EVOLUTION OF KARAMANA RIVER BASIN AND ITS IMPLICATIONS ON HYDROGEOLOGY: A GEOMATICS APPROACH USING MORPHOMETRIC ANALYSIS

FINAL TECHNICAL REPORT

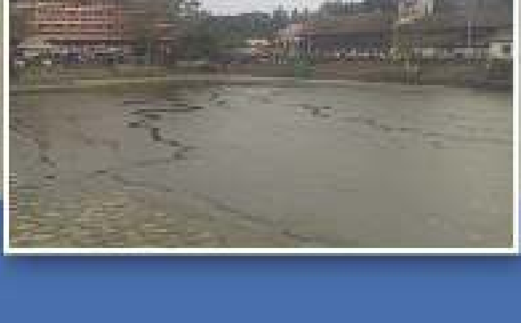
BACK TO LAB PROGRAMME

(Project Reference No: 029/WSD-BLS/2013/CSTE)

WOMEN SCIENTISTS DIVISION
KERALA STATE COUNCIL FOR SCIENCE, TECHNOLOGY AND ENVIRONMENT
GOVERNMENT OF KERALA

Submitted By
SREEJA R.

SCHOOL OF ENVIRONMENTAL SCIENCES
MAHATMA GANDHI UNIVERSITY
KOTTAYAM
2017



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AUTHORIZATION

The work entitled "*EVOLUTION OF KARAMANA RIVER BASIN AND ITS IMPLICATIONS ON HYDROGEOLOGY: A GEOMATICS APPROACH USING MORPHOMETRIC ANALYSIS*" by Ms. SREEJA R., was carried out under the "Back-to-lab" programme of Women Scientists Division, Kerala State Council for Science Technology and Environment, Govt. of Kerala. The work was carried out at School of Environmental Sciences, Mahatma Gandhi University, Priyadarsini Hills P.O. Kottayam, Kerala - 686560. The project was sanctioned wide Order No.1016 /2013/ KSCSTE dated 23.10.2013 for the duration of 3 years with Project Reference No: 029/WSD-BLS/2013/CSTE. The project was initiated on 23.12.2013 and completed on 22.12.2016 with a financial expenditure of Rs. 15,80,579/- (Rupees Fifteen Lakh Eighty Thousand Five Hundred and Seventy Nine). Group monitoring workshop (GMW) of Back-to-lab projects held during 3-4 May 2017, evaluated and graded the project work with 8/10 (Letter No. 124/WSD-BLP/KSCSTE/2017). The suggestions during the GMW is incorporated in this Final Technical Report.

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Sreeja R.

TABLE OF CONTENTS

ABSTRACT

The Study area, Karamana River Basin (KRB), is located between North latitudes 8°05' and 8°45' and east longitudes 76°45' and 77°15'and cover an area of 702 km^2. The Karamana river is a small mountainous river with main stream length of 68 km, drains through highland, midland and lowland physiographic zones. The average annual rainfall is 2600 mm which ranges from <1400 mm in coastal part to about 4200 mm in the northeastern portions.

The study area is composed mainly of crystalline rocks of Archaean age intruded by a number of dolerite dykes, pegmatites and quartz veins. Warkalli beds occurs as detached patches overlying the crystallines, along the coastal tracts. Quaternary deposits are seen in areas close to the river channels and coastal reaches. The major mineral resources are tile and brick clays, crystalline rocks, construction grade sand, graphite and gem minerals like chrysoberyl.

There are 30 local bodies (28 grama panchayats, Nedumangad municipality and Thiruvananthapuram Corporation) in the area have about 16 lakhs of population as per 2011 census. Major land use classes are forests, forest plantations, mixed crops, paddy lands and water bodies. Mining and other anthropogenic activities along with natural hazards like landslides, flooding etc., pose severe environmental problems. Major geomorphological units in KRB are lateritic uplands, buried pediments, flood plains, beach and coastal plains. 24.36% of the study area has >20% slope and 75.64% is of <20% slope.

Morphometric analysis of the KRB revealed that the drainage network is structurally and tectonically controlled, indicating evidences of uplift associated with folding and faults. Granulometric analysis reveals that pebbles and granules show comparatively higher proportions in the river stretch where the gradients and local turbulence are higher. In addition to the natural processes, manmade obstacles like check dams, bridges etc., also impart marked effect on sedimentological profile of the river. Statistical analysis also reiterates the findings. The mode of transportation in the river channel is mainly rolling and partly by rolling and suspension. Uniform suspension and graded suspension are the chief transportation mechanisms in the reservoirs. Pelagic suspension mode is observed in Peppara reservoir.

The net annual groundwater availability is 58.57 MCM, the gross annual groundwater draft is27.91 MCM, the calculated stage of groundwater development is 47.65 % and KRB

can be categorized for future groundwater development as ‘SAFE’. 30% of the basin shows very high to high groundwater potential.

In the settlement areas water is contaminated by the influx of sewage from domestic / urban centres. Precipitation has a direct control over the distribution of chemical signals in the fluvial environments of the study area. Considerable number of the groundwater samples are acidic in nature (27% in Non monsoon and 32% in Monsoon). 93% of the groundwater samples are bacteriologically contaminated. In the Non monsoon season, water in the river mouth regions shows high conductivity, salinity, Na and Cl values indicates sea water ingression due to reduced river flow.

Based on these findings, recommendations for the wise use and management of the water resources of the Karamana river basin has been formulated.

INTRODUCTION

Water is vital for the existence of life and so it is known as the elixir of life. The intensified use of the world's water resources in the last century has been hastened by the subtle and direct consequences of population growth at a scale unprecedented in human history. These developments occur amidst the natural variability in soil types, river drainage networks and climate along the world's watersheds (Naiman, 1992;Naiman et al., 1995; Walling and Owens, 2003;Arun, 2006). Land and water are two basic components that constitute the foundation of economic growth of a region. Their inter-linkage is very well manifested in a river basin environment. By and large, a river basin is an ideal unit of land surface. A thorough understanding of the various dimensions of river basin environment and its approach to conservation and management of freshwater systems is a daunting challenge to the mankind.

Management of rivers includes legal, social, and economic considerations, as well as scientific insights. Considering the importance of river basins in spatial planning, the Government of Kerala has initiated many developmental programmes at various levels, over the years. Reports indicate that many of the river basins of Kerala are degrading at faster rates consequent to various kinds of anthropogenic activities. The scenario is very worse in the river basins of the State, which horde industrial and / or urban agglomerations.

Kerala has verdant greenery and the major freshwater resources are river discharges (surface runoff) and wells or springs (groundwater).Even though, the state receives heavy rainfall at an annual average of about 3000 mm, the shortage of drinking water is alarming during summer months. Then the only source is groundwater. Dug wells are the major ground water extraction structures in Kerala. Almost every household has a dug well on which people are dependent for drinking and other domestic purposes. Geomorphology plays a vital role in groundwater occurrence and movement, which results from the evolutionary characteristics of a river basin. Geologically, in crystalline rocks the extent of weathering and fracture characteristics decide the groundwater conditions. Discontinuities like faults, dykes etc. act as barriers to groundwater flow. Porosity, permeability, grain size, lithification of the sediments, sedimentary structure and texture are the factors controlling the groundwater conditions in sedimentary areas.

Therefore, an attempt has been made in the present study for an integrated investigation using geomatics, through the combination of geomorphological, geological and hydrogeological characteristics, to bring out all the related parameters, which will be useful for the planning, development, conservation and management of the water resources in the Karamana river basin. The area selected for this study contains a comparatively virgin forest in the eastern fringes and settlements in the remaining parts with variable intensity. It also hosts the highly urbanized capital city of Kerala, Thiruvananthapuram.

The study area, the Karamana River Basin, is located between North latitudes 8° 05' and 8° 45' and east longitudes 76° 45' and 77° 15'. It is situated in the Thiruvananthapuram district of Kerala State (Fig. 1) and has a drainage area of 702 km^2.The Karamana river originates from Chemmunji mottai, a peak in Western Ghats mountain ranges at an elevation of 1717m amsl (above mean sea level). Physiographically the Karamana river basin is characterized by the coastal belt or lowland (between mean sea level and 7.5m amsl) in the west, the midland region (7.5 – 75 m amsl) characterised by laterites in the central portion and the highland (>75m amsl) in the east comprising the foot hills and hill ranges of Western Ghats, covered by crystalline hard rocks. The study area receives an average annual rainfall of 2600mm. While the southwestern part of the basin receives less than 1400mm of rainfall, the northeastern portion receives rainfall of about 4200mm.

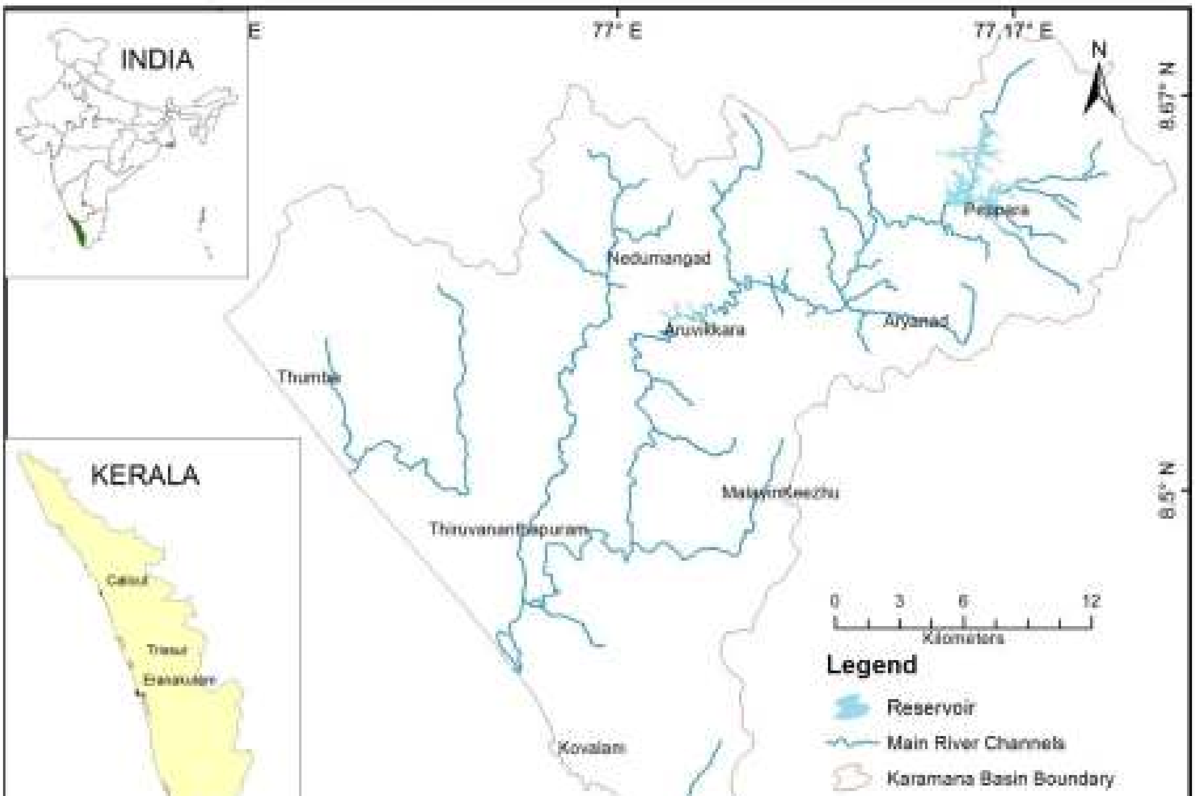

Fig.1 Location map of the Karamana river basin.

REVIEW OF LITERATURE

Researchers on fluvial environments favour either climatic or tectonic controls on any changes they decipher. It is also evident that these controls affect the structural settings and geology of the area, and in turn the hydrogeological system. To understand these systems and integrate the findings in a spatial orientation is a necessity and hence there is the importance of Geomatics comes as a tool or as a platform. To achieve this integration, wide range of literature available for the subject areas such as terrain characteristics, sedimentological processes, groundwater, hydrogeology, water quality etc., were referred intensively for this study and are described below.

Terrain Characteristics:

Outstanding studies with respect to the analysis of terrain characteristics was carried out by Wentworth (1930), Dury (1951), Chapman (1952), Strahler (1964), Cherley (1966), Kharwad (1971), Savindra Singh (1977), Reddi and Reddi (1983) in the last century and Ramanna (2014) recently. Under the influence of Horton (1945) the description of drainage basins and channel networks was transformed from a purely qualitative and deductive study to a rigorous quantitative science capable of providing hydrologists numerical data of practical value. Horton's work was developed in detail by Strahler (1950, 1952, 1958), Molton (1957), Morisawa (1959), Schumm (1956), Chorley and Morgan (1962) and Shreve (1967). Drainage basin morphologic studies have been carried out by Tantan (1971), Agarwal (1972), Dikshit (1977) and Chinnamani and Sakthivadivel (1981) and Ramanna (2014) for different basins in India.

The terrain/land systems mapping was developed by Commonwealth Scientific and Industrial Research Organisation in Australia (CSIRO) as a rapid method of reconnaissance survey of poorly mapped areas (Christian, 1957; Mabbut and Stewart, 1963). The primary aim was to establish a classification of the suitability of terrain/land for agricultural purposes. The method has been adopted by the Land Resources Division (LRD) of the Overseas Development Administration and Foreign and Commonwealth Office (formerly the Ministry of Overseas Development) in Britain. In the USSR a hierarchy of landform divisions is recognized in which units that are repeated in regular pattern form a 'landscape' (Solentsev 1962), which is equivalent to the terrain/land system. 'Landscapes' in the Russian approach are considered to be the surface expression of a homogeneous geological-geomorpholgical foundation. Verstappen (1966) has put forward that the interpretation of soils, geology and depositional and erosional processes come most readily through landform analysis and that is why geomorphology is a key element in land system mapping. Webster (1963), Bawden (1967), Brunt (1967), Olier et al (1967), Colwell (1968), Christian and Steward (1968), Webster and Beckett (1970) and Cooke and Harris (1970) are a few of the eminent scholars who had mapped terrain/land system boundaries based on studies from airphotos. Christian and Stewart (1968) have given a good account on the method of carrying out land system mapping. In the United States the Soil Conservation Service of the Department of Agriculture formalized a land capability classification for agriculture which resemble the terrain/land systems method. The United States system recognizes a therefore hierarchy from smaller to larger groupings of (i) capability units, (ii) capability sub classes, and (iii) capability classes (Klingebiel and Montogomery 1961). In India the land systems mapping is yet to take a good lead for land suitability classification for agricultural purposes. A few of the Indian authors who have made an attempt to map terrain/land systems in different regions are Srivastava and Narayan (1974), Tiwari (1977), Iyyer and Srinivasan (1977), Nanda (1978), Raghavaswamy and Vaidyanadhan (1980), Sambasiva Rao (1981, 1983 b & c), Sambasiva Rao and Nageswari (1983) and Ramanna (20140.

Morphometry:

Surface drainage characteristics of many river basins and sub-basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1952, 1957, 1964; Morisawa, 1959). The basic hydrologic unit is drainage basin, that have been used for morphometric and geomorphic characterization (Strahler, 1952; Chorley, 1969). They evolve under the close control of interplay between tectonics and climate (Rockwell et al., 1984; Bull and Knuepfer, 1987; Keller and Pinter, 1996; Delcaillau et al., 1998; Burbank and Anderson, 2001; Ramaswamy, 2006; Ambili, 2010). River basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology (Doornkamp and Cuchlaine, 1971; Strahler, 1957). Morhometry, the modern approach of quantitative analysis of drainage basin morphology was initiated by Horton (1945). Horton's law of stream lengths suggests that a geometric relationship exists between the numbers of stream segments in successive stream orders. The law of basin areas indicates that the mean basin area of successive ordered streams forms a linear relationship. Horton’s laws were subsequently modified and developed by several geomorphologists, most notably by Strahler (1952, 1957, 1958, and 1964), Schumm (1956), Morisawa (1957, 1959), Scheidegger (1965), Gregory and Walling (1973). Subsequently a number of books by Bloom (1991), Keller and Pinter (1996) have further propagated the principles of morphometric analysis. Stream profile analysis and stream gradient index by Hack (1973) is another milestone in morphometric analysis. The linear, relief and areal aspects of a drainage basin provide the quantitative information on the geometry of a fluvial system, and can be correlated with the hydrologic information (Rao, 1984). Many workers have used the principles developed by these pioneers to quantitatively study the drainage basin as a tool for landscape analysis (Sharma, 1987, Sinha-Roy 2002).

Quantitative measurements of morphometry is used as reconnaissance tools to make inferences about particular characteristics of an area, e.g., tectonic activity. Some geomorphic indices like hypsometric integral, drainage basin asymmetry, stream length gradient index, mountain front sinuosity etch are used a measure of active tectonics (Keller and Pinter, 1996; Sinha-Roy, 2002). Landforms are created via erosional and depositional processes, the geometry of which is controlled by the processes that shape them. Morphometric analyses require measurement of linear features, gradient of channel network and contributing ground slopes of the drainage basin (Nautiyal, 1994). The morphometric analysis for individual sub-basins has been achieved through measurements of linear, aerial and relief aspect of the basin and slope contribution (Nag and Chakraborty, 2003).

The basin geomorphic characteristics have long been believed to be important indices of surface processes. These parameters have been used in various studies of geomorphology and surface-water hydrology, such as flood characteristics, sediment yield, and evolution of basin morphology (Aryadike and Phil-Eze, 1989). Several researchers opined that drainage density, one of the major areal morphometric parameters, reflects the landscape dissection (Montgomery and Dietrich, 1989), soil and rock properties (Smith, 1958; Kelson and Wells, 1989), runoff potential, infiltration capacity of the land, climatic conditions and vegetation cover of the basin (Moglen et al., 1998; Verstappen, 1983; Patton, 1988; Macka, 2001; Obi Reddy *et al.*, 2004). By including basin characteristics such as elevation and main channel gradient, predictions of stream discharge were substantially improved in comparison to using only drainage area and precipitation. More recently, terrain characterization became an important part in modelling surface processes. The detailed analysis of morphometric and morphological character indicate the role of neotectonics in shaping the drainage basin.

Geographical Information System (GIS) and Remote Sensing techniques using satellite images are used as a convenient tool for morphometric analysis. Many workers have carried out morphometric analysis using these new techniques. Digital Elevation Model (DEM) and Shuttle Radar Topography Mission (SRTM) are widely used in drainage basin analysis. Srivastava (1997), Nag (1998), Ambili (2010) and Duarah et al. (2011) have carried out morphometric analysis of different drainage basins, while Nag and Chakraborty (2003) deciphered the influence of rock types and structures in the development of drainage network in hard rock areas.

Sedimentology:

Exponential increase in granulometric studies during the second half of the 20th century, brought out many interesting results of the complex mechanisms of sediment transport and deposition. Many studies on the size distribution of clastic sediments revealed the existence of statistical relationships between different size parameters such as mean size, sorting (standard deviation), skewness and kurtosis. The relation between mean size and sorting is particularly well established. The studies of Griffiths (1967), Allen (1970) and Hakanson and Jansson (1983) revealed that the best-sorted sediments are generally those with mean size in the fine sand grade. The interrelationship between grain size frequency distribution and depositional environments has been used successfully in many earlier studies to identify the depositional agent and also to recognize the operative processes of sedimentation of ancient terrigenous deposits (Quidwai and Casshyap, 1978; Goldberg, 1980; Khan, 1984; Ramanamurthy, 1985; Mahendar and Banerji, 1989; Pandya, 1989; Joseph et al., 1997; Majumdar and Ganapathi, 1998 and Lamy et al., 1998). Several attempts have been made to discriminate various environments from size spectral analysis, because, particle distribution is highly sensitive to the environment of deposition (Mason and Folk, 1958; Friedman, 1961, 1967; Griffiths, 1962; Moiola et al., 1974; Stapor and Tanner, 1975; Nordstrom, 1977; Goldberg, 1980; Sly et al., 1982; Seralathan, 1988; Padmalal, 1992; Badarudeen, 1997; Datta and Subramanian 1997; Mohan, 2000; Srinivas, 2002; Yaacob and Hussain, 2005; Maya, 2005, Arun, 2006 and Sreeja et al, 2014). The most notable distinction of sands in modern environments like beaches, dunes and rivers can be demarcated by the scatter diagram of moment standard deviation (sorting) *versus* moment skewness.

The image of grain size spectrum, its properties and statistical parameters computed from size populations are used for getting insight into the transportational and depositional processes of sediments and sedimentary rocks in many of the earlier studies (Friedman, 1961; 1967; Visher, 1969; Blatt et al., 1972; Sly et al., 1982; Sajan et al., 1992; Serlathan and Padmalal, 1993; Arun, 2006; Sreeja et al, 2014 and many others). Existence of significant correlation between size frequency distribution and depositional processes was revealed by exhaustive studies on global scale. Proper selection and combination of statistical parameters can excellently be used to discriminate various environments of deposition of ancient as well as recent sediments (Folk, 1966; Griffiths, 1967; Friedman, 1967; Hails and Hoyt, 1969;

Allen, 1970; Goldberg, 1980 and Pettijohn, 1984). Furthermore, the particle size distribution can invariably influence the mineralogical (Mishra, 1969 and Patro et al., 1989) and chemical (Williams et al., 1978; Forstner and Wittmann, 1983) composition of sediments.

Passega (1957, 1964) established the relationship between texture of sediments and process of deposition rather than between texture and environment as a whole. He opined that a clastic deposit is formed from sediments transported in different ways. In particular, the finest fraction may be transported independently of the coarser particles. Swift sedimentary agents are characterized best by parameters which give more information on the coarsest than on the finest fractions of their sediments. Hence, the logarithmic relation between the first percentile (C) and median (M) of clastic sediments is highly significant in understanding the transportational regimes. Based on the log normal distribution of grain size characteristics Visher (1969) has identified three types of population such as rolling, saltation and suspension that indicate distinct modes of transportation and depositional processes. Other significant contributions in the textural attributes of clastic sediments are of Cadigan (1961), Fuller (1961), Greenwood (1969), John (1971), Davis and Fox (1972), Veerayya and Varadachari (1975) and Stocks et al. (1989).

Textural attributes of sediments from the different environments in Indian scenario have been attempted by many researchers like Sahu, (1964), Rajamanickam and Gujar (1985), Samsuddin (1986), Seralathan (1988), Jahan et al. (1990) Padmalal (1992), Badarudeen (1997) Srinivas (2002), Krishnakumar (2002), Maya (2005), Arun (2006), Ambili (2010) and Sreeja et al (2014). Textural characteristics of the fluviatile and estuarine sediments of the Nethravathy river basin have been studied by Narayana (1991). Rajamanickam (1983) and Rajamanickam and Gujar (1985) have investigated the grain size distribution of surficial sediments of west coast of India. Seetharamaiah and Swamy (1994) worked out the textural characteristics of inner shelf sediments of Pennar river, east coast of India. Seralathan and Padmalal (1994) carried out detailed textural studies of Muvattupuzha river and Vembanad estuary. Granulometric attributes of the beach, strand plain and inner shelf sediments of northern Kerala coast have been investigated by Samsuddin (1990). Studies on textural and sedimentological aspects of central Vembanad estuary were carried out by Padmalal (1992). Badarudeen (1997) carried out a detailed study on sedimentology of some selected mangrove ecosystems of Kerala. A detailed study on geochemical and sedimentological aspects of Kayamkulam estuary has been carried out by Srinivas (2002). Maya (2005) has made a detailed investigation on the granulometric characteristics of two major rivers of central Kerala, namely Chalackudy and Periyar. Arun (2006) and Sreeja et al (2014) conducted detailed investigations on the sedimentation pattern of Aruvikkara and Peppara reservoir catchments. Ambili (2010) investigated granulometric signatures in the evolution of Chaliyar river basin.

Groundwater and hydrogeology:

Groundwater studies have gained greater importance worldwide (UNESCO/IAHS, 1967; Wright and Burgess, 1992; Sheila and Banks, 1993; CGWB, 2012). In India, initial groundwater investigations were mostly restricted to the alluvial and sedimentary tracts (Singhal, 1984), but subsequently the studies have been extended to hard rock areas also. The means of exploration of groundwater was studied by Karanth, 1987 and he pointed out that water level fluctuation maps are indispensable for groundwater studies. Todd (1980) suggested that land subsidence could occur due to changes in underlying groundwater conditions. Chabdler and Whorter (1975) have estimated the salt-water intrusion in Indus river basin. The pumping test data and its interpretation were practiced by many workers (Adyalkar et al. 1966; Eagon and Johe, 1972; Sammel, 1974; Wesslen et al. 1977; Nightingale and Bianchi, 1980; Ruston and Sing, 1983; Sridharan et al. 1990; Boehmer, 1993; Sekhar et al. 1993; Levns et al. 1994; Kaehler and Hsieh, 1994; Saha, 2007). Philip and Singhal (1991) have compared the groundwater levels of different geomorphologic features in Bihar. The influence of topography and landforms on well yield was studied by many (LeGrand, 1967; McFarlane et al., 1992; Sridharan et al. 1995; Henriksen, 1995). An overall decrease in well yield with depth is reported from various crystalline rock terrains in different parts of the world (Davis and Turk, 1964; UNESCO, 1979; Woolley, 1982; Henrisken, 1995).

Geophysical methods and its applications for groundwater studies has been reviewed by a few workers (Zohdy et al. 1974; Worthington, 1977; Beeson and Jones, 1988; deStadelhofen, 1994). Verma et al. (1980) have used histograms, curve types and iso-apparent resistivity (based on apparent resistivity) and Schlumberger sounding curves to investigate the groundwater potential in hard rock areas. Paliwal and Khilnani (2001) has used Vertical Electrical Sounding (VES) surveys for the direct assessment of aquifer parameters. The significance of contouring the apparent resistivity to identify the groundwater potential areas, movement pattern etc. has been highlighted by Sarma and Sarma (1982), Balakrishna et al. (1984) and Balasubramanian et al. (1985).

The chemical composition of groundwater was studied by many (Lloyd, 1976; Daly et al., 1980; Raghunath, 1987) and it was found to be mainly related to soluble products of rock weathering with respect to space and time. In addition to the leaching of minerals, anthropogenic activities can adversely alter the chemical quality of groundwater as studied by several others (Sakthimurugan, 1995; Manivel and Aravindan, 1997; Laluraj et al. 2005; Sudhakar and Mamatha, 2004). Kalkoff (1993) has attempted to relate stream water quality with the geology of the catchment area of the Roberts Creek watershed, Iowa. Zaporozec (1972), Freeze and Cherry (1979), Matthess (1982) and Lloyd and Heathcote (1985), have given a detailed account of various methods of plotting the water quality data. Based on the dominance of anions and cations, the groundwater of Vaippar basin has been classified by Sivaganam and Kumaraswamy (1983). Gupta (1987) has evaluated the groundwater quality of the northern part of Meerut district, Uttar Pradesh. Changyan Tang (1989) used Collin's bar graph, Hill-Piper trilinear diagram, Durov's diagram, U.S.S.L diagram, Stiff and bar diagrams to analyse the groundwater quality. Kelley (1940), Eaton (1950) and Wilcox (1955) have proposed certain indices by considering the individual or paired ionic concentrations, to find out the alkali hazards and Residual Sodium Carbonate (RSC). Subba Rao (2008) studied the factors controlling the salinity in groundwater in parts of Guntur district, Andhra Pradesh. The Statistical Analysis and interpretation of water quality data was done by Selim et al. (2008).

Ramasamy and Bakliwal (1983) have stated that an integrated approach involving geology, geomorphology and landuse pattern using remotely sensed data could give significant information for targeting groundwater. Howe (1956), Ray (1960), Lattman and Parizek (1964), Boyer and Maguer (1964), Setzer (1966) and Mollard (1988) have extensively used the black and white aerial photographs in mapping the areal extent of various aquifer systems and lineament pattern for groundwater targeting. Researchers like Brakeman and Fernandaz (1973), Bowder and Pruit (1975), Moore and Duestsch (1975) and Ottle et al. (1989) have carried out the hydrogeological, structural and hydrogeomorphological interpretations with the help of satellite multispectral data. Gopinath (2004) studied the hydrogeological characteristics of the Muvattupuzha drainage basin.

Philip and Singhal (1991) showcased the importance of geomorphology for hydrological study. Thillaigovindrajan (1980) formulated the techniques of the practical utilization of remote sensing in groundwater exploration by studying various geomorphological units of southern Tamil Nadu. Thiruvengadachari (1978) has studied the hydrologic landuse pattern of the southern part of Tamil Nadu from satellite data. Sankar (2002) has evaluated the groundwater potential zones using remote sensing data of upper Vaigai river basin, Tamil Nadu. Remote sensing (SPOT-HRV data) is very effectively used in bringing out the relation between lineament and vegetation anomalies of Botswana

(Gustafsson, 1993). Siegal and Abrams (1976) Drury (1987), Sabins (1987) and Gupta (1991) used Digital image processing is for extracting information from digital data.

Groundwater pollution and pollution potential evaluation using Geographical Information Systems (GIS) was attempted by many (Aller et al. 1987; Halliday and Wolfe, 1991). In the northern part of Australia, salinity hazard mapping has been carried out by Tickell (1994) using GIS. Groundwater modelling based on GIS has been attempted by many (Richards et al., 1993; Roaza et al. 1993; El-Kadi et al. 1994; Shahid et al. 2000; Boutt et al. 2001). Srinivasa Rao and Jugran (2003) have applied GIS for processing and interpretation of groundwater quality data. Groundwater prospecting zones in Dala Renukoot area, Uttar Pradesh has been mapped through integration of various thematic maps using Arc/Info GIS (Pratap et al. (2000). In recent years many workers such as Teeuw (1995), Goyal et al. (1999) Saraf and Chowdhary (1998) Murthy (2000) and Lobo Ferreirae Catarina Diamantino (2008), have used remote sensing and GIS techniques for groundwater exploration and identification of artificial recharge sites. Several researchers have used GIS to delineate groundwater potential zones (Ravi and Mishra, 1993; Krishnamurthy et al. 1996; Shahid and Nath, 2001; Singh and Prakash, 2002; Jaiswal et al. 2003; Mondal and Singh, 2004; Erhan Sener et al. 2005; Vijith, 2007; Prasad et al. 2008; Girish Kumar et al. 2008; Kahya and Demirel, 2009; Ganapura et al. 2009; Reghunath et al. 2009; Balakrishnan, 2009, Sreela, 2009, Narasimha Prasad et al., 2013; Arun et al., 2014, Sreeja et al., 2015).

Water quality and Hydrogeochemistry:

Drainage basins form the natural unit for physical, industrial and social planning (Narasimha Prasad et al., 2007, Arun et al., 2013). The early researchers who recognised the obvious unitary feature of drainage basins, both of geometry and process include Playfair (1802), and Chorley et al. (1964). The overall balance between dissolved and sediment load carried to the oceans was computed by Holeman (1968), Meybeck (1976), Martin and Meybeck (1979) and Milliman and Meade (1983). Gibbs (1970) in his classic study discussed the mechanisms that control the world river water chemistry. Many investigations have been carried out on the physico-chemical aspects as well. Some of the notable studies are those of Ganapathi (1956, 1964) in the rivers Thambaraparani and Godavari; Deshmukh et al. (1964) in the river Kanhan; David and Ray (1966) in the river Daha; George et al. (1966) in the river Kali; Venkateswarlu and Jayanti (1968) in river Sabarmati; Venkateswarlu (1969) in the river Moosi; Ray et al. (1966) and Saxena et al. (1966), Agarwal et al. (1976), Bhargave (1985), Bilgrani and Duttamunshi (1985), in the river Ganga; Sreenivasan et al. (1979) and

Somasekhar (1985) in the river Cauvery; Badola and Singh (1981) and Nautiyal et al. (1986) in river Alakananda; Raina et al. (1984) in river Jhelum; Reddy (1984) in the river Tungabhdra; Zingde et al. (1985, 1986) in the rivers Aurarig and Ambika; Konnur et al. (1986) in the river Coum; Chacko and Ganapathy (1949) in the river Adyar; Chacko et al. (1953) in the river Malampuzha; Sankaranarayanan et al. (1986) and Maya (2005) in the river Periyar; Harilal et al. (2004) in Karamana and Neyyar; Babu et al. (2003) in Bharathapuzha; Babu and Sreebha (2004) in rivers draining into Vembanad lake; Singh et al. (2005) in Gomati river and Aji (2006) in Pamba river; Arun (2006) in Aruvikkara and Peppara reservoir catchments. The water quality studies of Muvattupuzha river have been performed by Balchand (1983). Nair et al. (1990) opined that considerable changes in the water quality of this river occurred after the establishment of the Hindustan Paper Limited located near Velloor. In addition to routine physico-chemical investigations, many studies are available on the pollution load assessments of Indian rivers as well. Of these, the works of Montwan et al. (1956) in the river Sone; David and Ray (1966), Bhaskaran (1970) in the river Ganga; Venkateswarlu and Sampathkumar (1982) in the river Moosi; Mahadevan and Krishnaswami (1983) in river Vaigai; Raina et al. (1984) in the river Jhelum; Agarwal (1986) in the river Chambal and Reddy and Venkateswarlu (1987) in the river Amaravati and receive special attention. The importance for choosing the river basin as a specific unit for environmental management studies is reviewed by Chattopadhyay and Carpenter (1990).

Several studies have been carried out to assess the hydrography of the major backwaters of Kerala by many researchers. These studies provide a fairly good picture of the highly dynamic environmental conditions prevailing in these water bodies. Rao and George (1959) studied the hydrology of the Korapuzha estuary. Manikoth and Salih (1974) studied the hydrography and nutrients of Cochin backwater system. Saraladevi et al. (1991) studied the nutrients from Kallayi, Beypore, Korapuzha and Mahe estuaries. Several studies have been carried out on various aspects of the Ashtamudy estuary, the second largest estuarine system of Kerala. Nair et al. (1983, 1984) and Nair and Azis (1987) studied the physico-chemical features of the Ashtamudy estuary. The physico-chemical features of Akathumuri–Anchuthengu–Kadinamkulam backwater was studied by Nair et al. (1983, 1984) as part of a survey on the ecology of Indian estuaries. The estuarine characteristics and physico-chemical features of the Periyar estuary were investigated by Sankaranarayanan et al. (1986). Premchand et al. (1987) studied the hydrography of Beypore estuary. Nair (1971) studied the hydrology of Kayamkulam estuary.

Similar studies are available on the major reservoirs and freshwater lakes of the world (Visser and Villeneuve, 1975; Stow et al., 1985; Hunsaker et al., 1986; Nilsson and Hakanson, 1992; Eckerrot and Petterson, 1993; Smith, 1993; Iordanishvili, 2000; Zilov, 2001; Bikbulatov et al., 2001; Silva et al., 2002; Evans and Monteith, 2002; Goransson et al., 2004 and Dzyuban, 2005) and from many states of India (Sugunan, 1995; Das and Singh, 1996; Das, 1999; Das and Kaur 2001; Al-Mikhlafi et al., 2003 and Das, 2005). But, it is unfortunate that much attention has not been paid on the water quality aspects of Kerala reservoirs and freshwater lakes (Khatri, 1985; Harikrishnan and Aziz, 1989; Sreejith, 1996; Krishnakumar, 1998, Jamuna et al., 2000 and Arun, 2006).

OBJECTIVES OF THE STUDY

Concern for water is growing nowadays and the importance of water for supporting life is gaining recognition due the complexities of interactions within and between ecosystems. The demand for water is increasing exponentially due to population explosion, recurring drought, agricultural, industrial and mining activities. Due to over exploitation of ground water, the ground water levels in many areas show a declining trend, which in turn tends to increase both the investment cost and the operational cost. This problem can be alleviated to some extent by artificially recharging the potential aquifers and efficient harvesting of the rainwater. To achieve this it is necessary to understand the geomorphology, geology and hydrogeology of the area. In this context, as a tool, morphometric analysis of the drainage basin will give insights on the terrain, tectonic history, lineaments and finally to the hydrogeological setup. Today geomatics emerges as a platform to collect, store, analyse, present and retrieve spatial data in any scale. As a technique Remote sensing permit rapid and cost effective natural resources survey and management. Geographic Information System (GIS) enables us to use, view and analyse the remotely sensed data along with field data as well as spatial data from other sources. Moreover remote sensing and GIS are playing a rapidly increasing role in the field of hydrology and water resources development. It is also a well known fact that for effective water resource management, drainage basin / watershed should be the unit of evaluation as well as management/remedial measures.

