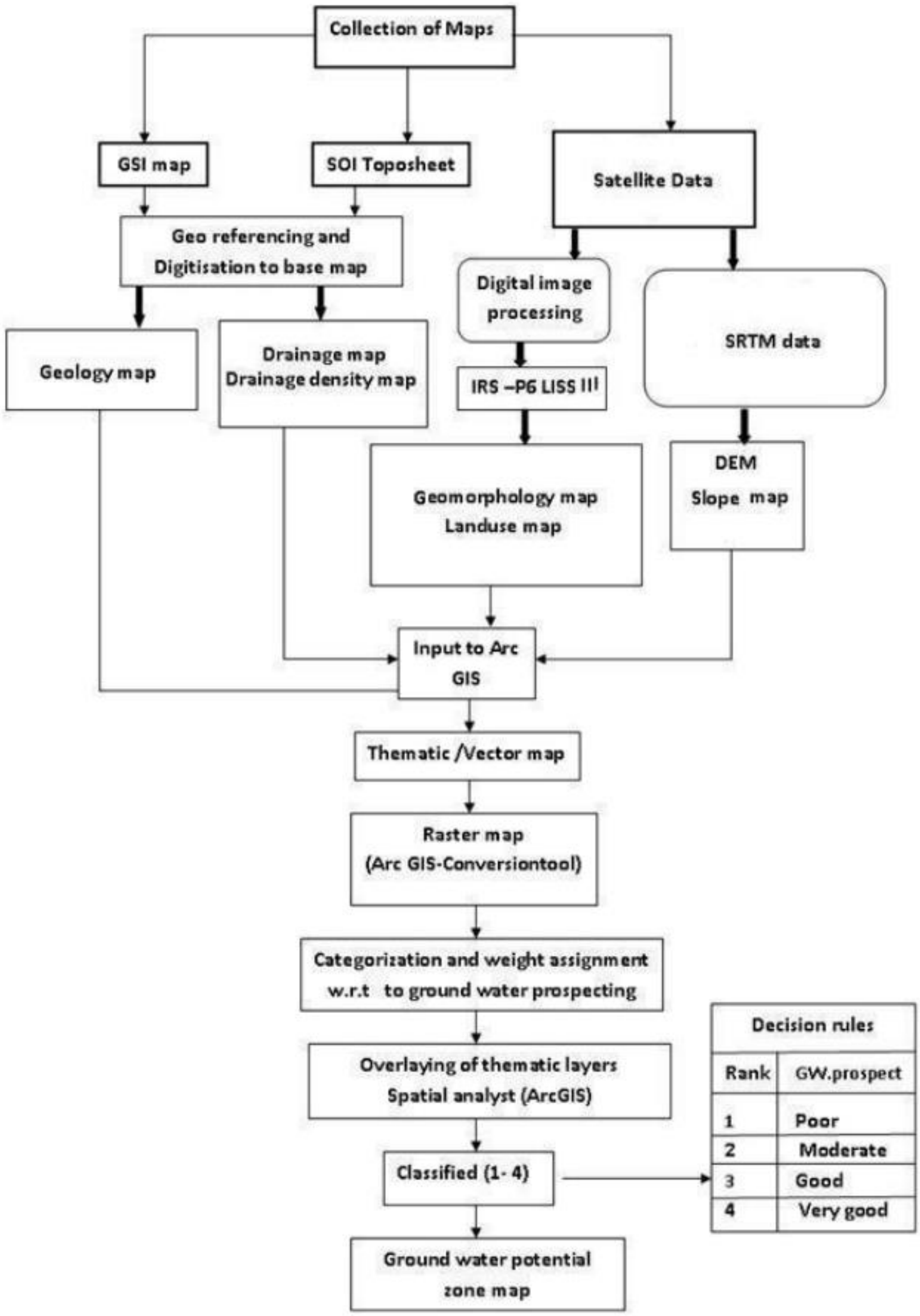


Fig. 3.12 Flow chart showing the methodology for groundwater prospect zone delineation.

CHAPTER - IV

WATER QUALITY AND RESOURCE POTENTIAL

Water resources of any region constitute mainly surface water and groundwater, with rainfall being the basic source. The primary concerns pertaining to water resources center around water resource management, specifically related to both quantity and quality issues and conservation of existing water resources to prevent further degradation and depletion. Other related measures are rejuvenation of degraded traditional surface water bodies (like ponds), enhancement of availability through water harvesting measures and ensuring adequate recharge of aquifers. More important is the judicious and economic use of both ground and surface water in agricultural, domestic and industrial sectors.

In the national and state water policies, drinking water receives first priority, followed by irrigation, industry, power, fishing and recreation. With increasing population, urbanization and industrialization, drinking water naturally receives the highest priority. In a regional perspective, there is significant variation in per capita fresh water availability for different population groups and other sectors.

This present chapter focuses on the water quality and resource potential of Karamana River Basin. The quantitative assessment is made on the basis of available data while in the present study emphasis is made on qualitative assessment of water resources, both surface and subsurface, of the basin as wells their resource potential. The chapter also treats current utilization status of surface and subsurface water resources, and also on possible future demands.

The various sources of water of the Karamana River Basin can be classified into two categories:

(1) Surface sources, such as (a) Ponds and lakes, (b) Network of streams, (c) Reservoirs and

(2) Sub-surface sources, such as (a) Springs, (b) Wells (c) Tube wells

Among the numerous ponds scattered throughout the basin, except in the case of a few, most of them are ephemeral. Large man-made ponds or pools of standing water are found in the lowland and midland zones of the basin. Many of these are temple ponds or irrigation ponds. There are nearly hundred small and large ponds found scattered within the basin and majority of valley head ponds supply water for irrigating paddy crop

Vellayani Kayal, the largest natural freshwater body in the Karamana River Basin, is elongate and aligned roughly in the N-S direction, with a maximum water depth of 2.30 m. It has significantly wide peripheral lacustrine plain which is seasonally inundated during high waters of the monsoon season. Vellayani Lake and its catchment cover an area of 38 km^2 and Fig. 4.1 shows the Geological map of Vellayani Kayal and the catchment area which includes parts of Thiruvallam, Nemom, Kalliyoor, Pallichal, Venganoor and Vizhinjam panchayaths. Effective catchment of the bunded area of the lake is only 21 km^2 and the areal spread of the perennial water body is only 0.84 km^2 and it goes up to 3 km^2 during monsoon floods. The Kayal is linked by a canal to the Karamana River to the northwest Studies show that nearly 75 % of the paddy fields of the peripheral regions of the Kayal have been converted to garden land for agricultural purposes.

4.1 WATER BALANCE ESTIMATION

Water balance estimation is an important tool to assess the current status and trends in water resource availability in an area over a specific period of time. Furthermore, water balance estimates strengthen water management decision-making, by assessing and improving the validity of visions, scenarios and strategies Water balance techniques, one of the main subjects in hydrology, are a means of solution of important theoretical and practical hydrological problems. On the basis of the water balance approach, it is possible to make a quantitative evaluation of water resources and their change under the influence of anthropogenic activities.

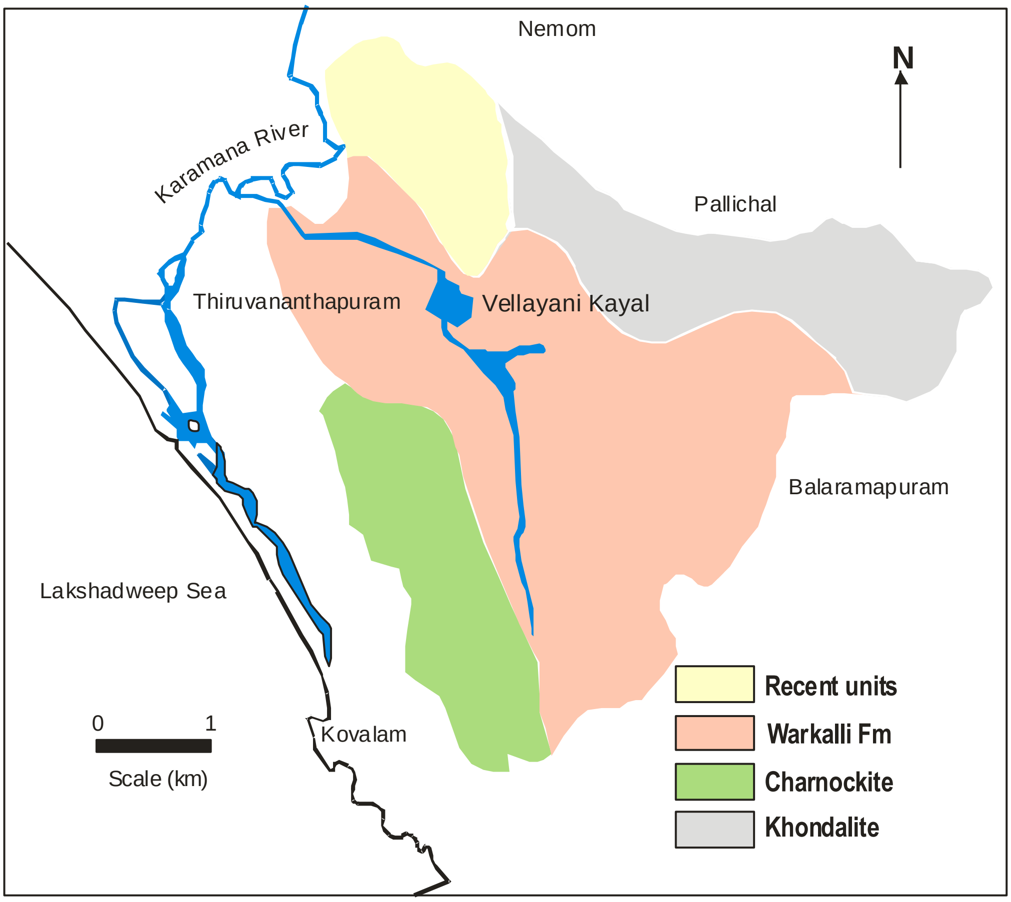


Fig. 4.1 Geological Map of Vellayani Kayal and its catchment

The simplest form of water balance equation is as follows:

$$P = Q + E \pm \Delta S$$

where, P is precipitation, Q is runoff, E is evaporation and ΔS is the storage in the soil, aquifers or reservoirs. In water balance analysis, it is often useful to divide water flows into 'green' and 'blue' water. 'Blue' water is the surface and groundwater that is available for irrigation, urban and industrial use. 'Green' water is water that has been stored in the soil and that evaporates into the atmosphere. The source of 'green' water is either rainfall or 'blue' water used in irrigation.

4.2 BASIC WATER QUALITY CONCEPTS

Water in its chemically pure form occurs rarely in nature. It is commonly found to carry a variety of constituents. Man's influence on water quality is quite apparent and is today a major concern. Efficient drainages and agricultural practices may result in drastic changes in the water quality of natural waters. Irrigation return waters also tend to increase total salts in the receiving water. Construction schemes, such as those connected with river training, flood control, low flow augmentation etc., considerably influence the quality regime of water. Mining activities often cause substantial water quality changes.

4.3 GENERAL CONSIDERATIONS OF DRINKING WATER QUALITY

Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking water can result in tangible benefits to health and therefore every effort should be made to achieve drinking water that is safe as practicable.

Safe drinking-water, as defined by World Health Organisation (WHO), is the one that produces no significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. The nature and form of drinking-water standards varies among countries and regions. There is no single approach that is universally applicable. Climate change in the form of increased and more severe periods of drought or more intense rainfall events leading to flooding can also have an impact on both quality and the quantity of water and will require planning and management to minimize adverse impacts on drinking water. Climate change also needs to be considered in the light of demographic change, such as the continuing growth of urban centers, which itself brings significant challenges for drinking water supply.

The physical, chemical and biological/microbiological qualities which are required to be carried out in water quality analysis are described in the following sections, under acceptability, chemical and microbial aspects that are currently in use and provide authentic water quality data on analysis. The results are provided in Table in Annexure A1, A2, A3, A4, B1 (A), B1 (B), B2 (A), B2 (B), B3 (A) B3 (B). B4 (A) and B4 (B).

4. 4 ACCEPTABILITY ASPECTS - TASTE, ODOUR AND APPEARANCE

4.4.1 Physical parameters

The data of physical parameters are given in Annexure A1, A2, A3 and A4.

4.4.1.1 Turbidity

Earlier the turbidity measurement was done using Jackson Candle Turbidity meter. Nowadays it is measured by Nephelometry, a technique that measures level of light scattered by the particles at right angles to the incident light beam. The unit of expression is Nephelometric Turbidity Unit (NTU). In the present study, the turbidity suspension was prepared as per standard procedure (APHA, 2005). The IS values for drinking water is 10 to 25 NTU. Turbidity in the dug well shows variation from 0.5 NTU to 1.7 NTU, while in tube or bore well it varies from1 NTU to 3 NTU, but in ponds the variation is from 17 NTU to 24 NTU and river water reveals high variation from 12 NTU to 68 NTU.

4.4.1.2 Colour

The Platinum-Cobalt Scale (Pt/Co scale or Hazen Scale) is a color scale that was introduced in 1892 by Allen Hazen, based on dilutions of a 500 ppm platinum cobalt solution in distilled water. Slight discoloration is measured in Hazen units (HU). Colour standards and reagents were prepared as per details mentioned in (APHA, 2005)

4.4.1.3 Taste and Odour

A new method to estimate taste of water sample has been developed based on flavour known as 'Flavour Profile Analysis' (FPA). The character and intensity of taste and odour discloses the nature of pollution or the presence of microorganisms.

4.4.1.4 Temperature

Cool water is generally more palatable than warm water and the temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. The upstream side of the study area shows low temperature ranging from 21 to 25 whereas the temperature of the lowland of the study area ranges from 28 to 30.

4.4.2 Chemical parameters

The chemical parameters are given in Annexure B1 (A), B1 (B), B2 (A), B2 (B), B3 (A), B3 (B), B4 (A) and B4 (B).

4.4.2.1 pH

pH value denotes the relative acidic or alkaline condition of water. The overall pH range of natural water is generally between 6 and 8 and recommended pH range for treated drinking waters is 6.5 to 8.5, pH lower than 4 will produce sour taste and higher values above 8.5 have bitter taste. The upstream side of the study area shows low pH ranging from 4 to 5.5.

4.4.2.2 Electrical Conductivity (EC)

Electrical conductivity is an index to represent total concentration of salts or a measure of ion stable solids in water. It is expressed as micro Siemens per centimeter (µS/cm). Till late 1970's the units of EC were micro mhos per centimeter (µmhos/cm). High level of electrical conductivity indicates the pollution status of the water body as well as tropic level of aquatic body. Moreover, high conductivity may increase the corrosion characteristics of water. EC of tube or bore wells ranges from 111 µS/cm to 894 µS/cm, but in the case of shallow and deep dug well EC is ranges from 95 µS/cm to 956 µS/cm in monsoon period. In post monsoon it shows variation from 135 µS/cm to 1024 µS/cm, EC of ponds ranges from 598 µS/cm to 3421 µS/cm for both the monsoons.

4.4.2.3 Total Alkalinity (TA)

The alkalinity of water is a measure of its capacity to neutralize acids. It is due to the presence of carbonates, bicarbonate, borate, silicate and phosphate together with hydroxyl ions in free state and is expressed as mg/L in terms of calcium carbonate. The various forms of alkalinity are (a) hydroxide alkalinity, (b) carbonate alkalinity, (c) hydroxide plus carbonate alkalinity, (d) carbonate plus bicarbonate alkalinity, and (e) bicarbonate alkalinity. In natural waters, the major portion of the alkalinity is caused by hydroxide, carbonate and bicarbonate that may be ranked in order of their association with high pH values. Alkalinity is an important parameter in evaluating the optimum coagulant dosage. Highly alkaline waters are usually unpalatable and excess alkalinity in water is harmful for irrigation which significantly leads to soil damage and reduce crop yield.

Titrimetric method has been adopted for the determination of total alkalinity. In the KRB, TA is ranging from 006 to 1.575 for both the monsoons in dug well, but in case of tube or bore well it ranges from 0.12 to 6.22.

4.4.2.4 Total Dissolved Solids (TDS)

Water as it travels in the atmosphere, through ground or over the land, dissolves a large variety of substances or salts. These substances in solution exist in their ionic form. The major cations (positively charged ions) comprise of calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}) and potassium (K^{+}) and the associated anions basically the sulphate (SO_4^{-}), bicarbonate (HCO_3^{-}) and chloride (Cl^{-}). Total dissolved solids (TDS) in water are the residues left after evaporation of the filtered water sample. The divalent cat ions (those having two positive charges) are responsible for the hardness of water. Other ions which may be present in smaller concentrations are B, F, Fe^{++}, Mn^{++}, and nitrate (NO_3^{-}). The aggregate salts are measured as total dissolved solids (TDS). As a rough approximation waters having less than 1500 mg/L TDS can be considered fresh water. The sum total of foreign matter present in water is termed as 'total solids'. Total solids is the matter that remains as residue on evaporation of the sample and subsequent drying at a defined temperature (103 to 105 °C). TDS of water samples were determined by the evaporation method of the filtered sample followed by gravimetric analysis. TDS in shallow and deep aquifers of midland and highland is ranging between 218.5 and 394.6 mg/L, but in the case of tube or bore well it shows variation from 36.8 to 614.8mg/L, while TDS in pond water shows a range from 226 to 580 mg/l.

Many dissolved substances are undesirable in water. Total solids consist of volatile (organic) and non-volatile (inorganic or fixed) solids. Further, solids are divided into suspended and dissolved solids. Solids that can settle by gravity are settleable solids. The others are non settleable solids. Acceptable IS limit for total solids are 500 mg/L and tolerable limit is 3000 mg/L. Higher levels of dissolved solids is not desirable in water and may produce distress in livestock. It may cause foaming in boilers, undesirable taste, gastrointestinal irritation, corrosion and incrustation.

4.4.2.5 Total Hardness

Hardness of water is mainly due to divalent metallic cat ions, bicarbonates and carbonates, such as Ca^{2+} and Mg^{2+} present in it. Major anions associated with these cations are sulphates, carbonates, bicarbonates, chlorides and nitrates. This type of hardness resulting from carbonates and bicarbonates is called carbonate hardness. The principal hardness causing cations are elements such as calcium, magnesium, strontium, iron (ferrous) and manganese. The hardness caused due to the presence of chlorides, sulphates etc., is termed non-carbonate hardness. The total hardness of water is defined as the sum of calcium and magnesium concentrations, both expressed as calcium carbonate, in mg/L. Hardness is of two types, temporary or carbonate hardness and permanent or non-carbonate hardness. Temporary hardness is one in which bicarbonate and carbonate ion can be precipitated by prolonged boiling. Non-carbonate ions cannot be precipitated or removed by boiling, hence the term permanent hardness. Total hardness of water samples was estimated by EDTA titrimetric method (APHA, 2005). Extended its value for drinking water is 300 mg/L as $CaCO_3$. The degree of hardness of drinking water has been classified in terms of the equivalent $CaCO_3$ concentration Table 4.1.

Table 4.1 Classification of hardness (equivalent $CaCO_3$)

Soft	0-60 mg/L
Medium	60-120 mg/L
Hard	120-180 mg/L
Very hard	>180 mg/L

4.4.2.6 Calcium (Ca^{2+})

Calcium cations (Ca^{2+}) and calcium salts are among the most commonly encountered substances in natural waters, ranging from zero to several hundred milligrams per litre depending on the source. Calcium often is the most abundant cation in river water. Ca leads to poor lathering, deterioration of clothes, incrustation in pipes and scale formation. The Calcium content in the study area ranges from 32 to 78.4 mg/L in aquifer,13 to 78.7mg/L in tube well and from 5.1 to 12.20 mg/L in pond water.

4.4.2.7 Magnesium (Mg^{2+})

Mg leads to poor lathering, deterioration of clothes, incrustation in pipes and laxative effect as sulphate. In aquifer Mg varies from 0.5 to 9.5 mg/L but in tube or bore well it is from 0.7 to 5.2 mg/L, while in pond water it is of 0.65 to 5.6 mg/L.

4.4.2.8 Sodium (Na^{+})

Sodium compounds naturally end up in water. Na stems from rocks and soils not only in seas, but also in rivers and lakes. In aquifer water Na is ranges from 14 to 142 mg/L but in tube or bore well it ranges from 0.6 to 38.6 mg/L, while in pond water the variation is from 0.1 to 2.4 mg/L.

4.4.2.9 Potassium (K^{+})

Potassium occurs in various minerals from which it may be dissolved through weathering processes. In aquifer water, K^{+} ranges from 0.001 to 0.172 mg/L, while in tube or bore well it is from 0.1 to 5.4 mg/L where as in pond water it shows a variation from 0.26 to .65 mg/L.

4.4.2.10 Chloride (Cl^-)

Chloride ion usually enhances corrosive properties of water especially when such water is in contact with stainless steel materials. It also affects taste of water. Chloride ion may be present in water in combination with one or more of the cations of calcium, magnesium, iron or sodium. Chlorides of these minerals are present in water because of their high solubility in water. Chloride was estimated by Mohr's titration method. Excessive presence of chloride in water indicates sewage pollution. 12 to 306 mg/L of Cl^- is seen in aquifer water and in tube or bore well it shows a variation from 0.1 to 2.24 mg/L. In pond water ranges from 1.1 to 9.8 mg/L.

4.4.2.11 Carbonate (CO_3^{2-})

High carbonate and bicarbonate increases SAR (Sodium Absorption Ratio) index. Bicarbonate and carbonate ions combined with calcium or magnesium will precipitate as calcium carbonate or magnesium carbonate when the soil solution concentrates in drying conditions. The concentration of Ca and Mg decreases relative to sodium and the SAR index will be higher. This will cause an alkalizing effect and increase the pH. Therefore when a water analysis indicates high pH level, it may be a sign of a high content of carbonate and bicarbonates ions.

4.4.2.12 Sulphates (SO_4^{2-})

Sulphates occur in water due to leaching from sulphate mineral and oxidation of sulphides. Sulphates are associated generally with calcium, magnesium and sodium ions. Sulphate in drinking water causes a laxative effect and gastrointestinal irritation leads to scale formation in boilers. Sulphate is sometimes reduced by microorganisms and therefore causes foul odour. It leads to corrosion problems under aerobic conditions. Desirable limit for drinking water is 150 mg/L. The variation in sulphate content in the waters of aquifer, tube well and pond are 0.001 to 0.049 mg/L, 0.001 to 0.003 mg/L and 4.1 to 113 mg/L respectively.

4.4.2.13 Fluoride (F)

Excess fluoride ions in water leads to damage of teeth (dental fluorosis), skeleton and other organs of the human body. Fluoride was determined by SPADNS method (APHA, 2005). Permissible upper limit of fluoride of BIS is 1.5 mg/L in potable water for protection of teeth. Higher concentrations of fluoride ions are undesirable and may cause mottled enamel in teeth, dental and skeletal fluorosis and other non-skeletal manifestations. 0.01 to 1.28 mg/L of fluoride is seen in aquifer, tube well have 0.01 to 0.98 mg/L where as in ponds ranges from 0.01 to 0.05 mg/L.

4.4.2.14 Nitrates (NO_3^-)

Nitrates originate from fertilizers of potassium nitrate and/or ammonium nitrate. Both of which are very soluble and do not bind to soils. Nitrates migrate easily to ground waters. The highest concentrations of nitrates are found in regions that are characterized by intensive agricultural activity such as lowland paddy cultivation. The nitrate concentration is 0.01 to 5.12 mg/L in aquifer, in the case of tube well it ranges from 0.01 to 4.86 mg/L, and in ponds it varies from 0.01 to 0.05 mg/L.

4.4.2.15 Phosphate ($(PO_4)^{3-}$)

Elevated phosphate concentrations originate mainly from anthropogenic sources, which include domestic waste waters rich in sewage and detergents, agricultural run-off enriched in inorganic fertilizers, manure and sludge from cattle raising farms, wastes of pulp and paper industry, vegetable and fruit processing, as well as manufacturing of chemicals, fertilizers and detergents. Effects of higher concentration of phosphates include enhanced algal growth and interference with digestion of food. Aquifers have 0.024 to 1.94 mg/L of PO_4, while in tube well it ranges from 0.01 to 0.06 mg/L and in ponds it varies 0.01 to 0.05 mg/L.

4.4.2.16 Total Iron (Fe)

Iron is found in natural conditions mainly as insoluble oxidized (ferrous) and reduced (ferrous) state. When it comes in contact with water, it form ferrous bicarbonate under favorable conditions. This ferrous bicarbonate is oxidized into ferric hydroxide, which is a precipitate. Iron can impart bad taste to the water, causes discoloration in clothes and incrustations in water mains. Desirable IS range of Fe in drinking water is 0.3 to 1.0 mg/L.

4.4.2.17 Biochemical Oxygen Demand (BOD)

BOD which is an empirical standardized laboratory test which measures the oxygen requirement for aerobic oxidation of decomposable organic matter and certain inorganic materials in water. The amount of dissolved oxygen needed by aerobic biological organisms is called BOD. Table 4.2 gives the guideline BOD values for classification of raw untreated water.