In this context the Karamana river basin has been selected as the study area, which caters a major part of the water demand of the Capital city of Kerala, Thiruvananthapuram by surface water and ground water, at present. Thiruvananthapuram Corporation and adjoining areas exclusively depends on the Karamana river basin for its drinking water needs. The aim of this study is to understand the effect of evolutionary processes and the resultant morphological features on the hydrogeological setup of the Karamana River Basin. This investigation envisages the following objectives.

- To understand the drainage and geomorphological characteristics of Karamana River basin.
- To assess lithological and structural controls on the evolution of Karamana River drainage system
- To understand the role of evolution of Karamana River drainage basin on its hydrogeological regime and to formulate proper water management strategies.

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MATERIALS AND METHODS

This study covers a spectrum of subject components pertaining to terrain characteristics, drainage network, sediments and water resources of the Karamana river basin. Various procedures adopted for data generation including sample collection, sample processing and analysis are described in this chapter.

FIELD WORK AND SAMPLING

A detailed fieldwork has been carried out in the Karamana river basin for the collection of primary and secondary data as well as sediment and water samples for various analyses. All the available data on geology, hydrogeology, borehole lithologs, water level fluctuation, pumping test results, rainfall and other related data were collected from different agencies in Kerala and also from published literature. Secondary data was collected from State and Central Government Departments like Kerala State Land Use Board (KSLUB), Central Ground Water Board (CGWB), Kerala Water Authority (KWA), Kerala State Electricity Board (KSEB), Kerala State Planning Board (KSPB), Department of Economics and Statistics (DES), Kerala Forest Department, various R&D centres under Kerala State Council for Science, Technology and Environment (KSCSTE), Agricultural Directorate, Universities in Kerala and offices of various local bodies in the Karamana river basin. This information is updated using necessary field checks / verifications as and when required.

50 observation wells were established in the Karamana River Basin for this study (Fig.2). The details such as location name, latitude, longitude, total depth, diameter, height of parapet, formation type etc. of each observation well were recorded before starting the monitoring. Seasonal depth to water level was monitored from these dug wells for the one years. The observed seasons are Pre-monsoon, monsoon and Post-monsoon. During the field visit, surface and subsurface geology of the area around the observation wells were recorded. Perenniality, water quality, usage, proximity to leach pits etc., were collected during the field visit and from the interaction with the respective well owner/users of the wells. Details of aquifer parameters such as transmissivity, specific capacity, specific yield, etc., have been taken from the already published literature of CGWB and Centre for Water Resources Development and Management (CWRDM). This was done as the well owners in the study area were not ready to spare their wells for pumping test. Three sample areas representing different physiographic regions such as low land, mid land and high land regions covering the Karamana River Basin and well inventory was carried out. Details of existing wells, growth and usage pattern of each well type, density of wells etc., have been determined through this

well inventory. All the above results have been integrated to determine the groundwater condition in the Karamana River Basin in terms of potential, present draft and future developmental prospects.

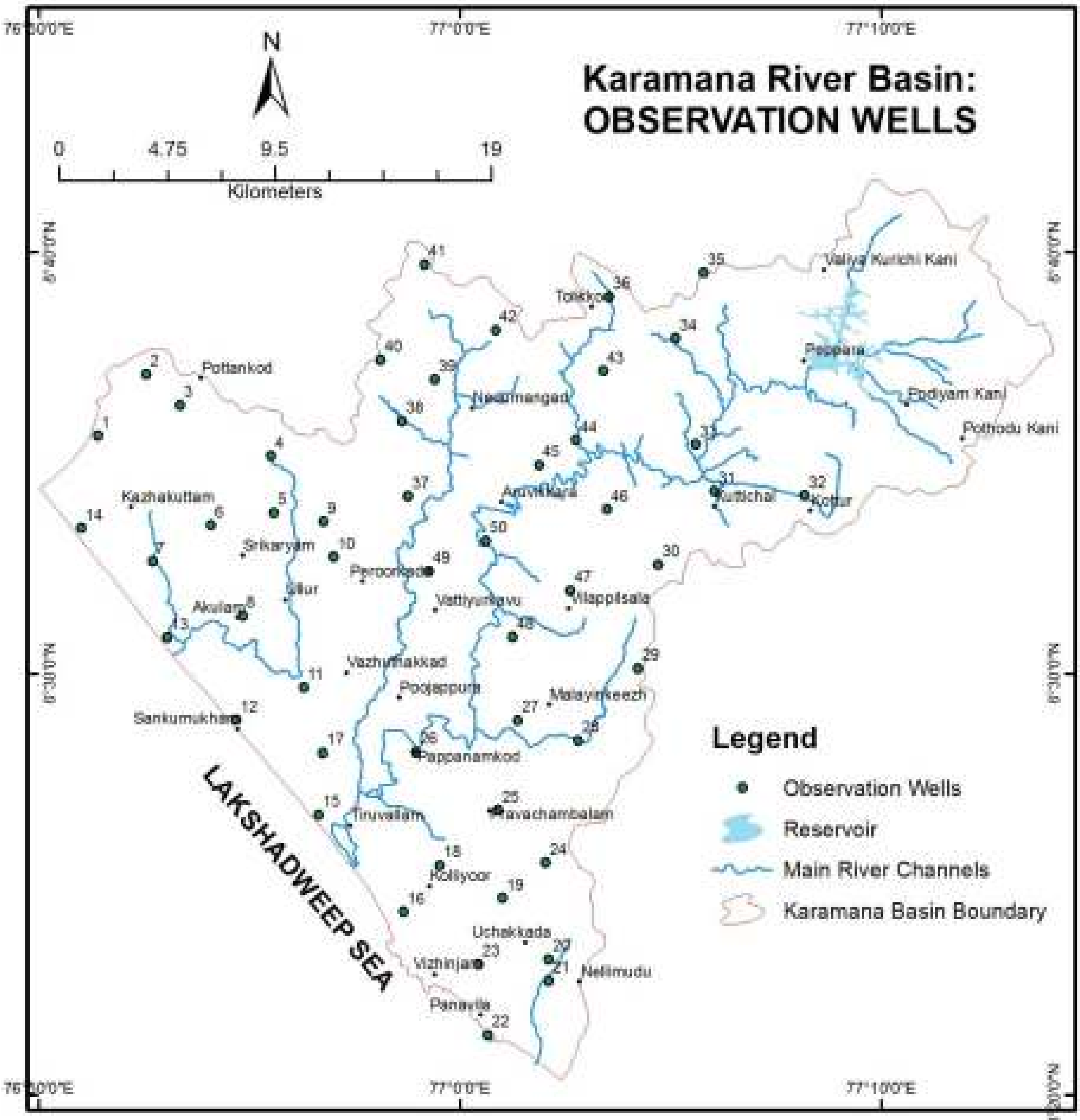


Fig. 2 Map showing observation well network in the Karamana river basin.

A total of 60 sediment samples were collected from the study area (tributaries / river: 50, Peppara reservoir: 7 and Aruvikkara reservoir: 3) for textural studies, during May 2014. The sediment sampling locations are depicted in Fig. 3. A stainless steel Van-Veen Grab was used to collect bottom sediments from the reservoirs as well as deeper parts of the river environment. From shallower reaches of the river / tributaries, sediment samples were obtained using a PVC pipe of 4 inch diameter.

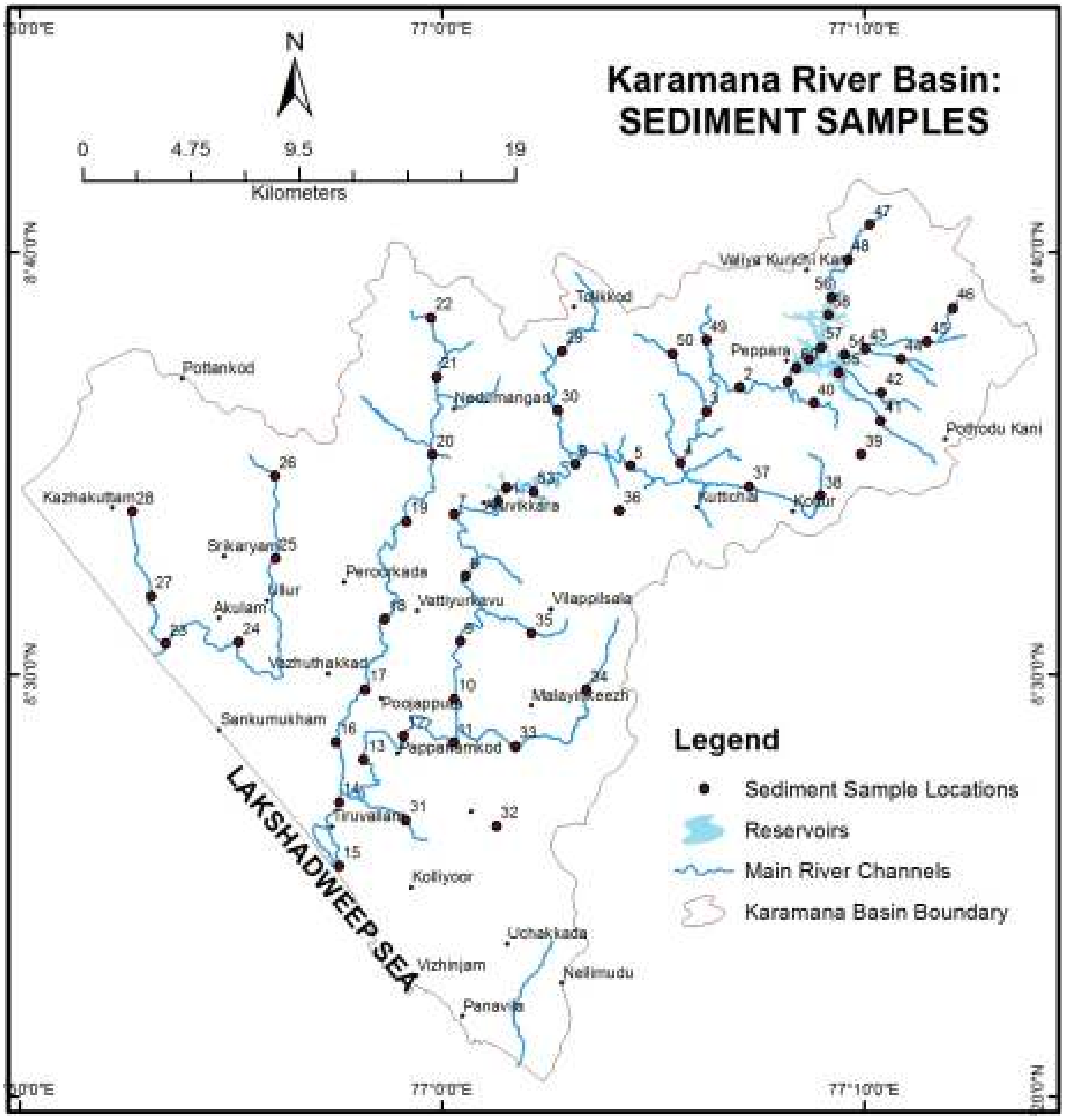


Fig. 3 Map showing sediment sampling locations in the Karamana river basin.

For determining water quality, samples were collected from all the 50 observation wells established in the river basin as well as 12 river sampling locations (Fig 4) during non-monsoon (in the month of March 2014) and monsoon (July, 2014) periods. Quality of water in terms of major physico-chemical parameters, have been determined for the Karamana River Basin. The water samples (2 litres) were collected from each location using a well-cleaned plastic bucket. The pH and electrical conductivity of water samples were noted in the field itself. Utmost care was taken to avoid contamination of the samples during sample collection and handling. All the samples were brought to laboratory and analysed for various parameters without much delay in order to achieve the objectives of the study.

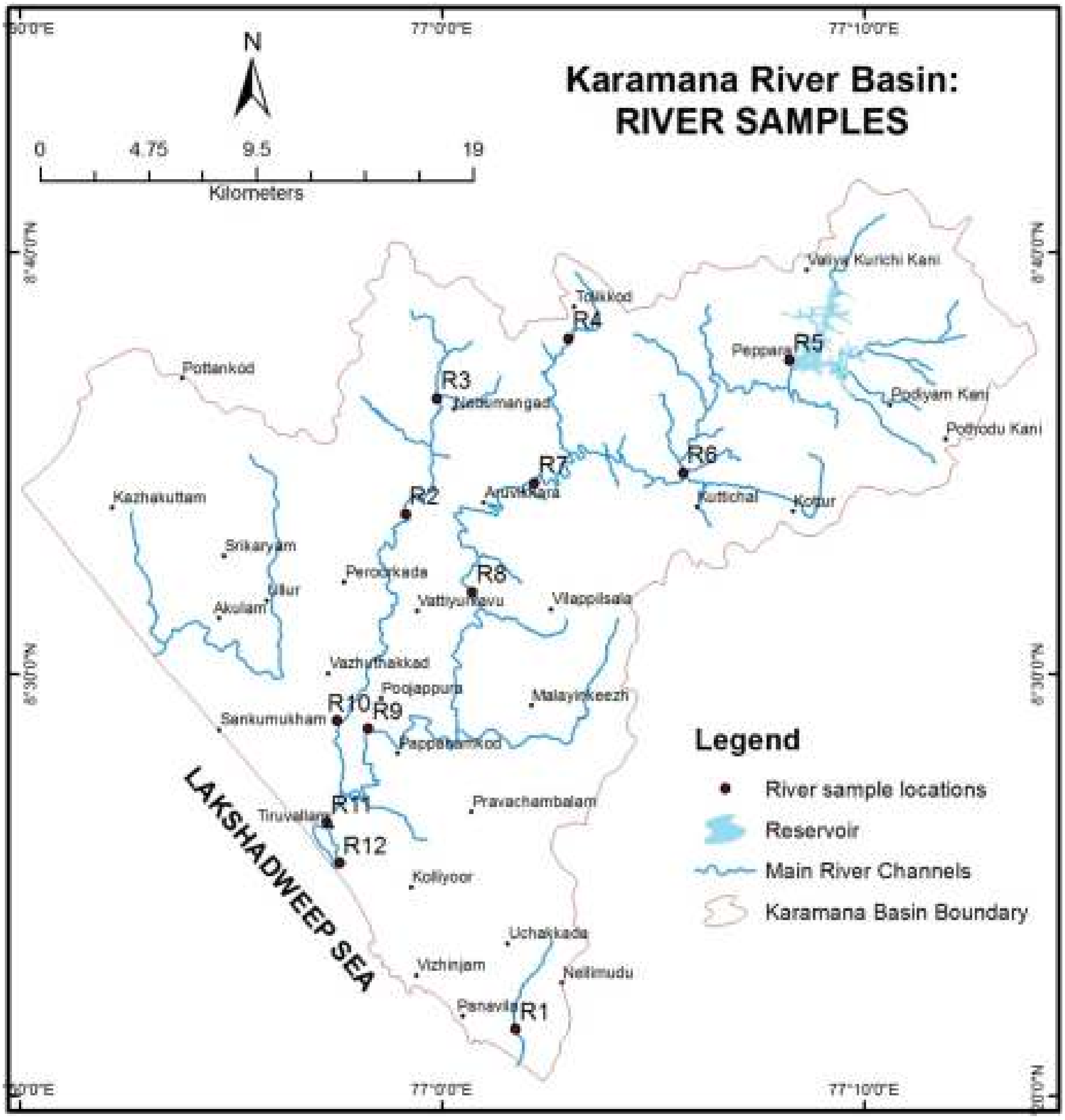


Fig. 4 Map showing river sampling locations in the Karamana river basin.

LABORATORY ANALYSES

Grain size analysis

The sediment samples were washed and dried on an air oven at 55±2°C to constant weight. Representative portions of the samples were sieved for 15 minutes on mechanical Ro-tap sieve shaker using a standard set of ASTM Endicott sieves arranged in the descending order of mesh size at half phi (1/2 ф) intervals (Carver, 1971). Mud dominant samples were subjected to combined sieving and pippette analysis for estimation of weight percentages of the grain size fractions. The methodology prescribed by Lewis (1984) was used for this purpose.

Of the two methods of computing grain size parameters of sediments namely moment method and graphic method, the latter was used in the present study. In moment method, grain size parameters are obtained directly from size data, whereas in graphic method quantitative readings are obtained from the data generated, using a graph (probability chart) drawn following the method of Folk (1966). The grain size in phi (ф) values was plotted against cumulative weight percentage on a probability chart and different percentile values for 5 ф, 16 ф, 25 ф, 50 ф, 75 ф, 84 ф and 95 ф obtained from the graph were used for the determination of various grain size parameters. The graphic method is widely being used to understand the grain size distribution of recently deposited sediments.

Various researchers suggested different formulae, for calculating these statistical parameters, but the widely accepted one is put forth by Folk and Ward (1957) and the suggested divisional points / limits are furnished in Table 1.

Mean grain size: Mean is the statistical average expressed in phi (ф) units and is calculated by the following equation:

$$\text{Mean size (Mz)} = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Median: Median is the middle value of grain size distribution. The value corresponding to □50 will be taken as median.

Mode: Mode is the most frequently occurring particle size in the grain size distribution. In some cases a single sample displaces two most dominant size classes. Such samples are called 'bimodal', if three dominant size classes 'trimodal', if many 'polymodal'.

Standard deviation: *(σ_1):*Standard deviation is a measure of sorting of grains constituting the sediment population. Uniformity within a sample can be measured by these parameters. It is one of the most useful parameters in recognizing the efficiency of the depositional environment.

$$\text{Standard deviation } (\sigma_1) = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Skewness (S_k): The asymmetry of the grain size distribution in a sediment sample is measured by skewness. The skewness, according to Folk and Ward, is the best measure as it covers the full curve.

$$\text{Skewness } (S_k) = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

Table 1 The divisional points / limits of statistical parameters

Sl. No.	Statistical parameter	Range	Class Terminology
1	Mean (□)	<-8	Boulder
	(Lewis, 1984)	-8 to -6	Cobble
		-6 to -2	Pebble
		-2 to -1	Granule
		-1 to 0	Very coarse sand
		0 to 1	Coarse sand
		1 to 2	Medium sand
		2 to 3	Fine sand
		3 to 4	Very fine sand
		4 to 5	Coarse silt
		5 to 6	Medium silt
		6 to 7	Fine silt
		7 to 8	Very fine silt
		>8	Clay
2	Standard	<0.35	Very well sorted
	deviation (□)	0.35 to 0.50	Well sorted
	Folk and Ward	0.50 to 0.71	Moderately well sorted
	(1957)	0.71 to 1.00	Moderately sorted
		1.00 to 2.00	Poorly sorted
		2.00 to 4.00	Very poorly sorted
		>4.00	Extremely poorly sorted
3	Skewness	>0.30	Very finely skewed
	Folk and Ward	0.30 to 0.10	Finely skewed
	(1957)	0.10 to -0.10	Nearly Symmetrical
		-0.10 to -0.30	Coarse skewed
		<-0.30	Very coarse skewed
4	Kurtosis	>0.67	Very platykurtic
	Folk and Ward	0.67 to 0.90	Platykurtic
	(1957)	0.90 to 1.11	Mesokurtic
		1.11 to 1.50	Leptokurtic
		1.50 to 3.00	Very leptokurtic
		>3.00	Extremely leptokurtic

Sign of skewness is often related to the energy conditions of the environment (Duane, 1964). Negative (coarse) skewness could be correlated with high energy and winnowing action (removal of fines) and positive (fine) skewness with low energy levels (accumulation of fines).

Kurtosis (K_G): Kurtosis is considered as one of the important textural parameters to distinguish various environments as explained by Mason and Folk (1958) and Duane (1964). It is a measure of the contrast between sorting observed in the central part of the particle size distribution with that of the tails.

$$\text{Kurtosis } (K_G) = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)} \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

Kurtosis represents the degree to which the particles are concentrated near the centre of the curve (platykurtic-broad curves, mesokurtic-middle and leptokurtic-peaked curves). Many curves designated as "normal" by the skewness measure turn out to be markedly non-normal when the kurtosis is computed.

The interrelationship between these parameters has also been used to elucidate the hydrodynamic conditions of depositional environments. In addition to this, the percentages of gravel (>2 mm), sand (0.063 – 2 mm) and mud (<0.063 mm) for gravel bearing sediments and sand, silt (0.063 – 0.004 mm) and clay (<0.004 mm) for gravel free sediments, were also plotted on the ternary diagram of Folk et al. (1970) to determine sediment types. The grain size classes like pebbles, granules, sand and mud were separated following the size limits of Wentworth (referred in Lewis, 1984) and studied for their differential segregation in the study area. The depositional processes worked out using the above statistical tools have been further illustrated by the CM - model established by Passega (1964).

Water quality analysis

The water samples were analysed for various physico-chemical parameters using standard methods (Grasshoff, 1976 and APHA, 1998). Nutrients and Fe were determined after filtering the samples through 0.45 µm millipore membrane filter paper. All colorimetric determinations were made by a double beam spectrophotometer (SHIMADZU UV 160A). The various methods used for the analyses are furnished in the Table 2.

Morphometric analysis

The morphometric parameters for the Karamana River basin has been computed following Horton (1945) and Strahler (1964) from the integrated drainage map prepared from SOI toposheet, DEMs and IRS P-6, LISS III satellite imagery with the aid of Arc GIS 10.0 GIS software.

LINEAR ASPECTS

Stream order: Stream order is directly proportional to the size of the contributing watershed, to channel dimensions and to stream discharge at that place in the system. The stream order from 1 to 7 are determined in the study area following the procedures suggested by Horton (1945), Strahler (1952) and Gleyzer et al. (2004).

Table 2 List of physico-chemical parameters studied in water samples and details of the methodology followed in the study

SI No.	Parameters	Methodology
1.	pH	Measured using a portable pH meter, ELICO Water Quality Analyser PE 136, with an accuracy of 0.001 pH units.
2.	Conductivity	Measured using a portable pH meter, ELICO Water Quality Analyser PE 136, with an accuracy of 0.1µs units.
3.	Alkalinity	Titration with standard acid using bromocresol green indicator.
4.	Chloride	Argentometric titration with chromate ions as indicator.
5.	Sulphate	Precipitation with barium chloride and measured the turbidity photometrically at 420 nm.
6.	Hardness	EDTA titration using Eriochrome Black T indicator.
7.	Calcium	EDTA titration using ammonium purpurate (Murexide) indicator.
8.	Magnesium	EDTA titration (Total (Ca+Mg), from Hardness - Ca).
9.	TDS	Filtration through 0.45 µm Millipore membrane filter paper and evaporation of water in platinum dish and drying of the residue till constant weight.

Stream number (Nu): The count of stream channel in its order is known as stream number. Total number of streams in each order for the sub-basins is counted separately. Stream number is also directly proportional to size of the watershed and channel dimension. It is obvious that the number of streams of any given order will be fewer than for the next lower order but more numerous than for the next higher order.

Bifurcation ratio: Horton (1945) and Strahler (1952) had defined bifurcation ratio as number of streams of one order to the number of the next higher order which can be expressed as

$$Rb = \frac{Nu}{(Nu+1)}$$

where Nu is the number of streams in a given order and Nu+1 is the number of streams in the next higher order. Average value of Rb for a given channel network can be estimated by determining the slope of the best fitted regression of logarithm of numbers (ordinate) on order (abscissa). The regression coefficient (R^2) is identical with the logarithm of Rb**.**

Direct bifurcation ratio (Rbd): Direct bifurcation ratio (Rbd) explains the nature of the drainage networks without considering the hierarchical anomalies (Guarnieri et al., 2008).

Direct bifurcation ratio (Rbd) for all the streams of different orders is computed using the equation,

$$Rbd = Ndu/Nu+1$$

where Ndu is the number of the fluvial segments of a given order that flow in segments of the next higher order Nu+1 (Avena et al., 1967).

Bifurcation index (R) Bifurcation index is the difference between the bifurcation ratio (Rb) and direct bifurcation ratio (Rbd) and it gives the useful information on the typology of the active erosive processes and on the evolution of basin, and depends on the presence of hierarchical anomalies (Guarnieri et al., 2008). Bifurcation index of the streams is determined by the equation

$$R = Rb - Rbd$$

Hierarchical anomaly number (Ha) Hierarchical anomaly number (Ha) corresponds to the minimum number of the first order segments necessary to make the network perfectly hierarchical (Avena et al., 1967; Guarnieri et al., 2008).

Hierarchical anomaly index (Δa) Hierarchical anomaly index (Δa) is defined as the ratio of the number of hierarchical anomaly (Ha) to the number of the first order network (N1) (Avena et al., 1967; Guarnieri et al., 2008).

$$\Delta a = Ha/ N1$$

Horton (1945) has worked out a relationship between the total number of stream segments and the constant bifurcation ratio as

$$Nt = (Rb^K-1)/(Rb-1)$$

where, K is the highest order of the basin, Rb is taken as the average value of the bifurcation ratio for the basin and Nt is the total number of stream segments.

Stream length: Stream length was measured with the help of ArcGIS software. To obtain the mean length of channel Lu of order u, the total length is divided by the number of segments Nu of that order (Horton, 1945), thus

$$Lu = \left(\sum_{i=1}^{N} Lu\right)/Nu$$

where Lu is the mean length of the channel of a given order, and Nu is the total number of streams in that particular order.

Length of overland flow (Lf): Length of overland flow is the length of water over the ground before it gets concentrated into definite stream channels which effect both hydrologic and physiographic development of drainage basins (Horton, 1945). The distance covered from the water divide to the nearest channel represents the length of overland flow, and is an important variable in which run off and flood processes depend (Zavoianu, 1985).

Sinuosity ratio (Si): Sinuosity ratio gives an idea how the channel deviates from straight path ie. wandering and meandering (Smart and Surkan, 1967). It is the ratio of channel length (Lu) of the main stream in a basin to the basin length (Lb) and is determined by the equation

$$Si = Lu/Lb$$

It is of great use in understanding the geomorphic characteristic of a basin and is used in the morphometric studies to distinguish between the various types of terrain and to ascertain the degree of establishment made by a drainage line in the area of influence. The degree of stream sinuosity fluctuates with time and stage of development of the basin in relation to the topographical and geological background. Channels with sinuosity index < 1.1 is described as straight, those between 1.1 and 1.5 are sinuous and those with sinuosity ratio > 1.5 are called meandering channels (Charlton, 2007).

AREAL ASPECTS

In addition to the mathematical relationship found in stream ordering, various aspects of drainage network forms are also found to be quantifiable based on the spatial distribution and area of the drainage basin. Areal aspects rely on the spatial scale variation of the drainage basin and is attributed to the inherent capability of the stream system to adjust itself by size adjusts in the stream segments. The following areal aspects of Karamana river drainage basin are computed.

Basin area (Au): Basin area of a given order is defined as the total area projected on a horizontal plane contributing overland flow to the channel segments of the given order, which includes all tributaries of the lower order. Basin size helps to determine the amount of water reaching the river. Larger the catchment area, greater will be the potential of flooding. Basin area of each sub-basin is measured using ArcGIS software.

Drainage density (Dd): This is an important indicator of the linear scale of land-form elements in stream eroded topography. Drainage density is the total length of all the streams in the basin to the area of whole basin (Horton, 1945). Factors affecting drainage density are the erodibility of the rock and climate. Drainage density (Dd) is computed using the following equation as suggested by Horton (1945)

$$Dd = \sum \frac{Lu}{Au}$$

where Lu is the total length of the streams in basin and Au is the area of the basin.

Stream frequency (Fu): Stream frequency refers to the number of streams per unit area. Horton (1945) introduced stream frequency and discusses the importance to ground water recharge characteristics in a river basin. It expresses the competence with which the channel system fills the basin outline (Chorley et al, 1985). Stream frequency is calculated by dividing the total number of streams (Nu) in a basin by the total basin area (Au).

$$Fu = \sum \frac{Nu}{Au}$$

Circularity ratio (Rc): Circularity ratio is the ratio of the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). This ratio is obtained from the equation

$$Rc = \frac{4\pi Au}{P^2}$$

where P is the perimeter of the drainage basin.

Elongation ratio (Re): Elongation ratio is the ratio between diameter of a circle having same area as that of the drainage basin and the maximum length of the basin (Schumm, 1956) and is determined by employing the formula

$$Re = Da/Lmax$$

Elongation ratio indicates how the shape of the basin deviates from a circle and is considered as the index to mark the shape of the basin.

Form factor (Ff): Horton (1932) proposed the form factor in order to express the shape of the basin quantitatively. Form factor governs the water course that enters the main stream (Gregory and Walling, 1985). If the basin is wider, the form factor will be comparatively higher and vice versa. Form factor is one of the parameters that explain the basin configuration. It is the ratio of the basin area to the square of the basin length (Strahler, 1968) and is expressed as,

$$Ff = Au/Lu^2$$

Compactness factor (Rcf): Compactness factor is used to express the basin shape, as a factor of deviation the basin area from a circle having the same area of the drainage basin (Gupta, 1999). This is computed from the equation

$$Rcf = Ac/Au$$

where Ac is the area of circle having the same perimeter.

RELIEF ASPECTS

Relief aspects of a drainage basin have great influence on the hydrologic response, and depend on the channel type and relative gradient of the basin. The following are the relief aspects considered for this study.

Basin relief (Rh): Importance of basin relief as a hydrological parameter has been recognized long before (Sherman, 1932, Horton, 1945; Strahler, 1964). Basin relief is an important factor in understanding denudational characteristics of the basin. Basin relief (Rh) is the difference between the maximum and minimum elevation of a drainage basin (Schumm, 1956). It is a parameter that determines the stream gradient and influences flood pattern and volume of sediment that can be transported (Hadley and Schumm 1961). Basin relief is computed by employing a simple function

$$Rh = H - h$$

where H is maximum elevation and h is minimum elevation within the basin.

Relief ratio (Rr): Relief ratio (Rr) is a dimensionless ratio of basin relief to the basin length (Schumm, 1956), and is expressed by the equation

$$Rr = R/Lb$$

Ruggedness number (Rn): In order to combine the qualities of slope steepness and length, a dimensionless number is developed which is the product of relief and drainage density (Strahler, 1958) and is determined by the equation

$$Rn = Rh \text{ x } Dd$$

Stream gradient: Stream gradient is the ratio of drop in a stream per unit distance, usually expressed as meters per kilometer. It is commonly used to measure the river slope and define relative difference in uplift (Merrits and Vincent, 1989). Hack (1957) explained that channel gradient is affected by lithology for basins of similar sizes. Steep gradient generally occurs in areas of resistant bed rock. A high gradient indicates a steep slope and rapid flow of water (i.e. more ability to erode); whereas a low gradient indicates a more nearly level stream bed and sluggishly moving water, that may be able to carry only small amounts of very fine sediment. High gradient streams tend to have steep, narrow V-shaped valleys, and are referred to as young streams. Low gradient streams have wider and less rugged valleys, with a tendency for the stream to meander. Stream gradient is computed by the formula

$$S= (E_1-E_2)/Ls$$

where E_1 - E_2 is the difference in the elevation between two points on the stream and Ls is the distance along the stream.

HYPSOMETRIC ANALYSIS

Hypsometric analysis is the study of distribution of ground surface area, or horizontal cross-sectional area, of a landmass with respect to elevation (Strahler, 1952). Hypsometric analysis was for the first time introduced by Langbein (1947) to express the overall slope and forms of the drainage basin. Hypsometric analysis permits comparison of drainage basins irrespective of scale issues (Dowling et al., 1998). hypsometric curves and hypsometric integrals are important indicators of watershed conditions (Ritter et al., 2002). The shape of the hypsometric curve explains the temporal changes in slope of the original basin (Giamboni et al., 2005). It helps in understanding the cycle of erosion (Strahler, 1952; Giamboni et al., 2005; Singh et al. 2008, Ambili, 2010) and in inferring characteristics of the complex morphologic processess in a basin (Strahler, 1952; Harlin, 1984; Moglen and Bras, 1995).

Hypsometric curve is obtained by plotting the relative area along the abscissa and relative elevation along the ordinate. The relative area is obtained as a ratio of the area above a particular contour to the total of the watershed encompassing the outlet. relative elevation is calculated as the ratio of the height of the given contour (h) from the base plane to the maximum basin elevation (H) (Sarangi etal., 2001; Ritter et al., 2002; Singh et al., 2008, Ambili, 2010). Hypsometric integral (Hi) is obtained from the hypsometric curve and is equivalent to the ratio of the area under the curve to the area of the square formed by covering it. In the present study, the elevation ratio method proposed by Pike and Wilson (1971) is used. The relationship is expressed as

$$Hi = \frac{Elev_{mean} \quad Elev_{min}}{Elev_{max} \quad Elev_{min}}$$

where Elev $_{mean}$ is the weighted mean elevation of the drainage basin estimated from the identifiable contours of the delineated drainage basin; $Elev_{max}$ and $Elev_{min}$ are the maximum and minimum elevations within the drainage basin.

Hypsometric integral expresses the unconsumed volume of drainage basin as a percentage of that delimited by the summit plane, base plane and perimeter. The value of hypsometric integral as a relative measure of erosion is limited to its higher values or to situations where the elevation of the original summit plane can be estimated. In the present study, drainage basins are classified by the shape of the hypsometric curve, absolute distribution of the elevation and by hypsometric integral.

Remote sensing

Remote sensing and Geographical Information System (GIS) were depended upon whenever necessary to study the features of the Aruvikkara and Peppara reservoir basins. IRS-IC LISS III satellite image of 2013 and Survey of India (SOI) topographic maps of 1967 (1:50,000) and 1988 (1: 25,000) were the other sources of information / analysis.

The digital satellite data (Resourcesat-1 LISS III) of the study area, downloaded from NRSC (National Remote Sensing centre) open archive was used for the study. LISS III is one of the sensors on Resourcesat-1, which provides multispectral data on four bands; two in visible (0.52 – 0.59 and 0.62 – 0.68 microns), one in infrared (NIR, 0.77 – 0.86 microns) and another one in short wave infrared (SWIR, 1.55 –1.70 microns) regions of electromagnetic (EM) spectrum. It has a spatial resolution of 24 m in visible and NIR region. The details of the satellite data are - Satellite: Resourcesat-1, Sensor: LISS III, Path: 100, Row: 68 and Date of Pass: 27.03.2013. In the present study, to assess the health status of vegetation in the study area, Normalized Difference Vegetation Index (NDVI) is carried out, which is an image enhancement technique. NDVI is a computation of ratio images using data in infrared and visible bands of the electromagnetic spectrum. It is defined as:

$$NDVI=(IR-R)/(IR+R)$$

where, IR is Infra red band, R is Red band.

This ratio image technique is most commonly used by vegetation scientists to correlate photosynthetic activity and vitality in green biomass by taking advantage of spectral behavior of vegetation in the IR and Red regions of the EM spectrum. Healthy vegetation reflects 40 to 50% of the incident NIR (0.7 to 1.1m) energy with chlorophyll absorption being 80 to 90% of the incident energy in the visible band (0.4 to 0.7m). Segmentation of NDVI images helps in differentiating forest cover density and understanding the health of vegetation.

Geographical Information System (GIS)

Making use of the Survey of India (SoI) toposheets of 1:50000 scale, basin boundary, drainage network and topographic maps were prepared for the Karamana River Basin. USGS SRTM 90 m and ASTER 30 m Digital Elevation Models (DEM) were also collected and referred. Aerial photographs and satellite imagery have been used to demarcate various geomorphological units and distribution of lineaments in the Karamana River Basin. These information have been integrated in GIS for the determination of morphometric characteristics, land slope and delineation of ground water potential zones. Using the field derived data, maps such as water table hydrographs, depth to water table, saturated thickness, depth to basement rock, recharge / discharge area, etc., have been prepared with the aid of Geographical Information System (GIS), namely ArcGIS. The integration of spatial and non-spatial data was done for analytical purposes. The values of various parameters, such as textural, and hydrochemical characteristics, were incorporated into GIS for getting an insight into the spatial variations.

COMPUTATION AND COMPILATION

The data generated in this study is processed using various statistical tools/ computational techniques. The results generated are evaluated in the light of available published research findings in India and elsewhere for drawing valid conclusions.

RESULTS AND DISCUSSION

GENERAL PROFILE OF THE STUDY AREA

Karamana river basin is selected for the present study. The entire catchment of Karamana river having an area of 702 km^2 and the total length of the main channel is 68 km. The study area falls within the jurisdiction of Thiruvananthapuram district. This section deals with the general characteristics, resource potential, resource exploitation and environmental settings of the Karamana river basin.