Microorganisms living in oxygenated waters use dissolved oxygen to convert the organic compounds into energy for their sustenance. Populations of these microorganisms tend to increase in proportion to the amount of food available and the microbial metabolism creates an oxygen demand proportional to the amount of organic compounds useful as food. Under some circumstances, microbial metabolism can consume dissolved oxygen faster than atmospheric oxygen can dissolve into the water. Fish and aquatic insects may die when oxygen is depleted by microbial metabolism. BOD is widely used as an indication of the organic quality of water. The BOD value is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20 °C and is often used as a rough measure of the degree of organic pollution of water. Most unpolluted streams will have a 5-day carbonaceous BOD below 1 mg/L. Moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/L. (Since DO estimation is the basis of BOD test, sources of interference in BOD test are the same as in the DO test.).

Table 4.2 Guideline BOD values for classification of raw untreated water (Source: CPCB, July 2001)

Quality class	Designated best use	BOD value	Note
A	Drinking water source without conventional treatment but with chlorination	2 or less	Could cause problems in treatment, larger Cl_2 demand and residual taste/ odour problem.
C	Drinking water source with conventional treatment	3 or less	

4.4.2.18 Chemical Oxygen Demand (COD)

In environmental chemistry, the chemical oxygen demand (COD) test is an indirect measurement of the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water like lakes and rivers. COD is a useful measure of water quality. It is expressed in milligrams per liter (mg/L), which indicates the mass of oxygen consumed per liter of solution.

4.4.2.19 Dissolved Oxygen (DO) / Oxygen Saturation

Dissolved oxygen (DO) or Oxygen saturation is a relative measure of the amount of oxygen that is dissolved or carried in a given medium, usually in water. It refers generally to the amount of oxygen dissolved in the soil or bodies of water. Environmental oxygenation can be important to the sustainability of a particular ecosystem. Insufficient oxygen (environmental hypoxia) may occur in bodies of water such as ponds and rivers tending to suppress the presence of aerobic organisms such as fish. Deoxygenation increases the relative population of anaerobic organisms such as plants and some bacteria, resulting in fish kills and other adverse events. Dissolved oxygen ranges from 3.9 to 5.5 in ponds water.

4.4.2.20 Total Suspended Solids (TSS)

Total suspended solids, usually abbreviated TSS, is a measure of particulate weight obtained by separating particles from a water sample using a filter, TSS in mg/L can be calculated as: (dry weight of residue and filter - dry weight of filter alone, in grams) / ml of sample x 1,000,000.

4.4.2.21 Total solids (TS)

Residue left after the evaporation and subsequent drying in oven at temperatures 103-105°C of a known volume of sample are total solids. Total solids include "Total suspended solids" (TSS) and "Total dissolved solids" (TDS) whereas loss in weight on ignition of the same sample at 500ºC+/-50ºC, in which organic matter is converted to CO_2 and H_2O while at controlled temperature to prevent decomposition and volatilization of inorganic matter as much as consistent with complete oxidation of organic matter are volatile solids under normal circumstances. Formal guideline values are not set for individual radio nuclides in drinking water.

4.4.3 Biological aspects

Consumption of drinking water that is contaminated with human and animal (including birds) excreta is considered as the greatest risk to public health, as being a source for pathogenic bacteria, viruses, protozoa and helminthes. The preferred strategy calls for prevention and reduction of entry of pathogens into water sources and reducing reliance on treatment processes for removal of pathogens. Microbial water quality often varies rapidly and over a wide range. Short term peaks in pathogen concentration may increase disease risks considerably and may trigger outbreaks of waterborne diseases.

WHO treats waterborne diseases as those that are caused by ingestion of drinking water, inhalation of water droplets or dermal contact with drinking water. Infectious diseases caused by pathogenic bacteria, virus and parasites (e.g. protozoa and helminthes) are the most common and widespread health risk associated with drinking water.

The pathogens that are transmitted through contaminated drinking water are diverse in characteristics, behavior and resistance. Table 4.3 provides the list of common pathogens that are transmitted through drinking water.

Microbial drinking water safety is not related to fecal contamination of pathogen alone. Other microbial hazards include the pathogen growth in piped water distribution systems (e.g. *Legionella*) and guinea worm (*Dracunculusmedinensis*). Toxic *Ciano* bacteria are also known to cause disease outbreaks and individual infection, under specific circumstances.

Chemical disinfection of water resources (eg. Chlorination) will reduce the overall risk of disease but may not necessarily render the water safe. For example, chlorine disinfection of drinking water has limitations against protozoan pathogens (*Cryptosporidium)* and some viruses. Disinfection efficiency may also be unsatisfactory against pathogens within flocks or particle which protect them from the action of disinfectants.

Bacterial examination of water is very important since it indicates the degree of pollution. Water polluted by sewage contains one or more species of disease producing pathogenic bacteria, such as *E.coli* (*Escherichia coli*), a normal inhabitant in the human intestinal tract in both healthy and sick persons. Therefore it is present in large numbers in domestic and municipal sewage. The presence of *E.coli* in water indicates contamination with sewage and of the possible presence of pathogenic microorganisms of human origin. So *E.coli* serves as an indicator of water contamination with sewage. The presence of *E.coli* forms in a water sample is determined by observing their growth in special culture media and making a statistical deduction regarding their number. The result is reported as most probable number (MPN) / 100 ml.

Depending upon the magnitude of treatment required, proper unit operations are selected and arranged in the proper sequential order for the purpose of modifying the quality of raw water to meet the desired standards. Indian Standards for drinking water are given in Table 4.4. The BIS (Bureau of Indian Standards) drinking water specification, is a voluntary standard, drawn up in 1983. A second revision (IS 10500) initiated in 2009 is still in its draft stage. The typical functions of each unit operations required in the treatment of raw water in water treatment plants are given in Table 4.5 and the types of treatment required for water from different sources are shown in Table 4.6.

Table 4.3. Common pathogens transmitted through drinking water

Pathogen	Health significance	Persistence in water supplies	Resistance to chlorine	Relative infectivity	Important animal source
Bacteria *Burkholderiapseudomallei*	High	May multiply	Low	Low	No
Campylobacter jejuni, C.coli	High	Moderate	Low	Moderate	Yes
Escherichia coli-Pathogenic	High	Moderate	Low	Low	Yes
E.coli-Enterohaemorrhagic	High	Moderate	Low	High	Yes
Francisellatularensis	High	Long	Moderate	High	Yes
Legionella spp.	High	May multiply	Low	Moderate	No
Leptospira	High	Long	Low	High	Yes
Mycobacteria(nontuberculous)	Low	May multiply	High	Low	No
Salmonella Typhi	High	Moderate	Low	Low	No
Other salmonellae	High	May multiply	Low	Low	Yes
*Shigella*spp.	High	Short	Low	High	No
Vibrio cholerae	High	Short to long	Low	Low	No
Viruses Adenoviruses	Moderate	Long	Moderate	High	No
Astroviruses	Moderate	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A virus	High	Long	Moderate	High	No
Hepatitis E virus	High	Long	Moderate	High	Potenially
Noroviruses	High	Long	Moderate	High	Potentially
Rotaviruses	High	Long	Moderate	High	No
Sapoviruses	High	Long	Moderate	High	Potentially
Protozoa *Acanthamoeba*spp.	High	May multiply	High	High	No
Cryptosporidium hominis / parvum	High	Long	High	High x	Yes
Cyclosporacayetanensis	High	Long	High	High	No
Entamoebahistolytica	High	Moderate	High	High	No
Giardia intestinalis	High	Moderate	High	High	Yes
Naegleriafowleri	High	May multiply	Low	Moderate	No
Helminths *Dracunculusmedinensis*	High	Moderate	Moderate	High	No
*Schistosoma*spp.	High	Short	Moderate	High	Yes

Table 4.4. Indian Standards for Drinking Water (IS: 10500)

Parameter	Desirable-Tolerable	If no alternative source available, limit extended upto
Physical		
Turbidity (NTU unit)	< 10	25
Colour (Hazen scale)	< 10	50
Taste and Odour	Un-objectionable	Un-objectionable
Chemical		
pH	7.0-8.5	6.5-9.2
Total Dissolved Solids mg/l	500-1500	3000
Total Hardness mg/l (as $CaCO_3$)	200-300	600
Chlorides mg/l (as Cl)	200-250	1000
Sulphates mg/l (as SO_4)	150-200	400
Fluorides mg/l (as F)	0.6-1.2	1.5
Nitrates mg/l (as NO_3)	45	45
Calcium mg/l (as Ca)	75	200
Iron mg/l (as Fe)	0.1-0.3	1.0

Table 4.5. Functions of Water Treatment Units

Unit treatment	Function (removal)
Aeration and chemical treatment	Colour, Odour, Taste
Screening	Floating matter
Chemical methods	Iron, Manganese, etc.
Softening	Hardness
Sedimentation	Suspended matter
Coagulation	Suspended matter, a part of colloidal matter and bacteria
Filtration	Remaining colloidal dissolved matter, bacteria
Disinfection	Pathogenic bacteria, Organic matter and Reducing substances

Table 4.6. Types of treatment required for water from different sources

Source	Treatment required
1. Ground water and spring water fairly free from contamination	No treatment or Chlorination
2. Ground water with chemicals, minerals and gases	Aeration, coagulation (if necessary), filtration and disinfection
3. Lakes, surface water reservoirs with less amount of pollution	Disinfection
4. Other surface waters such as rivers, canals and impounded reservoirs with a considerable amount of pollution	Complete treatment

4.5 MANAGEMENT OF WATER RESOURCES

Scientific management of water resource forms an integral aspect of the preventive management of drinking water quality.

The influence of land use on water quality and their relevant factors include:

- Land cover modifications
- Application of fertilizers, herbicides, pesticides and other chemicals
- Extraction activities
- Construction/modification of waterways and livestock density and application of manures
- Road construction, maintenance and use
- Various forms of recreation,
- Urban and rural residential development with particular attention to excreta disposal, sanitation, landfill and waste disposal,
- Other potentially polluting human activities such as industry, mining and military sites.

4.6 WATER QUALITY STANDARDS

Water quality standards may be classified as ambient water quality standards, specific water use related standards and effluent water quality standards. The Central Pollution Board has classified the inland water surface waters into 5 categories (class A to class E) on the basis of the best possible use of water as shown in Table 4.7. The classification has been made in such a manner that the water quality requirement becomes progressively lower from class A to class E. A water body may be subjected to more than one organized use. The use demanding the highest quality is designated as best use. A water body or stretch of river whose existing water quality does not meet the designated best use criteria requires action to mitigate the situation. Based on such analysis river action plans are formulated.

Table 4.7 Primary Water Quality Criteria for Various Uses of Fresh Water

(*After Central Pollution Control Board*)

Designated best use	Class	Criteria
Drinking water source without conventional treatment but after disinfection	A	1. Total coliform organisms MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved oxygen 6 mg/L or more 4. Biochemical oxygen demand 2 mg/L or less
Outdoor bathing (organized)	B	1. Total coliform organisms MPN/100mL shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved oxygen 5 mg/L or more 4. Biochemical oxygen demand 3 mg/L or less
Drinking water source with conventional treatment followed by disinfection.	C	1. Total coliform organisms MPN/100mL shall be 5000 or less 2. pH between 6 and 9 3. Dissolved oxygen 4 mg/L or more 4. Biochemical oxygen demand 3 mg/L or less
Propagation of wildlife, fisheries.	D	1. pH between 6.5 and 8.5 2. Dissolved oxygen 4 mg/L or more 3. Free ammonia (as N) 1.2 mg/L or less
Irrigation, industrial cooling, controlled waste disposal	E	1. pH between 6.0 and 8.5 2. Electrical conductivity less than2250 micro mhos/cm 3. Sodium absorption ratio less than 26. 4. Boron less than 2 mg/L2 mg/L

4.7 DISTRICT SCENARIO

Water potential of Kerala has been already dealt in Chapter I. According to the final figures of 2001 census, the population of the district stood at 32,34,356. According to the Provisional releases in April 2011 (Census, 2011), the population of Thiruvananthapuram district has been estimated as around 33,07,284 (an increase of 2.25 % over 2001). The district with its 33, 07,284 (17,23,084 females and 15,84,200 males) citizens, has a density of 1,509 persons per sq.km. The Thiruvananthapuram Corporation, the largest municipal corporation in Kerala, currently has a population of 7.52 lakhs (3.87 lakhs females and 3.64 lakhs males) against 7.44 lakhs in 2001. Table 4.8 shows the decadal growth of population in Thiruvananthapuram district from 1901 to 2011. Fig. 4.2 shows the various blocks of the Thiruvananthapuram district while Fig. 4.3 shows the Thiruvananthapuram Urban Area, Table 4.9 shows the estimated future water requirement in Mm^3 for Thiruvananthapuram district. It also includes the estimated future water requirement of Karamana River Basin. These figures are based on the estimates made by CWRDM (Centre for Water Resources Development and Management, (Kozhikode, 1995). No reliable subsequent estimates are available as of now. The average annual discharge of Karamana River is 836 Mm^3.

Table 4.10 gives the Block-wise ground water draft, future utilization and stage of development in Thiruvananthapuram District. Water scarcity is reported in various degrees from parts of Aryanad, Vattiyoorkavu, Kudappanakunnu, Poovachal, Vellanad, Malayinkeezh and Maranalloor Panchayats of Thiruvananthapuram district.

Table 4.8 Decadal growth of population, Thiruvananthapuram district, 1901 to 2011

Year	Population	Year	Population
1901	4,84,493	1961	1,744,431
1911	5,69,472	1971	21,98,606
1021	6,66,393	1981	25 ,96,112
1931	8,56,851	1991	29,46,650
1941	10,15,057	2001	32,34,707
1951	13,27,812	2011	33,07,284

Table 4.9 Estimated (Item-wise and River Basin wise) future water requirement (Mcm), Thiruvananthapuram District (CWRDM.1995).

Sl.No.	Item	Ayiroor,Vamanapuram and Mamam Basin	Karamana River Basin	Neyyar Basin
A	Average annual discharge, Mcm.	1324	836	207
B1	Water requirement for wetlands (3 crops) (Mm^3)	515	343	412
B2	Water requirement for garden lands (Mm^3)	240	123	90
B3	Projected water requirement for domestic use (A.D 2021) (Mm^3)	169.9	106.8	94.1
B4	Projected water requirement for industrial use (A.D 2021) (Mm^3)	45	45	45

Table 4.10 Block-wise groundwater draft, future utilization and stage of development in Thiruvananthapuram District (After CGWB, 2009)

Sl. No.	Assessment Unit/Block	Net annual groundwater availability	Existing gross groundwater draft for irrigation	Existing gross groundwater draft for domestic and industrial water supply	Existing gross groundwater draft for all uses	Allocation for domestic and industrial requirement supply up to next 25 years	Net groundwater availability for future irrigation development (3-4-7)	Existing gross groundwater draft for domestic and industrial water supply (6/3) *100
1	2	3	4	5	6	7	8	9
1	Varkala	18.41	8.96	5.91	14.87	7.50	1.95	80.76
2	Kilimanoor	23.50	10.65	7.82	18.47	9.99	2.86	78.60
3	Vamanapuram	49.24	8.41	8.28	16.69	10.80	30.03	33.90
4	Chirayinkil	17.28	13.71	7.02	20.73	8.84	0.00	119.97
5	Kazhakootam	20.09	6.73	10.19	16.92	12.68	0.68	84.22
6	Nedumangad	16.55	5.81	6.33	12.14	7.96	2.78	73.35
7	Vellanad	47.81	7.01	8.55	15.56	11.07	29.73	32.55
8	Thiruvananthapuram	14.90	2..94	8.29	11.23	10.12	1.84	75.37
9	Nemom	17.52	6.76	9.31	16.07	10.18	0.58	91.70
10	Perumkadavila	28.48	8.57	7.95	16.52	9.68	1023	57.99
11	Athiyannoor	11.13	5.63	6.93	12.56	8.72	0.00	112.80
12	Parassala	13.12	6.88	7.15	14.03	8.98	0.00	106.90
Total		278.03	92.06	93.75	185.79	116.52	80.68	66.82

Fig. 4.2. Map showing blocks of Thiruvananthapuram District

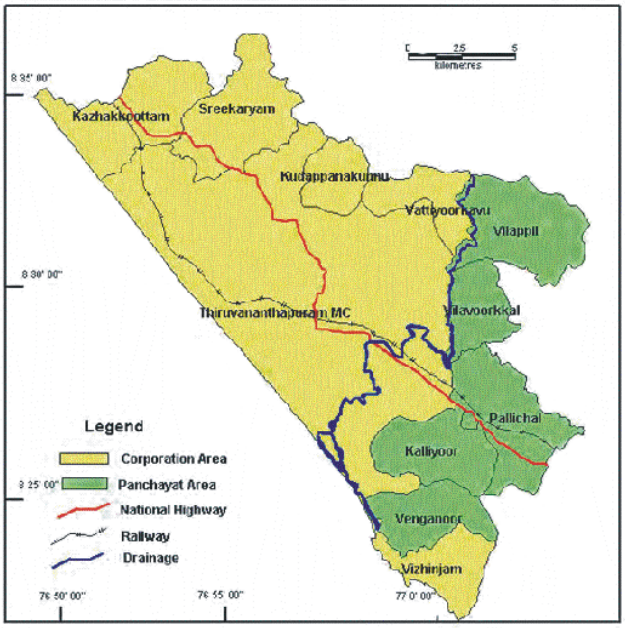


Fig. 4.3 Map of Thiruvananthapuram Urban Area

It is estimated that there are 3135 public dug wells and 1047 public bore wells in the district. Among these, 372 of the former and 682 of the latter are presently out of service. Surveys also indicate that about 10, 447 families depend on public wells and public bore well for their water needs.

4.8 EXISTING WATER SUPPLY SCHEMES

Thiruvananthapuram water supply scheme, initially known as Wellington Water Works and commissioned in 1931, is one of the oldest water supply schemes in the nation. Water is sourced from the Karamana River from a reservoir of 2.0 Mcm at Aruvikkara, about 13 km NE of the city. The capacity of the reservoir has been later augmented with the construction of Peppara Dam with a storage capacity of 70 Mcm located in the reserve forest. Peppara Dam ensures a steady supply of water as and when required in the Aruvikkara reservoir. The annual total water resources of Thiruvananthapuram district is 793 Mcm of which with surface water contribution is 83.7% (664 Mcm) and while 16.3% (129 Mcm) is yielded by groundwater Further, numerous wells scattered over the district makes a substantial source for fresh water, which supports the water needs of an estimated 68 % of the population of the district. However, majority of the families of Thiruvananthapuram block, Nedumangad, Neyyattinkara and a few other localities get their need met by the public distribution system. In addition, there exists practice of using terrestrial water resources (ponds, streams and springs) for domestic use, especially in the midland zone and highland zone, which face relatively higher degree of water scarcity in the district.

4.9 ASSESSMENT OF WATER QUALITY

In order to assess the spatial and temporal changes in the water quality, in terms of acceptability, chemical and microbial aspects, water samples were collected from streams, dug wells, deep dug wells and ponds during monsoon and post-monsoon seasons. Analytical results are shown in Appendix Annexure A-1, A-2, A-3, A-4, B-1 (A), B-1 (B) B-2 (A), B-2 (B), B-3 (A), and B-3 (B).

4.9.1 Data base and methodology

For the Karamana River Basin, available data from various agencies have been utilized for the quantitative and qualitative assessment of water resources (the surface and subsurface water). The physical, chemical and bacteriological analysis of several samples of both surface water and groundwater were made following standard sampling procedures.

4.9.2 Materials and methods

Water sampling was carried out in the year 2012. 126 stream water sample were collected, analyzed and the results are provided in the annexures B1(B), B2(A), B2(B), B3(A) B3(B). B4 (A) and B4 (B). Sampling sites in the Karamana River and its major tributary (Killi Ar) are distributed right from the source up to the river or stream mouths (Fig.4.4 and Fig 4.5).

The sampling sites of the trunk stream of the system were selected at the confluence of lower order streams with that of 6th order. Care was taken to ensure that the sampling site should be representative of the river reaches and also that the changes in water quality variations with time can be interpreted with confidence. All the samples were taken from the main current (medial zone), i.e., 20 to 30 cm below the surface to avoid collection of scum. At river junctions, the sampling points were selected sufficiently downstream where proper mixing of waters is assured. Collected samples were transferred to cleaned sample bottles (1000 ml polyethylene bottles) immediately after collection. The temperature of the water samples and their pH values were recorded immediately after collection. The collected water samples were used to determine the parameters related to (a) the acceptability aspects (such as taste, colour odour, appearance etc; (b) chemical aspects (pH, EC (μS/cm), dissolved oxygen (mg/L), etc and (c) microbial aspects of the samples.

Surface water samples were also collected from 62 ponds, 102 dug wells and 74 tube wells and analysed for the various physicochemical parameters. The analytical results of the water samples (both surface and subsurface) are provided in Annexure, A1 ,A2, A3, A4, B1(A), B1(B) B2(A), B2(B), B3(A) B3(B) B4(A) and B4(B).

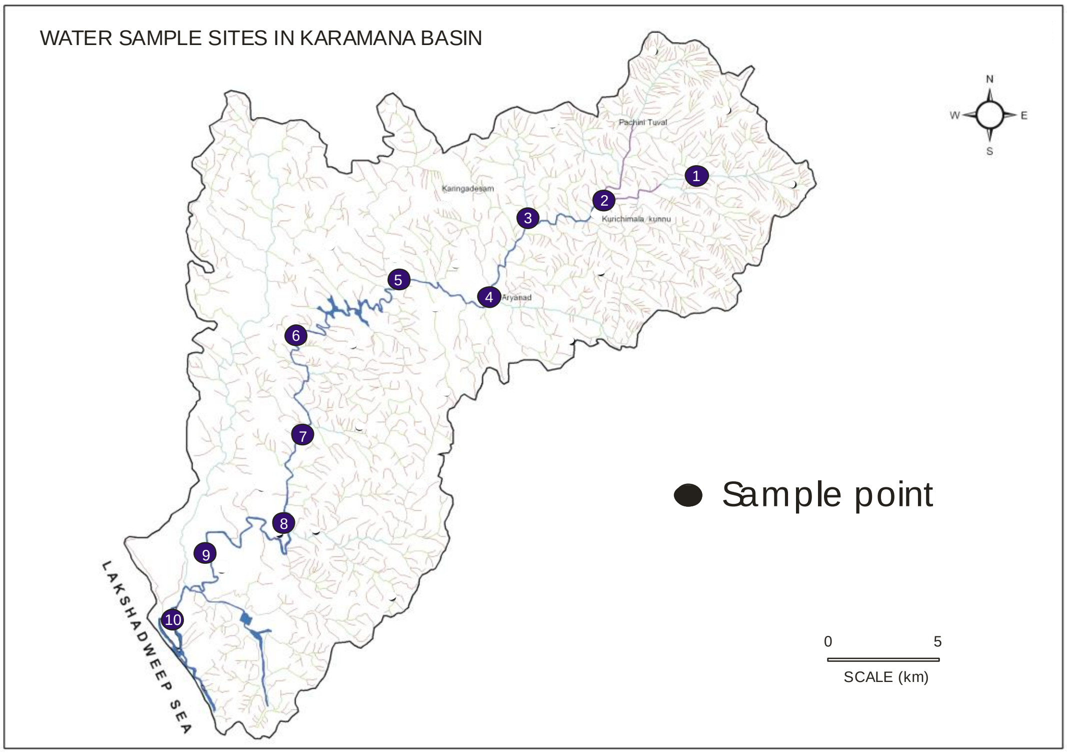


Fig. 4.4 Sampling locations of stream water samples collected from KRB.

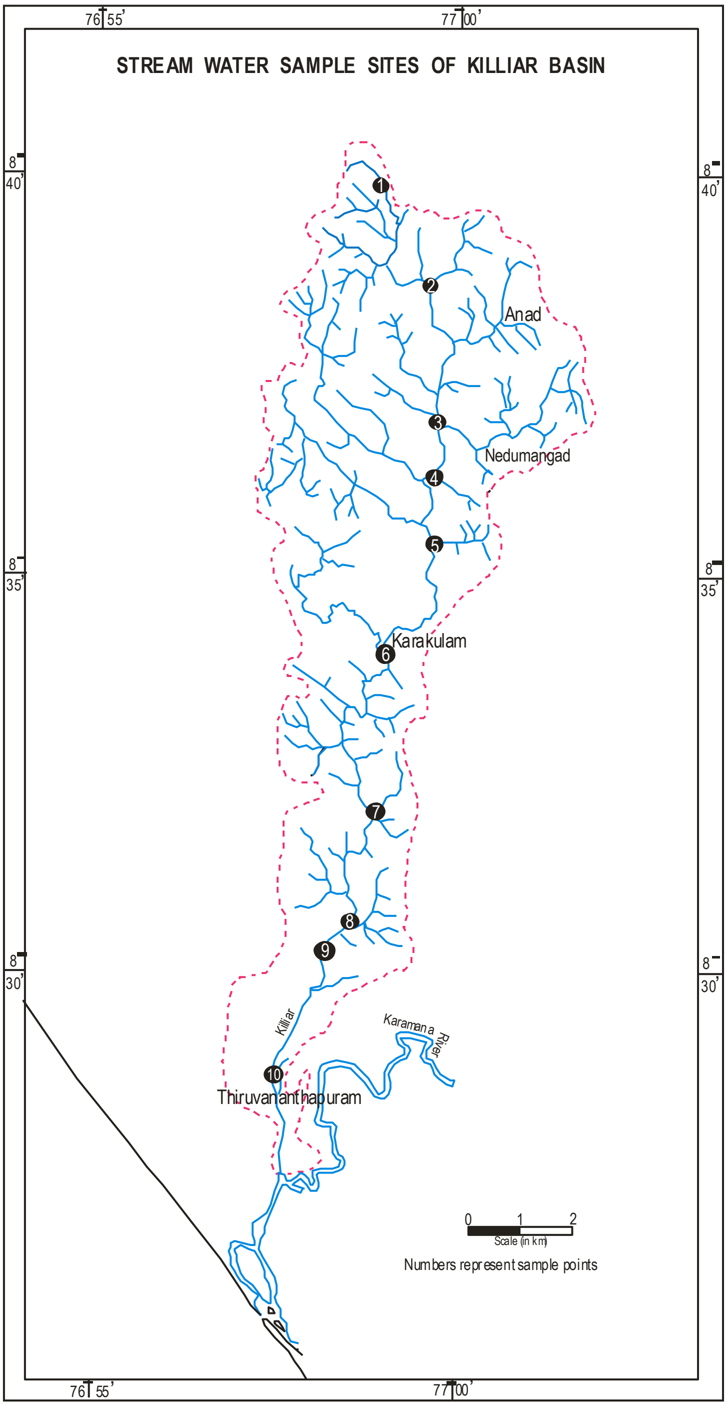


Fig. 4.5 Sampling of stream water from the major tributary of KRB.

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4.10 SURFACE WATER STATUS OF KARAMANA RIVER BASIN

Several surface and subsurface water samples were collected from various parts of the Karamana River Basin and these were analyzed to determine their physical and chemical attributes.

Results of the (surface and subsurface) water sample analysis on comparison of the rural segment of Karamana River Basin with the urban patches amply reflect the influence of urbanization on the physical and chemical attributes of water. In 1997, the State Legislature Committee on Environment reported that the pollution caused by the release of raw sewage into the Killi Ar near the Jagathy bridge was at an 'explosive' level. The same year the State Pollution Control Board issued notice to the KWA to immediately stop the practice of discharging of untreated sewage into the Karamana River.

The downstream segments of Karamana River, which flows roughly through the eastern edge of Thiruvananthapuram city showed marked differences in water sample attributes with respect to the northern upstream segment. Beyond Thiruvallam, the river water is increasingly foul smelling and is attributable to a deterioration of river water due to direct disposal of solid and liquid waste from the urban catchment and b) the TS canal opening into the river course. In addition, untreated effluent from Milma Dairy Plant at Ambalathara is another point source of pollution. The heavily polluted Parvathy Puthenar (TS) canal joins the Karamana River at Munnattumukku in coastal village of Poonthura.

The heavy pollution of the downstream stretches of Karamana River resulted in unsanitary conditions for devotees visiting the famous Parasurama Temple at Thiruvallum to pay obeisance to their departed ancestors. The flow stagnation in summer due to formation of river mouth bar intensifies the stench at the bathing ghats near the temple which puts off even the most fervent devotees from taking the customary bath. In a bid to obviate the need for devotees to immerse themselves in polluted water, the Travancore Devaswam Board has installed showers at the bathing ghat.

4.11 WATER CHEMISTRY

The analytical data of the surface water (ponds and streams) samples collected from Karamana River Basin are shown in Annexure A3, A4, B3 (A), B3(B), B4(A) ,B4(A) and B4(B)

4.12 GROUNDWATER STATUS OF KARAMANA RIVER BASIN

Groundwater, a replenishable resource and its proper (economic) development on a sustainable basis (both on local and regional scale) warrant scientific assessment of quantity and quality. Therefore, the National Water Policy stresses periodic scientific assessment (PSA) of groundwater resources of the country. Based on the 1984 methodology, the groundwater resource of Kerala was estimated twice, i.e., during 1989 and 1992. Later, based on recommendations of a high power committee a new methodology was proposed in 1997 (The Groundwater Estimation Methodology, 1997) for use by the states / union territories. The 1997 methodology reckons drainage basin or watershed as the basic unit in computation. However, as there is non-availability of suitable data, blocks/tehsils were also recommended as basic geographic units for groundwater estimation. In Kerala, the 1997 scheme is followed by the CGWB. In the present study the estimation of groundwater resource is carried out on the basis of the data published by the CGWB in which blocks are considered as the basic units for groundwater estimation.

Recharge (a vital input in computations) of aquifers follow various routes, like rainfall, canals, surface water bodies, irrigated fields, water conservation structures etc. The current methodology of estimation of groundwater resources in India recommends computation of recharge figures separately for monsoon (June to September) and non-monsoon seasons. NE monsoon, which accounts for more than 10 % of the total rainfall contribution to the local aquifer and this is calculated as non-monsoon recharge. Then the values are normalized. Moreover areas with more than 20 % slope (hilly areas) were removed from recharge computation. Recharge using water level fluctuation method was computed based on water level data collected by CGWB from a large number of observation open wells tapping phreatic aquifer. Measurement taken in the month of April is considered as the pre-monsoon water level and the subsequent measurement is taken as the post-monsoon level. The water level data of the five year period from 1994-1998 have been used in the recharge calculations.

As already noted in Chapter 2, major portion of the Karamana River Basin is under agriculture, which is followed by forests. Irrigation of the tract is mainly by surface water. Among the 15 types of major crops listed as cultivated in the basin, paddy, coconut and rubber top the list. The average annual rainfall of the Thiruvananthapuram district is estimated as 1623.9 mm, where SW monsoon contributed 48.9 percent of the total rainfall followed by NE monsoon contributing 28.3 percent. The normal rainfall of the district is 2001.6 mm. The normal monthly rainfall in mm for the period 1901-1999 is given in Table 4.11

Monthly Rainfall (in mm) in Thiruvananthapuram district for the period 2006-2010 shown in the Table 4.12. Rainfall data for the district is the arithmetic average of rainfall data of various stations.

The spatial distribution of rain fall shows an increase from coastal tract in the west to the eastern highland zone. On the average, annual rainfall in the coast is only 1600 mm while at Ponmudi and Peppara located in the highland zone is over 3000 mm and around 4,810 mm respectively (Jayson and Christopher, 2008).

Table 4.11 The average monthly rainfall in mm for the period 1901-1999 (Data from CGWB)

Montrh	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Rainfall	22.6	24.5	39.9	108.2	211.4	350.8	234.7	134.9	148.7	276.1	195.5	73.2	1820.5

Table 4.12 Rainfall data for the period from 2006 to 2010 (Data from CGWB)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2006	18.9	0.0	73.7	81.4	289.7	239.1	190.2	122.6	47.9	521.4	296.7	13.9	1881.1
2007	0.3	1,7	3.7	213.3	167.2	348.7	306.6	177.2	279.1	327.8	213.8	117	2156.6
2008	0.0	24.6	276.0	158.3	89.8	116.3	286.0	180.6	202.6	363.9	195.2	38.2	1931.5
2009	0.0	0.0	60.0	44.6	206.9	183.3	204.2	87.3	183.4	119.4	346.3	42.5	1474.1
2010	108.3	0.0	73.1	109.4	216.7	237.0	234.9	118.7	114.1	414.3	326.0	188.3	2144.8

4.13 SUBSURFACE HYDROGEOLOGY

Section 3 to 4 of Chapter II gives an overview of the distribution of rock types in the Karamana River Basin. Groundwater occurs in shallow aquifers in phreatic condition and across all rock units (i.e., Precambrian crystallines like charnockites, khondalites and associated units in deeply weathered, or partly weathered and jointed state) including the most recent sedimentary rocks (Warkalli Formation of Tertiary age and younger units).

Laterite, the most wide spread lithologic cover in the basin extends over most of the midland and part of highland, is a highly porous geo-hydrologic unit, and acts as good aquifer. But due to its highly porous nature, the groundwater of these aquifers drains off “soon” after the monsoon season. Laterite forms potential aquifers along valleys and is known to sustain medium capacity irrigation wells. However, in localities with steep surface gradients and summits of hills, laterite can sustain only domestic supplies, since the groundwater table drops off soon after cessation of monsoon season.

In deeper aquifer groundwater occurs in confined to semi-confined conditions associated with deeper portions of crystalline rocks and especially along lineament controlled/dependent, relatively wide fracture zones/surfaces, interconnected joints and fissures. In such deep weathered zones in the midland of Karamana River Basin, groundwater is developed through dug wells of medium capacity to meet irrigation needs. Though, along hilly tracts (high land zone) crystalline rocks have a relatively thin weathered mantle, domestic dug wells are feasible in most of these areas. However, at places the dug wells are ephemeral and go dry during summer. According to CGWB, there are about 5 to 7 potential aquifers within a depth range of 200 m in Khondalites rock units of in the discharge range of 30 to 1200 lpm. Transmissivity in these aquifers ranges from 0.94 to 9.03 m^2 /day.

Among the various formations of Tertiary age, lithounit belonging to Quilon Formation composed of limestone and calcareous clays are encountered in subsurface in the northern parts of the District (but beyond the boundary of Karamana River Basin) such as Varkala and Edavai (where the total thickness of the formation is known to range from 34 m to 64 m). Similarly the older Vaikom Formation, most extensively developed formations of Tertiary succession of Kerala, is represented by strata of a few meters thickness in the subsurface only in the northern part of the district and thus being outside the Karamana River Basin. Recent alluvium is comparatively thinner or almost absent in the northern parts of Thiruvananthapuram district, but towards the south its thickness increases and at Chackai (within the Karamana River Basin) it is known to attain a thickness of 18 m and extends laterally for 5-6 km. Fig.4.6 shows the hydrogeology of Thiruvananthapuram Urban Area.

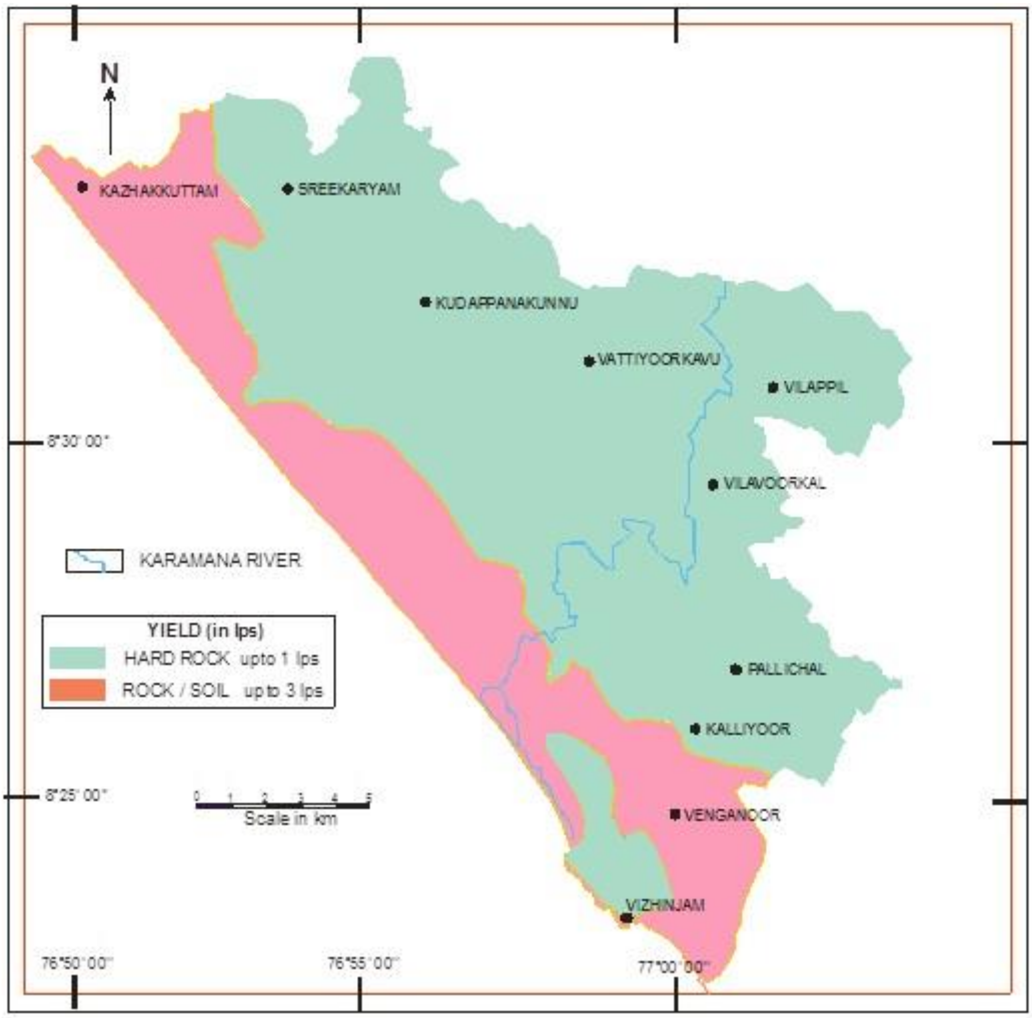

Fig. 4.6 Hydrogeology of Thiruvananthapuram Urban Area

4.14 DEPTH TO WATER TABLE

In major part of the Karamana River Basin the depth to water table ranges between 5 mbgl and 10 mbgl during premonsoon times and from 2 to 5 mbgl in the post-monsoon. On the basis of water table elevation map data, it can be inferred that (1) Ground water flows from northeast to southwest following the general drainage pattern, (2) The sediments are more permeable in the southern part of the basin and (3) Karamana River is effluent in major part of the basin.

Fluctuation of water table mostly depends on factors such as (1) Replenishable recharge from rainfall, (2) Seepage from surface water bodies,

(3) Inputs to ground water body by applied irrigation, (4) Losses due to evapo transpiration, (5) Discharge from ground water extraction structures and (6) Groundwater movement. Fig. 4.7 and Fig 4 .8 shows the fluctuation of the depth of water table in Thiruvananthapuram Urban Area during the year 2009 (Source: CGWB).

In the lowland zone of the basin, where the unconfined aquifers occur in alluvium, water level variation is from 1.00 mbgl to 6 mbgl in pre-monsoon. The larger values are associated with southern parts of the lowland zone. The corresponding range for post -monsoon is only 0.25 mbgl to 2.00 mbgl. In comparison with other parts of the basin, the depth to water level in alluvial tracts of the lowland zone in both pre and post monsoon months is the least or lowest. The shallow water level characterized by low amplitude of water level fluctuation in the area is probably a reflection of the location of the alluvial tract in the groundwater discharge zone.

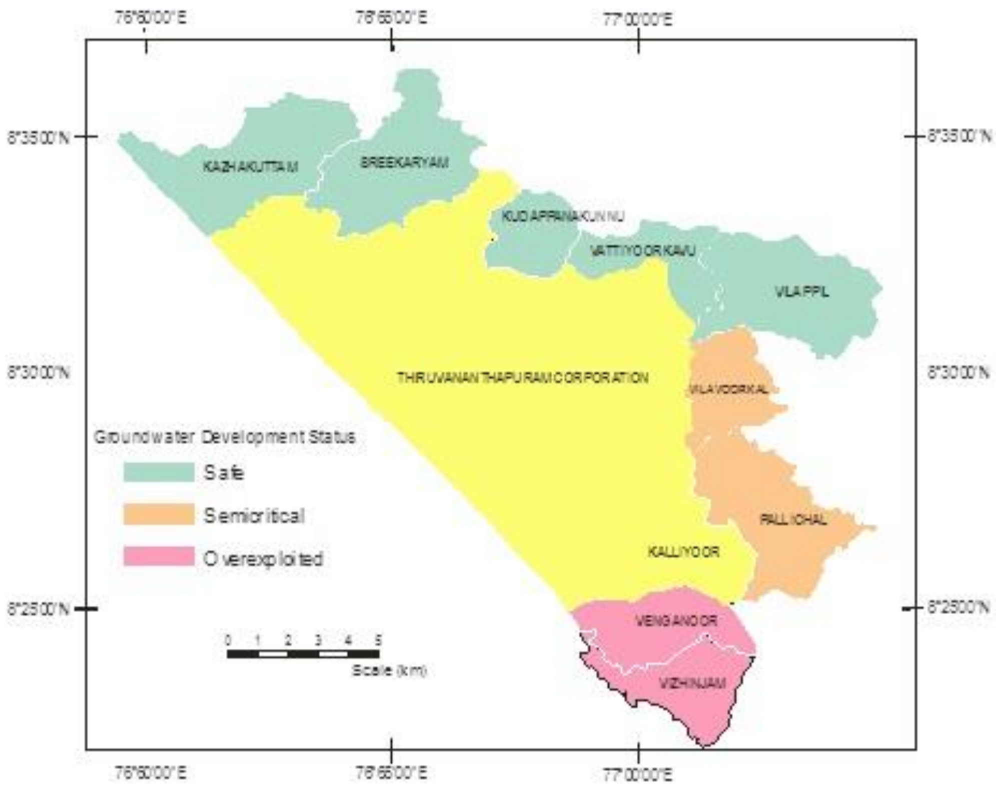

Fig. 4.7 Groundwater development status of blocks of Thiruvananthapuram Urban Area (Source CGWB)

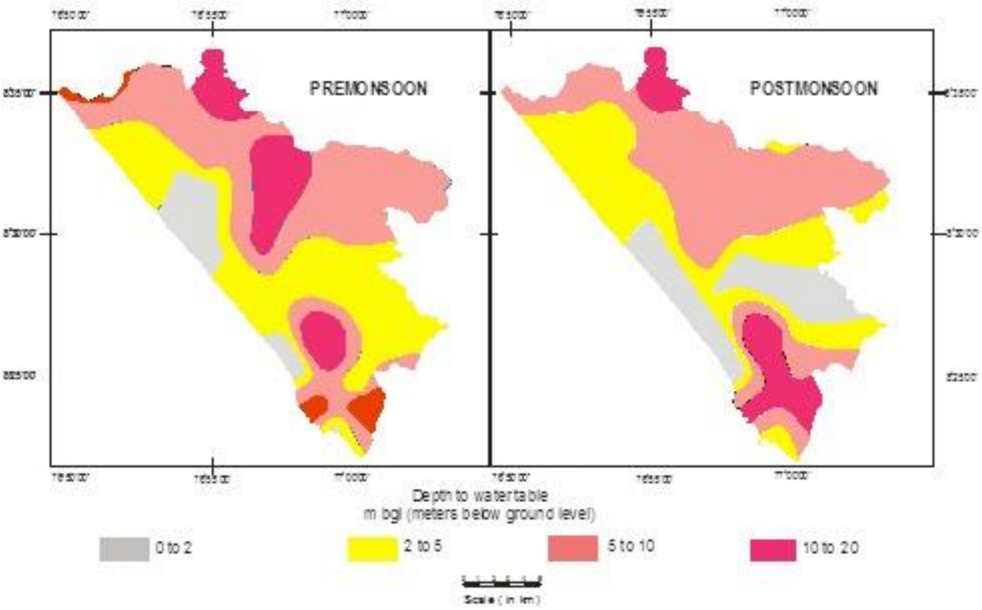

Fig. 4.8 Fluctuations of depth of water table in Thiruvananthapuram Urban Area

In lateritic terrains of midland the depth to the water level is only 1.75 mbgl in a site south of Panavoor while it reaches values over 19 mbgl around the Vellayani Kayal in the 2nd quadrant of the basin. For post-monsoon, corresponding maximum and minimum values for laterite aquifers range between 1.00 mbgl and 12 mbgl. It is significant to note that during pre-monsoon and post-monsoon, the depth to water table reaches highest or maximum in lateritic terrain of the basin. The water level variation in aquifers associated with various crystalline rocks of Karamana River Basin ranges from 3.5 mbgl to 13.00 mbgl where wells get water from these rocks. The corresponding minimum and maximum values during post-monsoon in crystalline aquifers are 1.00 mbgl and 8.00 m bgl respectively.

Seasonal fluctuation of water level in various unconfined aquifers of Karamana River Basin, associated with alluvium, laterite and crystalline rocks indicates that there is notable rise in water level (0.50 m to 5.00 m) in major portion of the basin. The long term trend analysis of water level fluctuation in Thiruvananthapuram district by CGWB for the period from 1997 to 2006 shows that there is a rising as well as lowering of the water level during pre and post-monsoon (CGWB ,2005).

4.15 GROUNDWATER QUALITY

Quality of the groundwater in the Holocene aquifers of KRB and associated coastal area has already been discussed in Chapter II. The analytical data of the groundwater samples collected from other parts of the Karamana River Basin, Fig.4.9 shows the location map of water samples collected from the study area (dug well, tube well, and ponds) especially the midland and highland regions, are given in Annexure A1, A2, B-1(A), B-1(B), B-2(A) and B-2 (B). A total of 102 groundwater samples collected from dug wells and 74 sample tube wells/bore well s, 10 dug well samples were selected, which are fed by shallow (phreatic) aquifers and also collected samples from 74 tube wells / bore wells, 10 water from analyzed. Samples for hydrochemical analysis were collected from a bore well located in the midland zones of the basin which is fed by deeper aquifers.

The sample collections were done during the monsoon (June to September) and post-monsoon periods as in the case of the samples collected for analysis of coastal Holocene aquifer of the basin. The nature of the well section, depth to the water level, temperature of water (ºC), turbidity, colour, taste and odour were recorded on site and chemical parameters of water samples such as pH, EC(μS/cm), TDS(mg/l), TH(mg/l), Ca^{3+}, Mg^{3+}, Na^+, K^+. Cl^-, SO_4^- HCO^-_3, PO^-_4 and F were estimated, following the standard procedure of groundwater analysis recommended by the American Public Health Association (APHA, 2005).

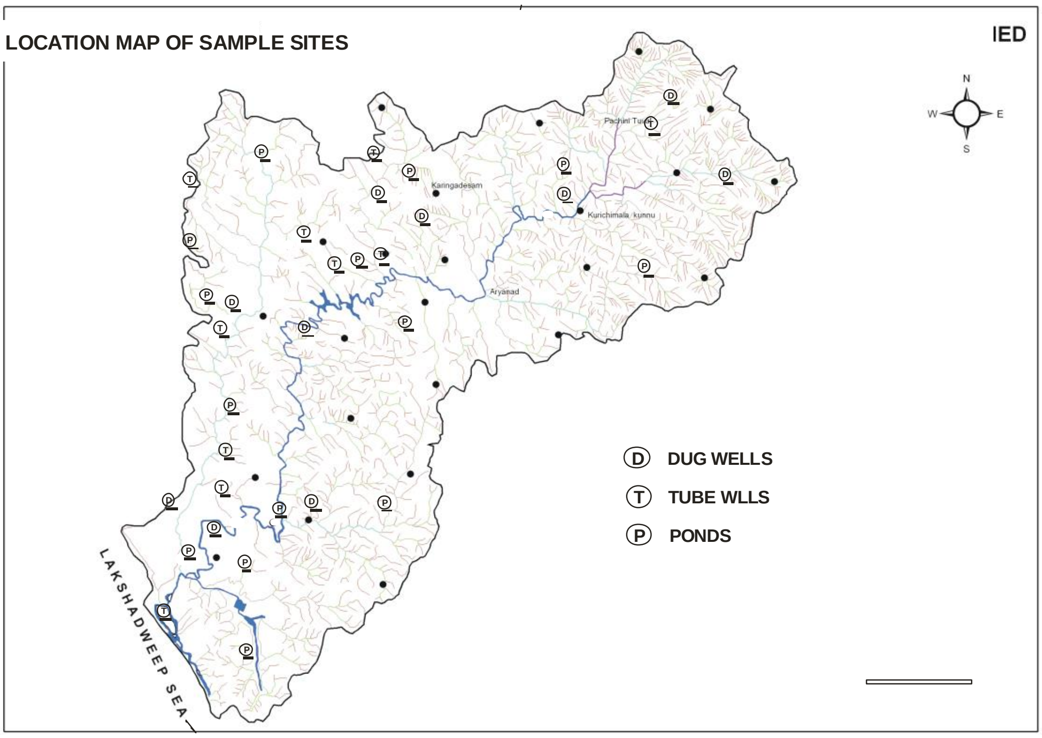

Fig. 4.9 Location of water samples collected from dug, tube wells and pond

The groundwater of major portion of the basin is generally potable except that in the southern portion of the lowland zone and in areas where polluted water forms part of the local recharge. The quality of groundwater in dug wells receiving water from fractured crystalline rocks exhibit electrical conductivity in the range from 95 µS/cm to 1024 µS/cm at 25^{o}C.

Signs of deterioration of groundwater has also been noticed in the neighbourhood covering an area of roughly 3 km^2 in Vilappilsala, where a plant established by the city corporation to convert organic waste into bio fertilizer is located. The waste from the factory site has polluted the groundwater in low-lying areas in the neighbourhood, extending over an area of over 5 km^2. It has contaminated the local aquifer in toxic proportions as there are reports of incidents of skin death of cattle after drinking water fed by the local aquifer.