DRAINAGE: Among the west flowing rivers of Kerala, Karamana river ranks 15th and 17th with regard to river catchment and stream length, respectively. The Karamana river falls within the small mountainous river category (head water elevation between 1000 m and 3000 m amsl) of Milliman and Syvitski (1992). The river originates from the Western Ghat mountain ranges (Sahyadri hills) and flows through the coastal plains of Thiruvananthapuram district and merges with Arabian Sea, near Thiruvallam. Detailed description of the drainage characteristics are presented in the Morphometry section.

PHYSIOGRAPHY: The elevation of Karamana river basin ranges from mean sea level (msl) in the downstream end to about 1860 m above msl (amsl) in the mountainous eastern end. The broad landforms in the basin include high hills and low hills, lateritic mounds and isolated hillocks. The study area is comprises lowlands (3%), midlands (57%) and highlands (40%). Of the two reservoirs in the study area, the Aruvikkara reservoir spreads in the midland, while the Peppara reservoir is in the highland. The midland region is characterized by rugged topography comprising small flat-topped low mounts and broad valleys. The highlands are characterized by scarps, valleys, and mountains mainly covered with forests and / or forest plantations. The most dominant peaks in the study area are Agasthyamalai (1860 m), Chemmunji mottai (1717 m), Panditheri malai (1560 m) and Athirumalai (1594 m).

SOIL: The identified soil types in the Karamana river basin are forest loam, lateritic soil, riverine alluvium and coastal alluvium. The forest loam is organic rich and occupies the highlands of the study area constituting forests and forest plantations. Lateritic soil spreads a major portion in the midlands and a tongues of riverine alluvium blankets areas closer to the river channels and their flood plain areas. Coastal alluvium spreads along the coastal stretches.

CLIMATE: The study area experiences tropical humid climate. The area has an important place in the climatological map of India as the southwest monsoon system makes its entry and exit through the Thiruvananthapuram district. The components of climate at a macro scale are controlled by the geographic location, proximity to the Arabian Sea and physiographic character of the region. The extent of the vegetal cover does affect the climate at the micro scale. A year in the area could be divided into four seasons as mentioned below:

(i) Winter (January to February)

(ii) Hot Summer / Pre-monsoon (March to May) locally known as "*Venalkalam*"

(iii) South-West Monsoon (June to September) locally known as "*Edavapathy*"

(iv) Post-Monsoon (October to December) locally known as "*Thulavarsham*"

The temperature, pressure, wind speed, wind direction and relative humidity data collected from the Thiruvananthapuram meteorological station is taken as representative of the study area. A brief description of each parameter is given below:

<u>Temperature:</u> The annual maximum and minimum temperature of the area are 31°C and 24°C, respectively. Seasonal changes in temperature are not remarkable. The lowest maximum temperature recorded during the monsoon season is 29.5°C. The maximum and minimum temperature attain their peaks during hot summer / pre-monsoon season. March and April are normally the hottest months in a year. Temperature generally decreases towards the east due to increase in elevation.

<u>Pressure:</u> The air pressure decreases gradually from winter season to the lowest during monsoon. The monthly pressure values suggest that the air pressure is high during the month of January (1012.7 mb) when the temperature is at the minimum. The lowest pressure is recorded during May/June (1009.3 mb/1009.4 mb)

<u>Wind speed and direction:</u> The annual wind speed over the region is around 8 km/hr. The wind speed normally increases from northeast monsoon (5.3 km/hr) to a maximum at summer season (10.5 km/hr). The average wind speed over the sea during the southwest monsoon ranges from 24 km/hr (weak monsoon) to more than 66 km/hr (vigorous). <u>Relative humidity:</u> The relative humidity data reveals that the district remains highly humid (79%) throughout the year. However, during north-east and early south-west monsoons (i.e., from December to May), the relative humidity is slightly less compared to the rest of the year.

<u>Rainfall:</u> Study area experiences an average annual rainfall of about 238cm. While the southwestern part of the basin receives less than 140 cm of rainfall, the northeastern portion receives rainfall of about 420 cm. Fig. 5 depicts the mean rainfall distribution in the study area. The eastward enhancement in rainfall is not merely due to the altitudinal effect,

but also due to factors like slope of the ground, synoptic systems affecting rainfall, and configuration of land. The study area receives rain showers in all seasons. But, around 47% of the annual rainfall occurs under the influence of southwest monsoons. The thunder showers of post-monsoon and pre-monsoon seasons enable the district to get around 27% and 20% annual rainfall.

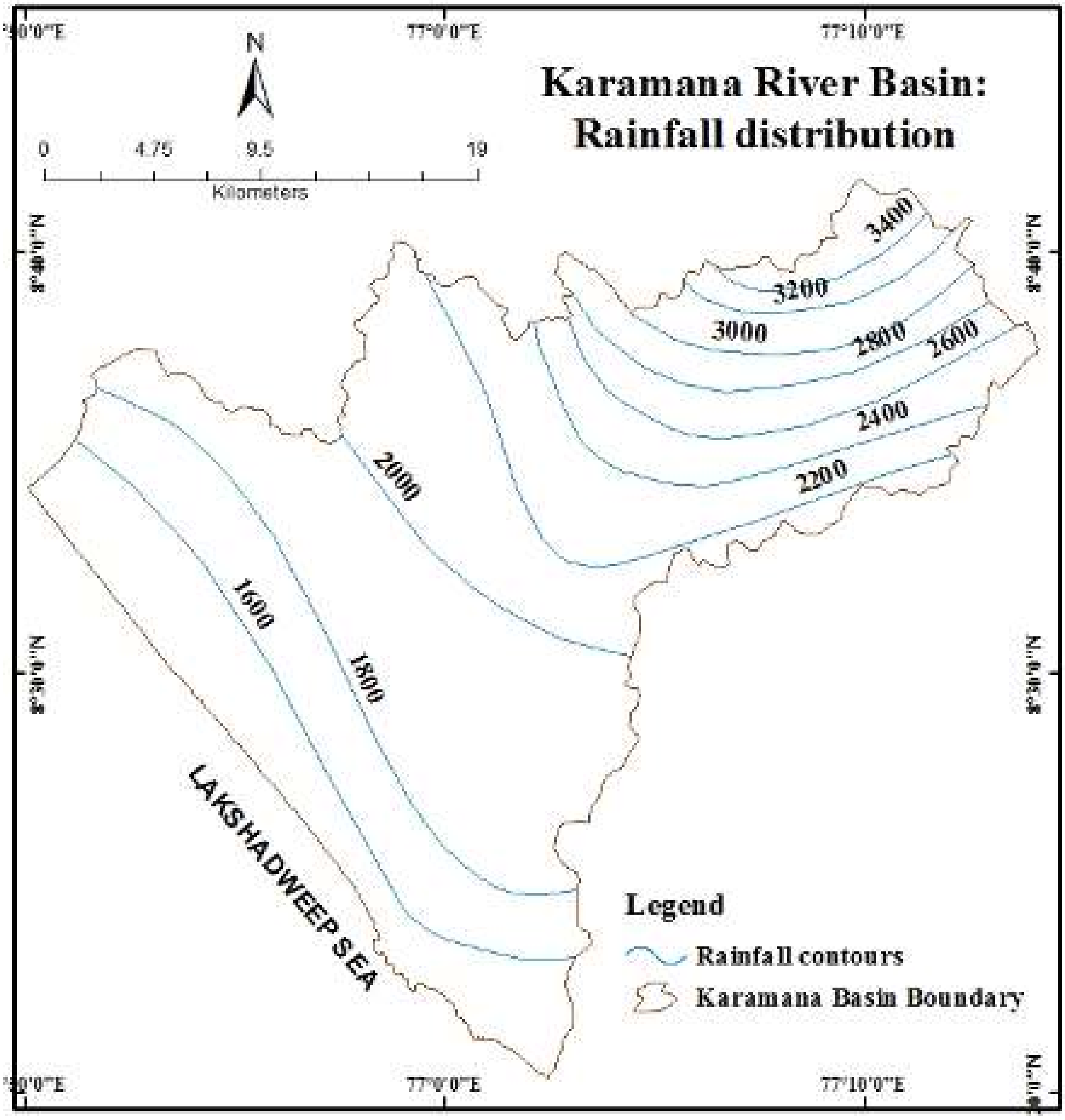


Fig. 5 Average rainfall distribution (mm) in the Karamana river basin (CWRDM, 1995).

Analysis of the last one hundred years of rainfall data reveals that the annual averages vary from 69% to 170% with respect to normal rainfall. Spells of heavy to very heavy rainfall produce floods. But its magnitude in terms of frequency and areal coverage can increase markedly due to anthropogenic factors like deforestation, inappropriate management of floodplains and unscientific agricultural practices (Eapen et al., 2000).

LAND USE AND LAND COVER**:** Agricultural lands cover a major part of the Karamana river basin (Fig. 6). Of the various land use classes identified in the study area, forests and forest plantations in the uplands constitute about 16.4%. The watershed area of Aruvikkara reservoir is used extensively for agricultural activities and settlements whereas the catchment of Peppara reservoir is mainly forest and forest plantations. Paddy cultivation is limited. Agricultural plantations cover a greater part (451.88 km^2; 64.37%) in the middle and lower regions (Table 3). Coconut, rubber, plantain and tapioca are extensively raised in the area.

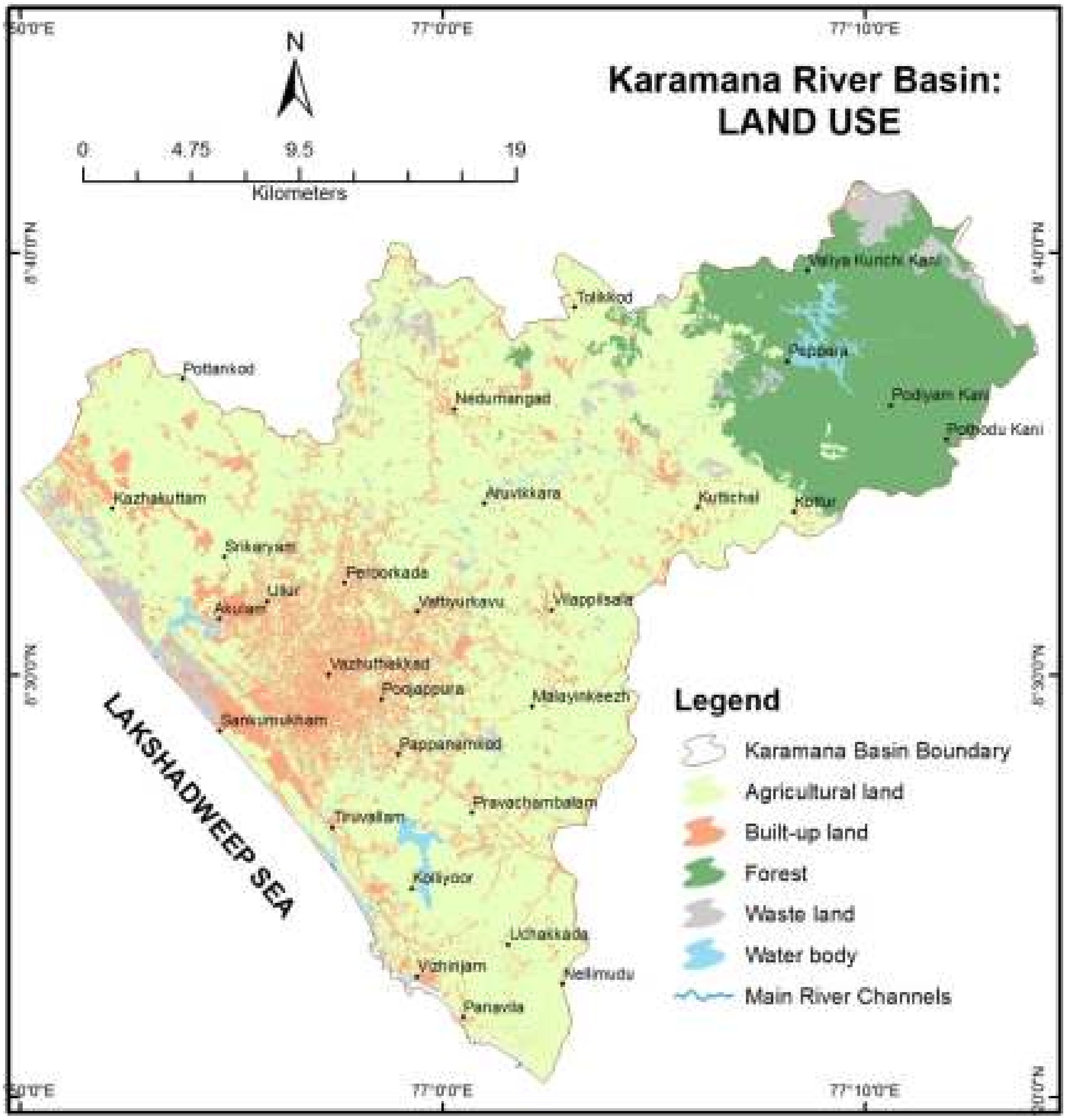


Fig. 6 Land use of Karamana river basin

Table 3 Broad landuse classes of Karamana river basin

Sl.No.	Landuse classes	Area (km^2)	Area (%)
1	Built-up land	97.78	13.93
2	Agricultural land	451.88	64.37
3	Forest	115.15	16.40
4	Water body	11.06	1.58
5	Waste land	26.13	3.72

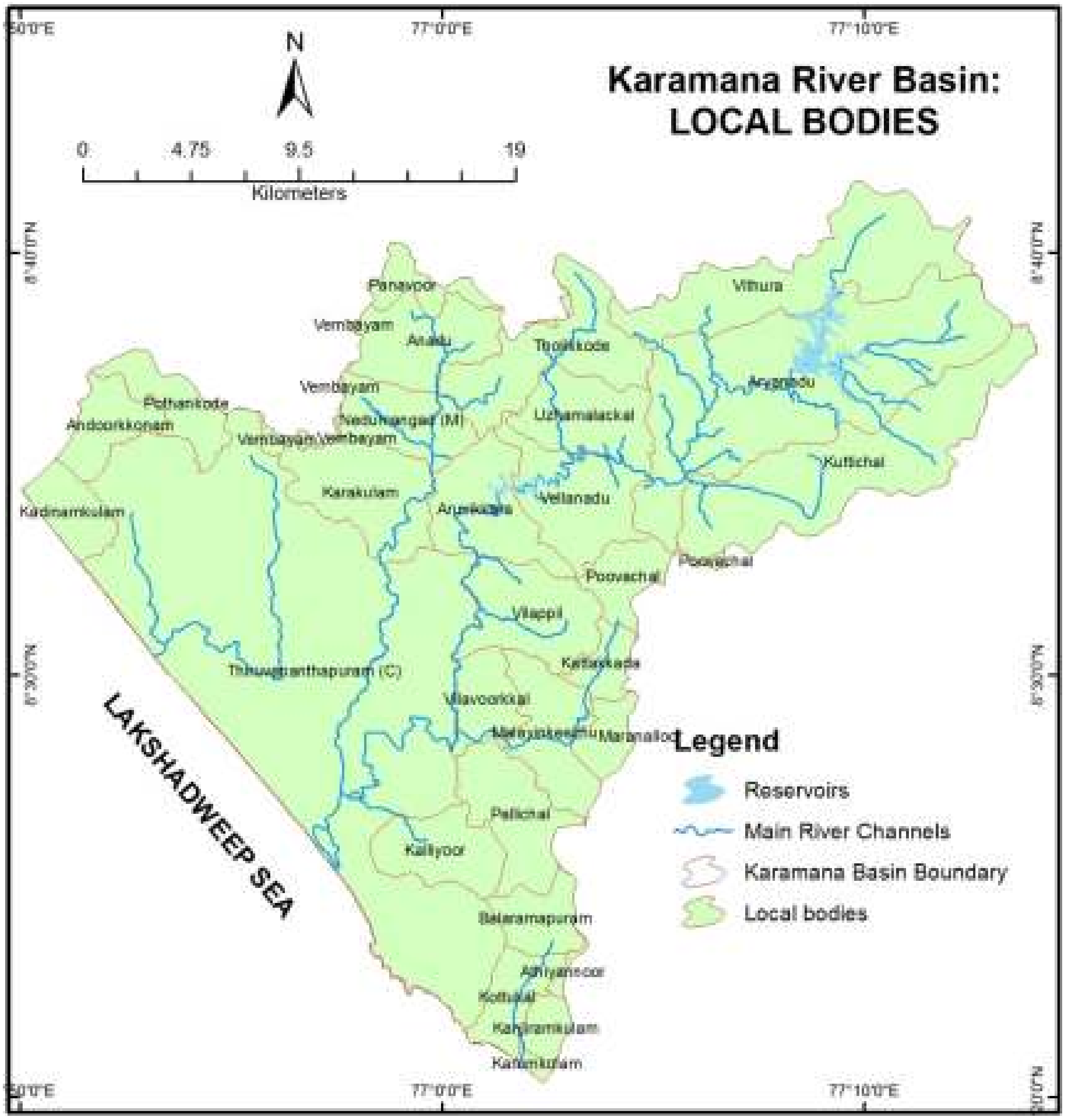


Fig. 7 Administrative divisions in Karamana river basin.

DEMOGRAPHY: A total of thirty local bodies fall either completely or partially within the study area. While the Karakulam, Tholikkod, Aryanad, Vellanad, Kuttichal, Uzhamalackal, Vilappil and Malayinkeezhu grama panchayats have a complete stake in the study area, the others have only a part. Fig. 7 depicts locations of various local bodies falling within the Karamana river basin. The total population in the study area is about 16.2 lakhs. Population density increases from North (eg. Vithura panchayat, 200 persons/km2) to South (Thiruvananthapuram Corporation, 4500 persons/km2). Furthermore, the forest areas in the eastern uplands host about 14 tribal settlements (Arun, 2006).

FLORA**:** The forest types in the Karamana river basin comprise tropical evergreen forests**,** semi-evergreen forests, mixed deciduous forests, sub tropical hill forests and *Myristica* swamps. The flora of Thiruvananthapuram district is well studied. About 1084 species of flowering plants are reported in the area. They belong to 569 genera and 132 families. The family Rubiaceae (32 genera and 85 species) rank first, followed by Poaceae (48/78), Orchidaceae (41/74), Fabaceae (33/68), Asteraceae (23/45) and Cyperaceae (13/42). The flora includes epiphytes (55 species), parasites (17 species), insectivorous plants (7 species) and saprophytes (2 species). The flora of Agasthyamalai and its environs shows high degree of endemism with 301 species, 45 of them local endemics, 5 new species and another 147 extremely rare species. Thus, Agasthyamalai is considered as the type locality of about 45 species of endemic plants and hence declared as a Biosphere Reserve. Twelve families show more than 40% endemism in this tract. Dipterocarpaceae are 100% endemics followed by Myristicaceae (75%), Lauraceae (68%), Anacardiaceae (67%), Balsaminaceae (67%), Arecaceae (64%) and Araceae (64%). It is interesting to note that 26 species listed in the Red Data Book of Indian Plants under category rare / possibly extinct have been recorded from this area. A study by Mohanan and Sivadasan (2002) listed 151 trees belonging to 51 families and 62 endemics (41% endemism), 6 rare and 8 threatened species exclusive to Peppara Wildlife Sanctuary area alone.

Agasthyamalai range harbours 124 medicinal plants used in *Ayurveda*, *Siddha* and modern system of medicine. Most of these plants are becoming rare due to over exploitation (Menon, 1999). *Arogyapacha* is one among them. The area is also famous for several wild relatives of cultivated plants like ginger, cardamom, cinnamon, garcinia, nutmeg, pepper, yam and taro. The Mahaveer plantations, Bonacaud is the only tea estate in the study area. Several degraded areas have been brought under plantations of Eucalyptus and Acacia.

FAUNA: Information on the lower group of animals from this forest is meager. The higher group of animals like Indian elephants, sambar, braking deer, Indian wild boar, Indian porcupine, three stripped squirrel, Malabar squirrel, flying squirrel, tiger, lion tailed macaque, Nilgiri tahr and gaur are reported from this location (Jayson and Christopher, 2008). Among these, elephants, sambars, wildboars, squirrels and guars are usually seen. In addition, reptiles like cobra, viper, python, rat snake etc, are also reported. The adjacent Neyyar wild life sanctuary is an important bird habitat. The presence of large number of avian fauna including some migratory birds are also observed in the sanctuary. The most common birds observed in the study area are common myna, common kingfisher, white breasted water hen, little green herom, malabar golden backed wood pecker, house crow, Indian cuckoo, koel, grey jungle fowl, hoppoe, jungle myna, Indian hill myna, darter (snake bird), little cormorant and little egret (Jayson and Sivaperuman, 2008).

NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI):

Normalized Difference Vegetation Index (NDVI) is a computation using data in infrared and visible bands of electromagnetic spectrum in satellite images. It is a ratio between spectral bands (infrared and red bands) to differentiate the health status of vegetation in an area and typically the value ranges from 0.1 to 0.6, with higher values associated with greater density and greenness of the plant canopy (Tucker et al., 1985; Holben, 1986; Prince and Justice, 1991; Lillesand and Kiefer, 1994 Srinivas, 2002; Arun, 2006 and Sreeja et al., 2015). NDVI of the study area is calculated from IRS LISS IV imagery of 2013 using ArcGIS Image analysis in Windows platform. According to NDVI there are seven classes in the study area (Table 4).

Table 4 NDVI classes of Karamana river basin

NDVI	Vegetation health status
<0	No vegetation (Water body / cloud cover)
0.0-0.1	Poor
0.1-0.2	Very low
0.2-0.3	Low
0.3-0.4	Moderate
0.4-0.5	Good
0.5-0.6	Very good

‘Good’ and ‘moderate’ vegetation are observed in higher proportions in the study area with patches of low vegetation. Water bodies and cloud cover typically show negative index values (Fig. 8). The NDVI values of 0.2 to 0.5, observed in the settlement and agricultural areas are due to the mixed vegetation containing coconut, arecanut and plantation crops. ‘Poor’ to ‘very good’ vegetation are observed in forest regions in the eastern portion. The mountain peaks are of ‘poor’ and ‘very low’ vegetation index. The forest categories are mainly degraded, deciduous and semi evergreen giving low NDVI values. And this may also be attributed to the deciduous habit of the vegetation and budding of new leaves preferably in the season when the imagery was taken (March 2013).

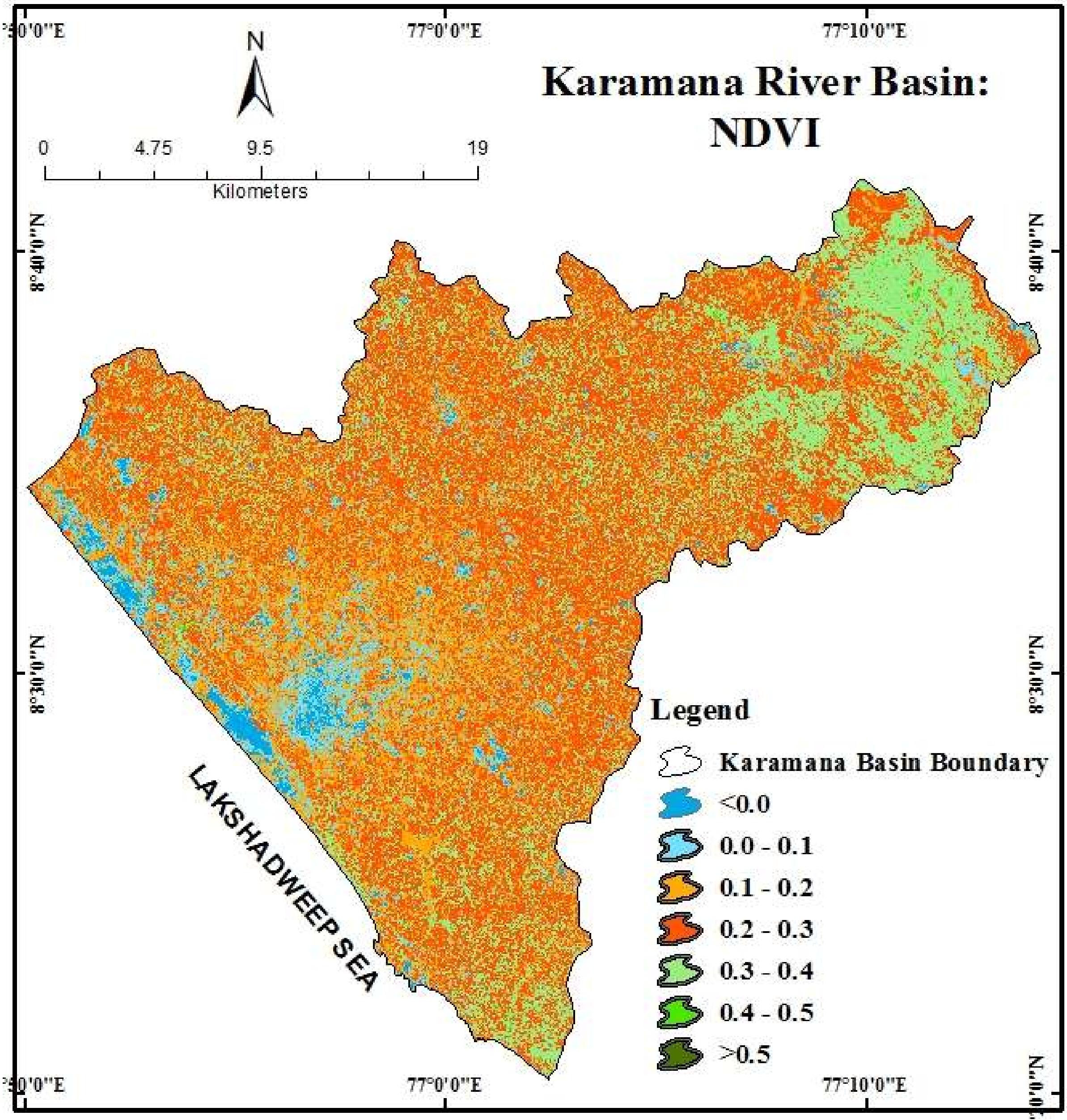


Fig. 8 Normalized Difference Vegetation Index (NDVI) of Karamana river basin.

MINERAL RESOURCES: The occurrence of mineral resources is closely linked to the geological formations as well as geomorphic setting of the area (Thampi, 1997). The Karamana river basin are endowed with a variety of mineral deposits, which include graphite, chrysoberyl (gemstone) and building materials like river sand, tile / brick clays, hard rocks etc. Rocks and minerals are the most vital earth resources for the development. An understanding of these resources is of utmost important in developing predictive models for future developments of the area.

Gem quality chrysoberyl is being illegally mined from many places. The mineral is usually associated with pegmatites (Jacob, 1965 and Gopalakrishnan and Chauhan, 1974). It occurs as an accessory mineral in veins that traverse the garnet-sillimanite gneiss and associated garnetiferous and non-garnetiferous quartzo-feldspathic gneisses of the khondalite suite of rocks and charnockites (Garson, 1979). The pegmatites are composed mainly of smoky quartz and feldspar with accessory amounts of biotite, muscovite, garnet, tourmaline, ilmenite, beryl and chrysoberyl (UNDP, 1983). Alluvial deposits in streams draining the mineralised zones are mainly worked for collecting gemstones (Menon et al., 1994). Three varieties of chrysoberyl are known to occur in southern Kerala. They are (i) ordinary chrysoberyl, having the colour of bamboo leaf; (ii) cymophane, which shines like a cat's eye (chattoyance) and (iii) alexandrite, which is lustrous like a peacock's eye. Gem quality chrysoberyl is known to occur in Bonakkad and adjoining areas as an accessory mineral in pegmatite veins. However, workable deposits are not known; even when clandestine mining of gemstones is frequently reported from the area.

In various parts of the study area, graphite concentration up to 15% is observed within khondalitic rocks. Vellanad, Changa, Kuttichal and Vithura are known to contain graphite concentrations in the gneissic rocks. Graphite from these four localities was mined for different durations by the Morgan Crucible Company. Graphite mining was once prominent in the Vellanad area, and constituted the entire graphite production of British India in the beginning of the last century. At present, no mining activities are reported from the area. Weathering of graphite enrichment zones has led to formation of graphite-clay masses with graphite content of over 20% is seen in Kuttichal and Vellanad areas (Soman, 2002).

Pre-cambrian crystalline rocks occupy a major part of Kerala. In the study area, the khondalites are inter-banded with garnetiferous-biotite gneisses, leptinite and narrow bands of charnockite. Graphite concentration, associated with pegmatite intrusion is a characteristic feature of this rock. The rock is mainly quarried for construction purposes. Garnetiferous-quartzo-feldspathic gneiss (garnet-granite) was considered as an integral unit of khondalite assemblages in the study area. Field relations, however, suggest their intrusive nature in many places. In some parts of the area, this rock unit is quarried as dimension stone. The crystalline rocks of good quality, apart from being used in construction activity, could be used as dimension stones, which have good market in India and abroad (Thampi, 1997). Hard rocks are extensively used in construction of buildings, roads, bridges, dams etc.

Laterites of Karamana river basin are both *in situ* and secondary (Narayanaswamy, 2001). *In situ* laterites are developed over various crystalline rocks of Pre-Cambrian period, viz: charnockite, khondalite, leptinite, gamet-biotite-hornblende gneisses. The secondary laterites, on the other hand, are developed over Tertiary sedimentaries. The present practice of laterite cutting, curing and using as bricks is progressively becoming unattractive due to high incidence of labour costs and non-availability of labourers. Appropriate mechanization in cutting laterite blocks and value addition by various treatments can enhance the use of laterite in building constructions.

Clay deposits found in Kerala are either of residual or sedimentary origin and are found as sizeable deposits. Tile and brick clays are associated with Neogene sediments (Singh, 1996 and Thampi, 1997). These are quarried extensively for brick making. The texture of such sediments in floodplain areas makes it a good raw material for tile and brick making industry (Thrivikramji, 1993). These resources are mined indiscriminately from many places of the study area, especially from river banks and paddy fields.

River sand and gravel are unavoidable ingredients in building construction. This resource is exhaustible and is fast getting depleted with no proper substitution in sight. These resources are concentrated in river basins through processes that took thousands of years. The sand that occurs in the channel bed falls in different categories (Colby, 1963). They are bed load and suspended load. No systematic study has hitherto been made to estimate the sand reserve of the Karamana river. However, CESS has made a Rapid Reserve Estimation (RRE) survey in certain stretches of the river. The study revealed that the channel segment between Pazhayaveettumoozhi *kadavu* in the south and the confluence of Attingal *thodu* with the Karamana river in the north, (river length = 16 km) contains a thick deposit of gravelly sand. Rock exposures are seen at some places. Thickness of sand varies from a few cm to over 4 m. The total riverbed deposit in this stretch is estimated about 1.4×10^6 m^3. The natural replenishment in this stretch is marginal as a considerable portion of sediments brought by the tributary channels are being trapped in the Peppara reservoir upstream. About 20% of the capacity of Peppara reservoir was lost after 20 years of operation, mainly due to frequent landslides in the catchment (Arun, 2006).

ENVIRONMENTAL PROBLEMS: The entire issues related to degradation of river basins can be addressed in two broad categories / titles: 1) anthropogenic and 2) natural. Deforestation, pollution, mining and quarrying, etc., fall under anthropogenic category, whereas erosion, flooding and landslides fall under the natural category.

In 1905, the area under forest cover in Karamana basin was about 32.2%. This has been reduced to 19.1% in 1965 and to 8.4% in 1973 (Krishnakumar, 2002). The whole forest area in the Karamana river basin is confined to the highlands, especially in the Karamana river basin. The rate of deforestation has been slowed down considerably in recent years. Construction of Peppara dam has also played a major role in the destruction of the forest wealth.

Environmental pollution affects human health directly or indirectly by undermining the life support systems in the biosphere. Industrial revolution, made great progress in technical spheres of human society, accompanied by environmental degradation due to large quantities of gaseous, liquid and solid wastes generated by human activities. In the study area, solid waste management is not practiced in a proper way which ultimately leads to incidences of dreadful diseases like Rat fever (Leptospirosis or Weil's disease), Hepatitis, etc. Among solid wastes, non-biodegradable substances like plastics could cause more nuisance to the public than degradables (CESS, 1999; Maya et al., 2000 and Aji, 2006). It is estimated that plastics constitute 7.3% of the total solid waste in Thiruvananthapuram city (Sreebha, 2000; Arun, 2006). Pollution of water systems is a grave problem to the aquatic flora and fauna. The composition of pollutants consists of acids, salts, heavy metals, hydrocarbons and pathogenic bacteria (Prasanthan and Nair, 2000). The changes due to various pollutants include rise in temperature, variation in pH, turbidity, high bacterial count, generation of hydrogen sulphide and low DO in water (Sreebha, 2000). Vehicular emission is a major causative factor for the decline in air quality of the study area. According to NATPAC (2001), vehicular emission is directly proportional to the fuel consumption and thus the number of vehicles.

Hard rock quarrying, river sand mining and floodplain mining for tile and brick clays are wide spread in the Karamana river basin. The river sand layers help the conservation of water for the summer flow and promote downward trickling of surface water to groundwater regimes. The indiscriminate removal of river sand, will lead to deepening of channel bed, slumping / collapse / erosion of river banks, lateral instability of channels, depletion of surface and base flow of rivers, reduced groundwater recharge to local aquifers, increased pollution of river water, such as increase in turbidity and consequent degradation of river ecosystem (Padmalal and Arun, 1998; Brown et al., 1998; Arun et al., 2003; CESS, 2005; Sreebha and Padmalal, 2006 and Arun, 2006). From the Karamana river basin about 80 tonnes of tile and brick clay and 16 tonnes of sand are being mined per day from the paddy fields and floodplains. A total of 8 hard rock quarries are working in the area and they together quarry about 200 tonnes of rocks per day. Soil quarrying is also widespread in the Karamana river basin.

The natural process of environmental degradation comprises landslides and flooding. High intensity of rainfall causes flooding. Landslides are caused by complex adverse conditions such as geology, weak soil, slip plains on steep slopes with torrential rains and excessive moisture regime, faulty land use and management. The various factors causing landslides are slope, material type, angle of slopes, rise in water pressure and changes caused due to deforestation. Several types of mass movements or landslide incidences have been recorded in Karamana river basin. It includes rock fall, rock slip and debris flow. Occurrence of landslides is concentrated mainly between 450 m and 600 m altitudes (CESS, 1998; Arun, 2006). Thick over burden, high gradient, degradation of natural vegetation along with heavy precipitation are the major causative factors triggering landslides in Western Ghats.

TERRAIN CHARACTERISTICS

The studies on terrain/land characteristics of the minor river basins such as Karamana river basin need to be emphasized in detail for the planning and development of land and water resources. Terrain refers to any tract of the earth surface, considered as a physical feature. Terrain analysis in its strict sense is a purely descriptive analytic science of topography (i.e. relief) with no consideration to genesis, history or dynamics. It is an integral part of any regional work in geomorphology, terrain can be broken down into relief, roughness and surface material. Relief is to a great extent the outward expression of internal structure. Relief can be analysed in terms of absolute and relative or local elevation, slope, lithology, profiles and superimposed profiles, hypysometric curve and altimetric frequency histogram.

The land form mapping procedure involves subdividing the country into areas that have common physical attributes which are different from those of adjacent areas. Terrain/land systems may range in size from only tens of km^2 upto some hundreds of km^2 within any one terrain/land system and vegetation (Christian and Stewart, 1952). According to Stewart and Perry (1953) the topography and soils are dependent on the nature of underlying rocks, the erosional and depositional processes that have produced the present topography and the climate under which these processes have operated. Thus, the terrain/land system is a scientific classification of land based on topography, soils and vegetation correlated with geology, geomorphology and climate. The drainage basin may be defined as the area which contributes water to a particular channel or a set of channels. It is the source area of the precipitation eventually provided to the stream channels by various paths. As such it forms a convenient unit for the consideration of the processes determining the formation of specific land slopes in various region of the earth. It provides a limited unit of the earth's surface within which basic climatic qualities can be measured and characteristic landforms described and a system within which a balance can be struck in terms of inflow and outflow of moisture and energy. The amount of precipitation that falls over a given drainage basin can be measured by given adequate instrumentation, the quantity of water that flows to the basin stream channels, the changes in ground water storage, evaporation, and evapo-transpiration by plants can also be estimated. In addition, rates and kinds of denudation, may be measured as materials transported in solution or as classic load in stream channels.

Survey of India Topography sheets on scale 1:50000, SRTM Digital Elevation Modal (DEM) of 90 m resolution, ASTER DEM of 30 m resolution, Landsat imageries as well as

IRS LISS III imageries are used to study the terrain characteristics of Karamana river basin.