The groundwater samples collected from most of the wells located in the urban area of Thiruvananthapuram exhibit notable regional and spatial variation in terms of physical, chemical and biological qualities. In the case of NO_2 the groundwater samples collected from dug wells of the basin exhibit significant difference between urban and non-urban localities. Higher concentration of NO_2 is noticed in groundwater samples collected from dug wells of the coastal tract of the basin.

The data also indicate significant seasonal variation in chemical quality of groundwater in terms of their content of inorganic phosphate. It is also true to a certain extent in the case of surface water resources of the basin. Presence of *E coli* can be noticed in all seasons in the groundwater samples of dug wells in urban sections of the basin. Chloride in well waters probably indicates leachate percolation and sewage pollution.

Chemical data of well water samples collected from Karamana River Basin are presented by plotting them on a Piper-trilinear diagram for monsoon and post-monsoon (Fig. 4.10, Fig. 4.11 and Fig. 4.12). The diagrams reveal the hydro chemical faces of the water samples for different seasons.

The characterization of groundwater samples of the basin on the basis of Piper diagrams is tabulated in Table 4.13 and Table 4.14 following the scheme proposed by Back and Hanshaw (1965). Wherein categories of groundwater (facies) are suggested on plots made in Piper Trilinear diagram. Their method is useful in the recognition of the variations or domination of cations and anion concentrations in water samples collected in monsoon and post-monsoon periods. Majority of dug well samples of the monsoon times of KRB fall within the domains 4, 2 and 6 while those of the post-monsoon belong to domains 2, 4 and 6. Moreover, it can be also observed that dug well samples of the monsoon fall within domains D, G and B in decreasing order. The same is true during the post-monsoon time. However, the percentage of samples varies.

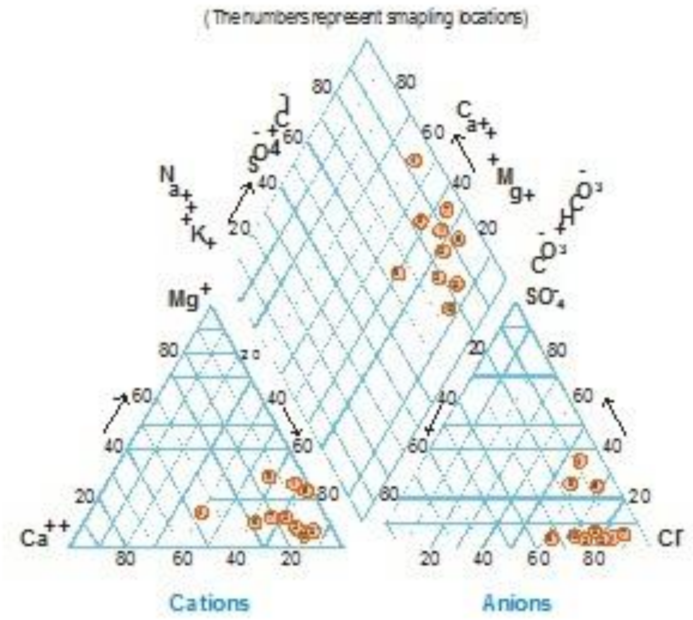

Fig. 4.10 Piper Diagram showing hydrochemistry of dug well samples (Post-monsoon)

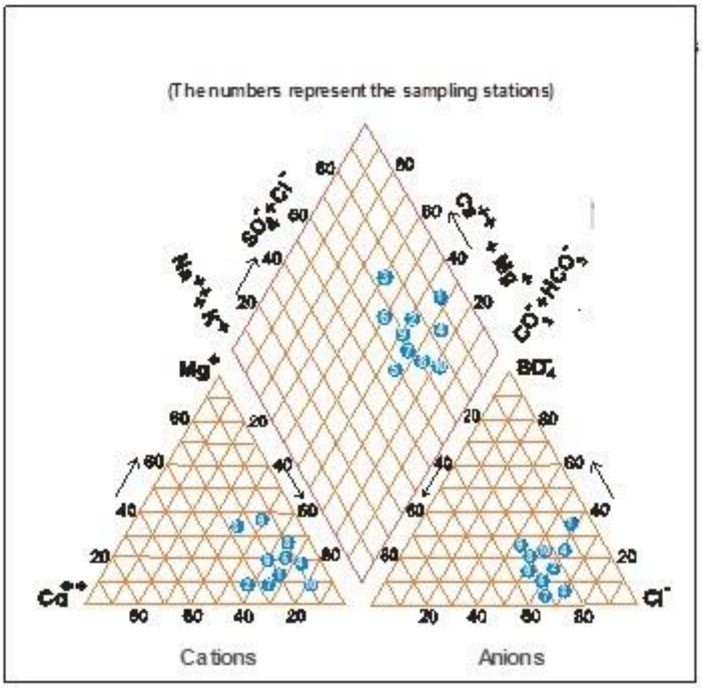

Fig. 4.11 Piper Diagram showing hydrochemistry of dug well samples (Pre-monsoon)

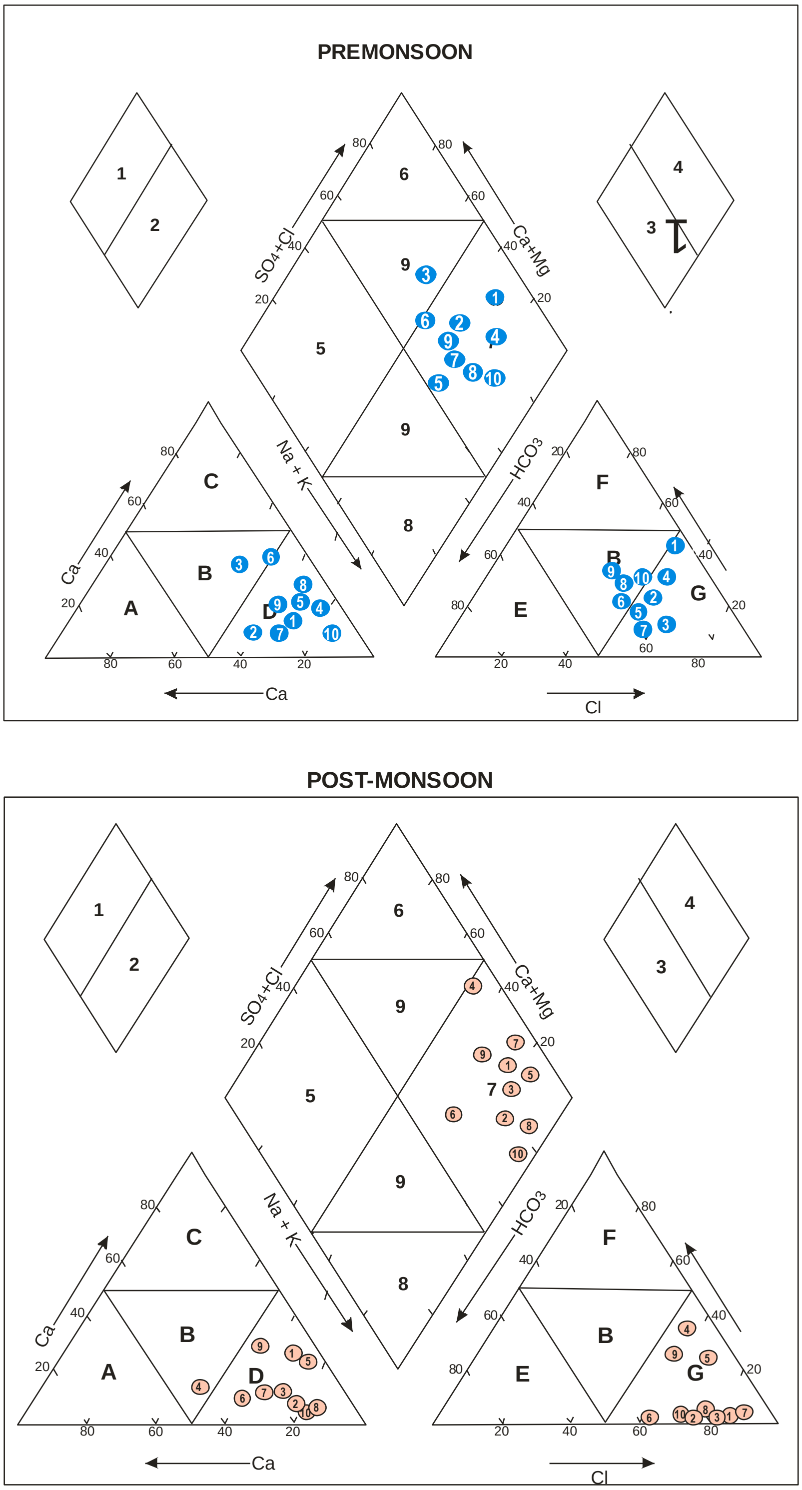

Fig 4.12 Piper-trilinear diagram for pre monsoon and post-monsoon

Table 4.13 Characterization of well water samples of Karamana River Basin on the basis of Piper diagrams (A)

Subdivision of the diamond (Fig. 6-13)	Characteristics of the sub-field of the diamond	Percentage of water samples in the category	
		Monsoon	Post-Monsoon
1	Alkaline earth (Ca+Mg) exceed alkalies (Na+K)	10	0
2	Alkalies exceed alkaline earths	90	100
3	Weak acids (CO2+HCO3) exceed strong acids (SO4 + Cl)	0	0
4	Strong acids exceed weak acids	100	100
5	Magnesium bicarbonate type	0	0
6	Calcium chloride type	90	100
7	Sodium chloride type	0	0
8	Sodium bicarbonate type	0	0
9	Mixed type (Nocation-anion exceeds 50%)	0	0

Table 4.14 Characterization of well water samples of Karamana River Basin on the basis of major ion percentages following Piper diagram (B)

(Water types are designated according to the domain in which they are plotted on the Piper diagrams)

Subdivision of the triangles (Fig. 4-13)	Type	Percentage of water samples in the category	
		Pre-monsoon	Post-monsoon
A	Calcium type	0	0
B	No dominant type	50	10
C	Magnesium type	0	0
D	Sodium and Potassium type	80	90
E	Bicarbonate type	0	0
F	Sulphate type	0	0
G	Chloride type	60	100

4.16 RANGE OF HYDROCHEMICAL VALUES (DUG WELLS, TUBE/BORE WELLS AND PONDS)

The range of hydro chemical values of water samples collected from dug wells, tube/bore wells and ponds of Karamana River Basin are shown in Table 4.15, Table 4.16 and Table 4.17.

Attributes of some of the dug well samples exceed the permissible limits in the case of pH, hardness, Na, and Cl. Presence of F is a notable feature of the well water in many localities in KRB. The range of hydrochemistry of tube/bore well samples (Table 4.17) indicates that pH ranges from 6.5 to 7.8, EC from 111 µs/cm to 894 µs/cm, TDS from 36.8 mg/l to 614.8 mg/l and TH from 10 mg/l to 612 mg/l. F content of tube/bore well samples of KRB exhibits a range of values from 0.001 to 0.006.

Table 4.17 gives the range of hydro chemical parameters of pond water of KRB. In this case the pH values ranges from 7.2 to 8.1. Dissolved oxygen (DO) ranges from 3.6 mg/l to 5.2 mg/l). E C is varying form 598 µs/cm to 3421 µs/cm TDS shows variation from 226 mg/l to 580mg/l, TH in pond water reveals low hardness (37.1 mg/l to 69.5 mg/l) compare to dug well (12mg/l to 986mg/l) and for bore well water samples of TH ranges from 10 to 612 mg/l. In dug well samples the content of Na is high (14 mg/l to 142.8mg/l) compared to the tube well (0.06 mg/l to 38.6 mg/l) and pond water (0.01 mg/l to 2.4 mg/l). Pond water reveals high content of Cl (1.1 mg/l to 9.8 mg/l) compared to dug well (12 mg/l to 306mg/l) and bore well (0.1 mg/l to 2.24 mg/l). Bore well reveals high content of K (0.018mg/l to 5.4 mg/l) compared to dug well (0.001 mg/l to 0.172 mg/l) and ponds (0.026 mg/l to 0.68 mg/l). Dug well shows high content of F varying from 0.01mg/l to 1.28mg/l compared to tube well. Bore well situated near the coastal side shows high content of salinity of 136.4 mg/l.

Table 4.15 Summary of hydro chemical attributes of groundwater of shallow and deep aquifers of midland and highland, KRB.

No	Attributes and permissible limit	Minimum	Maximum
1	pH (7- 8.5)	6	7.8
2	EC	95	1024
3	Salinity	0	216
4	Hardness (100)	12	986
5	TDS (500mg/l)	218.5	394.6
6	Na^{+} (50 mg/l)	14	142.8
7	K^{+} (10 mg/l)	0.001	0.172
8	Ca^{3+} (75 mg/l)	3.2	78.4
9	Mg^{3+} (150 mg/l)	0.5	9.5
10	Cl^{-} (200 mg/l)	12	306
11	NO_3^{-} (45mg/l)	0.1	5.12
12	SO_4^{-}(200 mg/l)	0.001	0.049
13	PO_4^{-}	0.024	1.94
14	F	-.01	1.28

Table 4.16 Range of Hydrochemistry of tube/bore well water sample of KRB (M&P)

Item	Minimum	Maximum
pH	6.5	7.8
EC (µs/cm)	111	894
TDS(mg/L)	36.8	614.8
TH(mg/l)	10	612
Ca^{3+}	13	78.7
Mg^{3+}	0.7	5.2
Na^{+}	0.6	38.6
K+	0.10	5.4
Total Alkalinity	0.17	6.22
Cl^{-}	0.1	2.24
NO^{3}	0.01	4.86
SO^{4-}	0.001	0.003
PO^{4-}	0.01	0.06
F	0.001	0.006
Salinity(ppt)	ND	136.4

Table 4.17 Range of Hydrochemistry of pond water samples of KRB

(Monsoon and post-monsoon)

Item	Minimum	Maximum
pH	7.2	8.1
EC (µs/cm)	598	3421
TDS(mg/L)	226	580
TH(mg/l)	37.1	69.6
DO(mg/l)	3.6	5.2
Ca^{3+}	5.1	12.2
Na^{+}	0.1	2.4
K+	0.26	0.68
Cl^{-}	1.1	9.8
NO^{3}	0.01	0.05
SO^{4-}	4.1	113
PO^{4-}	0.01	0.05

4.17 DISCUSSION ON HYDROCHEMICAL DATA OF STREAM WATER

Fig. 4.10 depicts the spatio temporal variability of TDS in the main stream of Karamana River Basin. Up to the sampling station No. 7 (Vellaiyakadavu) there is practically no variation in respect of solute load between the sampling seasons and especially from the origin. Obviously, the steeply climbing graph suggests peaking of load beyond station No. 10 (Thiruvallam). The monsoon load is seemingly an order of magnitude larger than that of post monsoon. In reality the water discharge during monsoon is very large compared to that of the base-flow (non -monsoon) season. The surface flow, the water seeping through the soil, the farm lands in the basin and residues from the domestic waste might all jointly contribute to the higher load flux in the monsoon. In a basin practically free of urbanization or a basin which is practically in the pristine state, the flood season chemical load vis-à-vis base flow is not very large is the rule of thumb. The Karamana River Basin by virtue of the anthropogenically altered or modified state therefore does not fully fall in line with that general rule. Most of the constituent such as Ca, Mg, Fe, Na, K, Cl, HCO_3, NO_3, SO_4 and PO_4 are increasing from upstream to downstream side in both seasons (monsoon and post monsoon). On the upstream side of both streams shows high purity, when they entire the urban area there by quality is decreasing and are worsening when they reach to the end of the downstream side.

Fig. 4.13, Fig. 4.14 and Fig. 4.15 shows spatial variation of TSS in Karamana River during monsoon and post-monsoon. This graph of TSS vs, river distance is equally instructive. Apparently there is a peaking of TSS at station No.4 (Aryanad) and beyond that toward downstream, the TSS for monsoon and non-monsoon does not follow any meaningful pattern. Yet the absence of pattern is construed as a reflective of the degree of human intervention. One of the human actions and consequent manifestation in the stream is the clandestine sand mining activity that goes uncontrolled in spite of the statutes and police vigil.

The sand mining preferentially focus on the fine aggregate grade sand and reject and leave behind the finer sediment in the channel. A sort of jigging with a "false bottomed" metallic basket is what makes the sand nearly clean of the mud which gradually builds up in bulk in the channel waters. As a result the water discharge in the stream, despite its seasonality does not show any visible TSS variations between the sampling seasons. It is more so with respect to the stream segment downstream of station No. 5 (Mundela).

Fig. 4.12 shows a graph in which the sampling stations are plotted against the total load, the latter in fact is a sum of TSS and TDS, and hence is not expected to display any drastic difference from the trends shown by the independent TSS and TDS plots. The general pattern or trend of the monsoon and non-monsoon seasons is a rough reflection of the pattern in the foregoing figures. What is instructive here is the stability of the pattern, i.e. a) the stable nature of the system and b) the extent of human intervention in the form of sand mining. Between station No.5 (Mundela) and No. 8 (Mangattukadavu) segment of the channel is perhaps most disturbed, and hence the TL flux does not show any systematic pattern.

The load data for Killi Ar is plotted in Fig. 4.16 and Fig 4.17 and is perhaps much more an urban stream than Karamana River. Though one of very small basin area and one without any major or minor dams, or water retention or diversion/regulation interventions, the TDS flux during monsoon and non-monsoon seasons is systematic and does not show a huge differences between the sampling seasons. The monsoon flux is slightly larger than the base flow flux. The TSS in Fig. 4.17 does not reflect the pattern of TDS, in that two peaks standing taller than the post monsoon season, calls for an enquiry. Despite the smaller channel size and basin area in Killi Ar the removal of channel sediment or even ancient channel sediment is common. The graph between station 5 (Azhikode) and station 8 (Maruthumkuzhy) is a segment where removable channel sediment is practically nil and hence nearly no variability between the seasons. However, the upstream of this segment, monsoon earns quite a good deal of TSS primarily derived from the erosion of the cultivated area in the basin, but with poor soil/land management practices. The peak at station No. 9 for monsoon can be explained by the sudden and quick release of the sediment from the urban area of Thiruvananthapuram, where road side gutters and the pavements are temporary sediment storages.

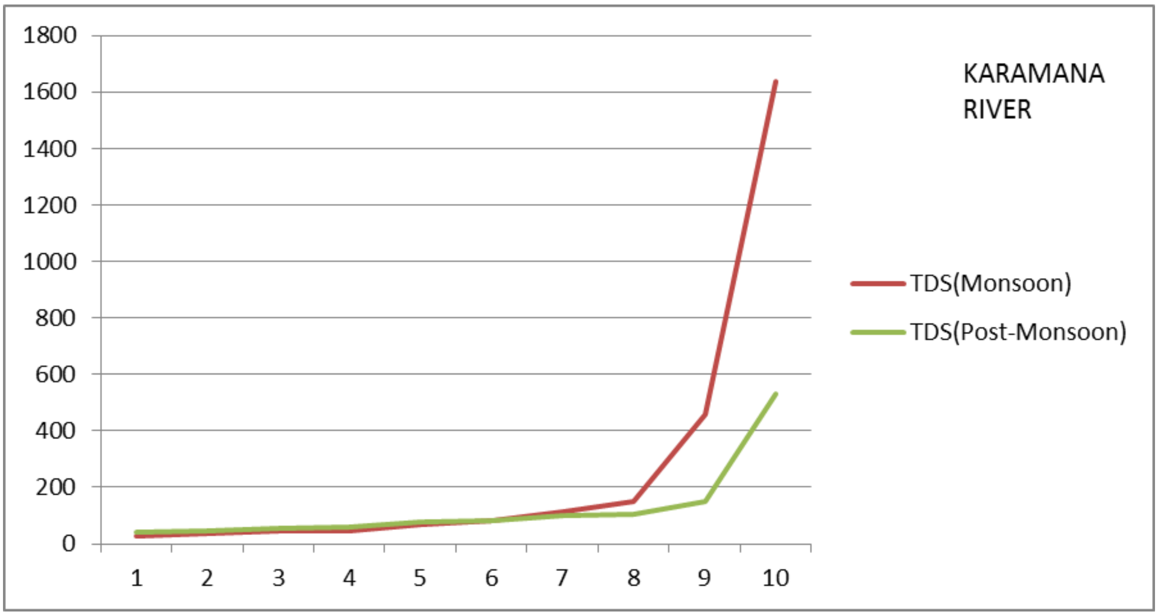

Fig. 4.13 Monsoonal and post-monsoonal spatial variation of TDS (mg/L) in Karamana River

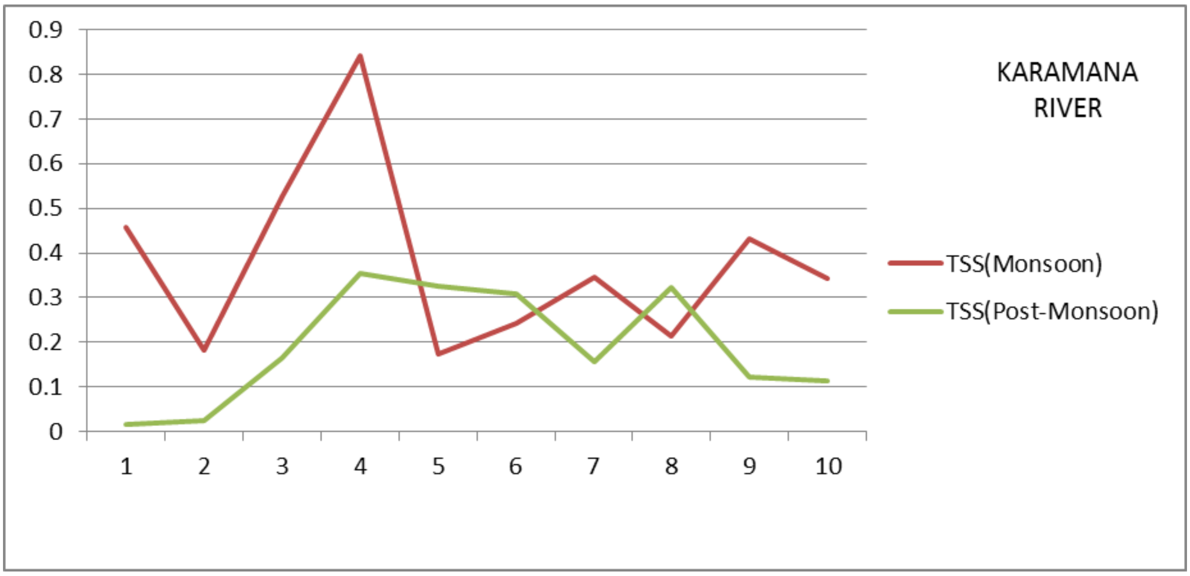

Fig. 4.14 Monsoonal and post-monsoonal spatial variation of TSS (mg/L) in Karamana River

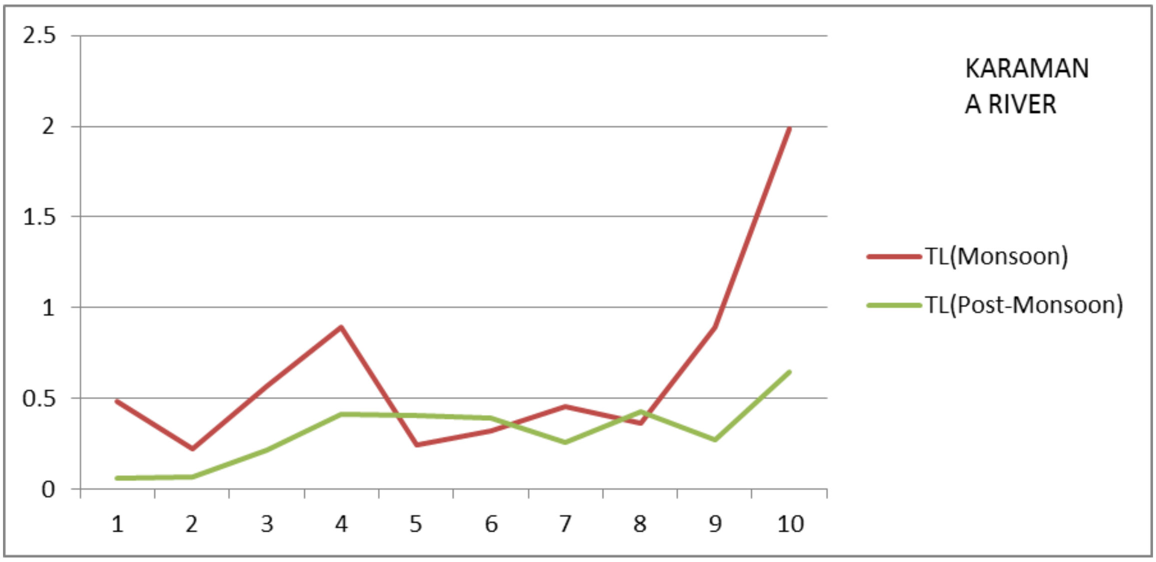

Fig. 4.15 Monsoonal and post-monsoonal spatial variation of TL (mg/l) in Karamana River

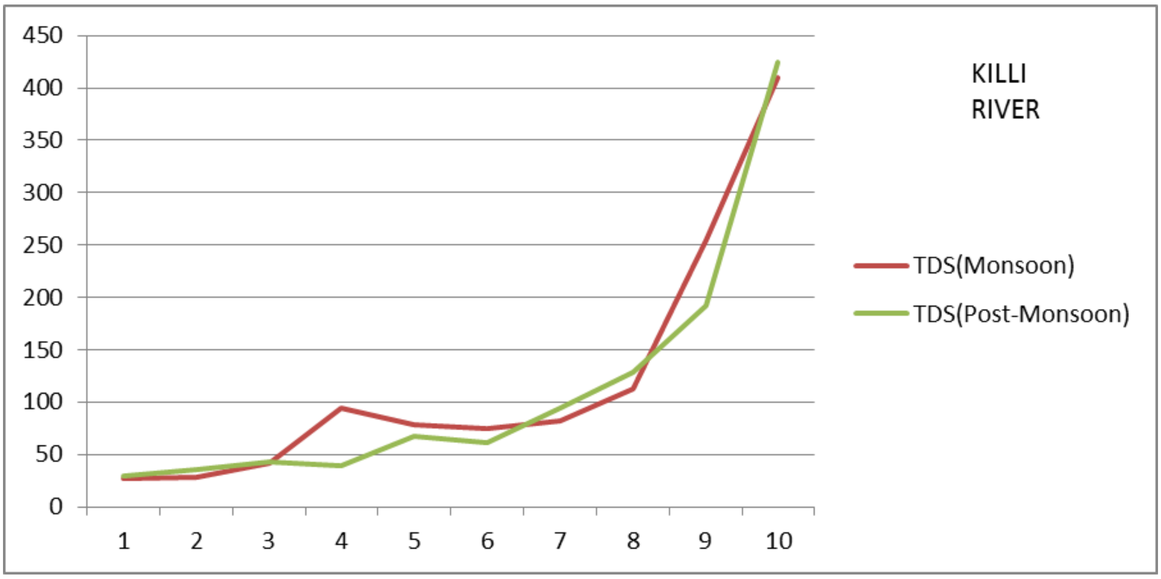

Fig. 4.16 Monsoonal and post-monsoonal spatial variation of TDS (mg/l) in Killi Ar

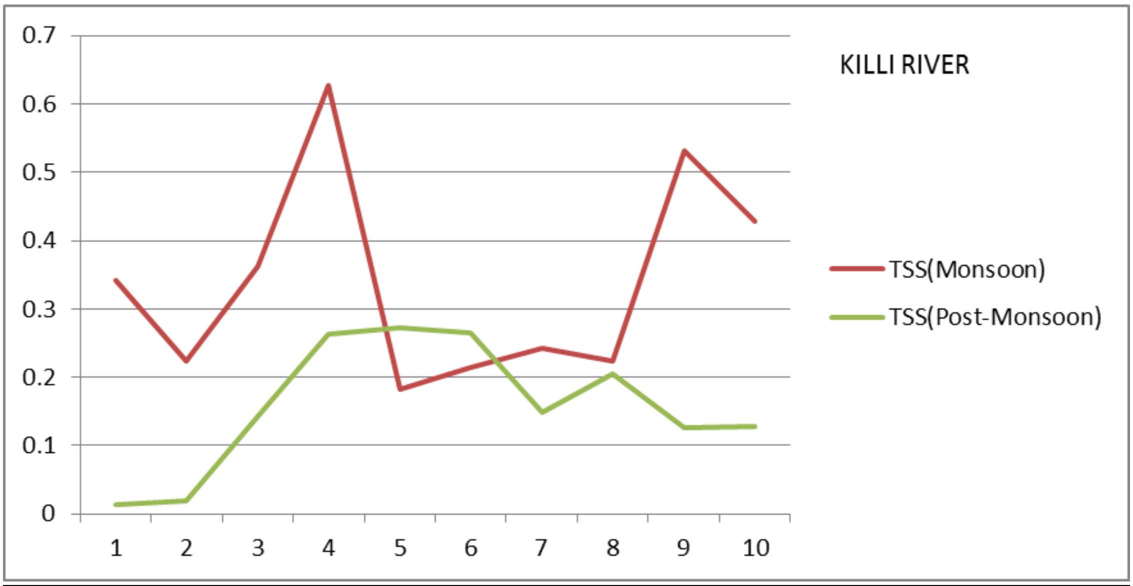

Fig. 4.17 Monsoonal and post-monsoonal spatial variation of TSS (mg/l) in Killi Ar

4.18 RESULTS AND DISCUSSION

Water resources of any region constitute mainly surface water and groundwater with rainfall being the basic source. In the National and State Water Policies, drinking water receives first priority, followed by irrigation, industry, power, fishing and recreation. This chapter focuses on the water resources potential of Karamana River Basin. Vellayani Kayal is the largest natural freshwater body in the Karamana River Basin. The quantitative assessment is made on the basis of collected data and qualitative assessment of water resources, both surface and subsurface of the basin is made on analytical data.

Water balance estimation is an important tool to assess the current status and trends in water resource availability in an area over a specific period of time. Furthermore, water balance estimates strengthen water management decision-making, by assessing and improving the validity of visions, scenarios and strategies. Water balance techniques, one of the main subjects in hydrology are a means of solution of important theoretical and practical hydrological problems. It is very difficult to precisely assess the quantity of water demanded by the public, since there are many variable factors affecting water consumption. Factors affecting per capita water demand in urban areas are varied.

CHAPTER V

SUMMARY AND CONCLUSION

There are three major themes in the present study, namely the Holocene aquifer of the Karamana River Basin, water resources potential of the basin and drainage morphometry. Since 1986 geomorphologic studies have been attempted on different scales for a number of river basins of Kerala following traditional methods and using modern techniques adopting GIS with variable degrees of success. However, for the present study, a method based on latest topographic sheets of Survey of India, with subsequent ground checks have been adopted.

Ground water in coastal areas has received considerable attention from various sectors of society, including scientific communities due to a host of issues potentially impacting of groundwater resource security. The Asia-Pacific region is on the verge of water scarcity. Being the production house of the world, many countries of Asia-Pacific are exploiting their natural resources, including the water resources, beyond their carrying capacity.

The Karamana River Basin which is a 6^{th} order basin, spreads over an area of 703 km^2. The main stream, the Karamana Ar has a length of 68 km and. its main tributaries are Killi Ar and Todai Ar. The basin extends from Chemmunji Mottai Peak (1717 m amsl) across the highland, midland and lowland zones of the Kerala. There are two dams in the basin. The chief soil types of KRB are red loams, coastal alluvium, and riverine alluvium lateritic soils. Nearly 63 % of the basin is presently under settlements, and some of these may be with homestead farms and tree crops.

The geographical extent, stratigraphical, hydrological, hydro chemical aspects and pollution status of the Holocene aquifer forming a portion of the Karamana River Basin has been studied on the basis of the data collected from various sources. A general picture of the Quaternary succession of the coastal tract of the basin is that the Quaternary sediments of Karamana River Basin are dominantly coarse sand with occasional silty and clayey intercalations, the latter hardly exceeding two percent of the bulk. Most portions of all the above lithounits are devoid of marine fossils and thereby indicate their fluvio-lacustrine origin of the most part of the succession. The dating of sediments of the coastal tract of Thiruvananthapuram District from samples collected from nine localities gave age ranging from 1800 to 30,000 YBP and radiocarbon dating by a recent study indicates that the second litho unit of the coastal tract of Thiruvananthapuram ranges in age from 10,700 years B.P to 7230 years B.P. Hence the Holocene succession of the Karamana River Basin can be considered to commence upward from the middle lithounit and the underlying portion of the Quaternary constituting the Pleistocene succession of the region. The maximum thickness of the Holocene stratigraphic units of the Karamana River Basin is restricted to about 20 m. Radiometric dating of peat samples gave values of 2.52 ky BP and 1.6 ky BP respectively thereby indicating their relatively younger Holocene age for the sediment enclosing them.

The hydrological properties of the Holocene aquifer of the basin is also elaborated in the study. An isopach map of the Holocene sequence of the Karamana River Basin has been prepared using drill log data collected from various sources which showed that the thickest succession of Holocene sediments occur east of Vettukad and Shangumughom. The water table fluctuation of the Holocene aquifer from two observation wells maintained by the Central Groundwater Board for the period from 1985 to 1993 revealed the fact that the maximum depth of the water table in Holocene aquifer is during the month of April and minimum in November. The rising of the water table in response to the monsoon rains are between 0.2 m and 1.00 m whereas the lowering in hot season are only 0.18 m to 0.82 m. In order to study the geohydrologic nature of the Holocene aquifer, sediment samples were analyzed. The results of the sieve analysis show that the Holocene sediments north of Vallakadavu are mostly sandy. However, south of Vallakadavu there is an enrichment of the finer fractions in Holocene sediment sand this is attributed to reworking of sediments due to proximity to the mouth of the Karamana Ar.

The study of the data on long term rise and fall in water level does not indicate any indication of overdraft from the Holocene aquifer of the Karamana River Basin. The specific yield of Holocene sediments of Karamana River Basin has been noted to range from 28 percent to 32 percent and the study also showed that the coefficient of storage for the Holocene aquifer of Karamanaranges from 0.028 to 0.032. Transmissivity value of Holocene aquifer of Karamana River Basin has been estimated to range from 280 m^2/day to 420 m^2 /day. The coefficient of permeability (hydraulic conductivity) of the Holocene aquifer has been noted to be very high ranging from 25.5 m/day to 45.0 m/day. The reported yield of the filter point wells and shallow tube wells tapping the potential aquifer zones in the Holocene aquifer ranges from 510 to 850 lpm.

From the various morphometric parameters analyzed it is inferred that the number of the streams decreases as the stream order increases. Mean basin areas increase directly with increasing magnitude of stream orders, according to the ‘law of drainage basins’. The mean bifurcation ratio indicate that geological structures of the basin have only negligible influence on the drainage pattern. Out of seven sub watersheds, the smallest sub basins SW I and SW possesses highest values for relief and slope. SW VI is of lowest gradient (0.001) and relief (81 m). This basin and SW IV and V fall mostly in coastal stretch with gentle slopes (0.001).

The significant relationship of stream length and stream number with stream order indicates uniformity of the geological setting, area and no large fluctuations of relief and slope. The slight dip in correlation between mean stream lengths and stream order is due to the disproportionate length of the sole sixth order channel in the Karamana River Sub Basin (SW VII). The fundamental characters of drainage basin (size, length, relief etc.) are used to interpret for the various fluvial processes. Among the three sub watersheds in the high relief areas, SW I and SW II show maximum values for drainage density, relief and slope and lowest values for length of overland flow and constant of channel maintenance. They belong to the category of ultra-fine drainage texture. This is aided by the occurrence of the resistant charnockitic terrain and thick vegetation of the area. The bifurcation ratios falling between

3 and 5 are generally attributed to considerable structural control. However, SW I and II though ultra-fine textured has significantly low drainage densities (3.83; 3.58) when compared to their stream frequencies.

Mean stream length of SWI and II are lower than other sub watersheds for all orders. This deviation might be due to the change in slope and topographic elevations. The highest value for Fs as exhibited by SWI and II is likely due to occurrence of closely spaced minor fractures/lineaments. This could partially account for its very fine textured nature. The influence of slope and elevation on texture is seen in SW IV, V and VI which fall exclusively in the coastal stretch with lowest slope gradients. These have the coarsest texture with wide spacing of stream channels. This is reflected in their low stream densities and frequencies resulting in their very coarse texture.

Ruggedness number is another vital index of dissection and run-off and the resultant erosion of a basin. The ruggedness number too follows the trend in texture exhibiting high values for SW I (4.82) and SW II (5.39). Thus these sub watersheds tend to have high runoff, high erosion potential and sediment load, low base flow and infiltration and high capacity for surface water storage. This would result in considerable potential for flood with higher peak flows. The Karamana River as a whole is characterized by gentle slope (0.04) and high relief (1609 m). The basin has intermediate texture (7.36/km), moderate drainage density (2.29 km/km^2), frequency (3.22/ km^2), low constant of channel maintenance (0.44 km^2/km) and length of overland flow (0.22 km).

The smaller value of Form Factor indicates the elongated nature of Karamana River Basin. Drainage density values and constancy of channel maintenance suggest that river basin has moderate run off, low erosion potential, sediment load, high groundwater storage and base flow. Intermediate drainage texture and moderate ruggedness values point to the subdued flood potential of Karamana River Basin. The mean bifurcation ratio indicates the geological structure of the basin which has least influence on the drainage pattern. Drainage pattern noted in the Karamana River Basin is dominantly dendritic in the lower reaches which is expressed by a homogeneity of texture and is indicative of lack of any significant structural control.

Regarding the water potential and hydrochemistry of the Karamana River Basin, the various water sources for the Karamana River Basin can be classified into two categories (1) Surface sources, such as ponds and network of streams and reservoirs and (2) Sub-surface sources, such as springs, wells, tube wells / bore wells. Among the numerous ponds scattered throughout the basin, except in the case of a few, most of them are ephemeral. Large man-made ponds or pools of standing water are found in the lowland and midland zones of the basin. Many of these are temple ponds or irrigation ponds. Majority of valley head ponds supply water for irrigating paddy crop. The calculated value of SAR of the ground water sample of the Holocene aquifer in KRB indicates that the water is suitable for agriculture.

The present study reveals that there is significant contamination of the Holocene aquifer of Karamana River Basin due to mixing of polluted waters from the canal. The physico-chemical parameters studied for the Holocene aquifers are pH, conductivity, TDS, alkalinity, hardness, BOD, COD, chloride, sulphate, nitrate, phosphate, fluoride, sodium, potassium, calcium , magnesium, total coli form and fecal coli form reveal that anions and cation concentrations to those of Ca, Mg, Na, HCO_3 and Cl exceeds the permissible limits for the drinking water.

Also it is observed that the groundwater samples collected from most of the wells located in the urban area of Thiruvananthapuram exhibit notable regional and spatial variation in terms of physical, chemical and biological qualities. In the case of NO_2 the groundwater samples collected from dug wells of the basin exhibit significant difference between urban and non-urban localities. Higher concentration of NO_2 is noticed in groundwater samples collected from dug wells of the coastal tract of the basin. Chloride in well waters probably indicates leachate percolation and sewage pollution. Groundwater samples near the STP site reveals high content of heavy minerals such as Cu, Zn, Pb, Cr, Cd, Ni, Mn, and Fe. The presence of TC can be noticed in all seasons in the groundwater samples of dug wells in urban sections of the basin. The groundwater of major portion of the basin is generally potable except for the southern portion of the lowland zone. It has been found that the majority of dug well samples of the monsoon times of KRB fall within the domains 4, 2 and 6 while those of the post-monsoon belong to domains 2, 4 and 6. Moreover, it can be also observed that dug well samples of the monsoon fall within domains D, G and B but for the post it is in D and G.

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ANNEXURE A-1

Physical parameters that accounts for the acceptability of the dug wells in the Karamana River Basin

Dug well No.	Location	Well depth (thickness in m)	DWL (m.bgl)	Monsoon					Post-monsoon				
				Temperature (oC)	Turbidity (NTU)	Colour (Hazen)	Odour	Taste	DWL (m)	Turbidity	Colour	Odour	Taste
1	Valavetty	19.5	16.1	26.5	5	0.1	Odourless	Tasteless	17.5	6	0.1	Odourless	Tasteless
2	Aryanad	6.3	3.7	24.3	6	0.1	Odourless	Tasteless	4.6	7	0.1	Odourless	Tasteless
3	Kuttichal	11.2	8.6	23.2	6	0.2	Odourless	Tasteless	10.5	7	0.2	Odourless	Tasteless
4	Munnakuzhy	21.4	17.2	23.8	7	0.3	Odourless	Tasteless	14.6	8	0.3	Odourless	Tasteless
5	Azhicode	6.8	3.2	23.5	8	0.2	Odourless	Tasteless	4.4	10	0.3	Odourless	Tasteless
6	Aruvikkara	8.4	4.4	23.8	6	0.1	Odourless	Tasteless	6.9	8	0.2	Odourless	Tasteless
7	Vattiyoorkavu	13.8	9.1	23.7	7	0.2	Odourless	Tasteless	12.2	9	0.2	Odourless	Tasteless
8	Thirumala	14.2	9.2	23.7	7	0.3	Odourless	Tasteless	13.1	8	0.4	Odourless	Tasteless
9	Pappanamcode	10.6	7.3	23.6	9	0.4	Odourless	Tasteless	8.9	10	0.5	Odourless	Tasteless
10	Thiruvallam	5.5	3.2	23.2	1.3	0.6	Odourless	Slight	5.7	14	0.7	Perceptible	Slight

DWL: Depth of water level

ANNEXURE A-2

Physical parameters that accounts for the acceptability of the tube wells in the Karamana River Basin

Tube well No.	Location	Well Depth (m)	Monsoon					Post-Monsoon			
			Temperature (oC)	Turbidity(NTU)	Colour(Hazen)	Odour	Taste	Turbidity	Colour	Odour	Taste
5	Valavetti	62	25.5	3	0.1	odourless	tasteless	ND	ND	odourless	tasteless
3	Aryanad	42	25	2	0.1	odourless	slightly saline	ND	ND	odourless	slightly saline
2	Parandode	46	26	1	ND	odourless	tasteless	1	1.1	odourless	tasteless
8	Uzhamalackal	54	24.5	1	0.1	odourless	slightly saline	ND	1	odourless	slightly saline
10	Moozhi	42	25	2	0.2	odourless	slightly saline	1	1.2	odourless	slightly saline
13	Azhicode	46	24.5	2	0.1	odourless	tasteless	ND	1	odourless	tasteless
15	Karakulam	62	26	1	0.1	odourless	tasteless	2	2.1	odourless	tasteless
16	Peyad	35	25	2	ND	odourless	tasteless	2	1.4	odourless	tasteless
17	Thirumala	44	26.5	1	0.1	odourless	tasteless	3	2.2	odourless	tasteless
18	Thiruvallam	58	25	3	0.2	odourless	slightly brackish	4	3	odourless	slightly brackish

ANNEXURE A-3

Physical parameters that accounts for the acceptability of the ponds in the Karamana River Basin

Ponds No.	Location	Depth maximum (m)	Monsoon					Post-monsoon				
			Temperature (oC)	Turbidity(NTU)	Colour(Hazen)	Odour	Taste	Temperature (oC)	Turbidity(NTU)	Colour(Hazen)	Odour	Taste
1	Panavoor Moozhi	3.5	25.2	18	3	odourless	tasteless	25.6	20	2.5	odourless	tasteless
2	moodu (Cherayilkonar	4	25	14	4	odourless	tasteless	25.2	18	3	odourless	tasteless
3	Kuttichal pond	3.5	26	19	5	odourless	tasteless	26.2	22	4	odourless	tasteless
4	Vellanad pond	4.5	26	19	6	odourless	tasteless	26.4	20	5	odourless	tasteless
5	mangad Kulavikkonam	6.5	26.1	26	7	odourless	slight	26.5	286	5	slight	slight
6	Vattiyoorkavu	5	26	17	8	odourless	tasteless	26.4	18	4	odourless	tasteless
7	Housing Board Jn (Temple pond).	4	26	22	8	odourless	slight	26.8	26	6	slight	slight
8	Pappanamcode Ela pon	4.5	25.3	24	11	odourless	slight	25.6	28	8	slight	slight
9	Mangattukadavu Ela por	4	25.2	19	18	odourless	tasteless	25.5	24	17	odourless	tasteless
10	Palickal Ela pond	5	25.4	24	24	odourless	tasteless	25.7	26	30	slight	tasteless

ANNEXURE A-4

Physical parameters that accounts for the acceptability of the streams of Karamana river in the Karamana River Basin

Sl.No	Location	Description of the site	Monsoon				Post-monsoon				
			Temperature (oC)	Turbidity (NTU)	Colour (Hazen)	Taste	Temperature (oC)	Turbidity	Colour (Hazen)	Odour	Taste
1	Peppara	Protected Forestland with forest plantaions	26	12	14	Tasteless	27	13	8	No odour	Tasteless
2	Flank of Kurichimala	Protected Forestland with Kani settlements	24.5	12	16	Tasteless	26	14	10	No odour	Tasteless
3	Kilicode	Protected Forestland with Kani settlements	25	14	18	Tasteless	28	14	11	No odour	Tasteless
4	Aryanad	Washing /bathing ghat, settlements with mixed crops, local market , roadside shops and thick riparian	24.5	15	32	Tasteless	26	13.5	24	No odour	Tasteless
5	Mundela	Sand mining site, settlents with rubber cultivation	25	16	38	Tasteless	31	15.5	26	No odour	Tasteless
6	Irumba	Bathing /washing ghat with neighbouring reclaimed paddy land	25	14	44	Tasteless	30	14	32	No odour	Tasteless
7	Vellayakkadavu	Bathing /washing ghat	26	17	56	Tasteless	29	15	48	No odour	Tasteless
8	Mangattukadavu	Bathing /washing ghat with tapioca and coconut cultivation	24.5	19	60	Tasteless	28	19.5	56	No odour	Tasteless
9	Karamana Bridge	Bathing /washing ghat and urban settlement with coconut cultivation	26	36	66	Tasteless	32	45	58	No odour	Tasteless
10	Thiruvallam Temple	confluence of Killiayar and Parvathiputhenar, urban settlents and coconut cultivation	30	68	74	Slight	29	74.5	68	Foul smelling	Slight
				Killi *Ar*							
1	Panavoor	Scattered settlement with homested gardens	26.5	ND	1.4	Tasteless	27	Clear water	8	No odour	Tasteless
2	Puthenpalam	Rubber plantations	26.5	ND	1.2	Tasteless	28	Clear water	9	No odour	Tasteless
3	Pazhakutty	Urban settlement	27.5	1	2.1	Tasteless	28.5	Slight	10	No odour	Tasteless
4	Valikkode	Semi-urban settlement	28.2	2	1.5	Tasteless	29	Slight	22	No odour	Tasteless
5	Azhikkodu	Semi-urban settlement	29.5	2	2.4	Tasteless	31	Slight	24	No odour	Tasteless
6	Karakulam	Semi-urban settlement	28.3	1	2.2	Tasteless	30	Moderate	29	No odour	Tasteless
7	Vazhayila Bridge	Semi-urban settlement	27.5	3	3.1	Tasteless	30	Moderate	44	No odour	Tasteless
8	Maruthumkuzhy	Urban area	29.5	2	2	Tasteless	31	Moderate	53	No odour	Tasteless
9	Killipalam Bridge	Urban area	29.5	4	3.6	Tasteless	32	Moderate	54	No odour	Tasteless
10	Homeo College Bridge	Urban area	29.4	5	4.1		32	High	61	Bad odour	Slight

Annexure B - 1(A)

WATER QUALITY DATA - DUG WELLS OF KARAMANA BASIN

CHEMICAL ASPECTS OF DUG WELL WATER OF KARAMANA BASIN (MONSOON PERIOD)

Sl.No	Location	pH	EC (µs/cm)	TDS(mg/L)	TH(mg/l)	Na^+	K^+	Ca^{3+}	Mg^{3+}	Cl^-	$HCO_3 + CO_3$	NO_3	SO_4^-	PO_4^-	F
1	Valavetty	6.3	95	23.2	12	1.8	0.172	3.2	1.4	18	0.236	0.1	0.002	0.846	0.05
2	Aryanad	6.8	98	29.4	18	2.6	0.025	4.4	2.8	16	1.575	0.13	0.014	1.937	0.016
3	Kuttichal	6.6	133	192.4	27	3.8	0.002	6.3	2.6	28	0.021	0.16	0.002	1.091	0.012
4	Munnakuzhy	6.9	168	76.4	38	7.6	0.106	8.3	2.8	32	1.398	1.22	0.016	1.004	0.033
5	Azhicode	6.6	469	231.5	36	16.1	0.196	4.2	3.6	108	0.006	1.42	0.045	1.926	0.008
6	Aruvikkara	6.7	548	18.5	73	32.1	0.072	11.3	5	48	0.022	2.36	0.039	1.98	0.043
7	Vattiyoorkavu	7.6	346	348.8	157	28.4	0.004	21.6	7.8	95	0.02	2.26	0.002	0.024	0.009
8	Thirumala	7.1	465	36.8	356	27.2	0.001	30..3	5.6	102	0.024	2.42	0.001	1.504	0.005
9	Pappanamco	7.8	482	286.8	324	46.6	0.018	33.6	4.6	124	0.047	3.11	0.011	0.035	0.006
10	Thiruvallam	7.6	956	327.8	842	138.6	0.025	64.2	7.5	224	0.013	4.86	0.003	0.184	0.931

Annexure B - 1(B)

CHEMICAL ASPECTS OF DUG WELL WATER OF KARAMANA BASIN (POST-MONSOON PERIOD)