REGIONAL GEOLOGY

The area that falls within Kerala forms an important segment of the South Indian Precambrian terrain, where the Archaean continental crustal rocks such as granulites, granites, gneisses and greenstones are excellently preserved. Geologically, the state is occupied mainly by three major rock units 1) Precambrian crystallines, 2) Tertiary sedimentaries, and 3) Quaternary deposits. About 85% of Kerala is covered by crystalline rocks and the remaining by Tertiary and Quaternary sedimentaries. A major portion of the crystallines and Tertiaries are capped by laterites. Along the coast, sedimentary formations (Tertiaries and Quaternaries) overlie the crystalline basement. The sedimentary formations range in age from Miocene to Recent. Table 5 shows the general geological sequence of Kerala (GSI, 1995; Najeeb, 1999).

Table.5 General geology of Kerala State (GSI, 1995; Najeeb, 1999)

Era	Period	Group	Lithology
Quaternary	Holocene	Marine Fluvio-marine Fluvial	Sand Clay and silt Sand, silt, clay
	Pleistocene	Palaeo-marine	Sand Pebble bed
Tertiary	Mio-Pliocene		Laterite
	Mesozoic (61-144 Ma)	Acid Intrusive	Quartz vein
		Basic intrusive	Pegmatite Dolerite
PRECAMBRIAN	Proterozoic	Migmatite Complex	Hornblende gneiss Hornblende-biotite gneiss Granite gneiss
	Archaean	Charnockite Group	Charnockite/charnockite gneiss Pyroxene granulite Hornblende-biotite gneiss
		Peninsular Gneissic Complex	Magnetite quartzite Quartz-mica schist Fuchsite quartzite
		Wayanad Group	Amphibolite Metapyroxenite Talc-tremolite-actinolite schist

Base not recognized

Precambrian crystallines

The Precambrian crystallines occupy a considerable area of Kerala, and include charnockites, garnet-biotite gneisses, hornblende gneisses, khondalites, leptinites and cordierites. A large part of the crystalline rocks underwent polymetamorphic and polydeformational activities (Soman, 2002). High-grade schists and gneisses (ultramafic and foliated) of Wayanad and Sargurs cover some regions in the north. The meta-igneous charnockite group of rocks predominates in the state followed by meta-sedimentary khondalite group. The Precambrian crystallines are traversed at several places by acidic (granite and pegmatite) and basic (gabbro and dolerite) intrusions. The salient features of the major rock types are discussed in the following sections:

a) Khondalite group : The name "Khondalite" was originally proposed by Walker (1902) to the unusual series of rocks after the hill tribe of "Khonds" in Kalahandi hill tracts of Orissa in Eastern Ghats Belts, where these rocks are extensively seen. The khondalite group of rocks in Kerala includes garnet-sillimanite gneiss, graphite gneiss, calc granulite, garnet gneiss, patchy charnockite and quartzite. Age determination of these rocks indicates a range of 670 to 2200 million years (Santosh, 1987 and Chacko et al., 1988). Khondalite group of rocks represent metasedimentary rocks of granulite grade that are exposed mainly in the area south of the Achankovil Shear Zone (ASZ) as well as the areas around Palghat gap. The khondalite group comprises essentially of garnet-sillimanite gneiss containing varying amounts of graphite, quartz and orthoclase.

b) Charnockite group: Charnockites, charnockite gneiss, cordierite gneiss, pyroxene granulite and hornblende granulite are grouped under the charnockite group of rocks. They are the most widespread group of rocks in the hinderlands and are common in the districts of Pathanamthitta, Kottayam, Ernakulam, Thrissur, Malappuram and Kasaragod. Charnockites are massive in appearance but on close examination yield well developed foliations and deformational banding. They also occur as bands within migmatites and khondalites. In addition to these, patchy charnockites are reported from many parts of Kerala by several researchers (Ravindrakumar et al., 1985 and the references therein). Charnockites are characterised by minerals like hypersthene, feldspar, quartz, hornblende and garnet.

c) Acid intrusives: Granites, pegmatites, and quartz veins are the common acid intrusives observed in Kerala. Apart from this, patches of syenitic intrusions are also reported from the state. The granite bodies generally occur as fault / lineament controlled plutons emplaced between 500 to 700 Ma ago (Santhosh and Drury, 1988). At several places, the Precambrian crystallines are traversed by simple and complex pegmatites and quartz veins.

d) Basic intrusives: Gabbro and dolerite constitute the most common basic intrusives emplaced within the Preambrian crystallines. Two distinct systems of basic dykes are recognized. They are (1) NNW-SSE trending leucogabbro that are exposed intermittently for over a length of 100km and (2) The NW-SE trending dolerite dykes. K-Ar isotope dating has yielded 81±3 Ma for former and 65-70 Ma of age for the latter (Radhakrishna et al., 1989)

Tertiary sediments

Sedimentary formations equivalent to Cuddalore and Rajahmundri sandstones of Mio-Pliocene age are reported from the coastal regions of Kerala State. The Tertiary sedimentary formations of Kerala unconformably overlie the Pre-Cambrians (Paulose and Narayanaswamy, 1968). Exposures are seen mostly in the southern and northern parts of coastal Kerala and contain essentially Neogene and Quaternary sediments. The thickness of these sediments exceeds 600 m in parts of Alappuzha district. The Tertiary sediments are classified (Raha et al., 1983) into three groups; viz, (1) Vaikom Formation (sandstones with gravel and carbonaceous clay), (2) Quilon Formation (limestone and calcareous clays) and (3) Warkalli Formation (sandstones and clays with lignite).

Laterites

Laterite is a common rock type capping the Preambrian crystallines and Tertiary sedimentaries of Kerala. It is composed essentially of hydrated oxides of Fe and Al with minor amounts of Mn, Ti, V and Zr. The rock can be classified in two groups; viz 1) laterite originated from sedimentary formations and 2) laterite originated from crystalline formations. The Tertiary sediments are widely lateritised due to its exposure to atmosphere. The crystalline rocks are lateritised on the top all along the midland and parts of the highland. The thickness of laterites at some places exceeds 30 m (Narayanaswami and Padmalal, 2003).

Quaternary sediments

The Quaternary sedimentary deposits, referred in Najeeb (1999) as Vembanad Formation, include peat beds of both marine and fluvial origins, sand bars and sandy flats alternating with present day marshy lagoonal clays and shell deposits. These are found in the entire stretch of sedimentary basin with preponderance over a large area between Chavara and Kochi. Raised sand beaches composed of fine-grained reddish sandy loam known as 'teris' also belongs to this formation. Beach ridges can be noticed along the Kerala coasts upto 15 km east of the present coast at Vaikom and Kumarakom. Mainly two sets of palaeo sand ridges are observed on 10°–190° direction and the other in 155° –335° direction with variations in their directions at various places (Nair and Padmalal, 2003). The beach ridges appear to be diverging out from a point just north of Thottapally spillway. This observed variation in the orientation of beach ridges is indicative of the coastline configuration changes during Holocene. Shell deposits occur in the backwaters like Vembanad lake, Asthamudi lake, etc. The Quaternary sediments are separated from the underlying Tertiary sediments often by a ferruginous clay / laterite layer.

GEOLOGIC SETTING OF THE STUDY AREA

Geologically, the Karamana river basin is composed of diverse rock types from Archaean crystallines to recent alluvium. The geologic set up of the Karamana river basin is depicted in Fig. 9.

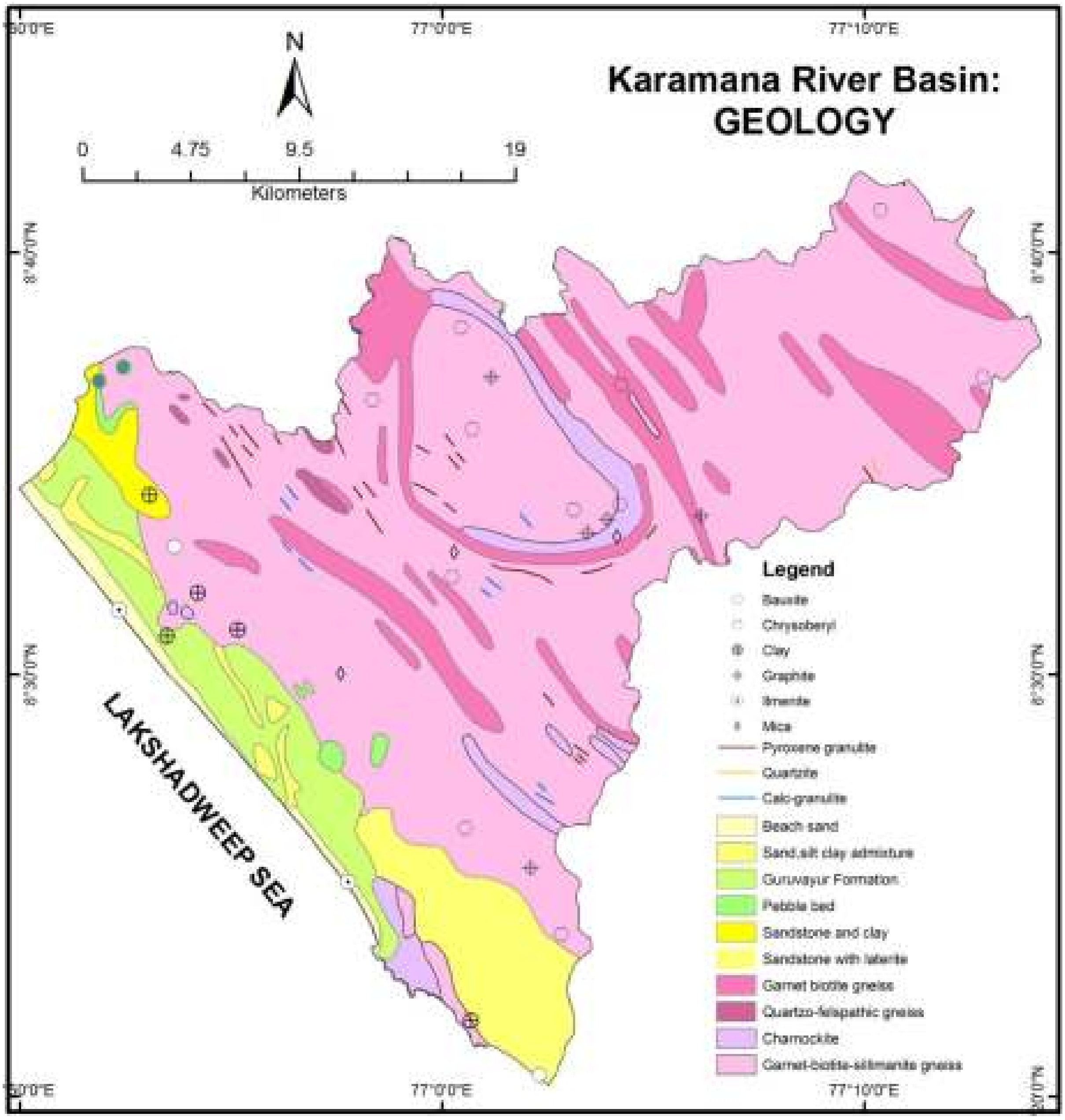
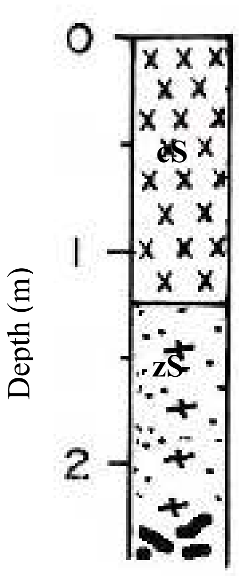


Fig. 9 Geology of Karamana river basin (Source: District resource map, GSI).

Most of the study area is composed of garnetiferous-biotite-sillimanite gneiss with or without graphite (khondalite). The remaining area is composed of garnet-biotite gneiss with associated migmatites, quartzo-feldspathic-hypersthene granulite and garnetiferous granite gneiss as the basement. These rocks are intruded at many places by acidic (pegmatites and quartz vein) and, basic (gabbro and dolerite) rocks. A few patches of quartzofeldspathic and calc granulites are also reported from the area. Pyroxene granulite occures within the khondalite as thin discontinuous lenticular bands in foliation planes. Sedimentary formation of miopliocene age occures as detached patches conformably overlying the crystallines, along the coastal tracts. Quaternaries include pebble beds, coastal sands and alluvium. Chrysoberyl is concentrated in the skarn zones of pegmatite with khondalite. The graphite occurrences in this area are considered to be high grade, averaging more than 75% fixed carbon (GSI, 2001). Graphite occurs as flaky disseminations in garnetiferous sillimanite gneiss, localised along fold closure of regional dimension and also along pegmatite intrusion in graphite bearing calc-gneisses and calc-sillimanite gneisses of Khondalite group.



Yellowish clayey sand with appreciable quantities of organic matter.

Off-white, clayey sand with low organic matter.

Off-white, silty sand with low organic matter. The sand grains are angular to sub-angular.

Off-white, silty sand with decayed wood remains.
The decayed wood is ^{14}**C dated 3300±90 y BP.**

Fig. 10 Litholog near Aryanad (Arun,2006).cS - Clayey sand;zS - silty sand; sM - sandy mud; Peat.

A few patches of Quaternary sediments represented by pebble beds, sand and clay deposits are also reported from midland regions also. Fig. 10 shows litholog of the Late Quaternary deposits exposed on clay / sand mining pits at Aryanad and a peat sample collected at a depth of 2.5m below ground level is C^{14} dated (Arun, 2006) 3300 ± 90 years before present (ybp). This is a clear evidence of the occurrence of Late Quaternary (Holocene) sediments in the upper reaches of the study area.

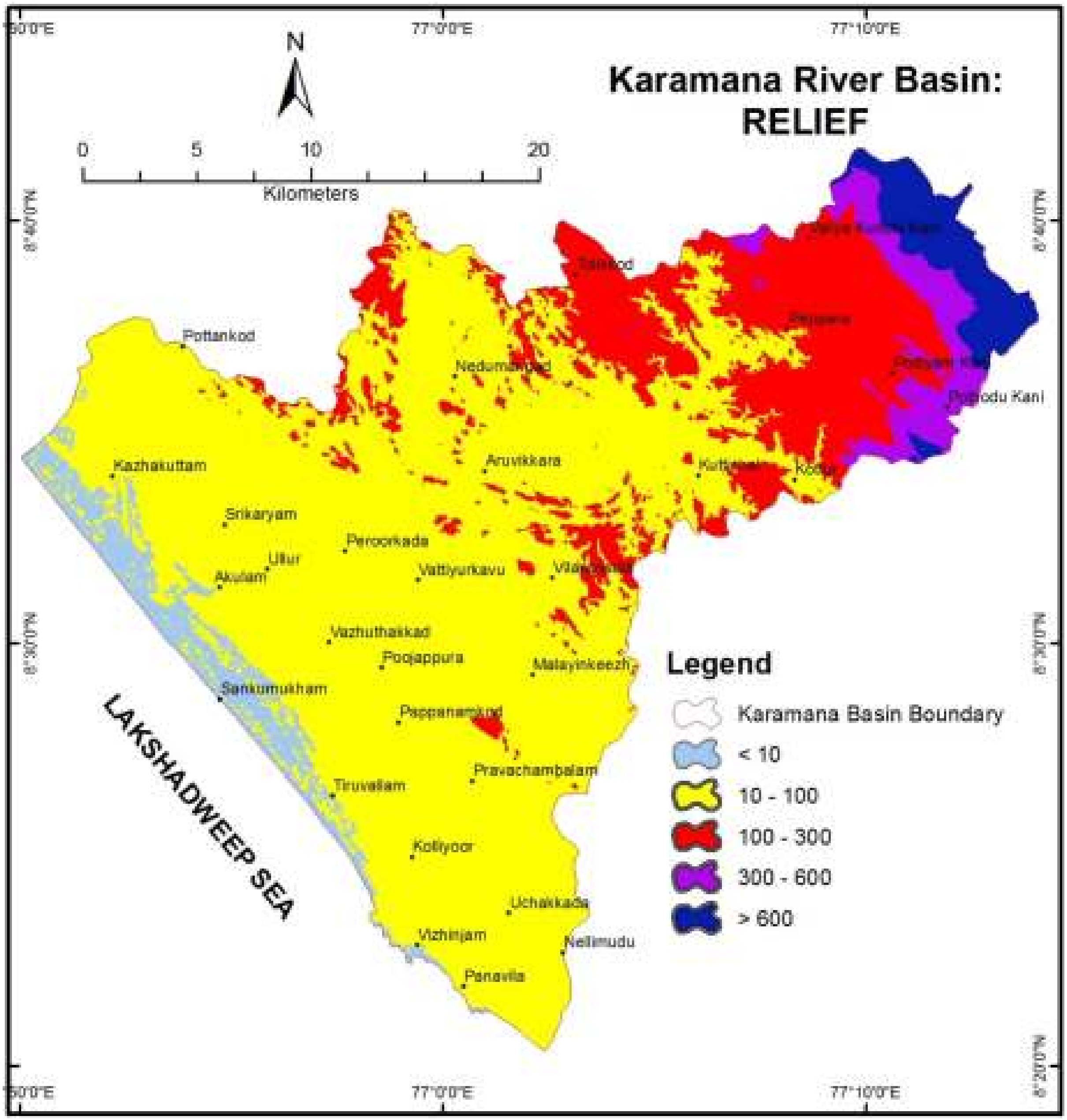


Fig. 11 Relief features (in metres) of Karamana river basin

RELIEF

Relief features of the Karamana river basin is given in Fig. 11 and the digital elevation model (DEM) generated using Arc GIS software is presented in Fig 12. Lateritic undulating hills, steep slopes and Western Ghats mountains characterize the basins. Altitudinal ranges of 10m, 50 m, l00 m, 300 m and 600 m are observed in the study area. Agasthya malai is the highest point in the area with an altitude of 1860 m amsl.

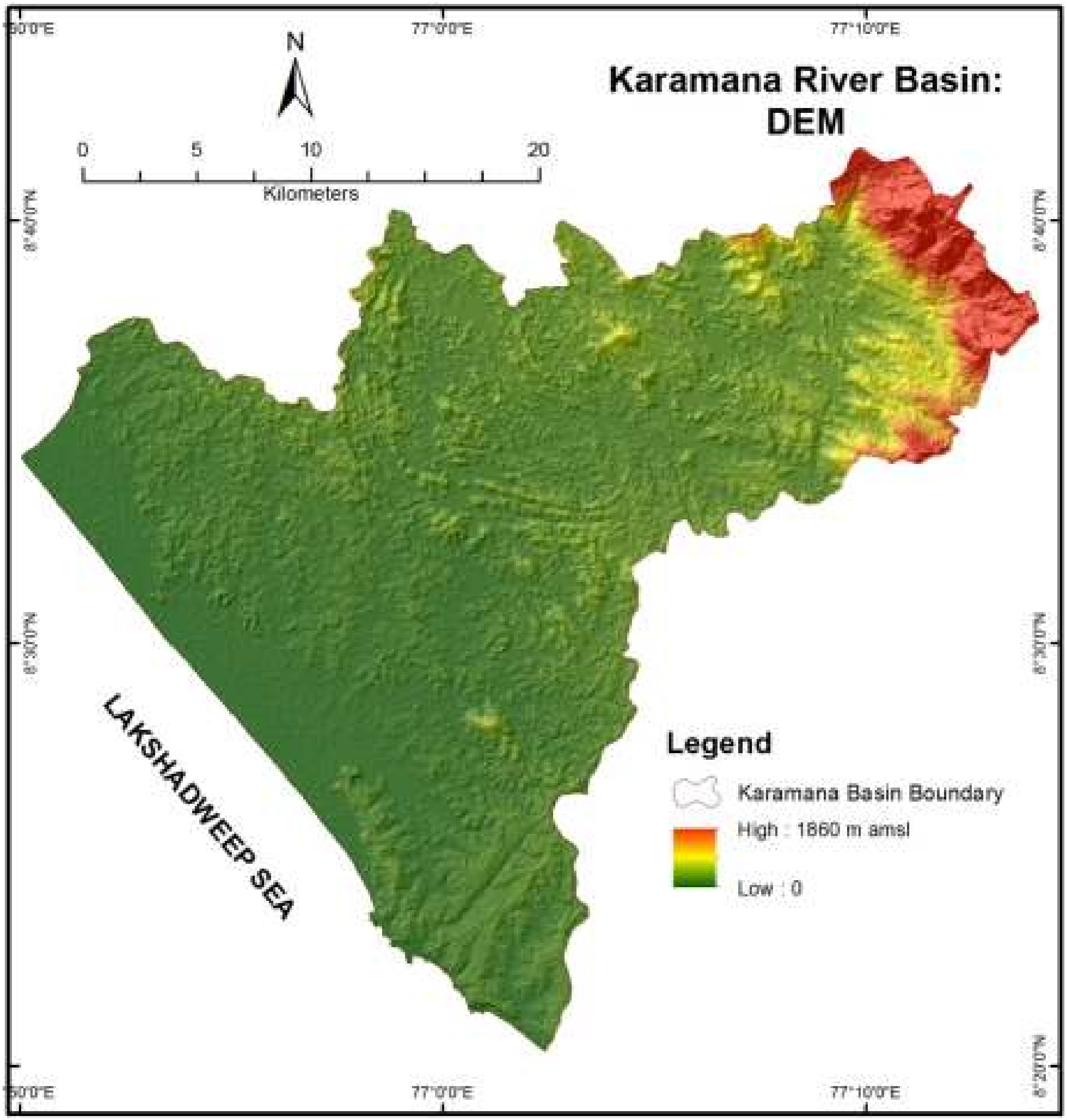


Fig. 12 Digital Elevation Model (DEM) of Karamana river basin

The relief is found to be undulating till 100 m altitude, and above this height, the relief features are more rugged. The interfluves within the high ranges of the basin are in the altitudinal range of l00 – 300 m. The altitudinal range of 300 – 600 m marks the western fringe of Western Ghat mountain ranges. The region between Thamraparni river basin and the study area is in the altitudinal range of 1500-1800 m. Distribution of area under various altitudinal categories in the Karamana river basin is given in Table 6. From this table, it is observed that about 80% of the area falls in <300 m and 40% in <100 m altitudinal zones. Only 2.5% of the study area falls in the altitudinal category of >1000 m.

Table 6 Altitudinal coverage of Karamana river basin.

Altitudinal range (m amsl)	Area (km^2)	Area (%)	Cumulative area (%)
<10	32.20	4.587	4.59
10-50	251.40	35.812	40.40
50-100	235.52	33.550	73.95
100-200	111.97	15.949	89.90
200-300	19.89	2.833	92.73
300-400	10.69	1.523	94.25
400-500	8.30	1.182	95.44
500-600	7.27	1.036	96.47
600-700	5.41	0.770	97.24
700-800	4.41	0.628	97.87
800-900	3.64	0.518	98.39
900-1000	3.08	0.439	98.83
1000-1100	2.69	0.384	99.21
1100-1200	1.63	0.232	99.44
1200-1300	1.54	0.219	99.66
1300-1400	1.75	0.249	99.91
1400-1500	0.51	0.072	99.98
1500-1600	0.11	0.016	99.99
>1600	0.01	0.001	100.00

Based on the type of geomorphic processes operating in Karamana river basin and the nature of cross profiles, 5 distinct relief classes are identified in the area (Chattopadhyay and Chattopadhyay, 1995). They are:

(1) High ranges of the Western Ghats: This unit lies above 600 m altitude and includes deep valleys, scarp slopes and high mountains. The State boundary in the east more or less coincides with the crest line of the Western Ghats. The topography is highly rugged and the relative relief is as high as 1200 m in some locations. This unit covers about 2.97% of total geographical area of the Karamana river basin.

(2) Foot hills: This zone includes the bounding slope of the Western Ghats with an altitudinal range of 300 – 600 m. All along the Ghat section, it is marked as a continuous belt. Relief is rugged with interlocking spurs and steeply sloping valleys. Relative relief is around

300 m in some places. This unit accounts for more than 3.74% of the total area of the study area.

(3) Uplands: Area falls within the altitudinal range of l00 – 300 m is considered as upland. This unit forms the interfluves (found as east-west elongated lateritic ridges) and gradually merges with the western midland regions. The steep side slopes, narrow valleys and linear placement of the ridges and valleys indicate structural effects to which the area has been subjected during its course of evolution. This unit forms one of the identified planation surfaces in Kerala. It has an areal coverage of about 19 % in the Karamana river basin.

(4) Undulating midlands: The area lying between l0 m and l00 m altitude is considered as undulating midland region. The undulating midlands cover about 69 % in the Karamana river basin. A number of isolated hills sloping due west in the midlands are nothing but erosional remnants of various cycles of denudation process operated during the geologic past. The topography of the midland is generally rolling. Moderately high relief has been recorded at some places. This unit extends outside the study area even upto the coast and appears as coastal cliffs.

(5) Coastal Plains: The area with <10m altitudinal range is the coastal plains. Beach ridges are present in these stretches confined to the coast in the western part. Quarternary deposits of sand and alluvium floors the area and it covers 4.59 % of Karamana river basin.

SLOPE

The Karamana river basin exhibit a spectrum of slope classes from level - nearly level (A) to very steeply sloping (G) features. The slope characteristics of the study area are depicted in Fig. 13, and their details are summarised in Tables 7 and 8. Gently sloping (3 - 5%) to moderately steeply sloping (10 - 15%) classes cover a greater part (52.21%; 367 km^2) of the study area. Nearly level (<1%) to moderately sloping (1-3%) classes constitute 6.83% (48 km^2) and occupy in the lower part of the study area. Steeply sloping to very steeply sloping areas (287 km^2; 40.95%) are confined to high altitude zones.

Table 7 Broad slope classes of Karamana river basin

Sl. No.	Slope classes	Area (km^2)	Area (%)
1.	Moderately steeply sloping to Very steeply sloping	48	6.83
2.	Gently sloping to moderately sloping	367	52.21
3.	Nearly level to very gently sloping	287	40.95

Table 8 Slope classes and slope ranges

Slope class	Slope range (%)	Description
A	0 – 1 %	Level - nearly level
B	1 – 3 %	Very gently sloping
C	3 – 5 %	Gently sloping
D	5 – 10 %	Moderately sloping
E	10 – 15 %	Moderately steeply sloping
F	15 – 30 %	Steeply sloping
G	>30 %	Very steeply sloping

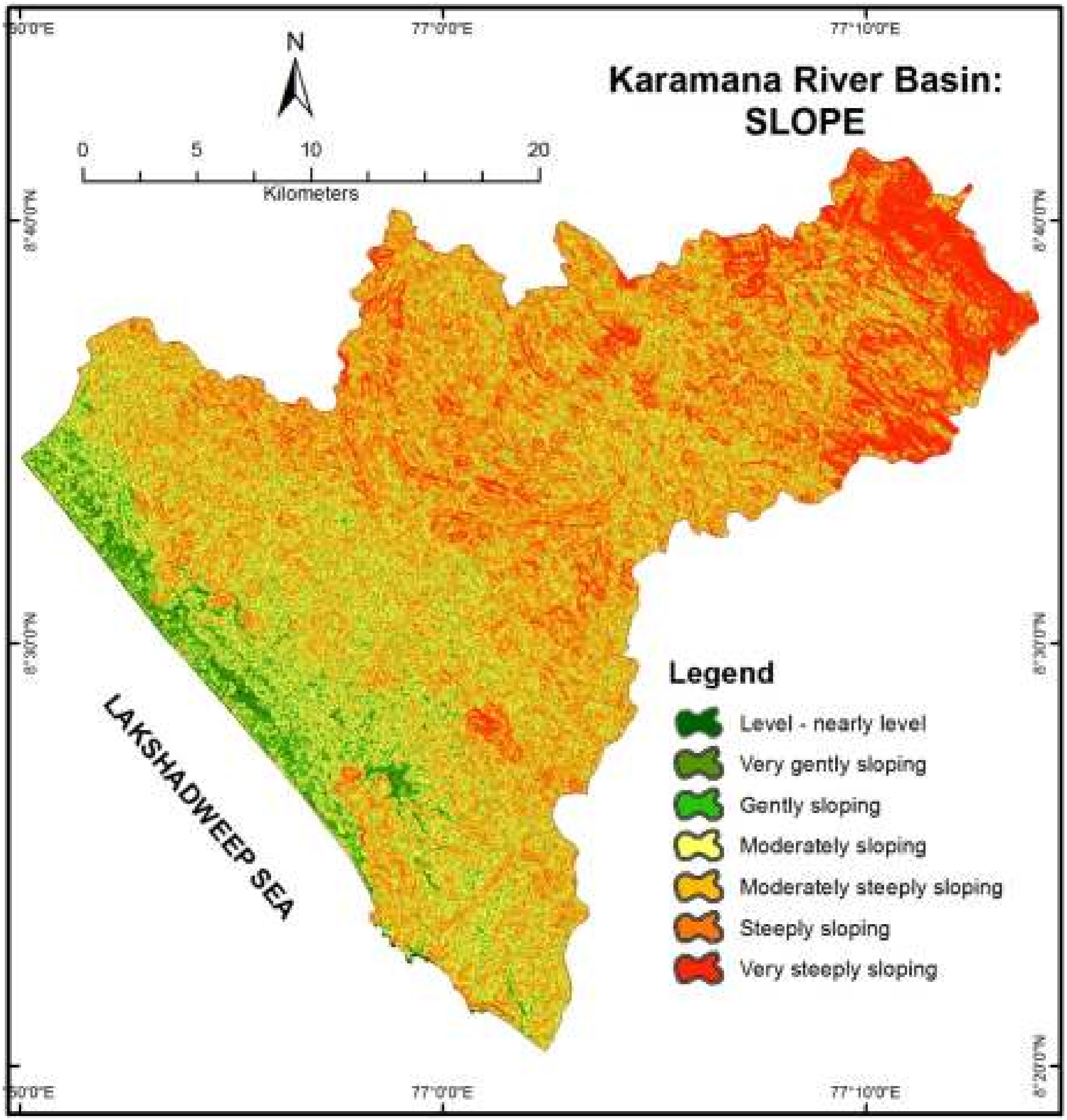


Fig. 13 Slope map of Karamana river basin

DRAINAGE

Among the west flowing rivers of Kerala, Karamana river ranks 15th and 17th with regard to river catchment and stream length, respectively. The Karamana river falls within the small mountainous river category (head water elevation between 1000m and 3000m amsl) of Milliman and Syvitski (1992). The river originates from the Western Ghat mountain ranges (Sahyadri hills) and flows through the coastal plains of Thiruvananthapuram district. The crest of the Western Ghats constitutes the interfluves between the Karamana (west flowing) and the Thambraparni (east flowing) river basins.

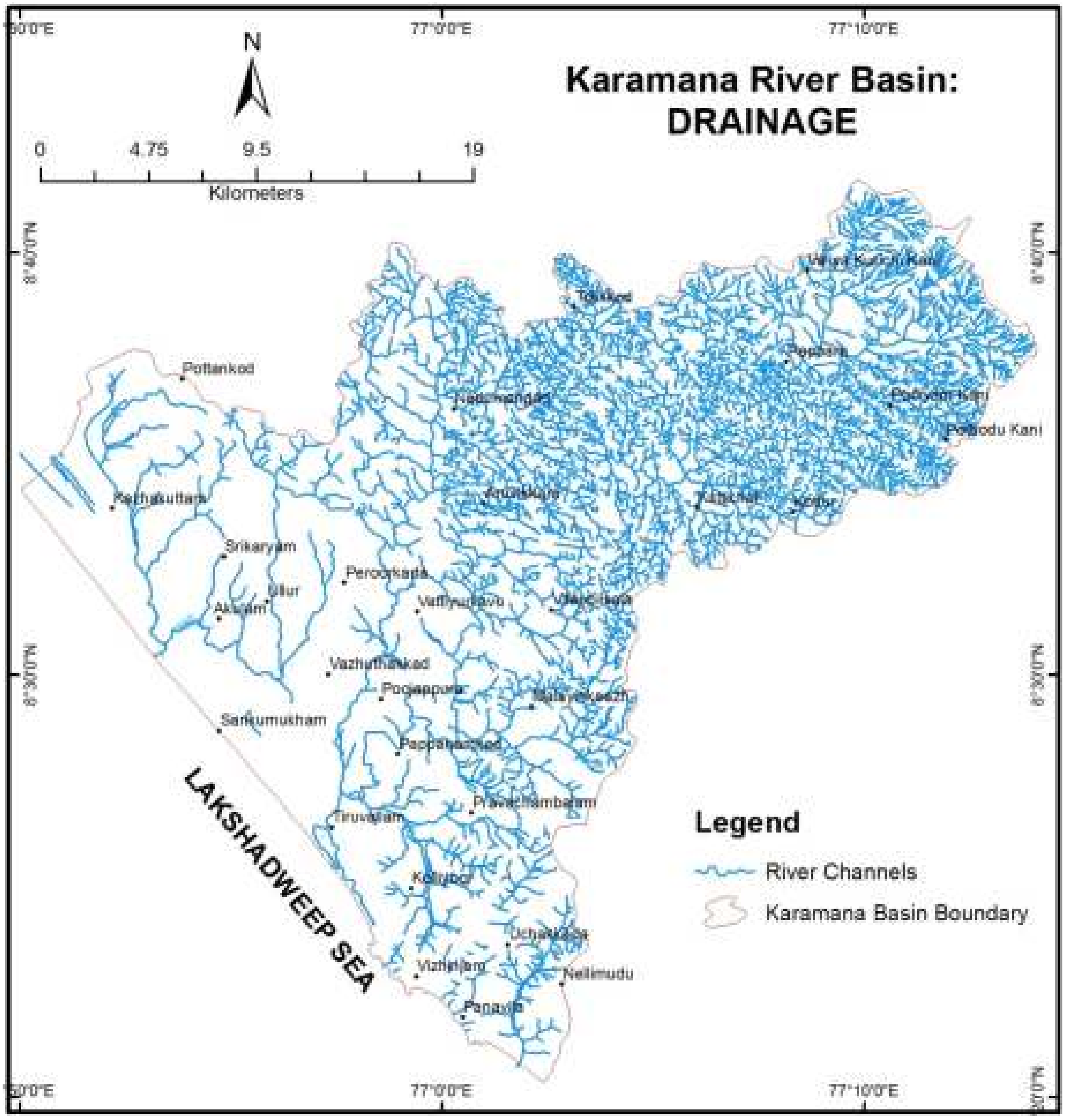


Fig. 14 Drainage network of Karamana river basin

The river originates from *Chemmunji mottai*, a peak in the Sahyadri hills at an altitude of 1717m amsl. Along the course of the Karamana river, there is a 71 m waterfall at Pachani thuval, 2 km downstream of *Chemmunji mottai*. Vazhapazhatti *Ar* and the Attai *Ar*, originating respectively from Panditherimalai (1560 m) and Adirumalai (1594 m), join together at an altitude of 249 m amsl and merge with the Karamana river at about 2 km downstream of the Pachani thuval waterfall. Further downstream in the midlands, five more tributaries join with the Karamana river (Fig 14) at different locations; among which, Kavi *Ar* is the prominent one. Another tributary, locally known as Thodayar originates from the Bonakkad Hill at an elevation of 1020 m amsl, flows almost parallel to the Karamana river for a short distance along its upper reaches and then merges with the master channel near the Peppara dam. Attingal *thodu*, originating from Kalakkavu (220 m amsl) near Vithura, joins the Karamana river near Theviar hill located about 3 km downstream of Peppara dam. Other two major tributaries joining with the Karamana river down to the Attingal *thodu* confluence are Kottur tributary and Chit *Ar*. While the former joins with the Karamana river near Aryanad town, the latter merges with the river near Puthukulangara. Mylom tributary joins the Mainstream near Vilavurkal. Killiyar the major tributary of Karamana river joins near Kalady after draining through the eastern parts of Thiruvananthapuram City. In addition to these, the Karamana river is fed by numerous small order channels originating from places like Chuliamalai, Chettikunnu, Manikettiyamalai, Pachamalai reserved forest, Valiyamalai hills etc,. The Karamana river meanders through the coastal plains and finally merges with Arabian Sea, near Thiruvallam.

STRUCTURE AND TECTONICS

The Karamana river basin, being part of the Indian Peninsular shield, have suffered intense tectonic activity, which is registered in the form of dislocation of stream courses. The Karamana river drains mainly through khondalitic terrain. The river has incised into the planation surfaces and because of nearly uniform bedrock lithology the channel pattern is more a reflection of structural features rather than of lithologic inhomogenities. The NW-SE axial traces of nearly upright large-sca1e folds of gneissic foliation and banding are cut by the river (Soman, 2002). However, the change of course and the channel orientation are generally controlled at many places by prominent fracture zones and joint planes. At Aruvikkara, the N-S course of the river is controlled by well-developed N-S trending vertical joints.