Sl.No	Location	pH	EC (µs/cm)	TDS(mg/l)	TH(mg/l)	Na^{+}	K^{+}	Ca^{3+}	Mg^{3+}	Cl^{-}	$HCO_3 + CO_3$	NO_3	SO_4^{-}	PO_4^{-}	F
1	Valavetty	6.4	135	28.8	14	1.4	0.124	3.2	1.4	12	0.209	ND	0.001	0.204	0.01
2	Aryanad	6.3	109	26.2	17	2.6	0.02	3.4	2.9	14	1.364	0.1	0.011	1.325	ND
3	Kuttichal	6.2	156	194	23	3.1	0.012	5.3	2.7	18	0.024	0.12	0.012	1.072	0.002
4	Munnakuzhy	6.1	268	96.4	32	5.8	0.96	7.8	1.9	21	1.22	1.2	0.014	1.006	0.024
5	Azhicode	6	441	132.4	34	9.8	0.28	4.34	2.6	86	0.16	1.4	0.034	1.714	0.004
6	Aruvikkara	6.4	590	118.2	82	12.4	0.084	12.4	3.1	64	0.02	2.12	0.009	1.94	0.042
7	Vattiyoorkavu	6.2	456	249.6	124	18.8	0.005	20.8	9.4	88	0.18	2.16	0.005	1.02	0.018
8	Thirumala	6.1	508	124.6	368	28.4	0.012	33.6	8.4	128	0.14	2.64	0.006	1.644	0.014
9	Pappanamco	6.5	524	288.4	376	52.4	0.016	42.4	7.4	152	0.04	3.64	0.018	0.142	0.01
10	Thiruvallam	6.6	1024	394.6	986	142.8	0.036	78.4	7.8	306	0.016	5.12	0.014	0.194	1.28

Annexure B - 2(A)

WATER QUALITY DATA -TUBE WELLS OF KARAMANA BASIN

CHEMICAL ASPECTS OF TUBE WELL WATER OF KARAMANA BASIN (MONSOON PERIOD)

Sl.No	Location	pH	EC	TDS(mg/l)	TH(mg/l)	Na^+	K^+	Ca^{3+}	Mg^{3+}	Cl^-	$HCO_3 + CO_3$	NO_3	SO_4^-	PO_4^-	F
1	Valavetti	6.5	132	36.8	10	1	0.18	1.3	0.4	ND	0.12	ND	0.002	0.06	ND
2	Aryanad	6.6	111	39.8	12	0.6	0.82	2.5	1.2	NDF	1.96	ND	ND	0.37	0.006
3	Parandode	6.8	142	184.8	14	1.2	1.06	5.4	1.6	0.4	0.142	0.1	0.002	0.05	ND
4	Uzhamalacka	7.1	216	215.6	21	3.2	2.44	7.9	1.8	0.2	1.26	0.02	0.001	ND	0.003
5	Moozhi	6.6	342	322.6	18	5.6	2.92	6.5	2.4	1.8	1.04	0.42	ND	0.02	ND
6	Azhicode	6.9	422	422.2	32	8.4	2.67	14.6	3.1	0.8	1.42	0.34	0.003	ND	ND
7	Karakulam	7.3	308	348.8	46	11.4	3.58	18.6	4.4	0.9	0.98	0.28	ND	0.024	0.002
8	Peyad	7.2	628	134.6	52	8.4	5.4	20.6	5.2	1.06	1.02	0.44	0.001	0.004	0.001
9	Thirumala	7.6	470	278.1	64	13.2	1.66	43.8	3.1	1.4	0.98	3.11	0.011	0.005	ND
10	Thiruvallam	7.4	715	414.8	546	38.6	2.78	66.42	3.8	2.24	1.21	4.86	0.002	0.014	ND

Annexure B - 2(B)

WATER QUALITY DATA -TUBE WELLS OF KARAMANA BASIN

CHEMICAL ASPECTS OF TUBE WELL WATER OF KARAMANA BASIN (POST-MONSOON PERIOD)

Sl.No	Location	pH	EC	TDS(mg/l)	TH(mg/l)	Na^+	K^+	Ca^{3+}	Mg^{3+}	Cl^-	$HCO_3 + CO_3$	NO_3	SO_4^-	PO_4^-	F
1	Valavetti	7.1	167	52.6	16	ND	0.1 0	1.8	0.3	ND	0.26	ND	0.002	ND	ND
2	Aryanad	68	185	44.7	18	ND	1.14	2.9	0.2	ND	1.34	ND	ND	0.02	0.004
3	Parandode	6.9	242	210.3	21	1.1	0.18	4.4	4	0.1	1.08	ND	0.002	ND	ND
4	Uzhamalacka	7.3	354	266.8	26	1.2	1.94	8.5	6	ND	2.8 8	0.01	0.001	ND	0.002
5	Moozhi	6.6	380	368.2	28	3.2	2.36	11.2	1.2	0.8	2.6	0.3	ND	0.01	ND
6	Azhicode	7.1	468	412.8	39	6.1	2.12	24.6	2.4	0.2	3.94	0.22	0.003	ND	ND
7	Karakulam	7.4	393	354.3	51	7.4	1.3	22.7	4.6	0.6	4.82	0.26	ND	0.004	ND
8	Peyad	7.4	568	268.9	68	4.2	1.06	26.8	3.6	0.06	6.22	0.36	0.001	0.003	0.001
9	Thirumala	7.8	566	322.7	69	6.1	1.24	51.2	2.8	1.1	2.62	2.98	0.011	0.002	ND
10	Thiruvallam	7.5	894	614.8	612	28.4	1.28	78..7	4.7	1.02	3.14	4.09	0.002	0.005	ND

Annexure B-3(A)

WATER QUALITY DATA- PONDS -KARAMANA BASIN

CHEMICAL ASPECTS OF PONDS OF KARAMANA BASIN (MONSOON PERIOD)

Sl.No	Location	pH	EC	TDS(mg/l)	DO(mg/l)	TH(mg/l)	Na	K	Ca^{3+}	SO_4^{2-}	Cl
1	Panavoor Moozhi	7.9	598	226	5.5	45.2	2.1	0.34	6.3	7.2	11
2	Thannimoodu (Cherayilkonam	8	1012	317	4.4	42.8	ND	0.26	6.1	11.3	8.2
3	Kuttichal pond	7.5	644	464	4.2	51.9	1.1	0.33	8.3	8.8	6.4
4	Vellanad pond	8.1	766	398	4.72	38.8	1.6	0.41	10.6	6.1	4.8
5	Nedumangad Kulavikkonam	7.6	895	386	4.8	37.1	2.1	0.54	8.4	8.9	3.6
6	Vattiyoorkavu	7.7	1064	410	5.1	41.6	1.4	0.37	5.1	5.4	9.2
7	Housing Board Jn (Temple pond).	8	1654	502	4.73	68.8	1.02	0.41	6.4	6.1	4.1
8	Pappanamcode Ela pond	7.9	2382	524	3.9	61	1.01	0.58	6.6	4.4	3.5
9	Mangattukadavu Ela pond	7.6	3246	572	4.5	56.7	ND	0.35	5.7	11.2	7.1
10	Palickal Ela pond	7.9	1834	328	5.2	61.2	2.1	0.41	7.1	9.42	6.8

Annexure B-3(B)

WATER QUALITY DATA-PONDS-KARAMANA BASIN

CHEMICAL ASPECTS OF PONDS OF KARAMANA BASIN (POST-MONSOON PERIOD)

Sl.No	Location	pH	EC	TDS	BOD	TH(mg/l)	Na	K	Ca^{3+}	SO4	Salinity
1	Panavoor Moozhi	7.2	654	242	5.1	48.8	2.2	0.38	9.2	6.4	13
2	Thannimoodu (Cherayilkonam	7.6	1244	358	4.2	51.8	0.1	0.29	7.8	8.1	9.4
3	Kuttichal pond	7.3	713	484	3.6	56.3	1.3	0.38	11.4	7.2	7.6
4	Vellanad pond	7.7	806	406	3.98	40.2	1.8	0.52	12.2	5.12	5.1
5	Nedumangad Kulavikkonam	7.4	898	390	3.6	39.8	2.22	0.68	9.6	7.4	4.2
6	Vattiyoorkavu	7.5	1160	433	4.86	48.1	1.6	0.51	6.4	4.1	9.8
7	Housing Board Jn (Temple pond).	7.6	1688	567	3.89	69.6	1.13	0.53	8.2	5.8	4.6
8	Pappanamcode Ela pond	7.4	2258	555	3.6	67.3	1.09	0.66	7.4	3.2	3.9
9	Mangattukadavu Ela pond	7.2	3421	580	4.12	58.2	0.01	0.48	6.1	9.2	7.6
10	Palickal Ela pond	7.5	2068	366	4.66	66.2	2.4	0.49	9.2	7.47	7.4

ANNEXURE B-4 (A)

CHEMICAL ASPECTS OF STREAM WATER OF KARAMANA BASIN (MONSOON PERIOD)

Sampling Location	Ca^{3+}	Fe	Mg^{3+}	Na^+	K^+	Cl^-	HCO3-	NO_3	SO_4^-	PO_4^-	TDS	TDS/1000	TSS	TL
(1). KARAMANA RIVER (Trunk Stream)														
1	0.8	ND	1.01	3.1	0.2	12	11	1.34	ND	0.15	29.6	0.0296	0.4562	0.4858
2	0.92	4	1.04	3.44	0.5	14.42	10.2	1.24	0.18	0.14	36.08	0.03608	0.1826	0.21868
3	1.04	3	2.44	4.92	1.62	18.1	12.2	0.22	1.24	0.16	44.94	0.04494	0.5264	0.57134
4	1.62	5	4.06	4.8	2.44	14.2	12.4	1.5	1.82	0..22	47.84	0.04784	0.8422	0.89004
5	6.54	4	5.02	4.2	6.82	26.82	11	2.1	2.04	0..26	68.54	0.06854	0.1742	0.24274
6	8.9	6	6.24	5. 4	12.94	28.62	9.6	1.4	6.96	0.31	80.97	0.08097	0.2428	0.32377
7	44.06	4	4.54	4.8	19.32	18.44	10	1.5	4.92	0.32	111.9	0.1119	0.3452	0.4571
8	54.64	5	6.92	5.44	18.46	31.82	14	1	12.08	0.29	149.65	0.14965	0.2136	0.36325
9	120	6	124.96	8.42	38.64	126.2	14.4	3.8	16.24	0.33	458.99	0.45899	0.431	0.88999
10	358	9	605.24	86.42	74.84	380	15.8	16.22	93.2	0.37	1639.09	1.63909	0.344	1.98309
(2). Killi Ar														
1	0.62	ND	0.42	0.74	ND	14.9	8	1.5	0.03	0.14	26.35	0.02635	0.3422	0.36855
2	0.84	ND	0.68	0.88	2.68	14.12	8.5	0.5	0.22	0.15	28.57	0.02857	0.2246	0.25317
3	2.44	3	0.98	2.68	3.62	16.44	10	1.1	1.28	0.14	41.68	0.04168	0.3621	0.40378
4	2.44	2	1.08	12	41.44	18.02	9.5	0.4	6.82	0..16	93.7	0.0937	0.6268	0.7205
5	4.58	2	3.64	21.44	6.82	22.54	10.5	1.5	5.05	0..15	78.07	0.07807	0.1832	0.26127
6	6.88	4	6.22	2.4	8.24	25.68	12	1	8.24	0.24	74.9	0.0749	0.2146	0.2895
7	14.28	4	8.02	2.68	10.46	18.84	11.2	1.4	10.34	0.31	81.53	0.08153	0.2426	0.32413
8	31.08	5	11.42	1.98	7.34	32.24	12	1	10.08	0.33	112.47	0.11247	0.2242	0.33667
9	68.22	5	24.66	2.02	8.22	84.22	12.5	0.5	48.26	0.35	253.95	0.25395	0.5322	0.78615
10	96.24	6	60.24	39.42	14.64	111.02	14	3.2	54.22	0.37	409.35	0.40935	0.4284	0.83775

ANNEXURE -B- 4(B)

CHEMICAL ASPECTS OF STREAM WATER OF KARAMANA BASIN (POST-MONSOON PERIOD)

(1). KARAMANA RIVER (Trunk Stream)

Location	Ca^{3+}	Fe	Mg^{3+}	Na^{+}	K^{+}	Cl^{-}	HCO3-	NO_3	SO_4^{-}	PO_4^{-}	TDS	TDS/1000	TSS	TL
Peppara	0.98	ND	0.82	6.1	0.2	18	15.2	ND	0.1	0.1	41.5	0.0415	0.0164	0.0579
Flank of Kurichimala	0.96	0.1	0.76	8.44	0.22	22	13.5	0.1	0.13	0.11	46.32	0.04632	0.0236	0.06992
Kilicode	1.04	0.2	1.02	7.92	0.42	32	10	ND	1.32	0.12	54.04	0.05404	0.1644	0.21844
Aryanad	1.96	ND	3.2	10.8	0.3	36	7	0.4	1.86	0..24	61.52	0.06152	0.3536	0.41512
Mundela	3.08	1.5	4.62	9.2	1	44	14	0.2	2.14	0..28	79.74	0.07974	0.3268	0.40654
Irumba	5.18	0.5	4.88	11.4	3.5	38	12	ND	7.02	0.36	82.84	0.08284	0.3084	0.39124
Vellaikadavu	14.66	0.8	5.02	10.8	4.2	46	11	0.6	6.8	0.34	100.22	0.10022	0.1568	0.25702
Mangattukadavu	15.82	1	11..64	11.44	4.8	51	4	0.4	14.4	0.31	103.17	0.10317	0.3242	0.42737
Karamana	22.08	1.2	16.2	28.42	8.42	46	8.5	0.8	19.8	0.28	151.7	0.1517	0.1224	0.2741
Thiruvallam	28.22	3.54	59.8	86.14	10.2	196.44	19	1.8	124.4	0.42	529.96	0.52996	0.1126	0.64256
(2). Killi Ar														
Panavoor	1.34	ND	0.62	3.8	0.2	12	11	ND	0.06	0.12	29.14	0.02914	0.0142	0.04334
Puthenpalam	1.42	ND	0.54	3.44	0.22	20	9.5	ND	0.34	0.18	35.64	0.03564	0.0198	0.05544
Pazhakutty	1.94	ND	0.42	4.9	0.42	24	10	0.1	1.4	0.08	43.26	0.04326	0.1428	0.18606
Valikkode	1.08	ND	1.62	4.64	1.5	16	7	ND	6.84	0..18	38.68	0.03868	0.2624	0.30108
Azhikkodu	2.62	0.5	2.42	5.06	2.5	34	14	0.4	6.3	0..18	67.8	0.0678	0.2724	0.3402
Karakulam	3.8	ND	4.34	6.22	3.2	22	12	0.1	8.64	0.32	60.62	0.06062	0.2642	0.32482
Vazhayila Bridge	8.84	0.5	4.28	9.42	4	36	16	ND	14.6	0.34	93.98	0.09398	0.1484	0.24238
Maruthumkuzhy	16.24	0.6	8.24	18.26	4.6	54	14	0.3	12.4	0.23	128.87	0.12887	0.2044	0.33327
Killipalam Bridge	19 .74	1.2	36.48	37.12	7.4	42.5	12	0.4	54.3	0.28	191.68	0.19168	0.1264	0.31808
Homeo College Bridge	21.36	2.4	124.44	98.46	10.2	126.5	18	1.2	61.4	0.39	464.35	0.46435	0.1288	0.59315

Photographs

Plate 1 A view of Karamana River flowing down from Aruvikkara Dam

Plate 2 A water fall in Karamana River near Bonacaud

Plate 3 One of the major ponds at Uzhamalackal of Karamana River Basin

Plate 4 A section of the Holocene sediments of Karamana Basin showing stratification

Plate 5 A view of the reservoir of Peppara Dam

Plate 6 Garbage fillings in Parvathy Puthenar

Plate 7 Aquatic plant growth in Parvathy Puthenar

Plate 8 Sample collection of Holocene sediments

Plate 9 Confluence of Karamana River and Killi Ar at Thiruvallam.

Plate 10 Drilling bore well for water

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SW monsoon induced debris slides of the arterial roads of Karamana River basin

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ABSTRACT

Slope instabilities manifesting quickly and suddenly in the form of debris slides, landslips and landslides are natural hazards affecting the landscapes, particularly following a high intensity rain fall event. The loci of potential slides are regions and sites where the toe of a slope has been removed either by natural process (erosion by flood waters) or by anthropogenic causes (e.g., a cutting on a hill slope to lay a road or rail road or build a recreation arena or establishing a new township). Any cut and removal of the natural support at the toe of a hill tends induce a potential for frequent landslips, debris slides or landslides. Other natural causes of these forms of rapid mass wasting processes are natural disasters like earthquakes, volcanoes, wildfires, and floods. Excessive and intense rain has been identified as one of the immediate triggers of all categories of rapid mass wasting processes, including landslides, causing life and property damages, disruption traffic flow, sedimentation in farmlands and loss of crops and income to the farmer. Therefore, it is not unusual for landslides and similar mass movements to find a prominent place in the newspaper columns. In a monsoon climate dominated country like India, the states of Himachal Pradesh, the lesser Himalayan region, Nilgris of TN in south India and of late the sector of the western Ghats in Kerala are known for the landslide risk as well as incidence of some of the disastrous landslips and landslides. The rugged, moderate to high relief regions are ideal sites for such events especially after the heavy precipitations associated with the monsoons. In Kerala, midland (7.5–75.0m) and occasionally lower highland (>75.0 m) regions face one or two major events of landslides, of one type or other, and that too during the SW monsoon season that normally commences from between June 1^{st} and extending up to September 30^{th}. A case in point is the year 2007 - an *year of landslides in Kerala*- as the rain fall exceeded by 30% of the normal during the SW monsoon (Muraleedharan and Muraleedharan, 2008).

1 Anthropogenic interventions

During the past century, Kerala witnessed clear felling of natural and forest vegetation in the high land by British Raj to extract timber for export and for indigenous use, especially as railway sleepers, as well as for establishing plantations of tea, cardamom and coffee in the higher altitudes, and rubber in the lower altitude of the lower highland and midland. This period also saw a enormous increase in population and consequent rapid urbanization of the lowland and midland regions. Urban centres sprouted and grew initially along the side's navigable water courses, new roads and in the neighbourhood of their nodes. During the course of time these were gradually extended to the interior (midland and low highland zones). As a result of this and the growing economic activity in the hinterland extension and growth of road network further inland, became an urgent requirement.

This trend of clearing and conversion of vast areas of forests and grass lands and increasing replacement with monoculture destroyed the pristine floral biodiversity of the western flanks of Western Ghats. Contour bunding

Table 1. Road Side Debris Slides in Karamana River Basin during November 2010.

Sl. No.	Location	Location: Latitude	Location: Longitude	Slope category	Orientation and Direction	Length (m)	Height (m)	Approximate amount of debris	Type of material if any	Casualties
1	Karakulam	8°62′03″	76°99′20″	58°	Parallel to the road	2.6	4.9	65	Laterite	Nil
2	Aruvikkara	8°62′42″	76°99′46″	60°	Parallel to the road	3.2	5.2	55-60	Laterite	Nil
3	Vellanad	8°59′16″	77°21′94″	62°	Parallel to the road	3.1	6.2	45-50	Laterite	Nil
4	Vidura	8°49′67″	77°85′62″	71°	Parallel to the road	2.6	5.1	35-40	Laterite	Nil
5	Parandode	8°61′33″	77°35′02″	64°	Parallel to the road	2.2	3.1	45-50	Laterite	Nil
6	Peppara	8°62′44″	77°13′64″	65°	Parallel to the road	2.6	5.1	60-70	Laterite	Nil Some debris fell over an auto rickshaw
7	Bonnacaurd	8°67′44″	77°36′01″	59°	Inclined to the road	1.8	6.1	35-40	Laterite with unweathered boulders	Nil
8	Chanthanpara	8°66′37″	77°15′26″	66°	Parallel to the road	2.2	5.1	55-60	Laterite with unweathered boulders	Nil Affected some pedestrians

in steeper slopes, often interfering with natural drainage lines can be identified as a common feature in the newly settled regions of high land. All these jointly contributed to various forms of rapid and/or slow mass wasting processes in midland and highland. It is estimated that out of the total area of 38,863km^2 of the state, the Western Ghats occupies about 1800 km^2. Of this 1400 km^{2}is considered as critical zone of mass movements.

In this paper, we examine the phenomenon of debris slides that occurred during the wet days of 2010 in the Karamana river basin especially along some of the arterial roads that link the larger urban areas within and outside the basin. But for the major landslides in 1992, in the periphery of the Peppara Reservoir and lesser ones at Thennur and Peringammala, no major slides are reported from the basin. However, geomorphological indications of past, rapid mass movements, of varied types are recognizable in several localities along the upper reaches of the basin in the midland and highland zones. Table 1 gives the list of debris flow spots in the Karamana basin.

2 Geomorphic setting

The Karamana Basin (KB) in Thiruvananthapuram District with an aerial spread of 702 km^2 (Centre for Water Resources Development & Management 2010) is located between N. Lat. 8°21′ 49″ and 8°40′55″ and E. Long 76°49′46″ and 77°14′35″ (see SOI tope sheet No. 58H/2, 58H/3, 58D/14, and 58D/15). The main stem of the river net, the Karamana River has a length of 68 km. The annual water yield is estimated at 836 MCMs and the annual utilizable water is estimated at 462 MCMs (KSLUB, 1995). In terms of the basinal area, of the west flowing rivers of Kerala, KB ranks 15th position. The western margin of its basin coincides with parts of the eastern boundary of the Tambraparni River Basin of Tamil Nadu, which more or less forms the crest of the Western Ghats, where one of the peaks named ‘Chemmunji Mottai’ (1717 m above MSL) forms the source of the Karamana River.

3 Geologic makeup

The KB lying in the southern Khondalite Belt is characterized by the khondalites, i.e., mostly metasedimentary, garnetiferous quartzo feldspathic gneiss, with or without graphite (khondalites) and garnet-sillimanite-gneiss. Massive charnockites with granulitic texture, occur as bands and patches. Younger incipient charnockites are also reported from some localities within the basin. Other lithounits noticed in the basin include garnetiferous biotite gneiss and associated migmatites, leptynites, calc-silicate rocks, pegmatites and associated quartz veins. A minor body of dolerite, of younger age (61–144 Ma) is also recorded from a locality of KB. The rocks belonging to Charnockite-Khondalite Group are exposed over about 75 percent of the area of the basin. Scattered exposures of these rocks are mostly confined to the midland and highland zone of the basin surrounded by laterite. Rocks of Tertiary and younger age mostly occupy the low-lying coastal zones as isolated patches encircled by Recent and Subrecent sediments; the latter often found restricted to low-lying portions of the basins forming valley flats and terraces as well as all along the coast (CESS, 1996).

4 Climate

As the basin is on the windward side of the Western Ghats, the rainfall in the region is much more than those areas on the eastern side of the Ghats. The KB benefits mostly from the SW monsoon (locally known as *Edavappathy*) and to a lesser extent from the retreating of SW monsoon(known locally as *Thulavarsham*). SW monsoon breaks over the basin generally by the end of May and accounts for nearly half of the annual rainfall. Generally, June is the month with maximum rainfall. A secondary maximum (related to the NE monsoon) occurs in the month of October. The period from January to March is generally a period of no or little rainfall in the KB. Annual rainfall varies from less than 200 cm to more than 300 cm, the amount steadily increasing from the coastal belt to the interior of the basin towards the Western Ghats. The precipitation from SW monsoon varies from 100 cm to 150 cm while that associated with NE monsoon ranges from 60 cm to 80 cm. The basin receives only 30 cm to 50 cm of precipitation during the remaining post monsoon period i.e., between January and May (Sujith, 2003)

5 Type and extent of weathering

The tropical monsoon climate with clear, alternating and distinct wet and dry seasons, has driven the chemical weathering process to finality by converting upper portions of most of the crystalline rock cover to laterite. All the silicate minerals, with the exception of quartz and durable accessories, have been transformed to kaolinite clay and limonite or hematite. A typical in situ profile of laterite in the KB shows a duricrust (which is amenable to tillage and cultivation), composed of goethite or hematite, followed downward by a clay - enriched zone that overlies partly altered parent rock, showing inherited structures generally in association with a layer of lithomarge. This lithomarge acts as a zone of structural weakness, as it lacks any degree of cohesion with the underlying parent unaltered rock. Also because of its characteristic texture of this lithomargic clay, this acts as a subsurface zone beyond which the downward percolating water, reaching there from upper zones of weathering, is nearly impeded. In other words, this transition zone separating and intervening between more porous upper zone and less porous gneiss (or other crystalline rocks) below, in localities of hill slopes, when exposed to intense precipitation over short periods of time, can act as a zone of rupture or dislocation, allowing the overlying material to quickly dislodge and move downward and outward forming a landslide or a debris slide/slip.

6 Reach and spread of roads

During the past centuries, traffic and trade in the region of Karamana River Basin have been carried on mostly through water ways and partly by means of laden bullocks and hired labourers on land. One of the earliest reference on a public traffic route occurs, in *Unninili Sandesam*, (a literary composition dated 14th century). It mentions an oldtime land route (known as '*kollaperuvazhi*' or '*Thiruvananthapuram–Kollam Nadakkavu*') a portion of which passed through the lowland zone of KB. The present Thiruvananthapuram–Kollam railroad roughly follows the same alignment of this historic land route. Until the first half of the 18th century there were only waterways and open tracks, the latter meant for foot travelers as well as for the members of the upper classes who rode on horseback or in palanquins. The first road, in the modern sense, in this portion of Kerala was constructed in 1751. This was followed by the construction of several others for traffic, passengers and military.