Although the river shows frequent meanders, particularly in the midland region, the general trend of the channel marks a number of changes in the course (Fig 14). These are: (1) from E-W to NE-SW in the upstream at the confluence of Todayar tributary, (2) from NE-SE in the upstream to E-W in the downstream at the confluence of Permakand tributary, (3) from E-W in the upstream to NE-SW in the downstream at the confluence of Attingal *thodu* tributary, (4) from NE-SW in the upstream to E-W in the downstream at the confluence of Kottur tributary, (5) from E-W in the upstream to NE-SW in the downstream at the confluence of Chit *Ar* (6) from NE-SW in the upstream to nearly N-S in the downstream at Irumba, (7) N-S arranged channel of Killiyar tributary upstream of Azhikode, (8) NE-SW in the downstream stretch of Killiyar, (9) NE-SW and NW-SE trending Mylom tributary, (10) N-S trending tributaries of Akkulam sub basin, (11) NW-SE orientation of the channels of Vellayani sub basin and (12) NE-SW, NW-SE and N-S segments of the Karamana main channel resulting in a meandering pattern. Generally, most of the changes of the river course take place at the confluence of the 4^{th} order streams. This is an indication of the mechanism of river capture, apart from the structural control (Anilkumar, 1994). The course of the major tributaries like Chit *Ar*, Attingal *thodu* tributary, Parandod tributary, Killiyar tributary, Vellayani tributary, Mylom tributary, the lower reaches of Kottur tributary and the main channel are almost parallel to the gneissic foliation and the bending of the country rock.

A major fold axis in the midland part of the Karamana river basin (Fig. 15) and presence of reasonably thick younger geological formations (as reported from Aryanad at a depth of 2.5 m below ground level is C^{14} dated 3300 ± 90 ybp by Arun, 2006), incision of river channel on its on older deposits (Fig. 16) and conglomerate deposits in areas close to the river channels are distinct evidences of neo-tectonic activities.

LINEAMENTS

Lineaments provide the pathways for groundwater movement and are hydro geologically very important (Seker, 1966). A lineament is defined as large-scale linear feature, which expresses itself in terms of topography of the underlying structural features. Lineaments, being surface manifestations of structurally controlled linear or curvilinear features, are identified from the satellite imageries by their relatively straight tonal alignments. Lineaments can be joints, fractures, dyke systems, straight course of streams and vegetation patterns. In hard rock terrains, lineaments represent areas and zones of faulting and fracturing resulting in increased secondary porosity and permeability. Hence they are good indicators of the accumulation and movement of groundwater. In Karamana river basin the lineaments are dominant in the midland region, followed by highlands and coastal region (Fig. 17). Major lineament direction is NW-SE. Most of these lineaments are found to follow linearly arranged valleys and hence are potential for groundwater development. The lineaments are cross checked in the field at a few places and found the water levels in the nearby existing wells at very shallow depth and all are perennial.

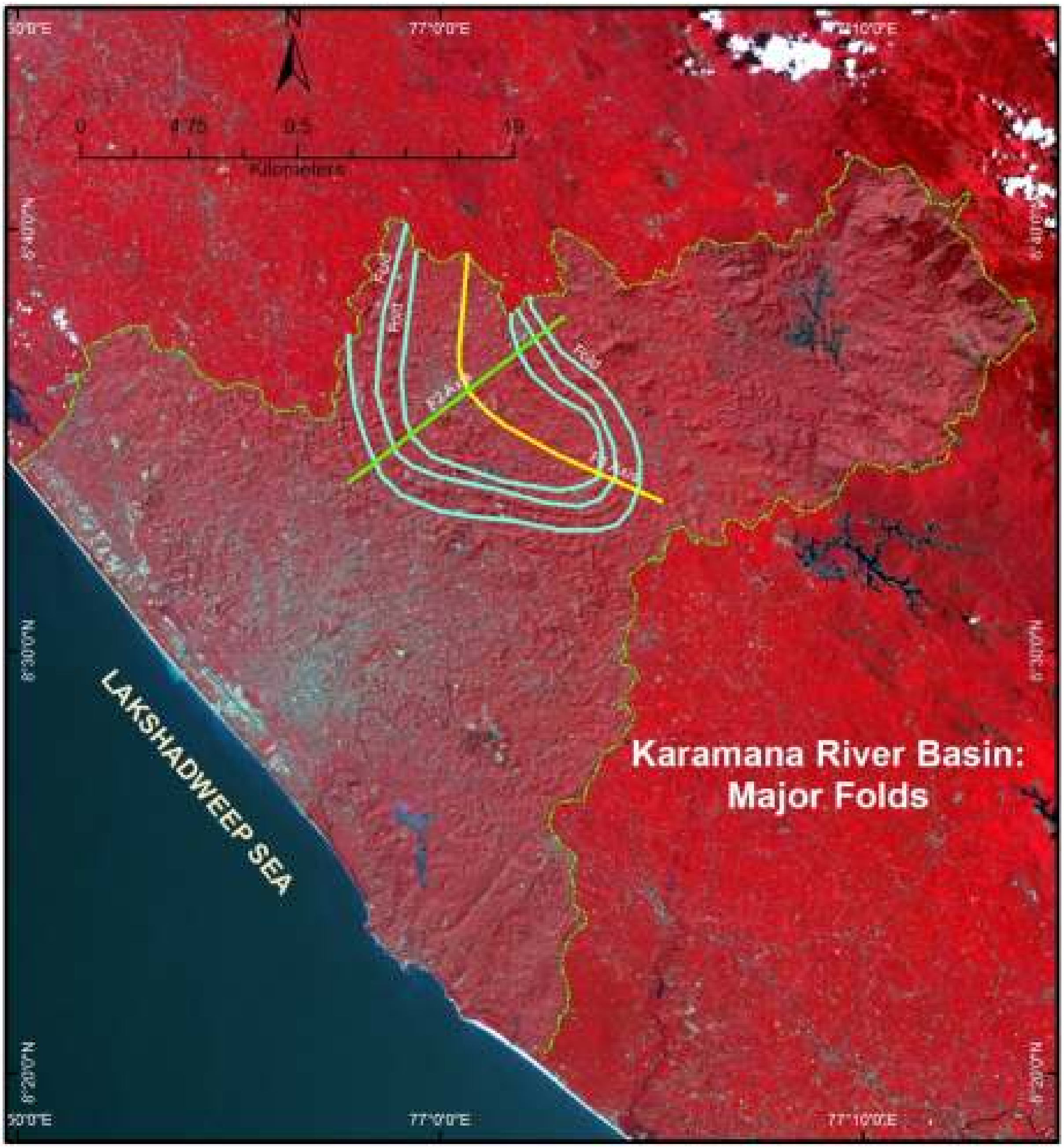


Fig. 15 Major folds in the study area observed from IRS LISS III image.

It is observed in some places that the lineaments intersect each other and such areas are expected to be more favourable for groundwater development (Seker, 1966; Narasimha Prasad and Sivraj, 1997; Narasimha Prasad et al, 2013, Sreeja et al, 2015). A lineament density map is a measure of quantitative length of linear features expressed in a grid. Lineament density map of an area can indirectly reveal the groundwater potential, since the presence of lineaments usually denotes a permeable zone. Areas with high lineament density are favourable for groundwater development (Haridas et al. 1994, 1998).

Fig 16.Channel incision of Karamana river near Aryanad

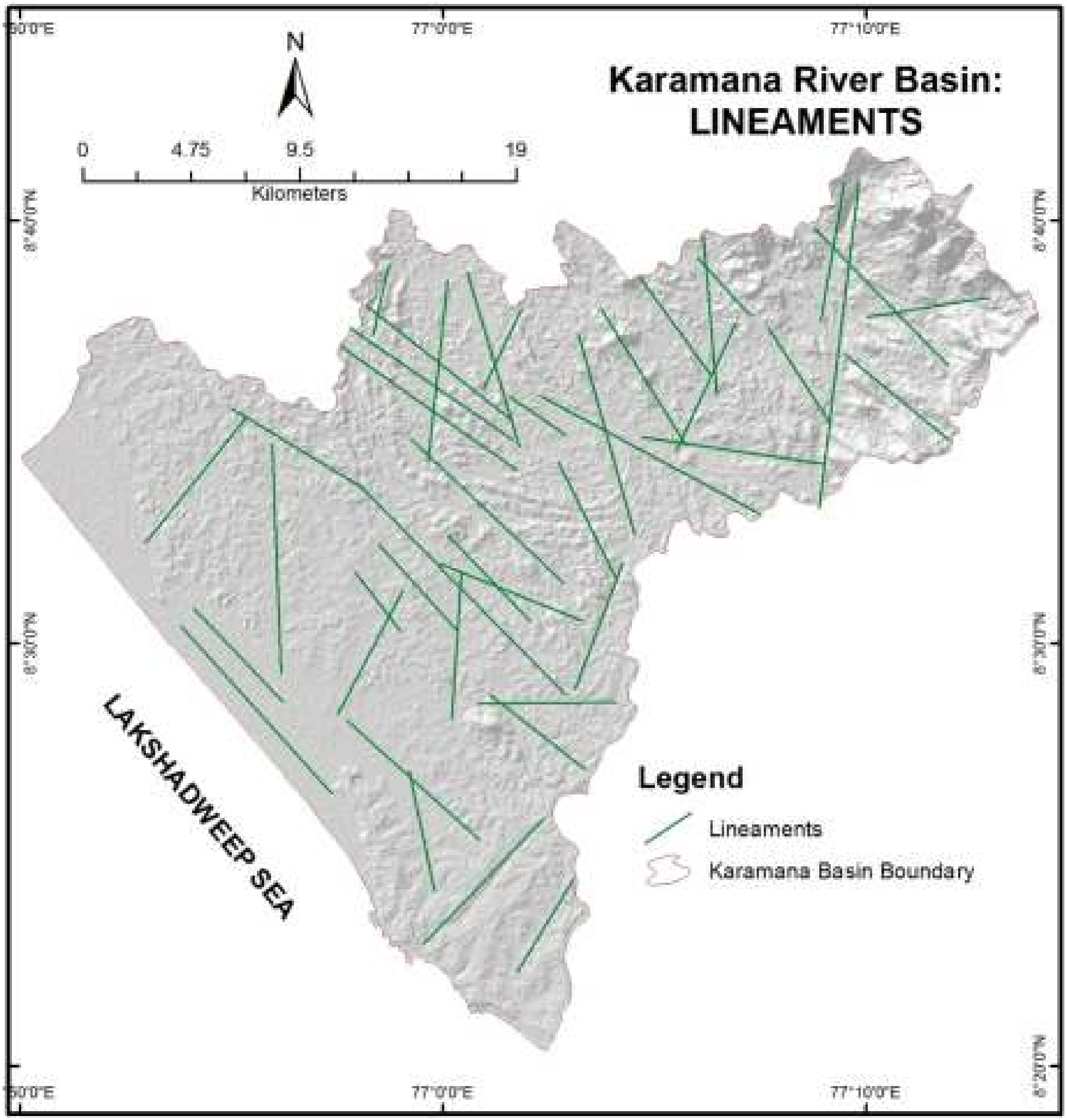


Fig. 17 Major lineaments of Karamana river basin

GEOMORPHOLOGY

Geomorphologically, the Karamana river basin exhibits undulating topography with steep slopes in the eastern reaches. The basin has been classified as lowland, representing the coastal belt, midland, comprising mostly of laterites and, highland region, covered by hard rocks. However there are small intermittent hillocks of 100 to 500 meters amsl in the midland region. These small hillocks of midland region are covered by laterites. Through remote sensing, various hydrogeomorphological features within the basin have been identified (Fig 18). Based on the relationship among the topography, lithology and drainage, the study area has been classified into different hydrogeomorphological units such as lateritic uplands, pediments, alluvial plains, flood plains, beach and coastal plains (Arun, 2006). In the Structural hills, the chances of occurrence of groundwater there depend on the fracture system. Structural hills are normally considered as poor source of groundwater (Sankar, 2002). However, in the study area the structural hills are characterized by a number of lineament intersections and therefore, in such places extraction of groundwater can be done through deep bore wells. Residual mounds are formed by the prolonged erosion and weathering of pre-existing surface features of the plateaux, plains and even original complex tectonic mountains and are considered as poor in groundwater prospecting. Pediments are formed where a thin veneer of soil overlies a hard rock terrain. The groundwater condition in pediments is expected to vary depending upon the type of underlying folded structures, fracture systems and degree of weathering. Groundwater prospecting in pediments can vary from normal to poor (Seker, 1966), but presence of any lineaments or fractures can provide some scope for movement of groundwater and hence good for groundwater exploration. Valley fills and water bodies are seen as isolated or inter connected patches in the entire study area. Valley fills result when streams dump their sediments suddenly due to obstruction and a reduction in flow velocity. Since they have high moisture content, they are thickly vegetated and can easily be identified in the imagery by their tone and texture. Valley fills are considered as good potential zones for groundwater exploration (Narasimha Prasad et al, 2007; Sankar, 2002; Sarkar et al, 2001).

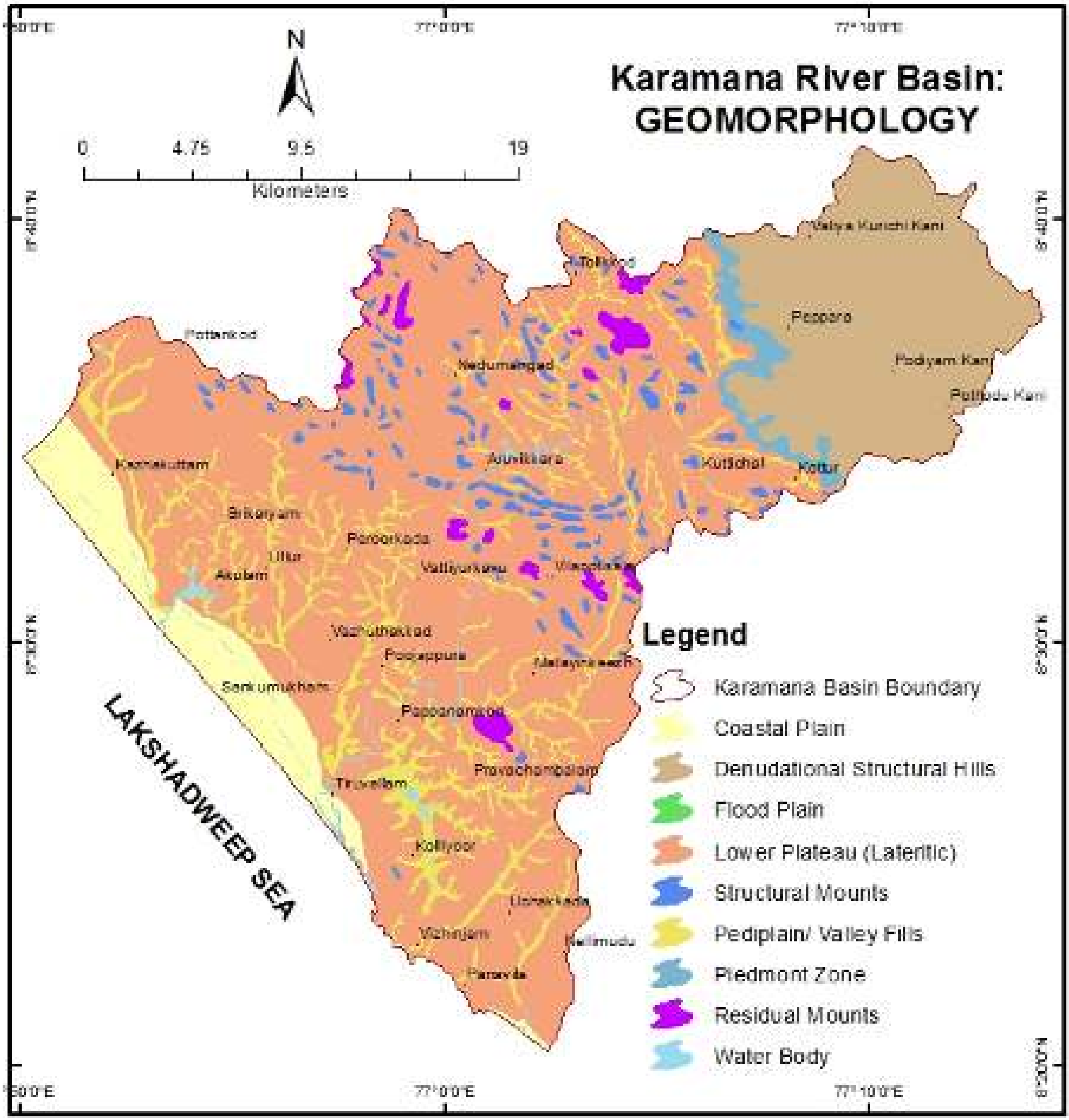


Fig. 18 Geomorphology map of Karamana river basin

MORPHOMETRIC ANALYSIS

The quantitative evaluation of form characteristics of surface landform units is refers as morphometric analysis. Generally, this is the common technique in river basin analysis, as morphometry forms an ideal component for interpretation and analysis of fluvial landforms. The composition of the drainage system of a river basin can be quantitatively expressed with stream order, drainage density, bifurcation ration and stream length ratio (Horton, 1945). It includes quantitative study of the various components such as, stream segments, basin length, basin parameters, basin area, altitude, volume, slope, profiles of the land which indicates the nature of development of the basin.

The evolution of any drainage basin is the result of interactions between matter and energy and the resistance of the topographical surface. The matter and energy act upon the variables defining the characteristics of a river basin. Some of these characteristics of a river basin can be quantified by morphometric studies (Zavoianu, 1985). Morphometric analysis is a major advance in the quantitative description of the geometry of the drainage basin. Morphometry is the measurement and mathematical analysis of configuration of the earth surface and the shape and dimensions of its landforms (Arun, 2006). Morphometric studies involve evaluation of streams through the measurement of various stream properties viz., linear, areal and relief aspects. It is an important tool for neotectonics and geomorphology, where the relation of natural landscapes to planet's interior dynamics is often masked by fast action of weathering and where the presence of drainage network anomalies and relief pattern discontinuities may be related with recent terrain movements (Zuchiewicz, 1991). Systematic analysis of morphometric parameters through integrated remote sensing and GIS could be effectively used in understanding the morphologic and hydrologic characteristics of the Karamana River drainage basin. In this chapter linear, areal and relief aspects of Karamana River drainage basin are discussed.

In this study, quantitative estimation of morphometric parameters was carried out for 14 sub-basins (4^{th} and higher-order basins directly joins the Karamana main channel or debouches to the sea) of the study area. The sub-basin watersheds and their watershed codes are furnished in Table 9. Two of the sub-basins namely, Akkulam (WS13) and Vizhinjam-Chappath (WS14) directly join the sea. The sub-basins WS01 to WS12 join with the 6^{th} order main channel of the Karamana River. WS15 is the whole Karamana main channel drainage basin. Drainages are digitally traced and the basin is subdivided into 14 sub-basins drained by the major tributaries.

Table 9 Sub basin watershed codes for the Study area.

Sl.No	Watershed Code	Sub basin watershed name
1	WS01	Thodayar Subbasin
2	WS02	Kaviyar Subbasin
3	WS03	Panamparathodu Sub basin
4	WS04	Anjunazhika Subbasin
5	WS05	Kottur Subbasin
6	WS06	Attingalthodu Subbasin
7	WS07	Paruthippara Subbasin
8	WS08	Eravur Subbasin
9	WS09	Chittar Subbasin
10	WS10	Killiyar Subbasin
11	WS11	Malayam Subbasin
12	WS12	Vellayani Subbasin
13	WS13	Akkulam-Veli Subbasin
14	WS14	Vizhinjam-ChappathSub basin
15	WS15	Karamana Basin

Stream orders and stream numbers are assigned to each streamlet. Stream lengths as per stream orders were measured using ArcGIS 10. Basin area, length and width of the sub-basins and the main Karamana basin was measured. Morphometric analysis was carried out and morphometric parameters obtained at sub-basin level. Morphometry of the drainage basin comprises three aspects – linear, areal and relief. These are computed from drainage maps following the procedures proposed by Horton (1945); Langbein (1947); Strahler (1952, 1968); Schumm (1956); Smart and Surkan (1967); Avena et al. (1967); Waugh (1995); Gupta (1999); El Hamdouni (2007); Guarnieri et al. (2008); Thomas et al., (2009); Dehbozorgi et al. (2010) as described in Chapter 2. Linear aspects include stream order (U), stream number (Nu), stream length (Lu), bifurcation ratio (Rb), mean length of streams of corresponding orders, stream length ratio, and mean stream length ratio. Areal aspects comprise basin area (Au), stream frequency (Fu), circularity ratio (Rc), elongation ratio (Rl), form factor (Rf), compactness factor (Rcf), constant of channel maintenance and drainage density (Dd). Relief aspects include basin relief (Rl), relief ratio (Rr), ruggedness number (Rn), channel gradient (Rs), sinuosity ratio (Sr) and hypsometric integral (Hi). All these parameters are computed and analysed for Karamana river drainage basin and the 14 sub-basins in the study area.

BASIN GEOMETRY

The sub-basin watersheds delineated for morphometric analysis in the study area are depicted in Fig. 19 and the respective geometric parameters are presented in Table 10. The biggest sub-basin watershed in the study area is WS13 (Akkulam-Veli sub-basin; 157.409 sq.

km) which debouches into the sea directly and the smallest one is WS07 (Paruthippara sub-basin; 7.331 sq. km), which joins the Karamana main channel. WS10 (Killiyar sub-basin) is the largest sub-basin among the sub-basins directly joining the Karamana river. The perimeter of WS10 is exceptionally high with respect to the area, resulting from the linear shape of the basin.

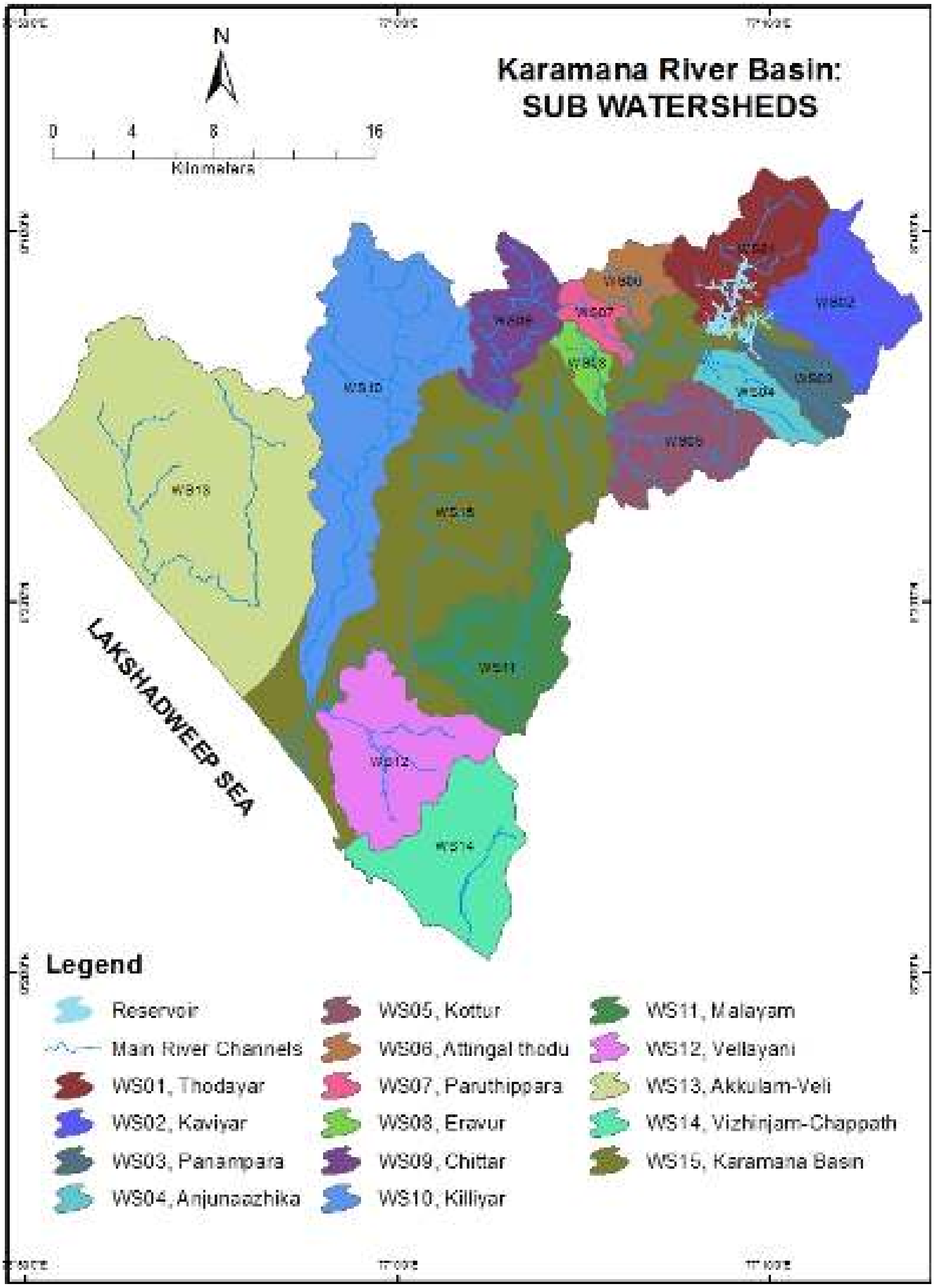


Fig. 19 Sub-watersheds of the study area for morphometric analysis.

Table 10 Geometric parameters of the Sub basin watersheds.

Sl.No	Watershed Code	Stream Order	Basin Area(Au) Sq.km	Basin Length (Lb) Km	Perimeter(P) Km
1	WS01	V	34.175	9.752	30.242
2	WS02	V	32.564	9.488	29.107
3	WS03	V	14.292	5.943	20.083
4	WS04	V	13.295	5.704	19.843
5	WS05	V	33.237	9.599	31.097
6	WS06	IV	11.849	5.343	19.364
7	WS07	IV	7.392	4.087	15.204
8	WS08	IV	7.331	4.068	14.054
9	WS09	V	25.936	8.337	31.158
10	WS10	V	93.445	17.267	70.352
11	WS11	IV	41.436	10.880	38.704
12	WS12	IV	46.591	11.629	35.799
13	WS13	V	157.409	30.702	56.811
14	WS14	IV	44.075	11.268	37.461
15	WS15	VI	500.516	45.667	145.902

LINEAR ASPECTS

Stream order (U), stream length (Lu), bifurcation ratio (Rb), mean length of streams of orders, stream length ratio, and mean stream length ratio were analyzed as the linear morphometric aspects of the sub-basin watersheds of the study area (Table 11). Horton’s law of geomorphology was tested for each sub-basin of the Karamana drainage system.

Stream order (U)

Stream order is the index of size and scale of the drainage basin. An approximation of the stream flow can be deduced from stream order. In the sub-basins of Karamana river basin, the highest orders are 4 to 6 indicating the moderate size of the sub-basins. Among the 5th order basins WS13 and WS10 are about 6 to 10 times larger in size than WS03 and WS04 (Table 11). In the 4th order basins, WS11, WS12 and WS14 are about 4 to 7 times larger than WS06, WS07 and WS08. The stream order of Karamana basin is 6, which indicates a moderate stream discharge, channel dimension and size of the basin.

Table 11 Linear morphometric parameters of the study area (Contd).

Stream Order	Stream number (Nu)	Stream length (Lu) Km	Mean stream length (Km)	Bifurcation ratio (Rb)	Stream length ratio	Length of overland flow (Lf)
WS01 Thodayar Sub-basin						
I	153	78.955	0.516	4.371	3.278	
II	35	24.083	0.688	5.000	1.885	
III	7	12.778	1.825	3.500	2.229	
IV	2	5.733	2.867	2.000	1.580	
V	1	3.630	3.630			0.137
Total	**198**	**125.179**				
WS02 Kaviyar Sub-basin						
I	255	93.163	0.365	4.1803	3.178	
II	61	29.313	0.481	4.0667	1.724	
III	15	17.002	1.133	3.750	1.740	
IV	4	9.769	2.442	2.000	1.777	
V	2	5.497	2.749			0.105
Total	**337**	**154.744**				
WS03 Panamparathodu Sub-basin						
I	173	51.205	0.296	4.325	3.701	
II	40	13.834	0.346	6.667	4.44	
III	6	3.116	0.519	3.000	0.284	
IV	2	10.974	5.487	2.000	16.285	
V	1	0.674	0.674			0.090
Total	**222**	**79.803**				
WS04 Anjunazhika Sub-basin						
I	145	42.197	0.291	4.677	5.138	
II	31	8.213	0.265	6.200	0.541	
III	5	15.184	3.037	2.500	3.508	
IV	2	4.330	2.165	2.000	13.585	
V	1	0.319	0.319			0.095
Total	**184**	**70.2422**				
WS05 Kottur Sub-basin						
I	282	30.349	0.108	4.147	0.368	
II	68	82.447	1.212	4.857	4.756	
III	14	17.336	1.238	4.667	1.175	
IV	3	14.752	4.917	3	14.671	
V	1	1.006	1.006			0.015
Total	**368**	**145.89**				

Table 11 Continued….

Stream Order	Stream number (Nu)	Stream length (Lu) K)	Mean stream length (Km)	Bifurcation ratio (Rb)	Stream length ratio	Length of overland flow (Lf)
WS06 Attingalthodu Sub-basin						
I	78	28.448	0.365	4.5882	2.827	
II	17	10.063	0.592	3.400	1.850	
III	5	5.439	1.088	5.000	1.341	
IV	1	4.057	4.057			0.123
Total	**101**	**48.007**				
WS07 Paruthippara Sub-basin						
I	53	16.861	0.318	3.533	3.322	
II	15	5.076	0.338	3.750	3.761	
III	4	1.350	0.337	4.000	0.239	
IV	1	5.640	5.640			0.128
Total	**73**	**28.926**				
WS08 Eravur Sub-basin						
I	59	15.948	0.270	4.214	2.382	
II	14	6.696	0.478	3.500	1.562	
III	4	4.286	1.072	4.000	1.127	
IV	1	3.804	3.804			0.119
Total	**78**	**30.734**				
WS09 Chittar Sub-basin						
I	257	73.287	0.285	3.779	2.855	
II	68	25.673	0.378	3.778	1.885	
III	18	13.623	0.757	6.000	2.204	
IV	3	6.182	2.061	3.000	0.744	
V	1	8.308	8.308			0.102
Total	**347**	**127.073**				
WS10 Killiyar Sub-basin						
I	291	113.633	0.391	3.880	2.278	
II	75	49.881	0.665	3.750	19.117	
III	20	2.609	0.131	4.000	0.187	
IV	5	13.916	2.783	5.000	0.528	
V	1	26.367	26.367			0.226
Total	**392**	**206.406**				

Table 11 Continued….

WS11 Malayam Sub-basin						
I	145	60.156	0.415	4.028	2.514	
II	36	23.930	0.665	5.143	1.931	
III	7	12.395	1.771	7	0.962	
IV	1	12.890	12.89			0.189
Total	**189**	**109.371**				
WS12 Vellayani Sub-basin						
I	66	38.973	0.591	3.882	2.178	
II	17	17.898	1.053	4.250	1.028	
III	4	17.405	4.351	4	3.898	
IV	1	4.465	4.465			0.296
Total	**88**	**78.741**				
WS13 Akkulam Sub-basin						
I	59	55.300	0.937	3.471	2.121	
II	17	26.072	1.534	2.833	1.679	
III	6	15.531	2.589	3	0.586	
IV	2	26.500	13.250	2	32.199	
V	1	0.823	0.823			0.634
Total	**85**	**124.226**				
WS14 VizhinjamChappath Sub-basin						
I	99	44.625	0.451	4.125	2.283	
II	24	19.550	0.815	6	1.977	
III	4	9.887	2.472	4	1.567	
IV	1	6.309	6.309			0.274
Total	**128**	**80.371**				
WS15 Karamana Basin						
I	2750	954.647	0.347	4.135	5.143	
II	665	185.632	0.279	4.433	0.527	
III	150	352.374	2.349	4.167	3.189	
IV	36	110.509	3.070	4.5	2.413	
V	8	45.801	5.725	8	0.670	
VI	1	68.373	68.373			0.151
Total	**3610**	**1717.340**				

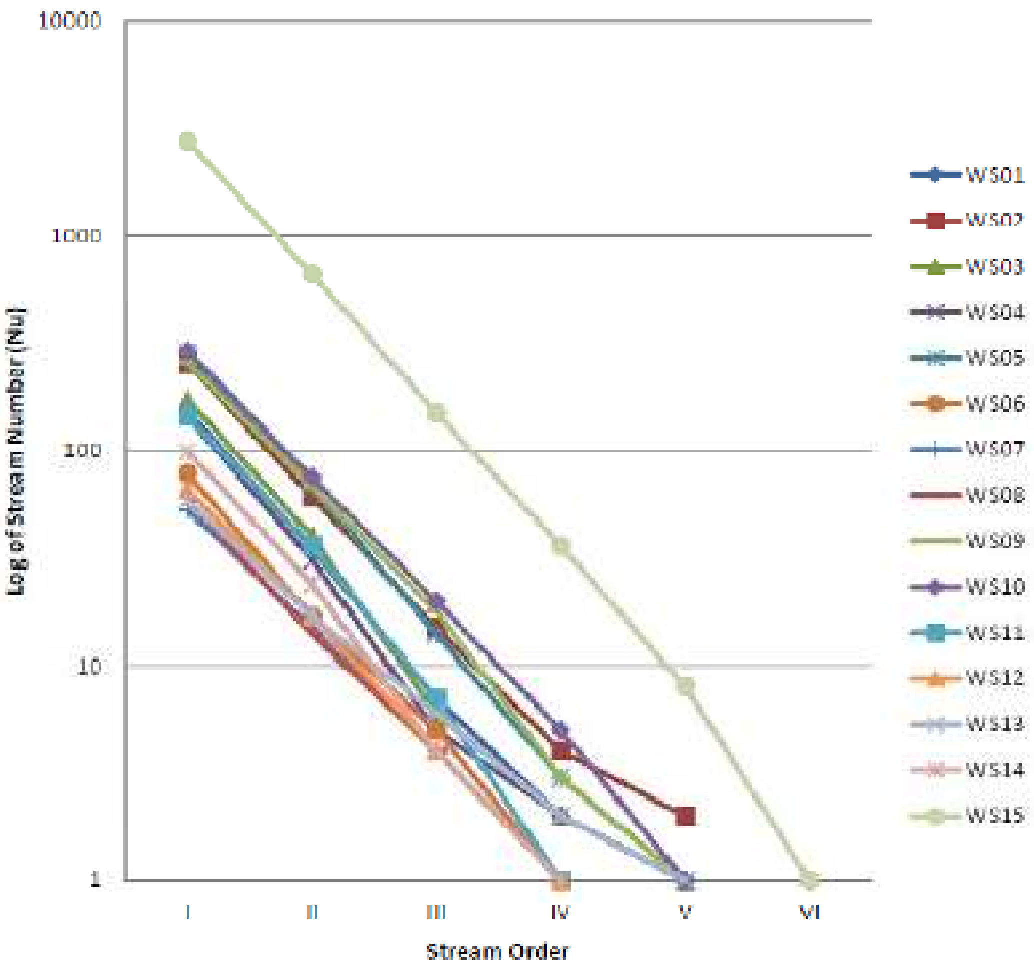


Fig. 20 The semi logarithmic plots of stream order and stream numbers for the sub basins of the study area.

Stream Number (Nu)

Generally, the number of the stream segments and the order are in reverse relationship, i.e., number of segments decreases as the order increases (Strahler, 1964) and the calculations of this investigation also agree with this observation. The higher stream number indicates lesser permeability and infiltration. Total number of streams in the sub-basins in the respective stream order categories are presented in Table 11. Total number of streams in Karamana River drainage basin is 3610. WS13 and WS14 have a total stream segments of 85 and 128 respectively. Plots of log of stream number against stream order for the sub-basins are represented in Fig. 20. As suggested by the observed high R-squared (R^2) values, exponential trend line is the best-fit model to explain the relation of stream order and stream number. More number of first order streams observed in the hilly regions of the study area indicates complex terrain and less permeable bedrock lithology. Large number of streams in the sub-basins indicate that the topography is rugged and the streams are intensely eroding their channels. Less number of streams in the WS13 irrespective of its drainage area indicates a mature topography of its terrain.