The memoirs of Lieutenants Ward and Conner (1827) covering the period 1816–1820, refers to some of these early tracks/roads traversing the Karamana Basin. During the decade 1862–72 substantial headway was made in road construction in this part of Kerala. One of the major roads traversing the basin from Thiruvananthapuram to Thenmala via Nedumangad was completed in 1876 and that one from Ulloor to Vamanapuram in 1877. The construction of the Main Central Road (M.C Road) to Kottayam was also started during this time and was completed in 1878. A road connecting Vembayam, Nedumangad, Aryanad and further to Shorlacode (Churulode), which runs more or less within the midland zone of the basin and was also opened during this period. The thirties of the last century witnessed rapid extension of road network to the interior of the basin. Roughly a decade before independence, in 1936, there were only five principal roads in the present Thiruvananthapuram District, traversing the basin. These were: (1). M.C Road (249 km,), (2). Thiruvananthapuram–Aramboly Road (86.8 km), (3). Thiruvananthapuram–Shencottah Road (103.37 km), part of which is today's State Highway No.2 and further onwards become part of NH 208 (Kollam–Thirumangalam Road) beyond Thenmala (4). Thiruvananthapuram–Kollam Road-forming part of the present NH 47 (71.19 km) and (5). Nedumangad-Shorlacode Road (62.75 km) i.e. present day Nedumangad–Shorlacode Highway (Sreedhara Menon 1962, pp. 456).

After 1945, a number of new roads for vehicular traffic have been constructed into the interior of the Karamana Basin. It is worth noting that the extension of road network from the urban, municipal and other administrative centres to the interior was largely influenced by factors which may be purely political, social, and economic or a combinations of these, in varying degrees. In most of the instances, these roads are not terrain-friendly, because of lack of scientific planning involving a study on the geomorphic/geotechnical aspects of the terrain along the proposed route for the roads. As a result, a variety of problems emerge either at the time or after the construction or extension of roads during the expansion of traffic network. This is especially true in the case of roads in the higher reaches of midland and highland.

7 Roads and slope stability

Several segments of the road network in the KB, especially in the midland and lower highland steeply cut across or along the toe of the hills, destabilizing such cuts in the event of heavy precipitation. Rain water soaking the regolith leading to higher pore pressures is the obvious triggering mechanism in most of these slides. In fact, there is a strong correlation between the intensity and duration of rain, and land/debris slide events in slopes destabilized by removal of the support at the toe to form a road-right-of-way or by erosion removal of the support along the outer bend of a stream course.

As the debris involved in the slide, passes across the pavement, blocking the normal flow of traffic, it needs to be removed quickly to re-establish the smooth flow

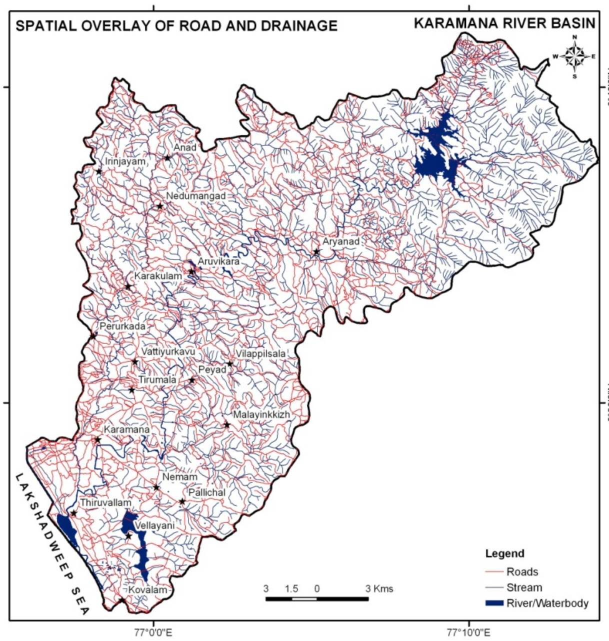

Figure 1. Roads, streams and standing bodies of water (reservoirs and lakes).

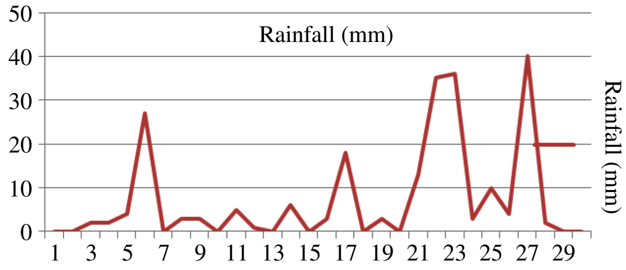

Figure 2. Date on X axis and precipitation (mm) in Y axis: Nov. 2010.

Table 2. Administrative Blocks, Karamana River Basin.

No.	Block Area,	km^2
1	Nedumangad	123.50
2	Vellanad	372.12
3	Thiruvanaanthapuram Rural	43.11
4	Thiruvananthapuram Urban	152.90
5	Kazhakuttam	133.38
6	Athiyannoor	73.73
7	Nemom	134.59
	Total	1033.30

of traffic. In the post slide phase, what remains for documentation and investigation are the rupture surface or plain and a portion of the dislodged material, i.e., soil, weathered rock and the slide plain. In this paper, we discuss the debris slides in some selected locations in the KB that occurred along the arterial roads during November 2010. Figure 1 depicts the present road network within KB and the stream courses of different orders along with lakes.

As noted earlier, the present climate of hot monsoon conditions of the basin, with both high and intense rainfall, has resulted in deep weathering profiles, on slopes that are near the limit of stability. Debris sliding is so common that it can be considered the norm rather than the exception in the landscape of KB. Intense rainfall together with accelerated rate of deforestation and farming of marginal land where population pressures in many parts of the basin are high, causes severe soil erosion almost everywhere in the higher reaches of the basin.

A mechanism of slope failure is the process that causes one component of a slope to move downhill in relation to another. A common misconception is that "the landslide" consists only of the mixture of soil and rock debris that lies in the slide path and on the road. But the debris is only part of a much larger phenomenon, and it is necessary to consider the slope failure as a whole if the slide is to be permanently stabilised. The time factor involved in debris slides is often a neglected. The occurrence of a landslide or debris slide event marks the start of a period of activity that may last at least several years, during which time the *landslide/debris slide grows*. The duration of instability depends upon the rock type and structure, but sliding process eventually diminishes as the slide approaches a stable angle.

8 Precipitation in KB during Nov. 2010

The IMD station nearest to the KB is the Thiruvananthapuram. Table 2 is the rainfall (precipitation) data for Nov. 2010 and cumulative rain fall after Oct. 2010 (source: "The Hindu" weather) is graphed in Figure 2, which shows occurrence of heavy precipitation the 6th, 17th, 21st and 27th of Nov. 2010. Further there is notable correlation between the dates of peaking precipitation and the incidence of the debris slides (Table 3).

9 Description of roadside debris slides of November–December 2010 in Karamana basin

Except the major landslides that occurred in 1992 in the peripheral region of Peppara Reservoir and a lesser ones at Thennur and Peringammala in the same year, no major slides are reported from the basin. However, the indications of past rapid mass movements of varied types are recognizable in several localities along the upper reaches of the basin in the midland and highland zones. The essential features of rapid forms of mass movements recognizable in KB are tabulated in Table 2 (given as Appendix I). It is important to note that all the debris slides contain more than one mechanism of failure. Appendix II lists some of the observed debris slides associated with SW monsoon season during the month of November 2010 in KB (Table 4).

Following is a narration based on the post facto visit to the sites and observational data gathered from each one of the sites.

Table 3. Data on precipitation, Nov. 2010 (Source: *The Hindu* weather report)

Date	Rain fall (mm)	Total rainfall (mm), after Oct., 2010	Date	Rain fall (mm)	Total rainfall, (mm) after Oct., 2010
1	0	413	16	3	468
2	trace	413	17	18	529
3	2	415	18	Trace	519
4	2	417	19	3	523
5	4	421	20	Trace	519
6	27	448	21	13	536
7	trace	448	22	35	572
8	3	451	23	36	608
9	3	454	24	3	611
10	0	454	25	10	620
11	5	458	26	4	624
12	1	459	27	40	664
13	0	459	28	2	666
14	6	465	29	0	666
15	Trace	465	30	trace	666

Table 5. Areas prone to debris slides/landslides (modified after USGS site).

On earlier landslides.
On or at the base of slopes.
In or at the base of minor streams.
Along the base or top of a land fill slope.
At the base or top of a steep cut.
On built hillsides with leach field septic systems.

10 Description of slides

10.0.1 Location A. Vanchuvam, Chullimanoor:

On 21-11-2010, at about 6.30 P.M, people in the neighborhood of the slide heard a loud thunderous sound caused by this enormous debris slide at Vanchuvam, about 5 km from Nedumangad along the Thiruvananthapuram–Shencottah state Highway. Debris containing top soil, standing vegetation and small and large boulders of laterite measured in decimeters to couple of meters or occasionally even higher, weighing 1500 to 2000 tons instantaneously broke off the slope along a gash of 30.0 m and slipped downward leaving a free face of3̃0.0 m length. The tongue of debris crossed the paved road blocking the road traffic, while its distal end jumped into a lower order stream of the adjacent Killi Ar basin. Regular traffic stood blocked for 24 hours.

The vegetation of the affected hill is mostly four yr old rubber trees and other mixed trees along the perimeter. Though the water laden displaced mass is dominated by laterite, it lacked boulders of very large dimensions. The slip blocked the traffic for about 24 hours and the debris covered the road pavement while the distal end of the tongue jumped into a 3^{nd} order stream - a tributary of Killi ar. (a major tributary of Karamana River).

A zone of gray to white kaolinitic clay, one of the outcomes of chemical weathering of khondalites, was noted 16.0 m above the road pavement in the scar left by the rupture surface of the debris slide. A small perennial pond (dia.=5̃.6 m), that occurred in the path of debris flow was overwhelmed and completely covered by debris. Reportedly, people in the neigbourhood heard a loud and thunderous noise that accompanied the instantaneous outward and downward sliding of debris down the slope toward the road pavement. The perennial pond perhaps suggests the abundance of groundwater filling the pore space in the regolith. The contour-styled-platforms sloping uphill and separating the rows of rubber plants would have affected a higher volume of charging of the subsoil with rainwater trapped in the platforms, leading to an increase in the pore pressure and decrease in the shear resistance. Apparently the heavy rain fall prior to the date of slide, the landscaping in the rubber plantation, the macro-structures like joints and fractures dipping toward the road pavement and the nearly vertical cut to form the right of way of the segment of the road steep jointly triggered the mass movement of the debris to slide headed to the pavement and the lower order stream along the other edge of the road pavement.

The top soil has a thickness of 1.6 m and underneath it is 10 m laterite. We can also see clay enriched laterite having 16m thickness from the ground surface or roads white in colour, promoting the land slip process. Below it, we can see loose laterite debris of 3.6 m, below it, land laterite of thickness of 12 m from the roads.

11 Location No B. Near the entrance of Keltron, Karakulam:

A debris slide occurred near Keltron entrance on 6.11.2010 Friday at about 9.30 am (Figure 3). The slide affected the Thiruvananthapuram–Shencotta Road near the main entrance to the Keltron establishment (12.8 km from Thiruvananthapuram) at 8°62′31′N 76° 99′86″E. The site contains thick growth of shrubs and

Table 6. Areas relatively safe of debris slides/landslides (modified afterUSGS site).

On hard, non-jointed bedrock unaffected in the past.
On relatively flat areas away/free from changes in slope angle.
At the top or along the nose of ridges.

Figure 3. Debris slide at Vanchuvam.

small trees (Figure 3).Top soil of about 1.50m thickness, under a thin blanket of colluviums, is seen on the area. Many trees were uprooted during the process of debris slide. The roots of trees, found exposed, were growing towards down slope direction. The total amount of material involved in the slide is about 10 tons and consisted of a mixture of colluviums, soil, laterite, lithomarge and some partly decomposed boulders of khondalite.

12 Discussion and summary

In India GSI has identified a large region as prone to landslide/debris slide which covers approximately an area of 0.392 million km^2, spread across 20 states (i.e., parts of Himalaya, Nilgiri, Ranchi Plateau and Eastern & Western Ghats). Among these, Sikkim and Mizoram fall under very high to severe hazard range. Many districts in the States of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Nagaland and Manipur come under high to very high hazard range. The hill tracts in the states of Karnataka, AP, TN, Maharashtra, Goa, MP and Kerala are grouped under low to moderate hazard-prone zones. Table 5 depicts the areas subject to repeated rapid scale mass wasting events. While planning for developmental activities like establishing townships, road/rail road alignments and similar other investments, such sites needs to be avoided or shall be undertaken only after implementing appropriate preventive measures. Further, if large tracts of land of the categories listed in Table 6 are handy, tracts with a history of land/debris slides may be avoided to align communication routes.

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A Geospatial Approach for the Demarcation of Groundwater Prospect Zones in Karamana River Basin

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ABSTRACT: *Integration of Remote Sensing data and the Geographical Information System (GIS) for the delineation of groundwater prospect zones has become a breakthrough in the field of groundwater research which assists in assessing, monitoring and conserving the groundwater resources. It is essential not only for sustenance of the human life but also for the economic and social progress of a region. A raster based GIS analysis (Overlay in Spatial Analyst tool) in ArcGIS 9.1 software has been utilized to demarcate Groundwater Prospect Zones for Karamana River Basin, Thiruvananthapuram District, Kerala. Individual themes like geology, slope, geomorphology, drainage density and land use/land cover are assigned with weightages accordingly and their corresponding categories are assigned with a knowledge based ranking according to their degree of prospect depending on their suitability to hold groundwater. The River Basin is classified into four zones in terms of its groundwater prospect which represents very good, good, moderate and poor zones. The coastal belt of the Karamana basin is categorised as very good, but the area is near to coastal belt is urbanized and the over abstraction of groundwater has impounded a negative impact to the quality and quantity of groundwater in the shallow aquifers. The eastern part of Karamana River basin is having Denudational hills (slope greater than 20%) and with high drainage density is categorised under poor prospect zone.*

Keywords: Karamana River Basin, Spatial Analyst Tool, Groundwater Prospect Zone.

INTRODUCTION

A systematic planning of groundwater development using modern techniques is essential for the proper utilization and management of this precious but shrinking natural resource. The optimal and sustainable development of the natural resource is pre-requisite, so that it is assessed rationally to avoid future problems regarding its qualitative and quantitative availability. In recent times, there has been a rapid growth in industrialization, population and agricultural activities that has lead to tremendous increase in demand for fresh water. Vagaries of monsoon and indiscriminate development of groundwater often result in declining trend of groundwater level (Kadam and Sankhua 2012). Remote sensing data in conjunction with necessary field investigations will effectively help to identify the groundwater potential zones and facilitate better data analysis and interpretation (Jasmine and Mallikarjuna 2011). Systematic integration of various surface features which influence the groundwater prospect is an important aspect in water management studies (Lee *et al.,* 2012). Integration of the information on the controlling parameters is best achieved through GIS, which is an effective tool for storage, management and retrieval of spatial and non-spatial data as well as for integration and analysis of this information for meaningful solutions. The recent development representing a tremendous forward leap in remote sensing technology that will significantly eliminate some of the lacunae associated with topographic map revision from existing topographical maps is the launching of the Shuttle Radar Topography Mission (SRTM) in February, 2000. Using the Synthetic Aperture Radar (SAR) interferometry to produce the first near-global high resolution digital elevation model (DEM) of the Earth, SRTM has created an unparalleled set of global elevations that is freely available for modelling, mapping and environmental applications (Gorokhovich and Voustianiouk, 2006).

IRS P6 (Resourcesat-1) has offered diversity in parameters of the images (spatial resolution, swath width, and spectral bands) by high revisit frequency as well as the possibility of the all-weather and round-the-clock radar imaging, make them applicable for solving most different economic tasks. IRS P6 LISS III an advanced remote sensing satellite built by ISRO (Indian Space Research Organization) is the tenth satellite in IRS series, has been utilized for generating some of thematic maps to generate Groundwater prospect map. This particular

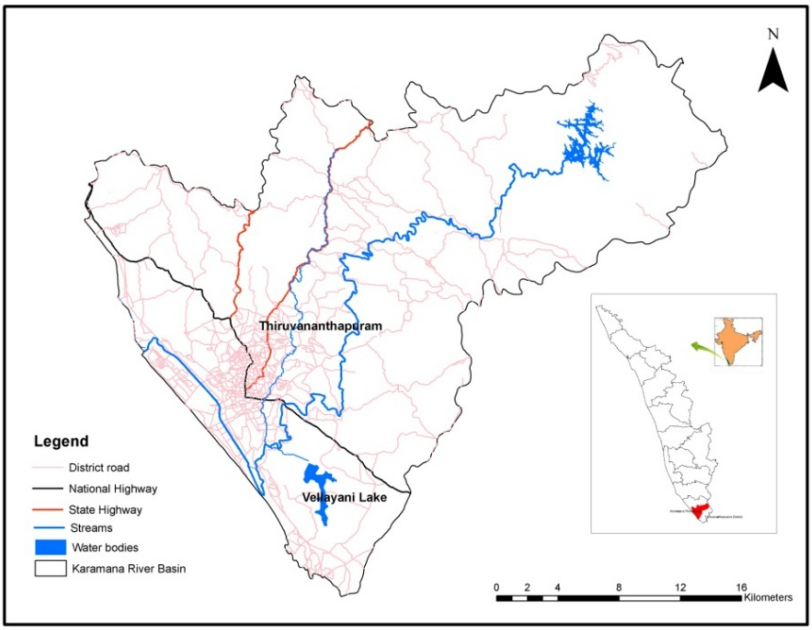

Fig. 1: Base Map of the Karamana River Basin

study of the area has considered both conventional survey and Remote Sensing and GIS techniques to generate several themes for the preparation of Groundwater Prospect Map. This investigation is mainly focused on the application of Geo-spatial technology to delineate the ground water prospect zones in Karamana River Basin.

The Karamana River Basin extends from 8° 21′ to 8° 41′ N latitude and 76° 51′ to 77° 13′ E longitude in the Thiruvananthapuram District of State of Kerala (Figure 1). The Karamana River has its origin from Chemmunji Mottai of Agasthyakoodam hills at an elevation of 1610 m amsl and the river is formed by the confluence of several streams such as Kaaviyaar, Attayaar, Vaiyappadyaar and Thodayaar and drains into the Arabian Sea. The largest tributary of the Karamana is the Killiyar, which flows for a distance of 24 kilometres. The catchment area of Karamana River receives high rainfall, as much as 3400 m annually, drops to 1600 mm near the coast. The river basin has two dams Aruvikkara and Peppara, which satisfies to a large extent of domestic need of urban settlements in the Thiruvananthapuram city.

MATERIALS AND METHODS

The main objective of this work is to use GIS and Remote sensing technique for the delineating the ground water prospect zones with in an area of 702.44 km^2. The unprecedented SRTM database combines global scope and high accuracy, so it offers many opportunities to extend present hydrologic studies to nearly the entire world (Julia *et al.,* 2007). Currently, the Shuttle Radar Topographic Mission 90 m resolution (SRTM) provides one of the most complete, highest resolutions, digital elevation model of the Earth. It is an ideal data-set for precise terrain analysis and topographic characterization in terms of the nature of altimetric distribution, relief aspects, patterns of lineaments and surface slope, topographic profiles and their visualization, correlation between geology and topography, hypsometric attributes and finally the hierarchy of terrain sub-units (Priyank and Ashis, 2010). IRS P6 (LISS III) data were utilized for generating the landuse/land cover map, ERDAS Imagine 9.1software was used for image processing of satellite data.. The thematic maps like Geomorphology, drainage map, Geology map were prepared using the data obtained from secondary sources and Survey of India topographical sheets (1:50,000 scale). The flow chart (Figure 2) given below clearly illustrates the methodology for demarcating the groundwater prospect zone.

RESULTS AND DISCUSSIONS

Geology and Geomorphology

The lithology of the study area is dominated by Khondalite gneiss and all along the coast, the fluvial coastal sediments is seen and adjacent to coastal sediments Warkali formation is present. The major distinct geomorphic units in the area are namely lower plateau lateritic and valley flats. The coastal belt with alluvial and beach deposit underlain by laterite, yields abundant of water. The geomorphological units identified in the basin in the ascending order of their groundwater prospects are: Lower plateau Lateritic units, Valley fills, Flood plain, Channel bar, Beach and swale complex are found in Karamana River basin that are characterized by various lineament intersections. Geomorphological units are given with more weightage for demarcating potential zone for groundwater. The Figure 3 given below shows the geology and geomorphology of Karamana River Basin.

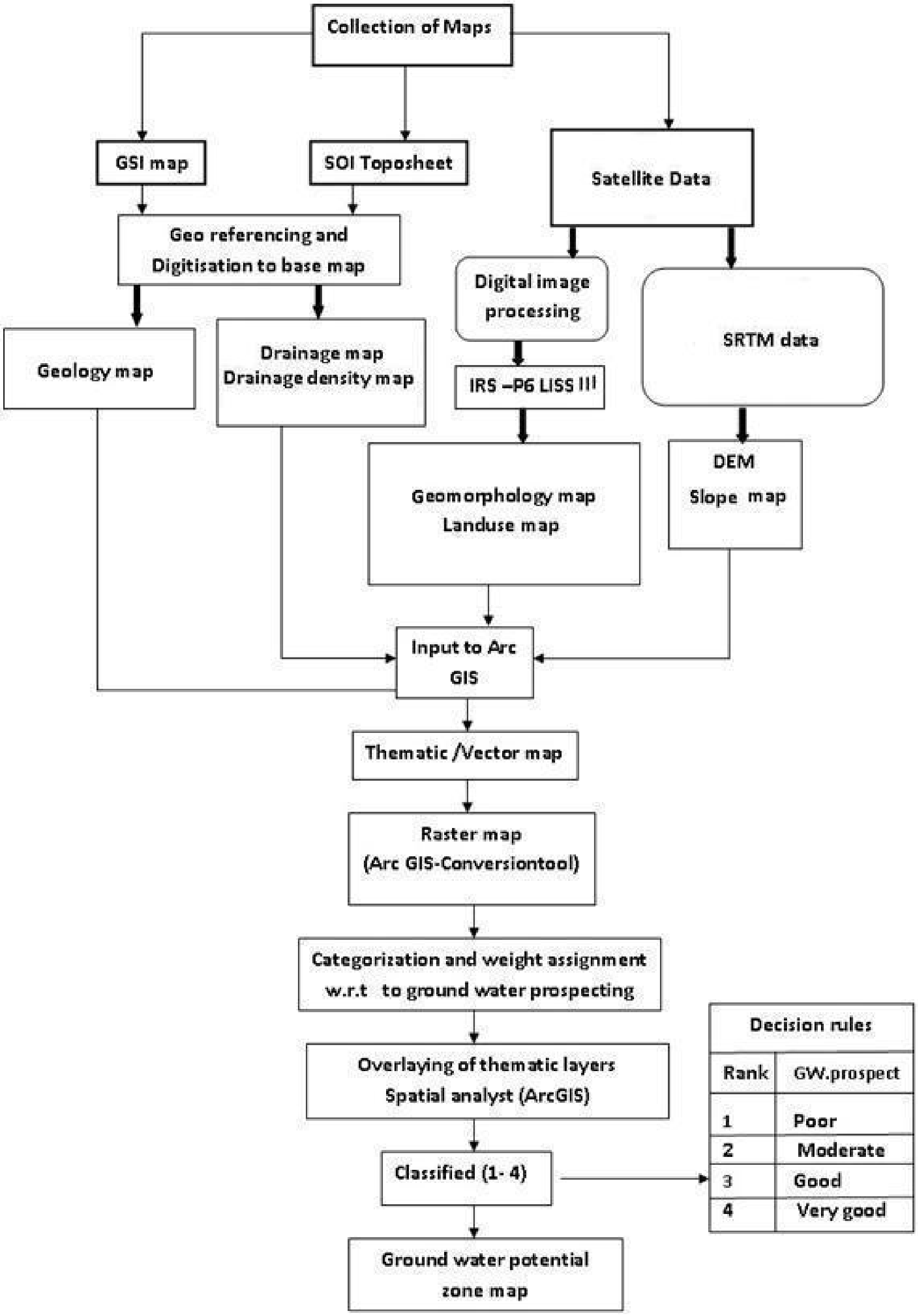

Fig. 2: Flowchart Showing the Methodology for Groundwater Prospect Zone Delineation

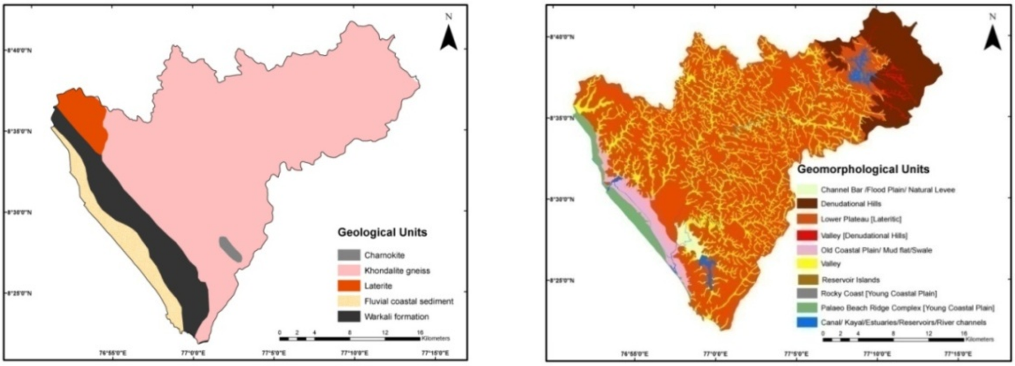

Fig. 3: Geological and Geomorphological Units of Karamana Basin

Slope Map and Landuse/Land Cover Map

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, whereas, high slope areas facilitates high runoff allowing less residence time for rainwater and hence comparatively less infiltration (Prasad *et al.,* 2008). The entire Karamana basin is classified into four-categories based on the percentage of slope and there is general increase in the slope percentage towards north-eastern part of the basin. In the preparation of groundwater prospecting map least weightage is given to steep dip (> 20%) whereas more weightage is given to gentle slope (0–5%) as slope plays a significant role in infiltration verses runoff.

One of the parameters that influence the occurrence of sub-surface groundwater occurrence is the present condition of land cover and land use of the area. Land use describes how a parcel of land is used for agriculture, settlements or industry, whereas land cover refers to the material such as vegetation, rocks or water bodies, which are present on the surface (Anderson *et al.,* 1976). For instance the rate of infiltration is directly proportional to the crown density of forest cover i.e., if the surface is covered by dense forest, the infiltration will be more and the runoff will be less. Due to urbanisation, the rate of infiltration may decrease (Sarkar *et al.,* 2001). The land

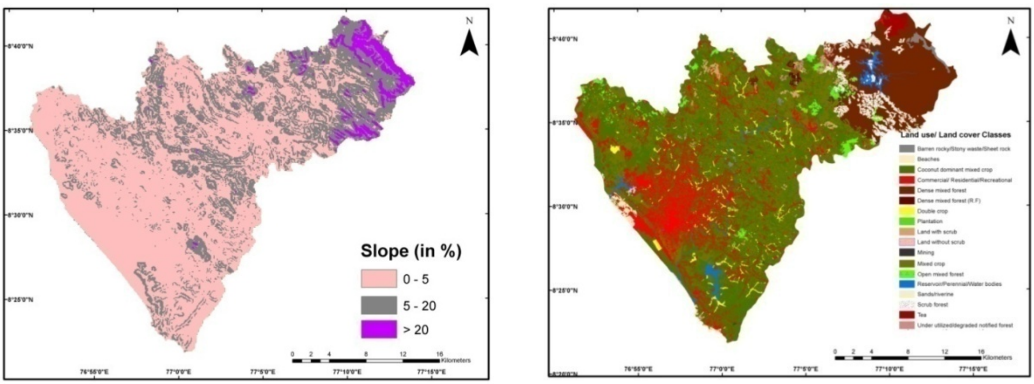

Fig. 4: Slope Map and Land Use/Land Cover of Karamana River Basin

use/land cover map shows that there is rapid growth in urbanization in all direction around the Thiruvananthapuram City. The upper reaches of Karamana River Basin is covered with dense forest and as coming towards the west direction the major type of landuse is mixed crop with coconut. The Figure 4 below shows the slope map and land use/land cover of Karamana River Basin.

Drainage Network and Drainage Density Map

The Karamana Basin is a sixth order basin with trellis pattern in the upper reaches and dendritic drainage pattern are seen in the mid land region. The stream order has been computed based on the method of Strahler (1964). Stream order provides information about topography, runoff and drainage network. Higher number of streams is developed in areas of impermeable lithology and higher slopes. Drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. Areas having high density are not suitable for groundwater development because of the greater surface run off. In the present study the extreme upstream part of the basin showing high Drainage density (0.9– 4.53 km/km^2). Low values of Drain density occur for basins in areas with highly permeable sub soil and thick vegetation cover. The Figure 5 below shows the Drainage network and Drainage density maps of Karamana River Basin.

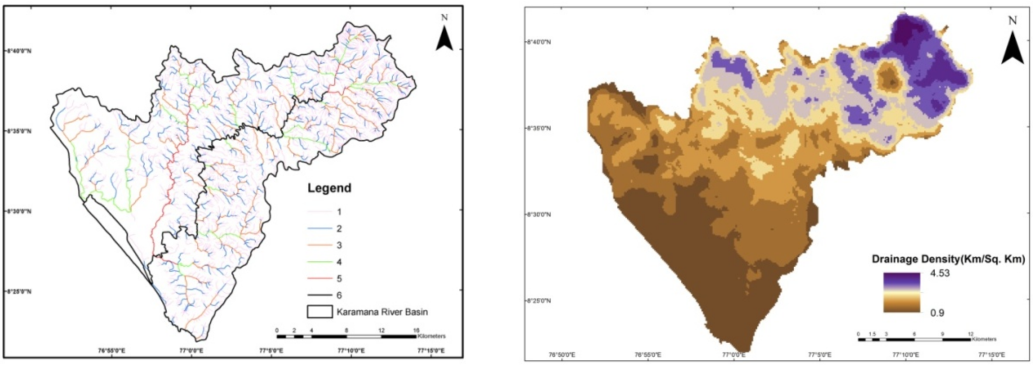

Fig. 5: Drainage Network and Drainage Density Maps of Karamana River Basin

Development of Groundwater Prospect Zone

The indiscriminate use of this vital natural resource is creating groundwater mining problem in various parts of world hence, the groundwater resource should be evaluated thoroughly, carefully and reliably to meet the ever growing needs (Todd 1959). The final integrated map was generated by applying the weighted sum analysis of Spatial Analyst tool in ArcGIS 9.1 software and this technique provides a better method for combining multiple thematic maps like by applying a common measurement scale of values to each raster, weighting each according to its importance, and adding them together to create an integrated map (Girish 2003). The final integrated map as generated by applying the weighted sum analysis in Arc GIS, This technique provides a method for combining multiple thematic maps by applying a common measurement scale of values to each raster, weighting each according to its importance, and adding them together to create an integrated map. In the present study the weighted sum analysis has been carried out by giving rank to individual parameters and weights to individual themes, according to their degree of prospect. Each theme was assigned a weightage depending on its influence on the movement and storage of groundwater and each unit in every theme map is assigned a knowledge based ranking depending on its significance to groundwater occurrence. The potential zones in the river basin is categorized as very good, good, moderate and poor depending on their characteristics to hold groundwater. The Figure 6 given below shows the Groundwater Prospect Zone Map of Karamana River Basin.

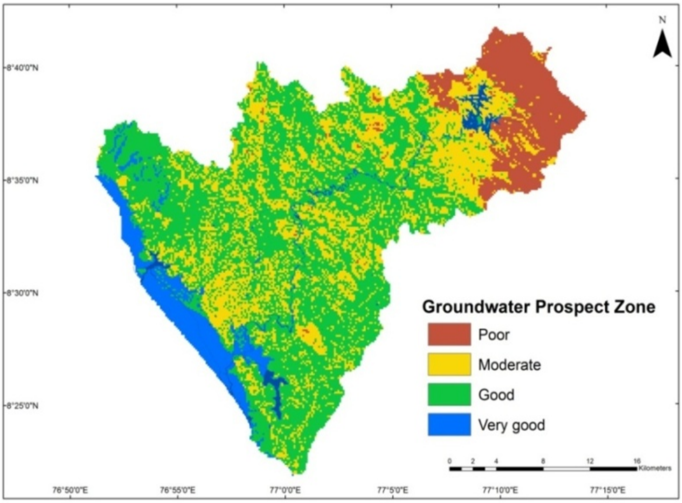

Fig. 6: Groundwater Prospect Zones in Karamana River Basin

A stretch of land along the coastal belt, the region near to Vellayani Lake and reservoir towards the north-eastern part of the study area are coming under the zone designated as very good (10.8% of the basin area). But the upstream premises to the reservoir having Denudational hills (slope greater than 20%) and with high drainage density is categorised under poor prospect zone. The extreme north-east and south-east part of the basin area is deficient in groundwater availability, i.e., 8% of the basin area is coming under the zone poor. 31% of the basin area is having a significant quantity of ground water resource, thus the area is designated as good zone. As the area near to coastal belt is urbanized, this has accounted over abstraction of groundwater has impounded a negative impact to the quality and quantity of groundwater in the shallow aquifers. About 50% of the study area is showing a moderate prospect in holding groundwater. Innovative technique like remote sensing and GIS have an immense role for the preparation of groundwater prospective zone mapping, for the sustainable development and more realistic data for the decision making policy. This potential map would provide first hand information to local authorities and planners about the area suitable for pinpointing the exploration of prospective wells and quality of the groundwater.

CONCLUSION

Integrated Remote Sensing and GIS can provide the appropriate platform for convergent analysis of diverse datasets for decision making in groundwater resource mapping and planning. The River Basin is classified into four zones in terms of its groundwater prospect which represents very good, good, moderate and poor zones. A stretch of land along the coastal belt, the region near to Vellayani Lake and the reservoir towards the north-eastern part of the study area are coming under the zone designated as very good (10.8% of the basin area). The upstream premises towards extreme north-east and south-east part of the basin area are deficient in groundwater availability, i.e., 8% of the basin area is coming under the zone poor. This particular region is having Denudational hills (slope greater than 20%) and with high drainage density is categorised under poor prospect zone. The 31% of the basin area is having a significant quantity of ground water resource, thus the area is designated as good zone. As the area near to coastal belt is urbanized, this has accounted over abstraction of groundwater has impounded a negative impact to the quality and quantity of groundwater in the shallow aquifers. About 50% of the study area is showing a moderate prospect in holding groundwater.

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represents all hydrogeological units. In Physico-Chemical Analysis, various quality parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Total Alkalinity (TA), Content of Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride(Cl^-), Sulphate (SO_4^{2-}), Iron (Fe), Sodium (Na^+), Potassium(K^+), Flouride (F^-)and Nitrate (NO_3^{2-}). Also all these parameters were compared with ICMR standards of water quality. In the present paper, *Pre* and *Post monsoon* water samples of the Thiruvananthapuram district are compared with ICMR standards of drinking water. The water samples are also been classified on the basis of TDS and TH. The suitability of ground water for irrigation is also determined using the USSL classification.

HYDROGEOCHEMICAL PROFILE OF AN URBAN RIVER - KARAMANA AR. THIRUVANANTHAPURAM DISTRICT, KERALA, INDIA.

(3)

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ABSTRACT

The surface water resources are most vulnerable to pollution because of their openness and ease of access to contaminants from domestic, agricultural, municipal, and industrial sources. The total load carried by a stream is generally classified into three types: (1). dissolved load or chemical load (DL), suspended load (SL) and bed-load (BL). Studies on river load had been keenly pursued by engineers, soil scientists and process geo-morphologists (Livingstone, 1963 and Subramanian, 1979; Vanoni, 1975). Several agencies at the national and state level (Centra Pollution Control Board, Central Water Commission, CGWB, GWD, Pollution Control Board and the Kerala Water Authority) have been monitoring the water quality, including the chemistry of solutes in water. The present paper, which forms a part of research on hydrological aspects of Karamana River Basin of Thiruvananthapuram District, Kerala. Kerala, attempts to provide the chemical status of water of the river in terms of the dissolved load or solute load (DL) transported by Karamana River of southern Kerala, during 2008.

The analysis of collected samples and the study of the graphical representation in Piper diagrams is highly instructive in that the monsoon and post-monsoon waters of KRB are distinctly dissimilar. Chloride ions dominate in most of the water samples collected during post monsoon period, ie, during the base flow period. Enhancement of chloride and bicarbonate ions during may be attributed to anthropogenic input in the basin associated with seasonal agricultural practices prevailing in the upper reaches of the basin. Aerosol deposition, anthropogenic contribution and contributions from rocks and mineral can be an explanation for higher concentration of Na ions.

HYDROCHEMICAL PROFILE OF AN URBAN RIVER - KARAMANAAR. THIRUVANANTHAPURAM DISTRICT, KERALA, INDIA.

(4)

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The river channels and river basins have been "plundered" by man right from the historic days. Modifications range from extraction of river resources like water, sediment, fisheries etc. and dumping of treated and untreated domestic and urban wastes as well as industrial wastes. As a result, there are practically no rivers in the world which qualify for the pristine nature of the water or river load. Ever increasing economic activities of the population of the basin has modified the channels and interfluves by new land use practices, extraction of timber from the forested uplands, farming industrialization, urbanization and so on. Such activities have made their adverse impacts, upon other including the realm of river water, in spite of its dynamic and renewable nature.

The Karamana Ar, a sixth order river, rising from the Chemunji mottai (1817 m above MSL) of the Western Ghats, and having a drainage ares of 702 km^2, flows through the state capital , the city of Thiruvananthapuram , before joining the Laccadive Sea in the suburb of Trivandrum. Killi Ar is a principal tributary of Karamana Ar. For meeting the drinking water needs of Trivandrum city and suburbs, two dams and reservoirs have been commissioned in the Karamana Ar- earlier one at Aruvikkara and the later one further upstream at Peppara.

In order to assess the chemical profile of the river water, 40 samples each were collected during the pre-monsoon, monsoon and post-monsoon seasons during the period 2008-09. Water qualities such as pH, conductivity, TH, and chemical ions like Ca, Mg, Alkalies, SO_4, inorganic PO_4, NO_2, TP, TN, silicate, F, Cl etc; have been estimated. The seasonal changes in the water chemistry have been analyzed. The results demonstrate a robust increase in pH in the water samples collected towards the downstream, such as, for example Thiruvallam, in Thiruvananthapuram Metropolitan Area.

The water samples also show a general seasonal variation in the hydrochemistry which is rather influenced by the variations in the water discharge. A close monitoring of water quality / water chemistry is very much imperative, as this river forms the source of drinking water for a population exceeding over a million , including the urban population of 8,60,889 in Thiruvananthapuram Corporation and its suburbs which forms the urban agglomeration.

South West Monsoon Induced Debris Slides of the Arterial Roads: A study in Karamana River Basin

S.Sakkir

Excessive and intense rain has been identified as the primary triggering factor for all categories of rapid mass wasting processes. Therefore, landslides and similar mass movements appear as familiar item of newspaper headings in Kerala during monsoon periods- especially during SW monsoon which normally starting from June and extending to the month of September. The year 2007 has been an 'year of landslides in Kerala' since the state has received 30% extra rain during SW monsoon . In the year 2010 SW monsoon continued up to the month of November in the state . A number of new roads have been constructed into the interior of the Karamana Basin since 1945. It is worth noting that the extension of road network from the urban, municipal and other administrative centres to the interior was largely influenced by factors which may be purely political, social , economic or a combinations of these , in varying degrees. In most of the instances, these roads are not terrain-friendly , because of lack of scientific planning involving a study of the geotechnical aspects associated with the newly planned traffic route. As a result, a variety of problems emerge either at the time or after the construction of extension of road networks . This is especially true in the case of roads of the higher reaches of midland and highland zone. Some of these form minor disasters in the locality. Many segments of these growing network of roads have steep cutting on one or both sides which are prone to debris sliding to a greater or lesser extent during heavy monsoon rains. The present paper which forms a part of a detailed geological, geomorphological and hydrological investigation of the basin, focuses only on some examples of selected rapid scale mass wasting processes that affected the arterial roads of Karamana River Basin during the month of November 2010. The present paper highlights the strong correlation between the intensity and duration of rain, and sliding of unstable slopes along the flanks of the arterial roads of the basin. As most of the slided debris falling down and covering the roads preventing traffic need to be immediately removed to allow vehicular traffic, the materials are removed without any delay , and only the scars are left as evidence of the slides on the road sides in many localities.

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Construction Grade Sand In Kerala Problems and Solutions

Padmalal. D

The extraction of sand has become one of the largest mining businesses in Kerala. Large quantities of sand extracted from rivers and their floodplains constitute a convenient source of fine aggregates for building constructions. As a result of over exploitation, river sand in Kerala is in short supply and the construction industry finds difficulty in achieving targets. This stresses the need for alternatives to bridge the gap between demand and supply. The problems related to sand mining are acute in Kerala as the rivers are small with limited sand resource in their alluvial channel. CESS studies reveal that the river channels in the storage zones are lowering at a rate of 5-25 cm/ year consequent to indiscriminate sand mining. Although research institutions like CESS and CWRDM are dissemi-

Distribution of Na and K in the sediments of Veli, Kochi and Kannur mangroves, Kerala

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The surface sediments of Veli consists an average concentration of 2.75% Na and 1.02% K. The content of Na and K in the surface (Na-2.14%; K=1.48%) and core sediments of Kochi (Cochin) mangroves are almost similar. Kannur mangroves exhibit an average of 2.41% Na and 5.56% of K. The mean enrichment of Na and K in the sediment cores KC_1, KC_2 and KC_3 are 2.93% and 1.8%, 2% and 4.65%, 2.13% and 1.23%, respectively. The enrichment of K over Na in Kannur mangroves could be either due to the contribution from the mangrove vegetative debris or fixation of these elements in clay minerals of the sediment substratum.

The major and minor elements are introduced in estuarine and mangrove environments either in solid/colloidal forms or in solution. Many of the element have multiple sources and are often associated with more than one host mineral. The geochemical behaviour of Na and K, pertaining to the mangrove environments, are scarce[1-4]. Present paper discusses the geochemical aspects of Na and K in the surface and core sediments of mangrove environments of Veli, Kochi (Cochin) and Kannur regions (Fig. 1).

A total of twenty eight sediment samples were collected. At Kochi three mangrove patches (located at Vypin, Malippuram and Vallarpadam areas) are selected for this study. The samples were collected from each station one each from landward (LP), intermediate (IP) and shallow water (SWP) profiles. The sediments along LP and IP were obtained by penetrating a PVC pipe of 10 cm diameter. From SWP the sediments were obtained using a van-Veen grab sampler. In addition to surface sediments, core samples were also collected from Veli (VC_1 and VC_2), Kochi (CC_1, CC_2, CC_3 and CC_4) and Kannur (KC_1, KC_2 and KC_3) man-

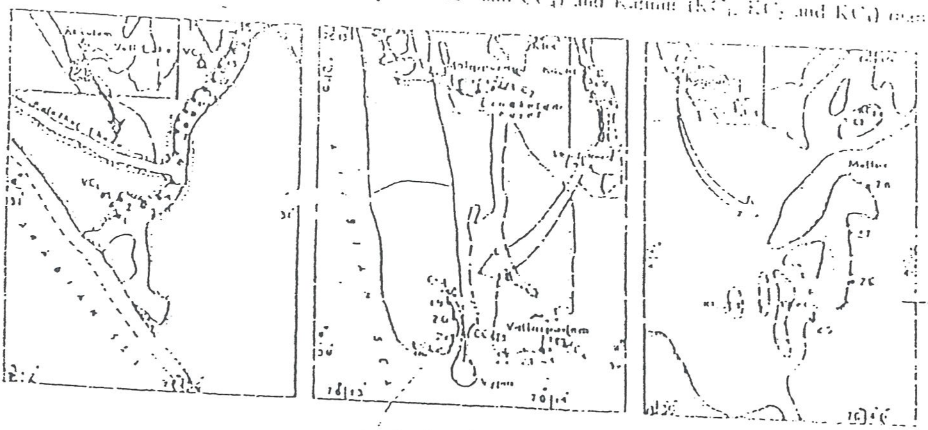

Fig. 1 — Sampling locations

grove areas. Core samples were cut into subsample of 10 cm intervals. The sediments were digested using HF, $HClO_4$ and HNO_3 acid mixture[3]. Na and K were determined using flame photometer[4].

In order to avoid the inter element and anionic effects, Fe and Al were removed from solution by precipitating with ammonia solution. Calibration curves were drawn separately and concentration of the above elements were estimated.

Surface sediments

The sediments recovered from Veli mangroves exhibit 0.8% to 8% of Na (av; 2.75%), while K shows substantially lower range in their concentration values (0.3% to 2.1%, av; 1.02%). The average distribution along profiles indicate that Na enriched more in three profiles (LP, IP and SWP) compared to K (Table 1). The spatial distribution of Na and K shows no specific trend, except at certain locations. The enrichment of Na and K in the sediments of Kochi mangroves, in general, range from 1.2% to 4.2% (av: 2.14%) and 0.6% to 2.7% (av: 1.48%), respectively. The average concentration do not bear marked variation along profiles. Compared to Kochi mangroves, Veli shows enhanced values of Na (av; 2.75%) and low concentration of K (av; 1.02%). Sediments of Kannur varies between 1% and 3.6% (av; 2.43%) of Na and 1.01% to 9.7% (av; 5.36%) of K. The K concentration in the IP shows 2 fold increase than LP and 1.5 fold enrichment than SWP. From the analysis of three mangrove sectors, it is lucid that, Na accumulation in these environments do not vary much while K displays considerable departures.

Core sediments

Vertical variation of Na and K for the three mangrove regions are depicted in Fig. 2. In core VC_1, the content of Na varies from 2.3% to 4.1% (av; 3.3%) and of K from 2.1% to 4.1% with mean value of 2.91%. The average Na (3.02%) value of core VC_2 shows almost near the value of core VC_1. The core VC_3 consists higher K values (av; 3.5%). The core KC_2 demonstrates more than 2 fold enrichment of K over Na and in core KC_3, the Na and K contents average about 2.13% and 1.23%. Na and K varies in consonance with each other (Fig. 2). The enhanced values of Na or K in the mangrove environments studied might be attributed to the said ion present in the aqueous solution that fill in the pore spaces of sediments. Considerable part of these elements can also be fixed with the lattices of clay minerals. These elements are not precipitated by hydrolysis. It is presumed that, in the clay fractions of these environments, the Na and K are bounded either by adsorption or cation exchange processes[5]. Na and K released during weathering remain in ionic solution, whereas Al reacts with silica to form clay minerals. The soluble products formed during weathering of plagioclase feldspars would be the primary source of Na in these mangrove environments. By considering the role of clay minerals in the fixation of Na, it seems that, the major part of Na in mangrove environments studied is tied up in montmorillonite/illite. Elevated value of Na over K is due to the tendency of Na to fix with clay minerals easily. The enhanced K content in Kannur mangroves might be from the decayed mangrove vegetative debris including the

Table 1—Ranges and averages of Na and K in the surface sediments of Veli, Kochi and Kannur mangroves

Samples	Range/ Average	Veli		Kochi		Kannur	
		Na%	K%	Na%	K%	Na%	K%
Landward sample	Max.	4.20	1.60	4.20	3.20	3.60	5.40
	Min.	0.80	0.20	1.20	0.60	1.90	1.01
	Av.	2.20	0.87	2.30	1.53	2.82	3.70
Intermediate sample	Max.	5.00	2.10	4.20	2.20	3.60	9.70
	Min.	1.00	0.20	1.20	0.90	1.00	5.40
	Av.	2.44	0.83	2.52	1.71	2.45	7.40
Shallow water sample	Max.	6.20	2.20	4.08	2.70	3.40	9.30
	Min.	0.80	0.80	1.20	0.60	1.30	1.01
	Av.	3.42	1.38	2.50	1.54	2.02	4.97
Overall	Max.	8.00	2.10	4.20	2.70	3.60	9.70
	Min.	0.80	0.30	1.20	0.60	1.00	1.01
	Av.	2.75	1.02	2.19	1.48	2.43	5.36

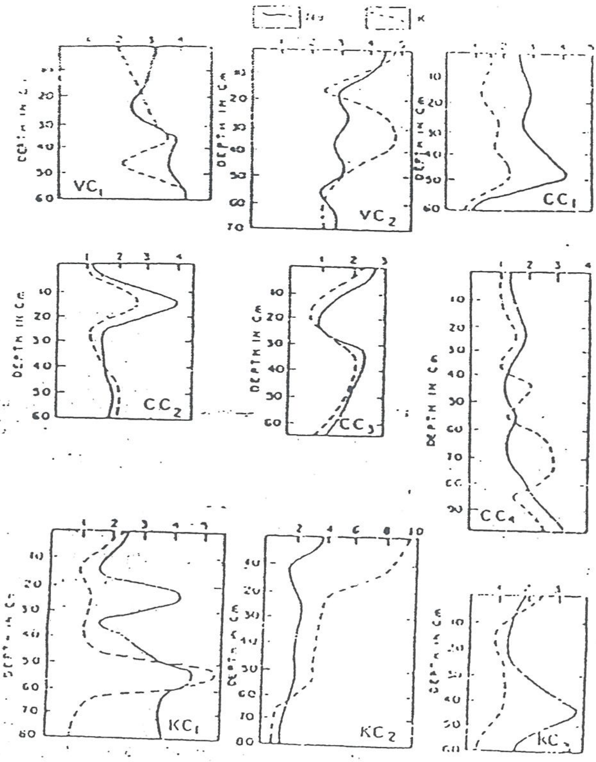

Fig. 2 —Variation of Na and K along sediment cores

litter fall of the area.

The source of K to the sediments is from weathering of rocks rich in orthoclase, microcline and biotite. Some part of K is tied up with illite, which has peculiar ability to fix K over [illegible] cations in its inter layers[6]. Considerably reduced concentration of K over Na might be owing to the removal of K by mangrove flora. Inspite of the above sources, the mangrove sediments will receive an additional load of K rich materials through the vegetal part of mangroves.

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