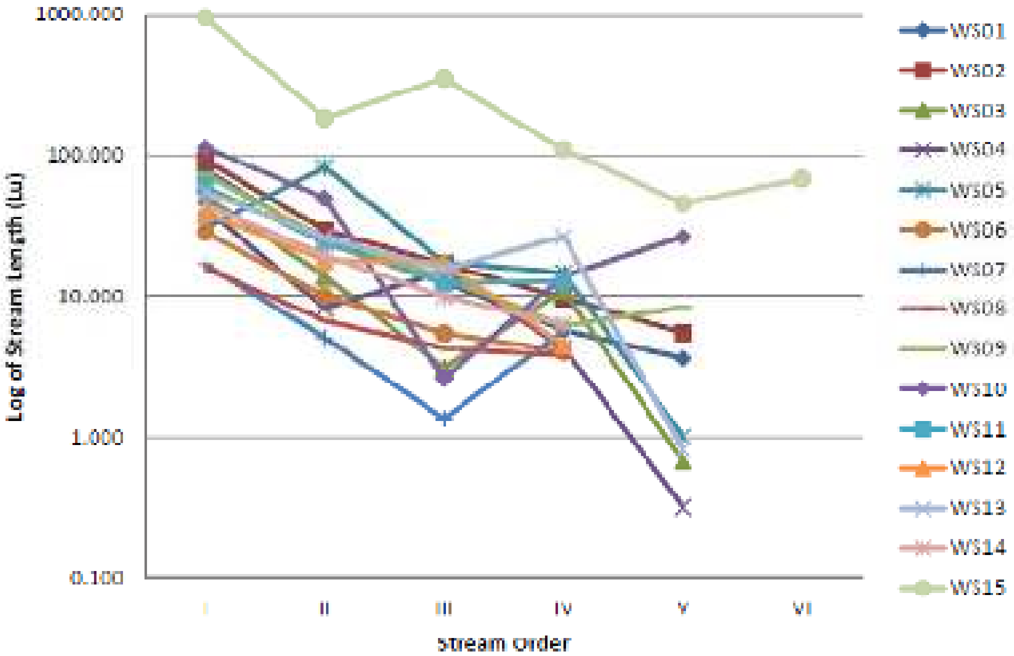


Fig. 21 The semi logarithmic plots of stream order and stream length for the sub basins of the study area.

Bifurcation ratio (Rb)

Bifurcation ratio is the measure of the degree of effect of drainage network of the terrain and has a significant control over the runoff (Chorley 1969; Mesa 2006). The bifurcation ratio will not be precisely the same from one order to the next, because of possibility of variations in watershed geometry and lithology, but tends to be a constant throughout the series. As the bifurcation ratio increases, the basin shape will be elongated and as the ratio decreases the basin gets broader and circular (Ambili, 2010). Bifurcation ratios characteristically range between 3.0 and 4.0 for watersheds in which geologic structures do not distort the drainage pattern. The theoretical minimum value of 2.0 is rarely approached under natural conditions but in the study area it is observed in the sub-basins WS01, WS02, WS03, WS04 and WS13 in their respective highest stream orders.

The bifurcation ratio of the sub-basins of the study area is found to range from 2 to 8 (Table 11). The lower orders of all the sub-basins have bifurcation ratio >3.5. This suggests that the basin is a highly dissected one and the upland zone of the basin is tectonically active as observed by Ambili (2010). High bifurcation ratio may also be due to the elongated shape of the basin (Strahler 1964; Zavoianu, 1985). When compared with other rivers originating from the Western Ghats, Karamana River has high Rb values. Rb of Achenkovil River ranges from 3.46 to 5.50 (Manu and Anirudhan, 2008), that of the Muthirapuzha (a tributary of Periyar River) is 2.58 to 4.95 (Thomas et al., 2009) and for Chaliyar it is 2.0 to 6.5 (Ambili, 2010). According to Zuchiewicz (1989) high values of bifurcation ratio can be found in drainage basins with young tectonic movements. The highest bifurcation ratio observed for the study area is 8.00 (WS15, Karamana main channel). The very high bifurcation ratio (V/VI = 8.00) of the Karamana main stream clearly indicates the factor of geological control on the drainage pattern.

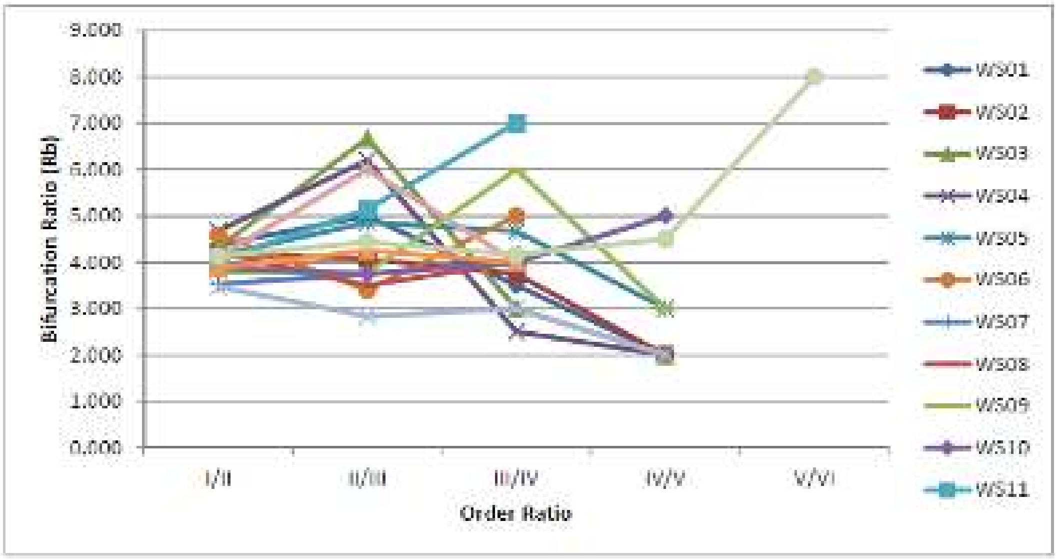


Fig. 22 The plots of stream order and bifurcation for the sub basins.

Contrary to Horton's (1945) postulations of stream order, it has been found that bifurcation ratio varies widely from order to order in all the sub-basins of the study area (Fig. 22). Guisti and Schneider (1965) suggested that bifurcation ratio within a basin decreases with increasing order, and that bifurcation ratio increases within the basin area initially and tend to become a constant. But in the study area, these concepts do not hold good for most of the sub-basins.

Verstappen (1983) pointed out that, a bifurcation ratio between first and second order streams which is considerably higher than that of higher order streams, indicates a state of accelerated erosion. But in the study area, the observation is not so pronounced. Ghosh and Chhibber (1984) opined that the variation in bifurcation values are a reflection of the differences in the shape and structure of the stream network. The high bifurcation ratios (>5) for the higher order streams of the study area may be attributed to structural disturbances, which in turn, have distorted the drainage pattern. According to Agarwal (1998), if the bifurcation ratio (Rb) is low, the basin produces a sharp peak of discharge, and if Rb is high, the basin yields a low but extended peak flow. The distinguishing dissimilarity in the Rb values of various orders among the sub-basins suggests the control of tectonic activities on drainage development.

Stream length (Lu)

Stream lengths are decreasing with increasing order of stream in most cases but vary in the case of a few sub-basins (sub-basins – WS03, WS04, WS05, WS10 and the main channel basin WS15) (Table 11). The plot of logarithm of stream length versus the stream order is of linear relationship; but with minor deviation (Fig. 23). Deviation in linearity in length of 4^{th} and 5^{th} order streams are linked to the rejuvenation of drainage due to tectonic activities.

Mean length is the average length of stream channel segments in a given stream order. It is a dimensional property revealing the characteristic size of components of a drainage network and its contributing basin surface. Horton (1945) postulated that the length ratio RL (ratio of mean length Lu of segments of order U to mean length of segments of the next lower order Lu-1) tends to be constant throughout the successive orders of a watershed. Mean stream length of a given order is generally greater than that of the lower order and any deviation in it may be due to variation in the slope and topography which again reflects the tectonic activity (Ambili, 2010). For sub-basins WS03, WS04, WS05 and WS10, mean length of the highest order streams is lower than that of the immediately lower orders, indicating change in stream gradient due to tectonic upliftment. The mean stream length varies from 0.108 km to 68.373 km; the highest value is for 6^{th} order in WS15 and the lowest is for 1^{st} order in WS05.

Singh and Singh (1997) observed that an increasing trend in the stream length ratio from lower order to higher order indicating their mature geomorphic stages and if there is a change from one order to another order, it indicates their late youth stage of geomorphic development. Accordingly, from the study it is revealed that all the sub-basins are in the youth stage. Sreedevi et al. (2005) and Magesh et al. (2011) opine that the variability in stream length ratio, among successive stream orders, is a reflection of differences between slope and topography. Hence it has an important control on discharge and erosional stage of the watershed (Sreedevi et al., 2009). Some anomalous values were observed in WS03, WS04, WS05, WS10 and WS13. The maximum value observed is 32.199 for the highest orders of WS13. The anomaly may be attributed to the non-equilibrium conditions in the drainage system. It may be due to the downstream extension of the higher order segment or an upward extension of tributaries.

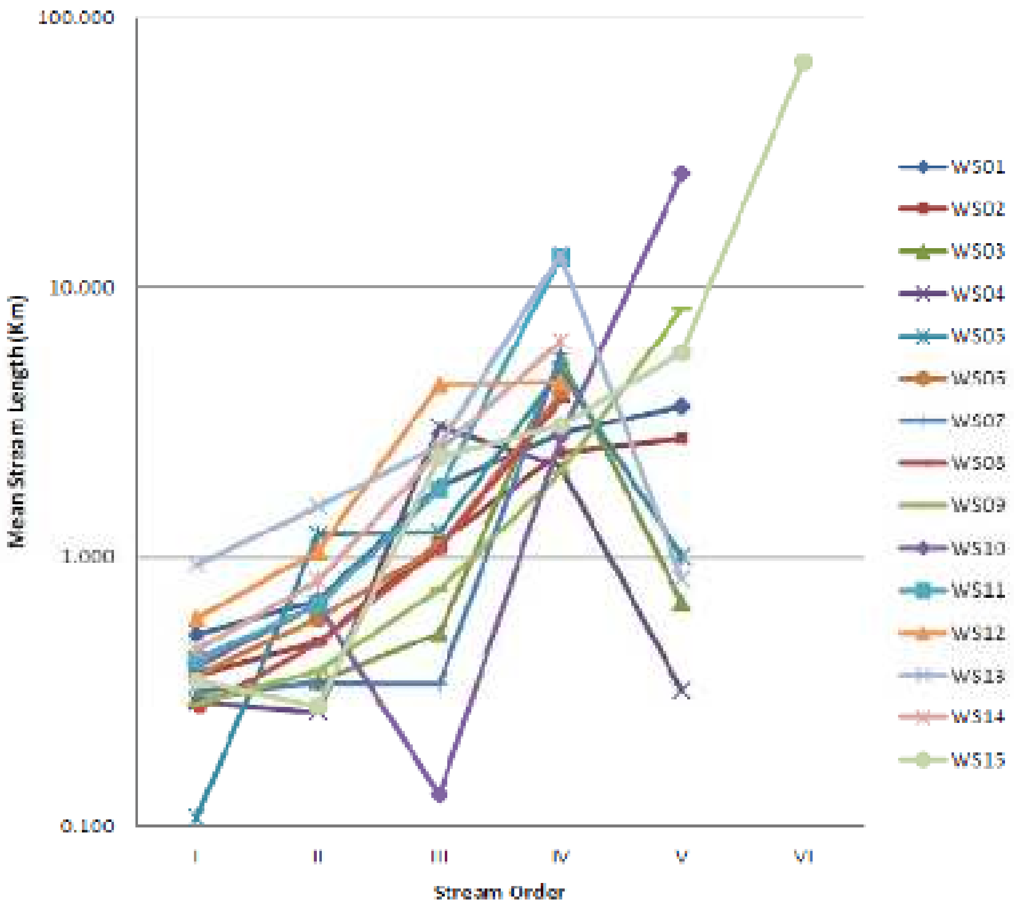


Fig. 23 The semi logarithmic plots of stream order and mean stream length for the sub basins of the study area.

Length of Overland Flow (Lf)

Surface runoff follows a path through down slope from the drainage divide to the nearest channel. Length of overland flow gives the sheet flow of water before it reaches a channel and is one of the most important independent variables indicating both hydrologic and physiographic development of drainage basins (Horton, 1945; Strahler, 1964). It indicates the quantity of water required to exceed a threshold of erosion. The length of overland flow of sub-basins of the study area ranges from 0.015 to 0.634 (Table 11), The highest values (>0.20) are observed for the sub-basins in the coastal lowland terrain such as, WS10 (0.226), WS12 (0.296), WS13 (0.634) and WS14 (0. 274). It indicates long flow paths and comparatively gently sloping terrain of these sub-basins, which facilitates more infiltration and less runoff. All other sub-basins show values less than 0.15, indicating that the sheet flow is less and the lower order channels are well developed, reflecting the steeply sloping terrain.

Sinuosity index (Si)

Sinuosity index is the ratio of stream length with the straight line distance. Schumm (1981, 1993) have demonstrated that much of the sinuosity variability of alluvial rivers reflects the variability of the valley slope, through experimental studies as well as field observations. Tectonic activities, local changes of sediment and water supply due to river junctions and changes in lithology are the main forces controlling the changes of valley floor slope (Schumm, 1986). Changes of valley slope controls the downstream changes of sinuosity. The sub-basins of the study area have sinuosity ratio varying from 1.006 to 1.565. The Karamana Main channel sub-basin (WS15) and Chittar sub-basin (WS09) shows sinuosity values of >1.5, indicating the meandering nature. All other sub-basins are of sinuous (Si = 1–1.5) nature.

AREAL ASPECTS

The parameters on areal morphometric aspects calculated for the sub-basins of the study area are given in Table 12 which comprises drainage density (Dd), stream frequency (Fu), circularity ratio (Rc), elongation ratio (Rl), form factor (Rf), compactness factor (Rcf) and constant of channel maintenance and Infiltration number (If).

Drainage Density (Dd)

Strahler (1964) defined drainage density as the total stream length per unit area in a given drainage basin. It is one of the important indicators of the landform element and provides a numerical measurement of landscape dissection and runoff potential (Chorley, 1969). Factors affecting drainage density are the erodibility of the rock and the climate of the area. The drainage density is low in semi-arid and arid climates but comparatively high in humid terrain (Gardiner, 1980). In general, low drainage density is favoured in regions of highly permeable subsoil materials, under dense vegetation cover, and where relief is low. Greater the drainage density and stream frequency in a basin, faster is the runoff, and flooding is more likely (Kale and Gupta, 2001). Drainage density of the sub-basins of the study area varies from 0.789 (WS 13) to 5.584 km/km^2 (WS 03). The drainage density has its highest value for the sub-basins in the highland terrain which may be associated with tectonism, highly resistant impermeable strata and high rate of precipitation. Drainage density less than 3.5 indicates a coarse texture (Strahler, 1957). Sub-basins WS10, WS 11, WS12, WS13 and WS14 are coarse textured (<3.5) while all other 9 sub-basins are fine textured. The Karamana Main Channel basin is also shows coarse texture (3.431). Strahler (1964) also noted that low drainage density is favoured where basin relief is low and vice versa.

Table 12 Areal morphometric parameters of sub basins in the study area

Watershed Code	Drainage density(Dd) Km/Km^2	Stream frequency(Fu) Km^{-2}	Circularity ratio(Rc)	Elongation ratio(Re)	Form factor(Ff)	Compactness factor(Rcf) Km	Constant of channel maintenance Km	Infiltration number(If) Km
WS01	3.663	5.794	0.469	0.677	0.359	2.131	0.273	21.222
WS02	4.752	10.349	0.483	0.679	0.362	2.071	0.210	49.178
WS03	5.584	15.533	0.445	0.718	0.405	2.247	0.179	86.733
WS04	5.283	13.840	0.424	0.721	0.409	2.358	0.189	73.120
WS05	4.389	11.072	0.432	0.678	0.361	2.316	0.228	48.599
WS06	4.052	8.524	0.397	0.727	0.415	2.520	0.247	34.535
WS07	3.913	9.876	1.699	0.751	0.443	0.589	0.256	38.644
WS08	4.192	10.640	0.466	0.751	0.443	2.145	0.239	44.605
WS09	4.899	13.379	0.336	0.689	0.373	2.980	0.204	65.551
WS10	2.209	4.195	0.237	0.632	0.313	4.217	0.453	9.266
WS11	2.640	4.561	0.347	0.668	0.350	2.878	0.379	12.039
WS12	1.690	1.889	0.457	0.662	0.345	2.190	0.592	3.192
WS13	0.789	0.540	0.613	0.461	0.167	1.632	1.267	0.426
WS14	1.824	2.904	0.394	0.665	0.347	2.535	0.548	5.296
WS15	3.431	7.213	0.295	0.553	0.240	3.386	0.291	24.747

Stream Frequency (Fu)

Horton (1945) defined the stream frequency of a basin as the number of streams per unit area. It is an index of the various stages of landscape evolution, since the occurrence of stream segments depends on the nature and structure of rocks, vegetation cover, nature and amount of rainfall and soil permeability. Greater the stream frequency, faster is the runoff and more likely the flooding. For the sub-basins of the study area, stream frequency varies from 0.54 to 15.533 (Table 12). Highest value of stream frequency is observed for sub-basin WS03 and lowest for sub-basin WS13. Stream frequency for the Karamana Main Channel drainage basin 7.2. Low stream frequency values (<3 per km^2) are observed in WS12 (1.889), WS13 (0.54) and WS14 (2.904) sub-basins, reflecting the gentle ground slopes, and greater rock-permeability in those basins, where the run-off is low and the infiltration is higher. There is a positive correlation with drainage density and stream frequency of the sub-basins in the study area suggesting an increase in number of streams with respect to increasing drainage density.

Circulatory Ratio (Rc)

Circularity ratio is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953). A circle have a circularity ratio of 1 and thus a stable, circular, homogenous basin will have the circularity ratio very close to 1. If it deviates from 1, irregularity of the basin shape increases. It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin Strongly elongated drainage basins have a circularity ratio between 0.40 and 0.50. Circular basin is more likely to have a shorter lag time and a higher peak flow than an elongated basin (Waugh, 1995). According to Mustafa and Yusuf (1999), the flow of water in an elongated basin is distributed over a longer period than in a circular one. The circularity ratio of the sub-basins of the study area ranges from 0.237 to 0.613 (Table 12). These value ranges suggests that the basins are highly irregular and elongated with longer lag time and low peak flow. Highest circularity ratio is shown by the sub-basin WS13 and lowest value by sub-basin WS10. Karamana main channel drainage basin has a circularity ratio value of 0.295 demonstrating its highly irregular and elongated nature and a longer lag time and a very low peak flow (Waugh, 1995; Mustafa and Yusuf, 1999).

Elongation Ratio (Re)

Elongation ratio is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). For regions of very low relief, the value of elongation ratio is found to be very close to 1 (Suresh, 2000). When the value deviates from 1, the area will have a strong relief and steep ground slope. Elongation ratio < 0.5 is observed in areas of low tectonic activity and when it is between 0.5 and 0.75, the area is moderately tectonically active. When elongation ratio value is > 0.75, the area is of strong tectonic activity (Kryzsowski et al., 1995; Ramirez-Herrera, 1998). The sub-basins of the study area shows elongation ratio ranging between 0.461 and 0.751 (Table 12), which indicates that all the sub-basins have very strong relief and steep slopes and are moderately tectonically active. The highest elongation ratio is exhibited by sub-basin WS07 & WS08 and lowest by sub-basin WS13. Karamana main channel drainage basin as a whole has an elongation ratio of 0.553. According to the elongation ratio, the sub-basin WS13 exhibits low tectonic activity where all other sub-basins exhibit values >0.5. This indicates the high relief and steep slopes in the basin attributed to moderately active tectonism.

Form Factor (Rf)

Form factor (Rf) is defined as the ratio of basin area to square of the basin length by Horton (1932). The form factor shows the inverse relationship with the square of the axial length and has a direct relationship with peak discharge (Gregory and Walling, 1973). Low form factor is indicated by basins which are elongated and narrow and high form factor indicates that the basin is broad and wide (Gregory and Walling, 1985). Low form factor also indicates less rainfall simultaneously over its entire area than an area of equal dimension but with a larger form factor (Gupta, 1999). Short, wide basins have the largest form factors (Magesh *et al*., 2013). The analysis showed that the form factor varies between 0.167 and 0.443 (Table 12), which suggests a very narrow and elongated shape for the sub-basins. The highest value of form factor is shown by the sub-basins 2 and 5 and lowest value by sub-basin 1. Karamana drainage basin as a whole has a low form factor value of 0.240 indicating the elongated and narrow nature of the basin.

Compactness factor (Rcf)

Compactness coefficient is used to express the basin shape, as a factor of deviation of the basin area from a circle having the same area of the drainage basin. A circular basin is the most susceptible form, from a drainage perspective because it will yield the shortest time of concentration before peak flow occurs in the basin (Nooka Ratnam et al., 2005). Compactness factor for the sub-basins of the study area varies from 1.632 to 4.217, which indicates the elongated shape of the sub-basins (Table. 12). Compactness factor is highest for sub-basin WS10 (4.217) and lowest for sub-basin WS13 (1.632). Higher compactness factor indicates that the basin is more elongated. Khavari et al. (2009) opined that relatively young basins in active tectonic areas tend to be elongated in shape. Through continued evolution or less active tectonic processes, the elongated shape tends to evolve to a more circular shape (Bull and McFadden, 1977). Ramirez-Herrera (1998) observed that rapidly uplifting mountains generally exhibit elongated steep basins; and as the tectonic movement diminishes, widening of the basins occurs from the upstream reaches. Elongated shape of the basins also indicate a young stage of evolution, caused by intense tectonic activity (Lykoudi and Angelaki, 2004). The Karamana river drainage basin has a compactness coefficient of 3.386 and can be considered as an elongated basin.

Drainage texture (Dt)

Drainage texture (Dt) is the product of stream frequency and drainage density. It is an expression of the relative channel spacing in a fluvial dissected terrain (Mesa, 2006). It is also called infiltration number which depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development of a basin (Smith, 1950; Dornkamp and King, 1971)). Soft or weak rocks uncovered by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. Sparse vegetation of arid climate causes finer textures than those developed on similar rocks in a humid climate (Dornkamp and King, 1971). The higher the Infiltration Number, lower will be the infiltration and higher runoff. The drainage texture value below 4 is categorised as coarse, 4–10 as intermediate, above 10 as fine and above 15 as ultra-fine (Smith, 1950). In the present study, it is observed that, the drainage texture of WS12 (3.192) and WS13 (0.426) are coarse, whereas WS10 (9.266) and WS14 (5.296) have intermediate drainage texture. All the other sub-basins comes under the ultra-fine drainage texture (>15) category. In fact, a fine drainage texture reflects lower permeability strata, supporting lower infiltration, while a coarse drainage texture indicates higher permeability strata, promoting greater infiltration.

RELIEF ASPECTS

Relief aspects computed for the Karamana drainage system are basin relief (Rh), relief ratio (Rr), ruggedness number (Rn) and stream gradient (S). The respective values are furnished in Table 13.

Table 13 Relief morphometric parameters of sub basins in the study area

Watershed Code	Basin relief (Rh)m	Relief ratio(Rr)	Ruggedness number(Rn)	Stream gradient (S)m/km
WS01	1259	0.129	4.612	82.230
WS02	1443	0.152	6.857	96.872
WS03	639	0.108	3.568	68.482
WS04	648	0.114	3.424	76.377
WS05	425	0.044	1.865	28.202
WS06	341	0.064	1.382	40.651
WS07	197	0.048	0.771	30.702
WS08	235	0.058	0.985	36.798
WS09	267	0.032	1.308	20.399
WS10	248	0.014	0.548	9.148
WS11	214	0.020	0.565	12.529
WS12	87	0.007	0.147	4.765
WS13	166	0.005	0.131	3.444
WS14	89	0.008	0.162	5.031
WS15	1513	0.033	5.191	21.103

Basin relief (Rh)

The difference between the highest and the lowest elevation of the basin is refered to as basin relief (Rh). Basin relief controls the stream gradient and thus influences flood patterns as well as the amount of sediment that can be transported (Hadley and Schumm, 1961). Sreedevi (2004) opined that basin relief is a significant factor in understanding denudational characteristics of the basin. Basin relief of the sub-basins of the study area ranges from 87 to 1513 m. Among the sub-basins highest basin relief is recorded for WS02 (1443 m) and lowest is for sub-basin WS12, Vellayani sub-basin. Basin relief of Karamana main channel drainage basin is 1513 m and is the highest value recorded in the study area (Table. 13). The high Rh values are attributed by the palaeo- and neotectonic regimen of the Western Ghats. With increasing basin relief, steeper hill slopes and higher stream gradients, time of concentration of runoff decreases thereby increasing flood peaks (Ambili, 2010). Also basin relief aspects of the sub-basins play an important role in drainage development, surface and sub-surface water flow, permeability, landform development and erosion properties of the terrain.

Relief Ratio (Rr)

The ratio of basin relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956) (Table 13). It measures overall steepness of a drainage basin and is an indicator of the intensity of an erosional process (Ambili, 2010).There is a direct relationship between the relief and channel gradient which correlates to hydrological characteristics of a drainage basin. The relief ratio normally increases with decreasing drainage area and size of sub-basins of a given drainage basin (Gottschalk, 1964). The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin could be found reflected in the sediment load per unit area – this is closely correlated with relief ratio (Schumm, 1956). Relief ratio of sub-basins of the study area ranges from 0.005 (WS13) to 0.152 (WS02). The sub-basins WS01, WS02, WS03 and WS04 exhibits relief ratio > 0.10 suggests that the area is marked by steeper slope and high relief, underlain by resistant rocks (Vittala et al., 2004). All other sub-basins have a relief ratio < 0.10 indicating the occurrence of gently sloping small ridges and mounds in the catchment. Among the sub-basins, higher values of basin relief indicates comparatively steeply sloping terrain of the Western Ghats and consequently higher intensity of erosional processes as well as sediment load.

Ruggedness number (Rn)

The ruggedness number is the product of basin relief and drainage density (Strahler, 1958). It indicates the structural complexity of the terrain. Ruggedness number summarizes the interaction of relief and dissection such that highly dissected basins with low relief areas are rugged and moderately dissected basins with high relief occur as rolled basin (Ambili, 2010). The basins having high Rn values are highly susceptible to erosion and have intrinsic structural complexity in association with relief and drainage density. As observed by Melton (1965) very high ruggedness number occurs for a high relief region with high stream density. Ruggedness number of sub-basins of the study area varies from 0.131 (WS13) to 6.857 (WS02) and for Karamana main channel drainage basin it is 5.191 (Table 13). The high values observed for the upland basins imply that these basins are highly dissected basins with moderate to high relief and intrinsic structural complexity.

Stream gradient (S)

Stream gradient is the slope of the stream channel and is measured by the difference in elevation between two points on a stream divided by the distance between the two points along the stream. A stream that flows upon a homogeneously erodible bedrock will tend to have a steep gradient near its origin, and a low gradient nearing zero as it reaches its base level. Homogeneous bedrock would be rare in nature and hard layers of rock along the way may establish a provisional base level, followed by a high gradient, or even a waterfall, as softer rock units are encountered below the hard layer. Stream gradient of sub-basins of the study area varies from 3.444 to 96.872 m/km (Table 13). The sub-basins WS01, WS02, WS03 and WS04 in the high ranges of the terrain exhibit very high stream gradients. It indicates the mountainous nature of the sub-basins. High stream gradient indicates steep slope and rapid flow of water and tends to have steep narrow V-shaped valleys. Moderate stream gradients are observed in WS05, WS06, WS07, WS08 and WS09, indicates that these basins flows from the high land to midland topography with comparatively wide valleys. Highest value of stream gradient is observed in the sub-basin WS02 drained by Kaviyar tributary. The Karamana main channel drainage basin exibits stream gradient value of 21.103 m/km. The lowest value of stream gradient is observed in the sub-basin WS13 (Akkulam-Veli sub-basin). Very low stream gradient of sub-basins WS12, WS13 and WS14 indicates that they have more nearly level stream bed with wider and less rugged valleys.

HYPSOMETRIC ANALYSIS

The science of measuring the elevation of features on Earth's surface with respect to sea level is termed as hypsometry. For drainage basin studies, hypsometry is a measure of the relationship between elevation and area in a basin, watershed, or catchment (Langbein, 1947; Strahler, 1952). Basin hypsometry is strongly tied to flood response and the erosional maturity of a basin. The products of hypsometric analysis are hypsometric integral (Hi) as a value and hypsometric curve as a graphical representation. The hypsometric analysis can be used as a morphometric parameter, i.e. hypsometric integral, to deduce its relationship with the area of watersheds (Khadri and Nithin, 2015). The hypsometric curve has been termed the drainage basin relief graph. According to Ritter (2002), hypsometric curves and hypsometric integrals are important indicators of watershed conditions. Variancess in the shape of the curve and hypsometric integral values are related to the degree of disequilibria in the balance of erosive and tectonic forces (Weissel, 1994). The hypsometric curve is related to the volume of the soil mass in the basin and the amount of erosion that had occurred in a basin against the remaining mass (Hurtrez, 1999).

Strahler’s (1952) theoretical evolution of landscape identifies three main stages: a youthful non-equilibrium stage (Hi = >0.6), a mature equilibrium stage (Hi = 0.35–0.6) and an old age (Hi = <0.35. Ohmori (1993) argued that in areas with concurrent tectonics and denudation, the results of hypsometric integral are the reverse of Strahler’s theory. If highly resistant geological rock type maintains a portion of the summit plane during considerable erosion of the rest of the basin, hypsometric integral may reach low values. In homogenously erodible material, continued erosion of the basin high point may stabilize hypsometric integral in a middle range of values between 0.35 and 0.6. In a tectonically very active zone, hypsometric integral will be >0.6 and when it is >0.5, the area is tectonically active (Huertrez et al., 1999; Chen et al., 2003). If part of the hypsometric curve is convex in the lower portion, it may relate to uplift along a fault or perhaps uplift associated with recent folding (El Hamdouni et al., 2007). High values of hypsometric integral are possibly related to young active tectonics and low values related to older landscapes that have been eroded and less impacted by recent active tectonics (El Hamdouni et al., 2007).

The mean elevation, maximum elevation, mean elevation and hypsometric integral (Hi) values for the sub-basins are computed and presented in Table 14. In the study area, the values range from 0.09 (WS15) to 0.54 (WS14). Most of the sub-basins show old age according to Strahler's theory. WS14 exhibits tectonically active nature. WS03 and WS04 shows mature equilibrium age with respect to the hypsometric values. Ohmori's observation may be valid in the study area, when compared with the geology and structural characteristics of the study area.

Table 14 Mean, minimum and maximum elevations and the computed hypsometric integral of the sub-basins in the study area.

Watershed Code	Mean elevation (m)	Minimum elevation (m)	Maximum elevation (m)	Hypsometric integral
WS01	394.609	100	1358	0.23
WS02	620.375	114	1557	0.35
WS03	333.460	105	736	0.36
WS04	321.166	91	722	0.36
WS05	124.095	67	492	0.13
WS06	137.444	82	416	0.17
WS07	118.764	75	245	0.26
WS08	121.633	68	303	0.23
WS09	124.139	64	331	0.23
WS10	74.487	15	263	0.24
WS11	64.755	19	233	0.21
WS12	36.695	5	101	0.33
WS13	36.604	2	168	0.21
WS14	51.324	5	91	0.54
WS15	142.836	2	1557	0.09

The hypsometric curves constructed for the sub-basins in the study area are presented in Fig. 24. The shape of the hypsometric curves for different basins under similar climatic conditions and approximately equal area of the basins also provide relative insights into the past movement in the basins. Scheidegger (2004) suggested three stages – youth, mature and old stages of landscape evolution (Fig. 24). The shape of the hypsometric curve explains whether alteration in slope has taken place in comparison to the original basin (Singh et al., 2008). Hypsometric curves for the Karamana main channel basin (WS15) and WS13 suggests that the river is at the old age (concave shape). The sub-basin WS14 exhibits Convex hypsometric curve. El Hamdouni et al., (2007) opined that, if part of the hypsometric curve is convex in the lower portion, it may relate to uplift along a fault or perhaps uplift associated with recent folding. All other sub-basins in the study area show convexity in the lower portion of the hypsometric curve, probably due to uplift associated with folding or faults as discussed in the terrain characteristics section.

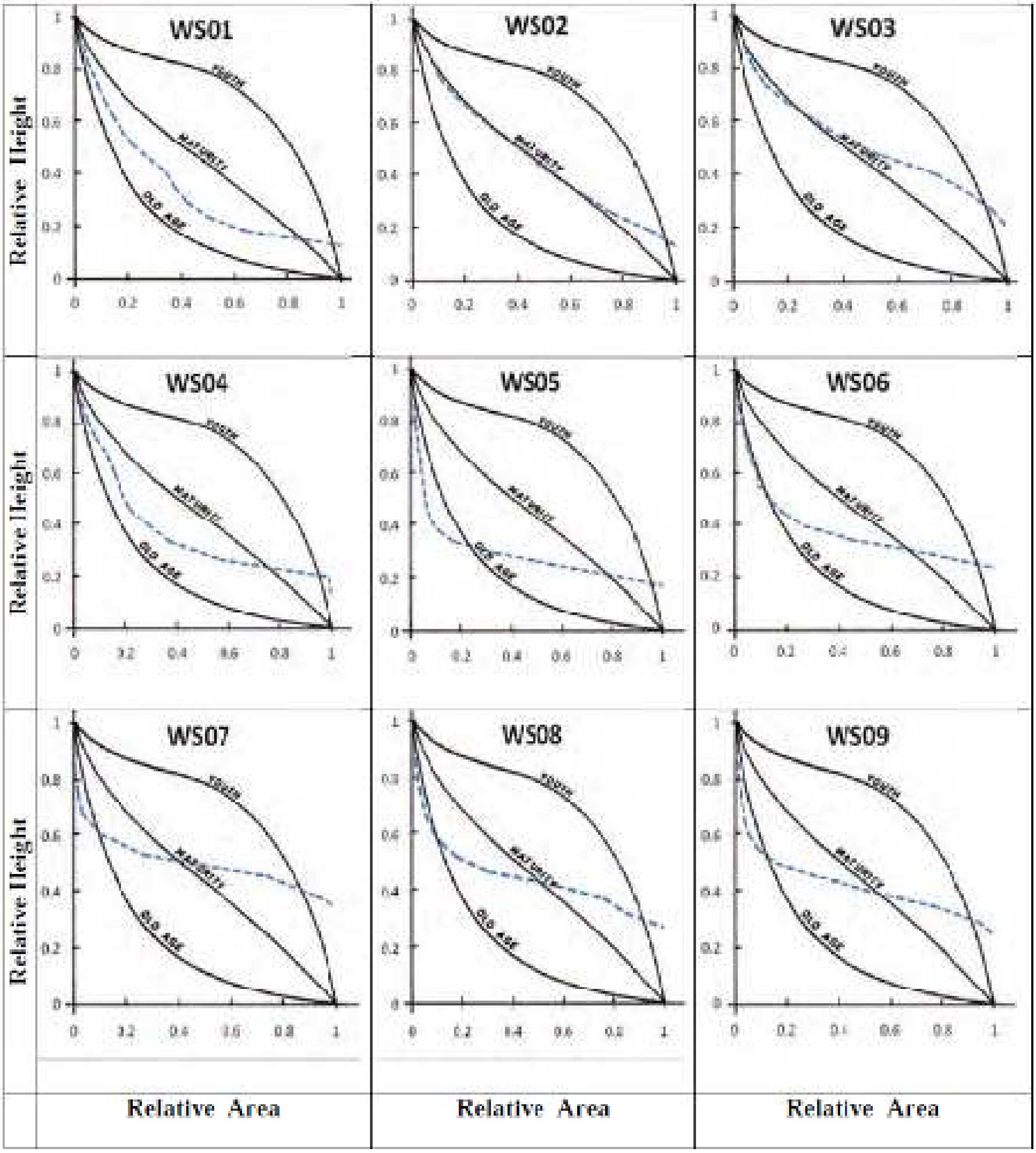


Fig 24 Hypsometric curves for the sub basins of the study area (Watersheds 1-9). (after Strahler, 1957 and Scheidegger, 1988)

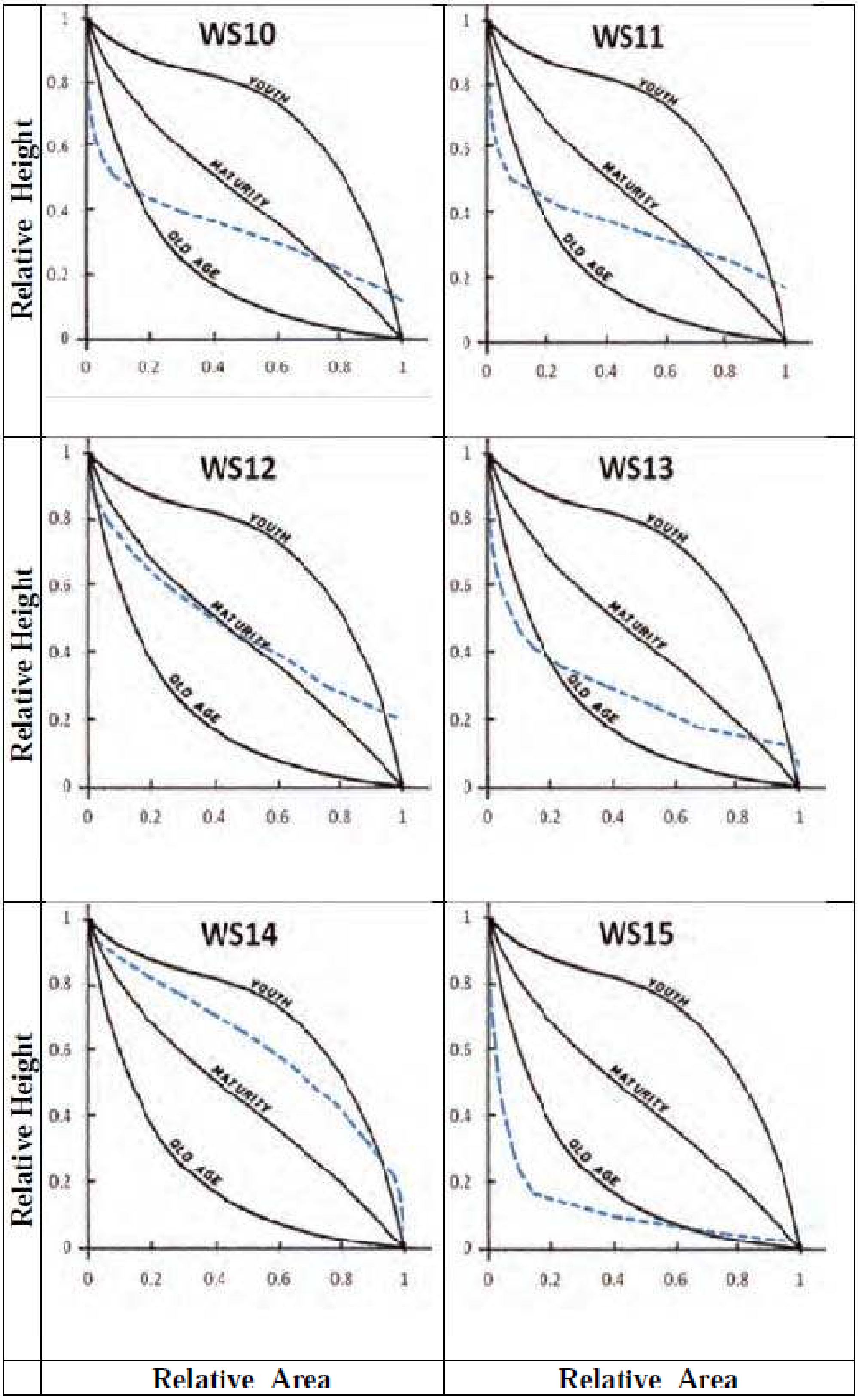


Fig 24 Continued. Watersheds 10-15.
(after Strahler, 1957 and Scheidegger, 1988)

RIVER BASIN EVOLUTION AND SEA LEVEL CHANGES

The tributaries of Karamana River do not display smooth concave profiles because of the prevalence of numerous knickpoints that are structurally controlled. Tributaries that flow through uniform lithology have high steepness index values indicating that the rate of uplift is exceeding the rate of incision. Tectonic uplift has been more important than river erosion, so that the tributary rivers could not develop an equilibrium profile. The actual form of the longitudinal profiles of the rivers is the result of continuous adjustment since Pleistocene until the present day.

Since stable base level results in the development of straight profiles, the analysis of longitudinal profiles of the tributaries of Karamana River suggest that base level history may affect the evolution of channel profiles. Knick point propagation may be a primary process of bed rock lowering along these streams and reflects the local tectonic events. Based on this, it has been hypothesized that the change in the base level due to uplift has resulted in the formation and propagation of the knickpoints. Stream length-gradient index values of the graded streams are homogenous and relatively high values indicate steepening of the slope.

River responses to active tectonics produce characteristic geomorphological features manifesting surface deformation in any area. River response to active tectonics depends upon the nature and amount of vertical movement in a river basin and the trend of the faults with respect to river flow. Geomorphic anomalies, such as deflected streams, compressed meanders, landslides, angular drainages and river ponding are the evidences of local tectonic movements.

The differential movements along the faults have produced tilting that triggered channel avulsion and shifted river flow from W to S and then to SW. In general, longitudinal profile, aggradation–degradation behaviour of channel, channel avulsion, pattern and cross-section morphology are some of the geomorphic expressions of active tectonics shaped the drainage basin. Later transverse faults have also affected the fluvial processes, channel morphology and fluvial avulsion.

Lineaments trending N-S, NE-SW, ENE-WSW, NNW-SSE and NW-SE marks the major drainage network in the drainage basin. Lower order streams follow the NW-SE lineaments and higher order streams follow N-S and NE-SW lineaments

The Western Ghats is fractured by numberous normal faults and the slow uplift of Southern Ghats might have taken place during the Mesozoic period. This had led to the development of initial relief. Uplifts in Mid Tertiary period has also led to development of valleys and low lands due to differential erosion. The formation of vast stretch of pediplain in central plains of the basin clearly depict a former planation surface. Among the landforms formed in the basin denudational and fluvio-denudational landforms are predominating in the eastern hilly terrain and central parts of the basin. The dissection in the hilly terrain are related to rejuvenation of the drainage owing to uplift that could have taken place during later part of Tertiary period.

Analysis of river profiles indicated that there could be prominent knick points in 40 to 90 and above 1,200 meters and indicates multicyclic development of river basin. The neotectonic activity is indicated by the development of lineaments, in NW-SE direction in eastern part of the basin.

The various stages in the development of a river valley are valley deepening, valley widening and valley lengthening. The fluvial processes dominated in shaping the present day river valleys in the basin are depicted by change in the river courses within the valley. Various erosional processes like hydraulic action, abrasion, corrosion, attrition, cavitation and corrosion have cut the bed of the river to widen, and deepen the river valley. Rivers cut down to their base level constantly adjusting the detailed morphology of their beds. Valley lengthening in the fluvial valley might have taken place by headward erosion and hydraulic action. Gradient, geological formation, changes in the base level and climatic changes are other factors which might have accelerated the process of lengthening.

Sudden changes in the climate and sea level might have resulted in the changes of river basin within the valley leading to widening, deepening the lengthening of river valleys and development of fluvial plains in the valleys and delta plains in the downstream. Moreover, the rate of down cutting is generally slow enough to allow processes causing lateral movement of channel to operate. This resulted in the formation of flood plains in the valley. Thus flood plains vary in width depending upon the size of the river. The relative ratio of down cutting and hardness of resistance of the rock depends on lithological material in the valley walls.

The changes in the micro climatic conditions might have also led to development of fluvial terraces in terrace plains. The formation of vast stretches of pediplains denotes that during the development of river basin in the past denudational processes like weatherning, mass wasting, erosion and deposition have played a significant role and reflects the paleo climatic influence. The plains and midlands of the basin might have experienced humid type of climatic condition, during which period, rapid down cutting and denudatinal activity might have denuded the mountain structures which were present on the present day pediplains and left behind a few remnants as residual hills. The prevalence of Tropical climate with plenty of rainfall in the Indian sub continent during Mio-Pliocene was inferred based on floral studies by Ramanujam (1968). Perhaps after a long humid period there was a slow change in the climate from humid to dry sub humid and semi arid in the basin and led to the formation of pediplains in the basin and led to the formation of central part of the basin. Thus the basin has experienced different climates during different geological periods. The later uplifts in Southern Ghats has led to the development of valleys and low lands due to weathering, mass wasting and terrestrial geomorphic processes. A few waterfalls present in the basin reflected that they are distinct knickpoints and denotes polycyclic development of basin. Majority of them seem to be controlled by structure and lithology.

In the coastal reaches abandoned and filled in river courses denotes former sediment deposits. The number and orientation of beach ridges in the lower part show distinct strandlines. Each straindline consists of a series of beach ridges lying almost parallel to each other and depict former shorelines of the basin. The beach ridges are build up by waves due to redeposition of sediments brought by the rivers during floods period into the Arabian Sea. Local emergence of sea level in between India and Sri Lanka around 4,200 - 150 years before present (yBP). has been reported by Stoddart and Gpinadha Pillai (1972) based on studies from massive pores from raised reefs at Pamban. In other words it depicts that the beach ridges would have been built up along the coastal plains after 4,020 - 150 yBP. Meijarink (1971) based on studies from air photos and a few sediment samples from the Cauvery delta has concluded that there must have been a fast rise in sea level from about 70 meters below Mean Sea Level during warm glacial period to the present level of the sea resulting in transgression over Pleistocene fluvial deposits. Naidu (1968) based on C^{14} dating of calcareous oolites samples separated from a sub-surficial layer of deep core sediments collected 200 km northeast of Kakinada suggests that there was lowering of sea level due to glaciation, off the coast of around 10,000 ± 155 yBP. Kalpin (1980) had described that between 17,000 and 6,000 yBP world ocean level was much below present day, whilst in the past 6,000 yBP, it did not vary beyond 10 meters. From the above C^{14} datings it reveals that the Coast of India has been subjected to both submergence and emergence. In this connection it may be pointed out that, the modern valley deposits as well as coastal deposits of the Karamana might have been formed after 6,000 yBP. However, it do not preclude to the much older formations present below the deposits. Finally it may be concluded that both changes in the climate, and in the sea levels along with exegenetic and endegenetic activities during the Mid Tertiary and Pleistenene period in particular might have led to development of Karamana river basin and majority of the present day landforms might have formed during the Pleistocene period.

SEDIMENTOLOGY

Grain size is a descriptive measure of clastic sediments. Comprehensive study of grain size distribution may yield information about the physical mechanisms during deposition. Knowledge on grain size classes is also used for unraveling the extent of transportation of sediments in both ancient and modern depositional environments. Furthermore, it is widely accepted and proved that variation in grain size is related to many aspects like channel morphology, source materials and process of weathering, abrasion and corrosion of grains and sorting processes during transportation and deposition (Blatt et al., 1972). Grain size imparts the properties like permeability and porosity of sedimentary aquifers as well, which in turn, have major social and economic relevance due to the groundwater conditions. All these factors have continued to make grain size analysis an important tool of research in aquatic environments.

Extensive studies on grain size characteristics in different parts of the world reveal the existence of significant correlation between size frequency distribution and depositional processes. Proper selection and combination of statistical parameters can excellently be used for discrimination of depositional environments. Apart from the environmental implications, the particle size distribution bears considerable influence on the hydrological properties of modern sediments. Hence an attempt has been made in this chapter to understand the particle size distribution of the sediments of the Karamana river basin.

Grain size variation

The sediment samples of the Karamana river catchment exhibits a spectrum of particle sizes ranging from pebbles to mud. Cobbles and boulders are excluded from the present study because of the difficulty in measuring size classes of these bigger particles. The details of different textural grades in the river channels and tributaries as well as the reservoirs are summarised in Table 15. Fig. 25 depicts the spatial variation of grain size fractions along the main channel of the Karamana river. River sediments are characterised by high amount of gravel with dominance of pebbles (av. 37.03%; range: 0.63–76.36%) over granules (av. 10.47%; range: 0.87 - 25.6%). The amount of pebbles decreases towards reservoirs and this change is more pronounced in the upper catchments (i.e., Peppara reservoir catchment) than the downstream reaches. As the river enters into the Peppara reservoir, the pebble content decreases drastically and touches a low average of 1.65% in the reservoir confluence. The sediments of Aruvikkara reservoir are devoid of pebbles.

Table 15 Percentage of various size grades in the sediments of Karamana river basin

a) River Channel Sediments

Sample No:	Pebble (1)	Granule (2)	Gravel (1+2)	Very Coarse Sand (3)	Coarse Sand (4)	Medium Sand (5)	Fine Sand (6)	Very Fine Sand (7)	Sand (3+4+5+6+7)	Mud (8)
Main Channel										
1	44.24	13.24	57.48	19.05	11.61	8.18	2.68	0.55	42.05	0.46
2	45.61	8.55	54.16	16.94	12.03	11.24	4.77	0.63	45.21	0.63
3	55.77	12.18	67.94	11.52	5.80	8.81	4.04	0.41	30.55	1.51
4	32.42	8.71	41.14	16.97	20.01	16.40	3.11	0.70	58.19	0.67
5	69.25	12.03	81.28	11.00	4.07	2.57	0.73	0.14	18.54	0.20
6	9.95	5.86	15.81	12.53	11.72	31.09	23.04	3.82	82.21	1.96
7	15.80	10.20	25.01	21.55	17.62	20.31	13.05	2.12	73.65	0.33
8	22.86	19.17	42.03	29.27	12.55	9.01	5.93	0.80	57.66	0.31
9	6.18	4.86	11.04	20.94	28.53	29.42	4.61	1.17	84.67	4.29
10	1.38	4.53	5.91	13.20	20.74	25.06	12.21	1.73	93.53	0.56
11	2.45	7.94	10.39	16.30	21.57	28.09	9.45	2.49	88.38	1.23
12	-	0.87	0.87	5.03	31.53	40.55	10.12	1.10	97.34	1.79
13	-	1.14	1.14	5.23	29.21	38.92	13.55	1.24	88.15	10.71
14	-	-	-	2.91	13.02	41.00	23.12	4.13	84.18	15.82
15	-	2.79	2.79	18.82	65.48	5.45	3.60	1.56	95.40	1.81
Killiyar Sub basin										
16	20.68	11.99	32.67	0.50	7.70	8.70	6.93	3.66	35.98	31.35
17	-	-	-	-	6.48	2.39	53.43	28.12	84.42	15.58
18	28.28	17.67	45.96	28.01	14.40	8.41	1.88	0.34	53.01	1.03
19	44.92	12.17	57.09	19.25	7.36	8.91	3.30	0.39	39.21	3.70
20	58.27	11.28	69.54	11.37	5.08	5.72	3.40	1.02	26.58	3.88
21	48.35	19.90	68.24	21.95	4.30	1.38	1.34	0.57	29.22	2.54
22	44.04	12.94	56.98	17.15	12.55	9.13	2.74	0.27	41.85	1.17
Akkulam - Veli sub basin										
23	-	-	-	0.32	1.17	8.23	25.75	8.65	41.91	58.19
24	48.93	11.20	60.13	12.12	5.79	9.42	8.67	1.21	37.22	2.65
25	20.48	25.62	46.09	23.82	20.39	7.84	1.32	0.13	53.49	0.42
26	21.55	16.30	37.85	25.21	28.86	8.80	0.55	0.26	61.71	0.38
27	-	2.40	2.40	7.42	21.29	34.10	25.61	6.10	94.51	3.09
28	14.81	5.98	20.79	12.50	30.05	31.25	5.85	0.51	79.20	0.01
Vellayani- Malayam sub basin										
31	-	-	-	0.08	0.19	2.01	11.53	14.58	28.39	71.61
32	4.05	4.54	8.59	38.66	39.40	25.14	6.19	1.17	90.45	0.95
33	1.91	10.16	12.07	21.01	26.68	29.22	9.34	1.53	87.18	0.75
34	0.03	11.38	11.90	34.05	42.55	7.00	1.84	0.69	86.78	1.25
35	5.40	12.07	17.56	35.02	35.14	9.72	1.67	0.11	81.66	0.78
Aryanad sub basin										
36	74.52	11.95	86.47	7.14	1.38	1.21	0.37	0.09	10.18	3.35
37	41.10	12.42	53.52	25.83	5.48	12.23	7.10	0.79	44.52	1.96
38	36.45	9.08	45.57	15.53	12.41	14.62	9.08	1.44	53.09	1.34
39	71.68	8.03	79.71	12.05	5.25	1.67	0.19	0.02	19.22	1.07
40	30.92	7.53	38.45	13.94	5.43	14.33	19.13	4.42	57.25	4.30
Upper Peppara sub basin										
41	40.82	10.00	50.82	15.90	16.58	14.15	7.53	1.08	47.91	1.27
42	43.95	12.20	56.27	20.41	12.39	7.82	1.61	0.44	42.67	1.06
43	-	2.79	2.79	7.18	29.47	35.15	12.96	1.51	96.27	0.94
44	49.01	12.51	61.51	28.70	5.95	5.88	2.12	0.31	36.94	1.55
45	57.77	9.05	66.82	16.54	9.28	5.57	1.23	0.15	32.76	0.42
46	76.38	10.08	86.46	8.63	1.82	1.37	0.48	0.11	12.39	1.15
47	67.63	18.61	86.23	2.79	3.05	5.17	1.93	0.47	13.42	0.35
48	67.42	6.26	73.68	13.04	7.23	4.02	0.85	0.12	25.30	1.02
Thollikode sub basin										
29	54.64	21.38	66.01	12.79	5.18	6.38	3.78	0.61	31.74	2.25
30	62.58	16.15	78.73	7.86	4.06	4.70	3.46	0.50	20.05	1.19
49	35.72	15.23	50.95	23.83	12.95	8.92	2.78	0.93	49.01	0.02
50	38.34	12.72	51.06	22.84	12.12	7.13	2.97	0.92	45.99	2.95

Table 15 Continued…..

b) Reservoir Sediments

Sample No:	Pebble	Granule	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Sand	Silt	Clay	Mud
	(1)	(2)	(1+2)	(3)	(4)	(5)	(6)	(7)	(3+4+5+6+7)	(8)	(9)	(8+9)
Aruvikkara Reservoir												
51	-	-	-	0.47	1.05	3.51	33.95	24.78	63.76	14.10	22.14	36.24
52	-	1.45	1.45	1.91	2.92	2.81	13.7	17.65	38.99	23.66	35.9	59.55
53	-	-	-	-	0.08	0.2	2.58	2.77	5.64	33.55	60.81	94.36
Peppara Reservoir												
54	11.58	6.19	17.77	7.13	10.63	9.19	6.86	2.66	36.46	14.35	31.41	45.76
55	-	-	-	32.14	7.71	11.57	11.04	2.33	64.78	11.56	23.66	35.22
56	-	-	-	-	22.49	7.17	21.89	2.96	54.51	17.82	27.67	45.49
57	-	-	-	0.08	0.60	0.79	3.82	20.97	26.25	46.58	27.17	73.75
58	-	0.25	0.25	0.5	3.77	4.96	4.37	2.35	15.96	51.05	32.71	83.79
59	-	-	-	0.12	0.04	0.21	0.62	2.02	3.02	59.97	37.01	96.98
60	-	-	-	-	-	-	-	0.07	0.07	24.93	75.00	99.93

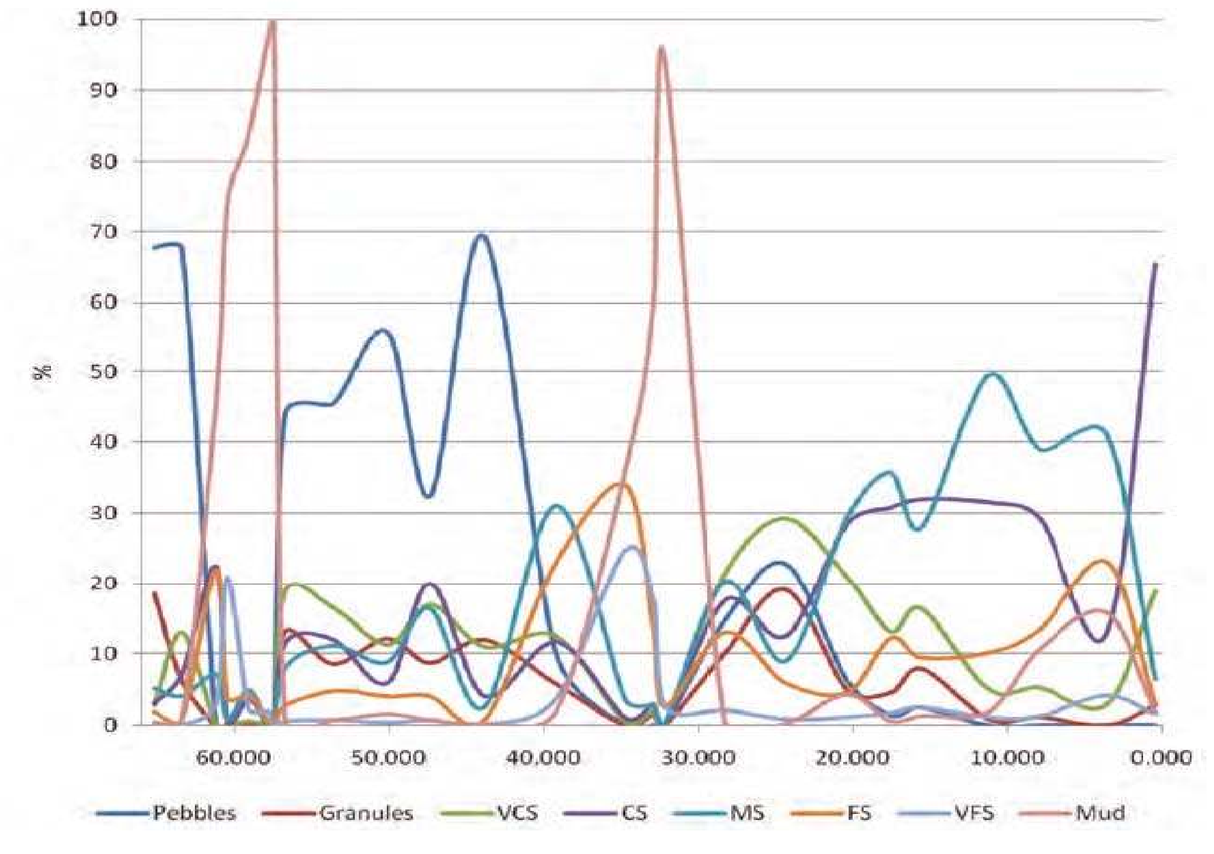


Fig. 25 Variation of Grain size fractions in the sediments of Karamana river system through the main river course. Distance measurements are from Karamana river confluence with Arabian sea (ie., river mouth). VCS - Very Coarse Sand; CS - Coarse Sand; MS - Medium Sand; FS - Fine Sand; VFS - Very Fine Sand

The variation of granules indicates a complementary pattern to that of pebbles. This is very much so in the study area and the average content of granules is 9.99 % (0.25–25.6%). In general, the subsequent locations of pebble highs are the sites of granule enrichments, though that is not so proportional. It may be attributed to the progressive decrease in competency of the river water downstream which allows pebbles to settle first and then granules. In the upper reaches, progressive reduction in quantity of pebbles is compensated by an increase in the granule content. The similarities in the variation of pebbles and granules at certain locations in the downstream reaches indicate the close range of size. Pebbles in such locations are finer in nature and are almost hydraulically equivalent to granules. The marked change in the flow regime between tributaries and reservoirs also imparts a strong bearing on the grain size distribution in the study area.

The coarse and very coarse sand fractions show a similar variation to that of granules along the river channel. In the upper catchments the coarse sand content is almost stable along the river course but, shows a downward increase in the main river channel as well as in tributaries. The variation of medium sand shows deviation from its coarser entities by exhibiting a general increase towards the reservoirs and shows further decrease towards dam site. This is in consonance with the flow characteristics controlled by terrain gradient and/or engineering structures constructed across the river channels. It is noted that the medium sand shows its peak values at the confluence zones of the reservoirs. The fine sand and very fine sand contents are negligible in the river channels, especially in the tributaries. The fine sand content varies considerably in different locations both in tributaries and in the main channel. Fine sand shows a marked increase in the arms of the reservoir adjoining the confluence zones and increases further towards the dam site. Mud content is negligible in the tributaries and the main channel as the flow conditions do not facilitates its deposition within these stretches.

Within the reservoirs, coarser entities, which are encountered in the river are totally missing or present only in subtle quantities. The Aruvikkara and Peppara reservoirs are floored mainly by mud-rich sediments. The mud contents in the sediments of Aruvikkara and Peppara reservoirs averages 63.38% (36.24–94.36 %) and 72.53% (35.22–99.93%), respectively. The content of mud increases progressively towards the dam site with a complementary decrease in coarser fractions. The average sand content of Aruvikkara reservoir is 36.13% and that of Peppara is 27.43%. The fine and very fine sand fractions contribute about 80% of the sand content in Aruvikkara reservoir.

A scrutiny of the grain size variation along tributaries and the river channel reveals a size-based segregation or sorting of the sediment particles along the river course. The maximum population of each successive finer fraction shows a shift towards the reservoirs. It indicates a gradual decrease in the competency of the river downwards. The observed gradation of size fractions is not so pronounced in the lower tributaries of the Karamana river system. The upstream tributaries show distinct size based sorting / segregation of sediment particles, probably attributed to the combined effects of terrain characteristics as well as impoundment by the Peppara dam. The lower reaches of the study area is subjected to intense anthropogenic activities (e.g. sand mining from in-stream and flood plain areas, agricultural activities on river banks and lack of sufficient river flow due to the dams) than the upper reaches. This in turn is reflected in the spatial distribution of grain size fractions in the river stretch especially down to the Peppara dam.

In the middle part of the study area, the Aryanad sub-basin (the area drained by three minor channels in the left bank of Karamana river upstream of Aruvikkara is referred to hereafter as the Aryanad sub-basin) shows only a minor shift in grain size distribution compared to Tholickode sub-basin (the area drained by Chit *Ar*, Parandod and Attingal *thodu*). The average size spectra of the Aryanad sub-basin comprises pebble (50.94%), granule (9.80%), very coarse sand (12.90%), coarse sand (6.59%), medium sand (8.81%), fine sand (7.19%), very fine sand (1.35%) and mud (2.40%). At the same time Tholickode sub-basin exhibits a slightly different size combination – pebble (47.81%), granule (13.88%), very coarse sand (16.74%), coarse sand (9.32%), medium sand (6.78%), fine sand (3.25%), very fine sand (0.64%) and mud (1.60%). The coarser entities (>1mm) except pebbles show high percentages in Tholickode sub-basin while finer fractions are comparatively low. This observed variation in the size population of sediments may be related mainly to the differences in relief features of the respective regions.

In the case of tributaries joining the lower part of the study area, Killiyar sub-basin exhibits pebble (40.75%), granule (14.32%), very coarse sand (17.87%), coarse sand (7.38%), medium sand (6.37%), fine sand (10.43%), very fine sand (4.82%) and mud (8.46%). While the size spectral distribution of Akkulam-Veli sub-basin is pebble (26.96%), granule (11.90%), very coarse sand (13.24%), coarse sand (17.93%), medium sand (16.27%), fine sand (11.08%), very fine sand (2.81%) and mud (10.79%). The gravel part is considerably low in this sub-basin evidently due to low relief of the catchment area. Vellayani-Malayam sub-basin shows further reduction in coarser fractions with increase in finer fractions as pebble (3.02%), granule (9.53%), very coarse sand (21.75%), coarse sand (28.67%), medium sand (14.74%), fine sand (6.11%), very fine sand (3.62%) and mud (15.07%). This clearly suggests that the relief features of the catchment directly influences the size spectral distribution of fluvial sediments.

Fig. 26 shows variation of different grain size fractions in the sub-basins, main channel, as well as the reservoirs. The tributaries and main channel record high content of gravel (pebble + granule) than sand and mud. The Peppara reservoir has high percentage of mud than the Aruvikkara reservoir, which is characterized by higher proportions of finer sand fractions (medium + fine + very fine). The transition zone of river and reservoir (ie, confluence zone) is occupied mainly by high proportions of coarse and medium sand fractions. These observations clearly bring out the difference in the hydrodynamic conditions prevailing in the respective sub-environments of the Karamana river basin.

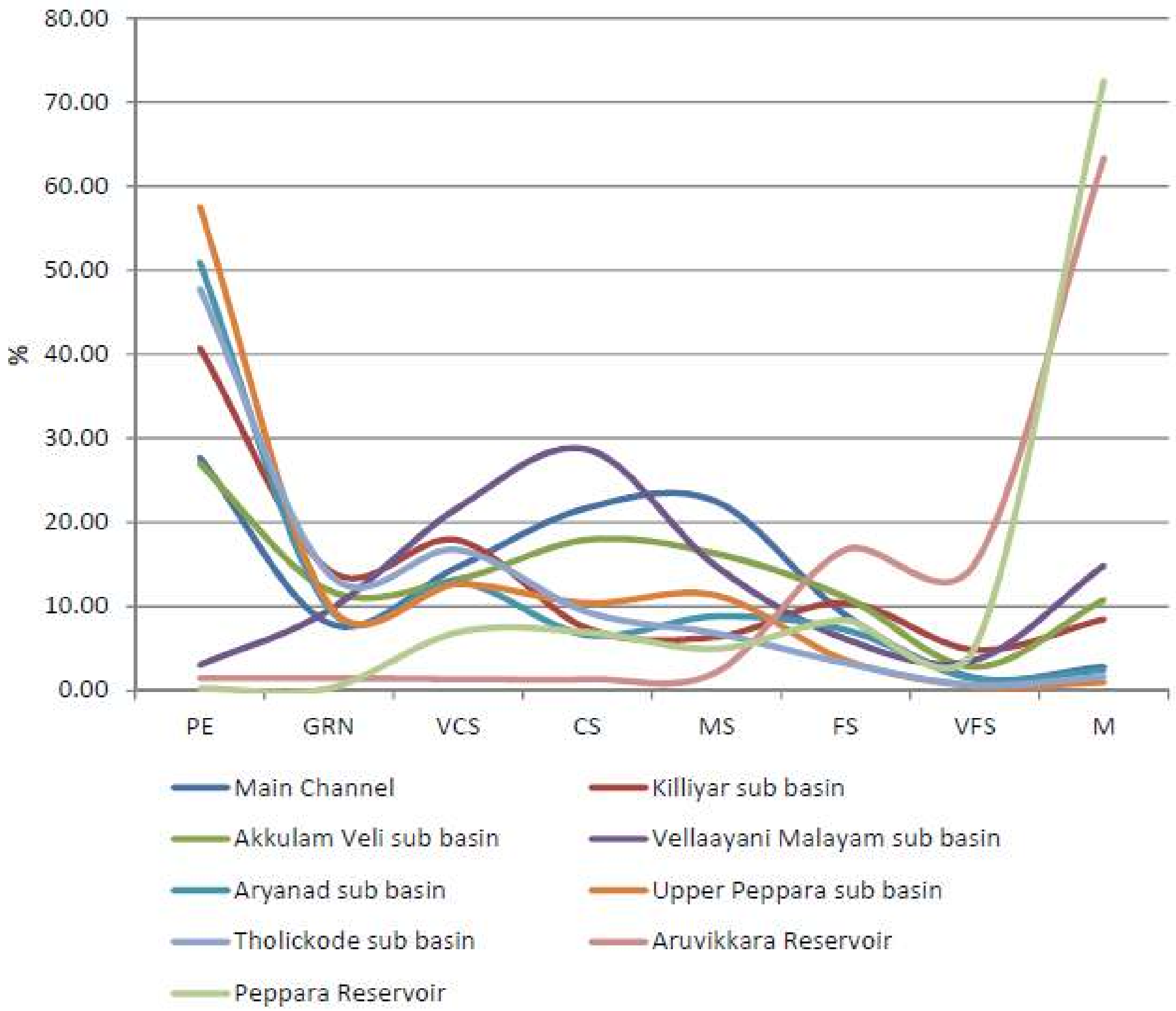


Fig. 26 Grain size distributions in the sediments of various sub environments in the study area (PE - pebble, GRN - Granule, VCS - very coarse sand, CS - Coarse sand, MS - Medium sand, FS - Fine sand, VFS - very fine sand, M - Mud).

Statistical parameters

The statistical parameters computed for the sediments of Karamana river basin are furnished in Table 16 and their variations along the longitudinal profiles of the main channel are presented in Fig. 27. The following sections summarize the major observations of this study.

Table 16 Statistical parameters of the sediments in Karamana river basin

Sl No.	Mean (Φ)	SD (Φ)	Sk	Ku
Main Channel				
1	-1.17	1.55	0.50	0.82
2	-1.03	1.68	0.47	0.68
3	-1.47	1.47	0.63	0.90
4	-0.52	1.60	-0.02	0.64
5	-2.03	1.16	0.49	1.60
6	0.87	1.81	-0.31	0.96
7	0.12	1.76	-0.09	0.84
8	-0.67	1.57	0.16	0.87
9	0.57	1.46	-0.13	1.57
10	0.82	1.21	-0.21	1.31
11	0.70	1.27	-0.10	1.18
12	1.20	0.70	0.12	1.83
13	1.26	0.78	0.08	1.30
14	2.23	2.20	0.55	3.15
Killiyar sub basin				
15	0.40	0.77	0.18	2.14
16	3.08	5.49	0.52	0.69
17	3.20	1.82	0.73	3.40
18	-0.22	1.42	-0.90	0.69
19	-1.07	1.69	0.65	1.04
20	-1.53	1.98	0.52	1.20
21	-1.65	1.26	0.44	1.07
22	-1.03	1.56	0.28	0.74
Akkulam-Veli sub basin				
23	6.70	4.35	0.45	0.65
24	-0.95	1.97	0.65	0.76
25	-0.80	1.32	0.04	0.77
26	-0.38	1.39	-0.64	0.66
27	1.62	1.18	0.10	1.09
28	0.13	1.52	-0.51	1.07
Vellayani-Malayam sub basin				
31	7.42	4.03	0.19	0.68
32	0.60	1.16	-0.21	1.39
33	0.52	1.23	0.10	0.75
34	0.85	0.84	-0.09	1.25
35	-0.07	1.01	-0.08	0.78
Aryanad sub basin				
36	-1.88	0.84	0.58	7.99
37	-0.83	1.80	0.52	0.70
38	-0.53	1.82	0.25	0.67
39	-1.92	1.10	0.55	1.60
40	-0.75	2.33	0.84	0.57
Upper Peppara sub basin				
41	-0.70	1.80	0.35	0.66
42	-1.17	1.51	0.47	0.88
43	1.20	0.58	0.70	0.53
44	-1.40	1.60	0.52	0.99
45	-1.58	1.35	0.69	0.87
46	-1.93	0.73	0.47	4.34
47	-3.30	1.45	0.42	1.70
48	-1.72	1.34	0.40	0.88
Tholickode sub basin				
29	-1.35	1.67	0.68	1.00
30	-1.77	1.31	0.66	1.53
49	-0.93	1.57	0.16	0.83
50	-0.98	1.74	0.26	0.99
Aruvikkara reservoir				
51	5.43	4.02	0.80	1.95
52	6.65	4.69	0.46	0.82
53	8.70	2.58	-0.52	0.71
Peppara reservoir				
54	4.42	5.84	0.39	0.72
55	4.10	5.62	0.57	0.87
56	5.13	5.21	0.66	0.85
57	6.15	2.72	0.46	0.75
58	7.37	3.54	-0.03	1.07
59	7.52	2.44	0.22	0.91
60	9.72	2.01	0.03	0.78

SD - Standard Deviation
Sk - Skewness
Ku - Kurtosis

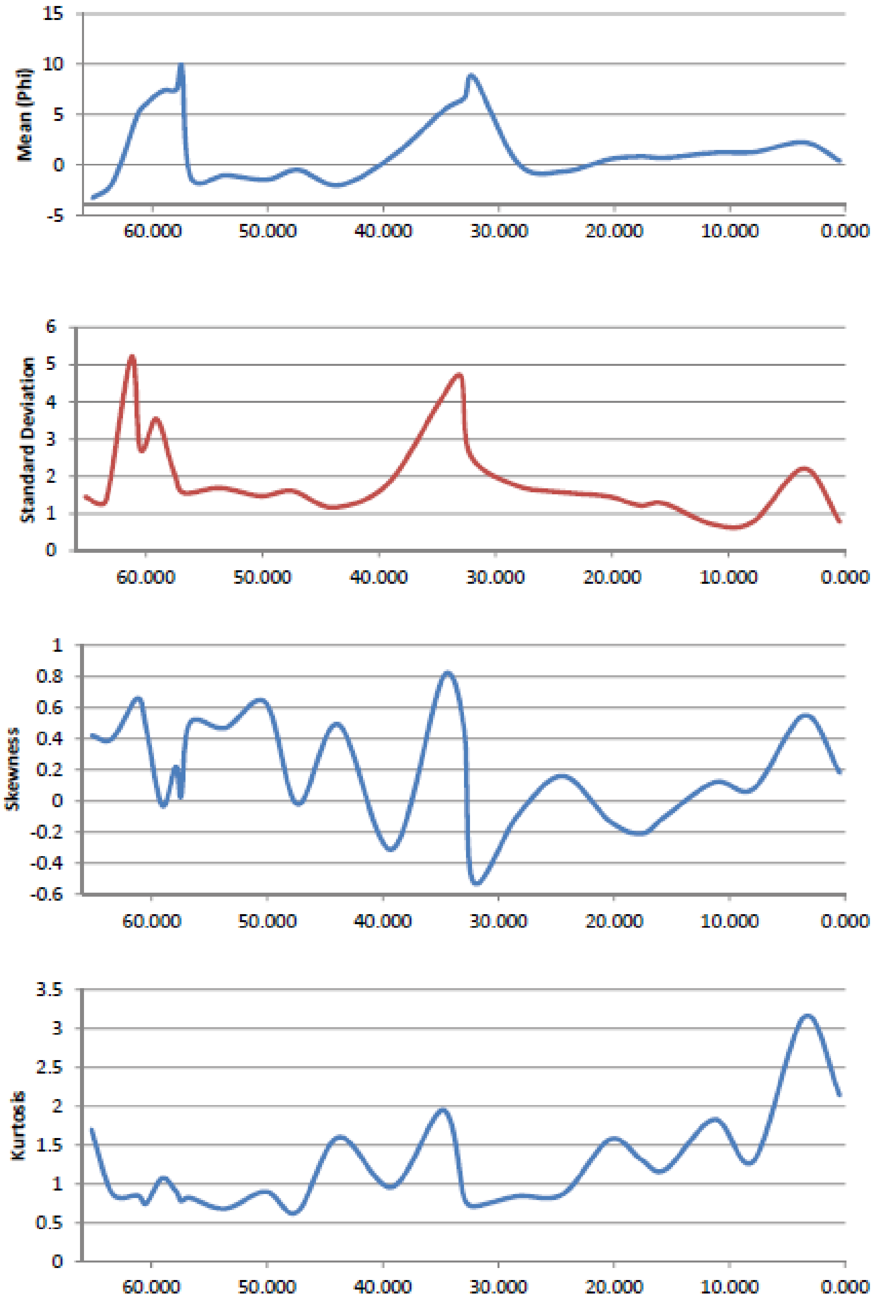


Fig. 27 Variation of statistical parameters of the sediments of Karamana river system through the main river course. Distance measurements are from Karamana river confluence with Arabian sea (ie., river mouth).

Mean size

The mean size of river sediments ranges from -3.3 to 3.08ɸ (pebble to very fine sand). Samples from the Vellayani and Akkulam lakes, the mean size is 7.42ɸ (very fine silt) and 6.7ɸ (fine silt). In the Upper Peppara tributaries mean size ranges from -3.3 to 1.2ϕ. The main channel accounts for mean values of -2.03 to 2.23ϕ. The mean size variations in Aryanad, Tholickode, Killiyar, Akkulam-Veli and Vellayani- Malayam sub-basins are -1.92 to -0.53 ϕ, -1.77 to -0.93 ϕ, -1.65 to 3.2 ϕ, -0.95 to 6.7ϕ, and -0.07 to 7.42 ϕ respectively. Samples from the Upper Peppara sub-basin clearly indicate a downstream increase in the phi mean size, whereas in the other sub-basins such a change is not so pronounced. Contrary to river sediments, the reservoir sediments show markedly high phi mean values (i.e., decrease in actual grain size in mm). The mean values of Peppara reservoir sediments vary from 4.1 (coarse silt) to 9.72ϕ (clay) and that of Aruvikkara reservoir ranges from 5.43 (medium silt) to 8.7 (clay) ϕ. In general the phi mean values exhibit an increase towards the dam site.

The spatial variation of phi mean along the river profile is depicted in Fig. 27 which shows an increase towards downstream up to the Peppara dam site. The channel below the dam has very low phi mean values which increases again towards the Aruvikkara dam. An abrupt decrease of phi mean in a location near Aryanad town may be attributed to the local turbulence resulting from a check dam constructed above the sampling point. Very low phi mean values are recorded in the Akkulam and Vellayani lakes. When the competency of the river water decreases, the coarser particles will be deposited first, while the finer be transported still further downstream. However, from Fig. 27, it is evident that the competency of the river water fluctuates at many places due to natural (rapids, rocky exposures within river channels, etc.) and manmade structures (dams, check dams, bridges, etc.). Damming of river reduces its competency at significant levels which in turn results in deposition of suspended sediment in the reservoir behind the dam as well as the natural lakes present in the Karamana river catchment.

Standard deviation

The sediment sorting improves when the spread size becomes narrow. Investigations show that mean size and sorting correlates well in sand and pebble grades and correlation worsens as the grain size increases. It is also proved that silt and clay show improved sorting as grain size increases.

In the river environment, the standard deviation varies between 0.58ϕ (moderately well sorted) and 5.49ϕ (extremely poorly sorted). In the sub-basins, almost all the samples are moderately well (0.58ϕ) to extremely poorly sorted (5.49ϕ). In the main channel the sediments are moderately well (0.7ϕ) to very poorly sorted (2.2ϕ). Sediments in the Aryanad sub-basin show moderately (0.84ϕ) to very poorly sorted (2.33ϕ) nature. In Tholickodu sub-basin sorting ranges from 1.31ф to 1.74ф (poorly sorted). In the Akkulam-Veli sub-basin, sorting fluctuates between poorly sorted (1.18ф) and extremely poorly sorted (4.35ф) categories. In the Killiyar sub-basin the sorting varies between poorly (1.26ф) to extremely poorly sorted (5.49ф). The Upper Peppara sub-basin shows 0.58ф (moderately well sorted) to 1.8ф (poorly sorted) standard deviation values. Moderately well sorted and moderately sorted samples are from the river confluence zones of Peppara reservoir. In general sorting improves towards the river confluence zone but with distinct fluctuations at certain locations. The observed increase in sorting is attributed to differential transport of sediments downstream. Inman (1949) opined that once the sediment attains maximum sorting values, any further fall in the competency of the transporting medium induces an increase in the content of finer particles in the sediments. This once again imparts immaturity to the sediments.

All the samples in the reservoir environments exhibit very poorly to extremely poorly sorted particle dispersion. The sediment sorting varies between 2.58ф and 4.69ф in the Aruvikkara reservoir and between 2.01ф and 5.62ф in the Peppara reservoir. The abundance of finer particles especially silt and clay imparts broad particle dispersion which in turn causes very poor sorting of sediments (Allen, 1970).

Skewness

In textural analysis skewness is considered as an important parameter because of its extreme sensitivity in sub-population mixing. Well-sorted unimodal sediments are usually symmetrical with zero skewness. In a fine skewed population, the distribution of grains will be from coarser to finer entities and, the frequency curve chops at the coarser end and tails at the finer. The reverse condition is characteristic of coarse skewed sediments. Martin (1965) has suggested that coarse skewness in sediments could be attributed to two possible reasons, 1) addition of materials to the coarser terminal or 2) selective removal of the fine particles from a normal population by winnowing action.

The river sediments of the Karamana river basin exhibit skewness values between -0.9 and 0.84. Variation of skewness along the river channel depicts marked fluctuations along its profile (Fig. 27). In Aruvikkara reservoir skewness varies from very coarse (-0.52) to very fine (0.8) category, while in Peppara, it varies from nearly symmetrical (-0.03) to very fine skewed (0.66). The variation of skewness is more complex in the reservoir environment. About 60% of the samples in the reservoir environment exhibit very fine skewness, 30% is symmetrical and others are fine skewed. Very fine skewness in the reservoir sediments is attributed to addition of silt and clay modes in the already deposited sediments. The presence of symmetrical and near symmetrical samples indicates an equal proportion of different modes.

Kurtosis

Kurtosis, the peakedness of the frequency curve, is a measure of the contrast between sorting at the central part of the size distribution and that of the tails. Fig. 27 shows the spatial variation of kurtosis along the profile of the river. Kurtosis of the river sediments ranges from very platykurtic to extremely leptokurtic (0.53–7.99). The Aruvikkara reservoir sediments are platykurtic to very leptokurtic (0.71–1.95) and that of Peppara reservoir are platykurtic to mesokurtic (0.75–1.07). In natural environments, the kurtosis values reflect fluctuations in the velocity of the depositing medium. Values greater than unity suggest greater fluctuations (Verma and Prasad, 1981) in the energy conditions of the depositing medium. The fluctuations are clearly pronounced in both the reservoir and river environment.

Classification of sediments

River sediments

The weight percentages of gravel, sand and mud in the river/tributary sediments of the Karamana river basin are summarised in Table 17. Since most of the samples contain significant amount of gravel, the textural classification of Folk et al. (1970) for gravel-bearing sand is followed here to decipher sediment types. From Fig. 28, it is evident that the river sediments show a wide range of textural classes. Gravel, sandy gravel, gravelly sand, slightly gravelly sand, muddy sandy gravel and sand are the sediment types encountered in river channels. Gravel, sandy gravel, gravelly sand, slightly gravelly sand and sand are encountered in the Upper Peppara sub-basin. Gravel dominates in the upstream part, but sand and gravelly sand are confined mainly to reservoir confluence. In Tholickode sub-basin, all the samples fall in the sandy gravel category. Gravel is found in the Aryanad sub-basin, while the upstream portions are floored by sandy gravel. In Vellayani-Malayam sub-basin gravelly sand and and slightly gravelly sand type sediments are observed except in the lake area, which is floored by sandy mud.. Gravelly sand sediments are found in the immediate vicinity of the Aruvikkara reservoir, where the tributaries join with the reservoir. In the main river channel, the sediment types are gravel, sandy gravel and gravelly sand. The gravelly sand type of sediments is encountered near the Aruvikkara reservoir and gravel dominates the river bed near Aryanad. The presence of gravel-rich coarser sediments in Aryanad may be attributed to the local turbulence generated by the check dam and bridge in the vicinity of the sampling site. The abundance of sand rich sediments confined to the reservoir confluence zone indicates that the competency of the rivers/tributaries is getting reduced due to reservoir waters.

Table 17 Sediment types of the Karamana river channel sediments.

Sample No.	Gravel %	Sand %	Mud %	Sediment Type (Folk et al., 1970)
Main channel				
1	57.48	42.06	0.46	Sandy gravel
2	54.16	45.21	0.63	Sandy gravel
3	67.94	30.55	1.51	Sandy gravel
4	41.14	58.19	0.67	Sandy gravel
5	81.26	18.54	0.2	Gravel
6	15.81	82.21	1.98	Gravelly sand
7	25.01	74.66	0.33	Gravelly sand
8	42.03	57.66	0.31	Gravelly sand
9	11.04	84.67	4.29	Gravelly sand
10	5.91	93.53	0.56	Slightly gravelly sand
11	10.39	88.38	1.23	Slightly gravelly sand
12	0.87	97.34	1.79	Sand
13	1.14	88.15	10.71	Slightly gravelly sand
14	0	84.18	15.82	Muddy Sand
15	2.79	95.40	1.81	Gravelly sand
Killiyar sub basin				
16	32.67	35.98	31.35	Clayey sand
17	0	84.42	15.58	Muddy sand
18	45.96	53.03	1.01	Gravelly sand
19	57.09	39.21	3.70	Sandygravel
20	69.54	26.58	3.88	Muddy sandy gravel
21	68.24	29.32	2.54	Sandy gravel
22	56.98	41.85	1.17	Sandy gravel
Akkulam-Veli sub basin				
23	0	41.81	58.19	Sandy mud
24	60.13	37.22	2.65	Sandy gravel
25	46.09	53.49	0.42	Gravelly sand
26	37.93	61.71	0.36	Sandy gravel
27	2.4	94.51	3.09	Sand
28	20.79	79.2	0.01	Gravelly sand
Vellayani-Maliyam sub basin				
31	0	28.39	71.61	Sandy mud
32	8.59	90.46	0.95	Slightly gravelly sand
33	12.07	87.18	0.75	Gravelly sand
34	11.99	86.76	1.25	Gravelly sand
35	17.56	81.65	0.79	Gravelly sand
Aryanad sub basin				
36	86.47	10.18	3.35	Gravel
37	53.52	44.52	1.96	Sandy gravel
38	45.57	53.09	1.34	Sandy gravel
39	79.71	19.22	1.07	Sandy gravel
40	38.45	57.25	4.3	Sandy gravel
Upper Peppara sub basin				
41	50.82	47.91	1.27	Sandy gravel
42	56.27	42.67	1.06	Sandy gravel
43	2.79	96.27	0.94	Sand
44	61.51	36.94	1.55	Sandy gravel
45	66.82	32.76	0.42	Sandy gravel
46	86.46	12.39	1.15	Sandy gravel
47	86.23	13.41	0.36	Gravel
48	73.68	25.3	1.02	Sandy gravel
Tholicode sub basin				
29	66.01	31.74	2.25	Sandy gravel
30	78.73	20.08	1.19	Sandy gravel
49	50.95	49.03	0.02	Sandy gravel
50	51.06	45.99	2.95	Sandy gravel

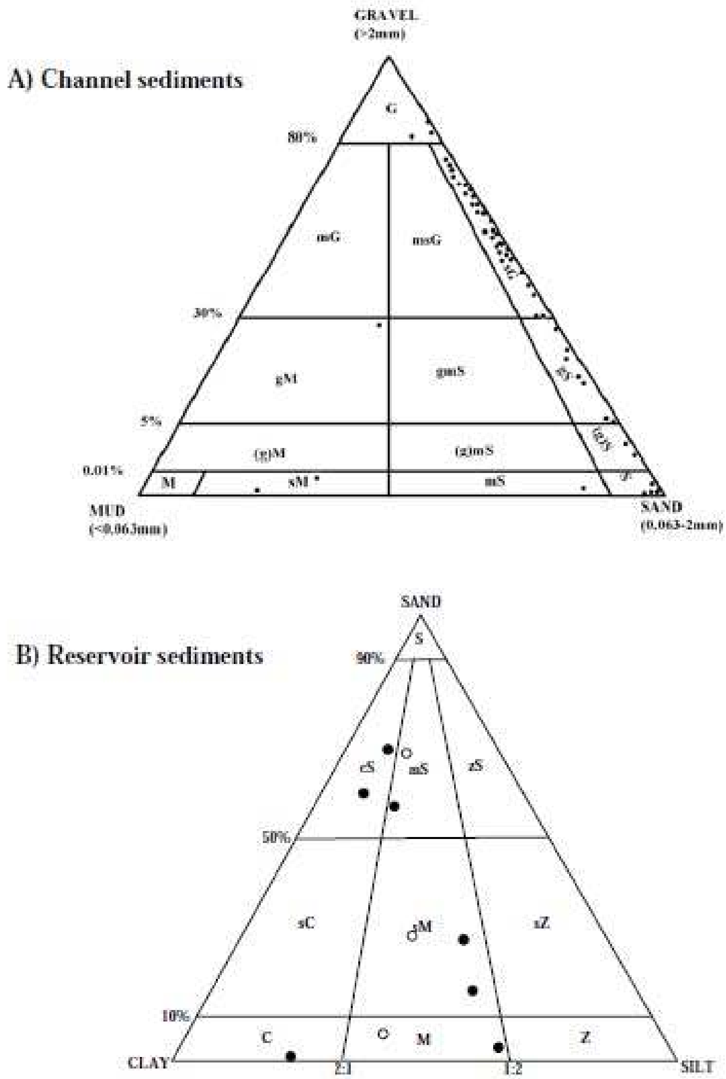


Fig. 28 Ternary diagrams showing the nature of surface sediments of the study area (after Folk et al., 1970). G - Gravel, sG - Sandy gravel, msG - Muddy sandy gravel, mG - Muddy gravel, gS - Gravelly sand, gmS - Gravelly muddy sand, gM - Gravelly mud, (g)mS - Slightly gravelly muddy sand, (g)S - Slighly gravelly sand, (g)M - Slightly gravelly mud, S - Sand, Z - Silt, C - Clay, cS - Clayey sand, sC - Sandy clay, mS - Muddy sand, sM - Sandy mud, M - Mud, zS - Silty sand and sZ - Sandy silt.

Reservoir sediments

The classification put forth by Folk et al. (1970) for gravel-free sediments is followed to decipher the sediment types of the reservoir environment (Fig. 28). The reservoirs are floored by a wide range of sediment types such as sandy mud, sandy silt, muddy sand, mud, clay and clayey sand (Table 18). Muddy sand and sandy mud predominates in the Aruvikkara reservoir. Mud is detected in the immediate vicinity of the dam. Clay and slightly gravelly sandy mud are observed in the central part as well as lower right arm of the reservoir, respectively. In Peppara reservoir the sediment type vary considerably; clay is detected very near to the dam site and clayey sand, muddy sand, sandy silt and sandy mud blanket the reservoir arms. Presence of gravel is observed in some locations and this may be contributed either from slumping/caving of the banks of the reservoir or from minor tributaries. In general sand rich species dominates in the arms of the reservoir whereas mud rich species dominates near the dam site. Unlike the Peppara reservoir, Aruvikkara reservoir is floored mainly by sand-dominant species indicating high-energy hydrodynamic regime prevailing in the reservoir for most parts of the year.

Table 18 Sediment types of reservoir sediments.

Sample No.	Sand+ %	Silt %	Clay %	Sediment Type (Folk et al., 1970)
Aruvikkara Reservoir				
51	63.76	14.10	22.14	Muddy sand
52	40.44	23.66	35.90	Sandy mud
53	5.64	33.55	60.81	Mud
Peppara Reservoir				
54	54.23	14.33	31.44	Clayey sand
55	64.78	11.56	23.66	Clayey sand
56	54.51	17.82	27.67	Muddy sand
57	26.25	46.58	27.17	Sandy mud
58	16.21	51.05	32.74	Sandy mud
59	3.02	59.97	37.01	Mud
60	0.07	24.93	75.00	Clay

Sand+ is the sum of Sand and Gravel fractions

Bivariate plots

Significant trends were observed by several investigators (Folk and Ward, 1957; Sahu, 1964; Friedman, 1967; Quidwai and Casshyap, 1978; Goldberg, 1980; Abed, 1982; Khan, 1984; Ramanamurthy, 1985; Pandya, 1989; Mahendar and Banerji, 1989; Joseph et al., 1997 and

Majumdar and Ganapathi, 1998) when they plotted the grain size parameters amongst each other. The interrelationship between grain size and frequency distribution has been widely used to discriminate the depositional environments and also to recognize the various operative processes of sedimentation. To bring forth the geological significance of textural parameters, researchers in sedimentology usually depend on the scatter plots of various statistical parameters (Lewis, 1984; Sajan, 1988; Padmalal, 1992; Badarudeen, 1997; Arun, 2006; Vinayan, 2009 and Ambili, 2010).

In this investigation also, an attempt has been made to unfold the information concealed within these cross-plots. Fig. 29 depicts the scatter plots of various statistical parameters of the sediments in the river and reservoir environments of the study area. The plots of phi mean and standard deviation in the riverine environment show that sorting worsens as the grain size increases. This is especially true in the case of main channel. Pebbles show best sorting in the main channel. In the tributaries granules (moderately sorted) and medium sands (moderately well sorted) show maximum sorting. The samples that show best sorting are those collected from the river-reservoir confluence zones. Majority of the samples are poorly sorted and falls in the mean size range of granules to coarse sand. The Aruvikkara reservoir sediments show a linear trend as the sorting worsens with an increase in phi mean values. But in Peppara reservoir no specific trend is observed among these parameters.

The plots of phi mean *versus* skewness are curvilinear both in the river and the reservoir environments. In the river channel the curve is convex upward whereas in the reservoirs, the curve is concave downwards. Combining these two gives a perfect sinusoidal curve reported earlier by Folk and Ward (1957) and Friedman (1961) in their studies. In the river, medium sands show an increase in skewness values with addition of finer fractions. The scatter plots between phi mean and kurtosis do not show any specific trend in the river environment. A perfect curvilinear pattern is observed in the Peppara reservoir, but no such pattern is observed in Aruvikkara reservoir. The cross-plots of standard deviation *versus* skewness reveal that increase in skewness could worsen sorting in river sediments. This may be attributed to addition of finer fractions after deposition. In the reservoirs all the poorly sorted sediments show fine skewness. Plots of skewness against kurtosis from the study area do not yield any significant trend in river environment. In the Peppara reservoir, very fine skewed sediments are extremely leptokurtic and show a curvilinear trend facing upwards. The scatter plots of kurtosis *versus* standard deviation in the reservoir environment show that as sorting worsens, the kurtosis tends to be platy. And, in the river sediments 75% of the samples are platykurtic to leptokurtic irrespective of the variation in sorting.

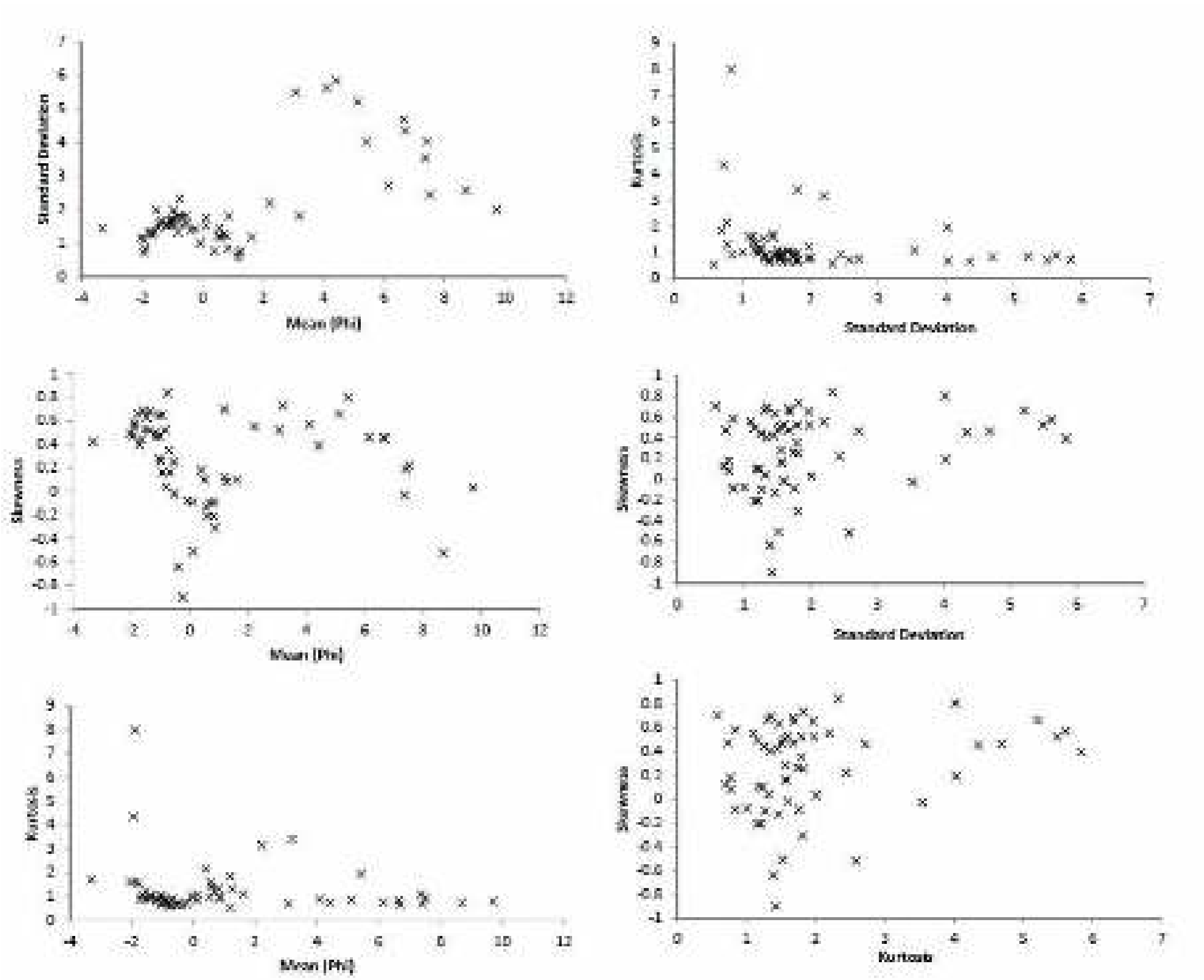


Fig. 29 Cross plots of various statistical parameters of the sediments in the Karamana river basin

6.3.6 CM Pattern

The CM pattern of the river and reservoir sediments of the study area is depicted in Fig. 30. The values of first percentile (C - approximate value of the maximum grain size; Passega, 1957) and the median (M) in microns are presented in Table 19. Fig. 30 represents a complete model of tractic current and consists of several segments such as NO, OP, PQ, QR and RS indicating different modes of sediment transport (Passega, 1957; 1964). According to Passega

(1964), the position and size of these segments may vary, although some are much more common than others. Transport of sediment by a given mechanism implies that sediments of certain sizes are available under certain hydraulic conditions. Therefore, a deposit is represented only by a few segments shown in Fig. 30. Some samples of the reservoirs deviate from the standard segments of the tractive model of Passega (1964).

Table 19 First percentile (C) and Median (M) values of the sediments of the study area.

Sample No.	C (Microns)	M (Microns)
River channel sediments		
1	7464	3249
2	9190	3031
3	9190	4287
4	6964	1320
5	12553	5098
6	7210	420
7	6727	812
8	8282	1682
9	8000	595
10	4595	483
11	4620	460
12	2000	451
13	2140	440
14	1414	277
15	2800	760
16	6964	483
17	379	144
18	8282	1803
19	6964	3482
20	17148	4595
21	13929	3864
22	9190	2462
23	616	27
24	13929	4000
25	8000	1741
26	8000	758
27	2549	354
28	7464	595
29	8000	4287
31	308	8
30	8574	4595
32	6063	595
33	4920	650
34	3630	930
35	7460	1040
36	8282	4141
37	7464	2828
38	8000	1741
39	10556	4925
40	6964	4595
41	7464	2144
42	9190	3249
43	2928	451
44	9849	3864
45	8000	4757
46	8000	4287
47	32000	11314
48	11314	4000
49	11713	2144
50	12126	2297
Reservoir sediments		
51	3732	268
52	7464	149
53	966	139
54	379	27
55	901	6
56	129	7
57	25	1
58	660	102
59	2144	32
60	171	1

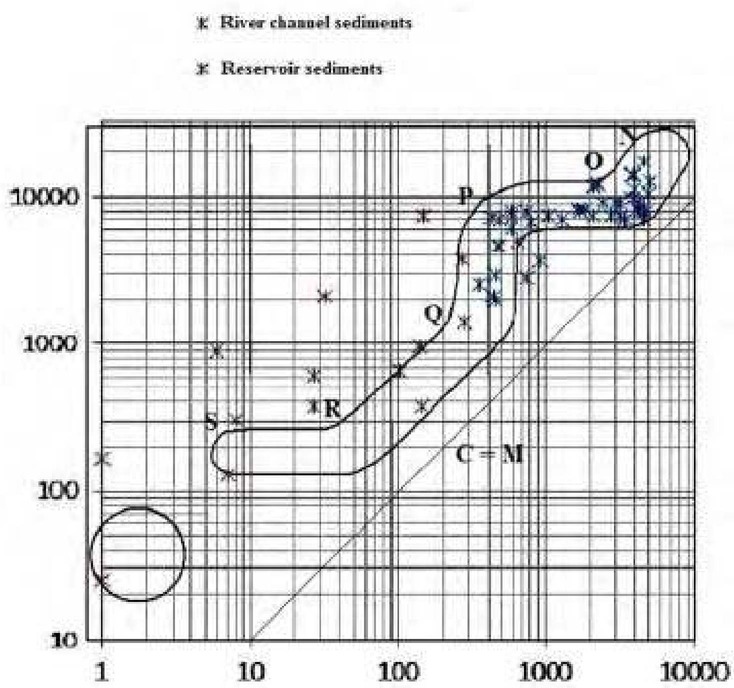


Fig. 30 CM Pattern for the sediments of the study area.

The river sediments fall in the NO, OP and PQ segments. The segment NO represents the coarsest bed materials, which are larger than 5000 microns of C. These particles are transported by rolling and are deposited in the river channels of the area. The rolling mode of transportation is prominent in the pebble-rich tributary channels where the competency of the river water is enormously high due to the high gradient of the terrain. The segment OP consists of particles with diameter roughly between 4000 and 5000 microns of C, which are moved mainly by rolling and suspension. The segment PQ represents particles ranging from 1400 to 4000 microns of C and indicates that these particles are moved predominantly by suspension and partly by rolling. Sediments from the reservoir confluence zone fall mainly within the segment PQ indicating a marked change in the river competency. Since the river sediments are gravelly and sandy in nature, the segments QR (graded suspension) and RS (uniform suspension) are totally missing in the river environment.

Unlike the river, the reservoir environment is characterised by well-defined QR and RS segments. Some samples fall in the segment NO, indicating addition of sediments by minor tributaries or by side slumping. The segment QR is parallel to the C = M line and is represented by reservoir sediments and the transportation is mainly by graded suspension. Graded suspension is a bottom suspension characterised by upward decreasing concentration and grain size. In the uniform suspension, which generally overlies the graded suspension, concentration and grain size are relatively constant. The silt and clay-rich sediments fall in the RS segment which indicates the role of uniform suspension in transporting these sediments. The clay-rich sediments falls in the region marked as T in the diagram. This area is characterised by pelagic suspension and the samples are from the immediate vicinity of the dam. Some of the reservoir samples show notable deviation from the ideal pattern indicating the complexity in the transportational/depositional regime prevailing in the reservoir environment. Some of the scattered samples fall within type fields VII and VIII. The type VII is a uniform suspension deposit and the sediments of type VIII are deposits of finest uniform/pelagic suspensions.

DISCUSSIONS

The river channels in the Karamana river basin receive clastic sediments through different processes, the chief among them are; 1) hill slope processes and 2) channel processes. The former (i.e., hill slope process) controls the quantity of sediments made available to the river channel through rain splash detachment, overland flow and a variety of mass movement mechanisms. The latter (the channel process), on the other hand, controls the balance between deposition and transport, and supplies additional sediments through channel erosion. The sediments generated from these processes move through the river channels depending on the velocity / hydraulic conditions in the channel reach and rate of supply of bed materials from upstream channel reaches/tributaries or by other means (Petts and Forster, 1985).

Detailed granulometric analysis of sediments of river channels reveal that, there is a progressive decrease in grain size downstream. Coarser particles like pebbles and granules register comparatively high values in river reaches with higher channel gradients and/or local turbulence. For example, the main channel, especially in the upstream portions of Aryanad, records higher proportion of coarser particles like pebbles and granules (>52%) than the finer entities, compared to samples collected from the lower reaches. As velocity increases in these high-gradient zones, more and more grains in the finer entities of the particle spectrum become entrained and can be selectively moved downstream leaving the coarser particles as lag concentrates. In addition to the physiographic controls, rock exposures within river channel, meanders, man-made structures like dams, bridges and check dams also have a profound effect on the overall dispersal pattern of sediment particles. Contrary to the river channels, the reservoirs receive fine sediments as the particle size decreases towards dam site. The impoundment causes obstructions in the natural stream flow and hydrodynamic conditions. The reduction in flow energy in the river–reservoir confluence induces rapid sedimentation and settling of particles based on its size. The nature of accumulated sediments in the vicinity of Karamana river confluence with the Peppara reservoir clearly depicts progressive deposition of sediment particles as it encounters the reservoir waters (Arun, 2006; Sreeja et al, 2014). Minor fluctuations in the size population if any, noticed along the river profile could be explained in the light of natural or man-made obstacles in the respective areas, a process established previously by Shideler and Flores (1980). In addition to the longitudinal variations in grain size characteristics, variations are also noticed across the river profiles as well. The observed grain size variation is in consonance with the progressive decrease in flow energy of the river water. Compared to the main river channel, the tributaries exhibit marked fluctuations in the grain size distribution due to the effect of gradient changes and obstacles in the river course. The phi mean increases (i.e., grain size in mm decreases) downstream, consequent to progressive decrease in the flow energy. The gradual decrease in grain size in the direction of river flow results from two important processes namely differential transport (Allen, 1964; Seralathan, 1979) and abrasion (Thiel, 1940). Both these processes operate simultaneously and bring about a net decrease in the mean size. Though there are quite a number of opinions on the effect of transportation and the impact of grain size, the size *versus* distance relationship is not fully established.

Differential transport along a stream channel is generally initiated by progressive decline or fluctuation in the competency of the transporting agent. The change in fluvial morphology and mean discharge of sediments seems to be the most important factor for progressive downstream decrease in the competency of the river. Fluctuations in the competency of the transporting agents are largely governed by the seasonal variation in the discharge. But the decrease in the grain size along the river sediments downstream is to a greater extent related to the physiography as well as fluvial morphology. The foregoing discussion reveals that a change in the river pattern is one of the factors affecting decline in the competency of transporting agent, which in turn brings about decrease in mean size of the river sediments downstream.

Grain size spectral studies reveal that pebbles and granules dominate the river environment while the reservoirs are floored by mud-rich sediments. Allen (1970) stated that the downstream decrease in phi mean and progressive enrichment of finer spectral classes would be ascribed by two processes; a) abrasion and b) progressive sorting. Laboratory studies of Thiel (1940) and Berthois and Portier (1957) have revealed that abrasion plays a significant role in the transformation of textural classes downstream. But this view was later countered by Kuenen (1959, 1960) who opined that abrasion is not so significant in a fluvial setup with sandy sediments. Instead progressive sorting will be the main reason causing textural diversities. Since, the river channels of the study area show abundance of pebbles and granules, abrasion is the principal process of size reduction rather than progressive sorting.

Standard deviation decreases significantly downstream, or in other words, the sorting of the sediments improves in the master channel. The maximum sorting is observed in the river–reservoir confluence zones and it worsens within the reservoir especially towards dam site. The improvement of sorting is attributed to differential transport of the sediments. There is a tendency for the sediments to attain normal distribution progressively in the downstream end. Such a tendency arises from the progressive lagging behind of larger particles whose presence imparts comparatively ill-sorted character to the sediments upstream compared to downstream. Inman (1949) made a suggestion that once a sediment attains maximum sorting values any further fall in competency results in the increase of fine particles in the sediment which will then “round the turn” on the curve. Generally, decrease in the standard deviation without any abrupt change in the values, indicates the absence of very fine particles.

The skewness of sediments is a sensitive indicator of depositional environment (Friedman, 1961, 1967; Martin, 1965 and Moiola et al., 1974). Perfectly sorted symmetrical and unimodal sediments have a skewness value of zero. The positive skewness indicates a relative increase of the coarse admixture in the sediments over the fine while in the case of negative skewness the converse is true. Folk and Ward (1957) made a generalization that the pure modal fractions are in themselves nearly symmetrical, but the mixing of the modes produces negative skewness in the sediment due to two possible causes: (i) addition of material to the coarser terminal, or (ii) subtraction of fines from the normal population.

There are many fluctuations observed in the skewness of sediments from very positive to very negative values. The high positive skewness indicates that the sediments are predominantly of coarse mode. Addition of fine mode to coarse sediments results in the skewness being changed from very positive to positive and then near symmetrical. The relationship between phi mean size and skewness in the sediments of Karamana river basin substantiates this view.

GROUNDWATER CONDITIONS AND HYDROGEOLOGY

Water is the elixir of life and the availability of safe drinking water is the primary requirement of the society. Due to the rapid economic growth and consequent expansion, the need for developing water resources has become more pressing than ever before. Availability of water is going to be one of the major issues confronting civilizations in the coming decades. Kerala is known for its lush green landscape, evergreen forests, serene water bodies, ponds, springs and wells. The major freshwater resources are surface runoff (mainly river discharges) and groundwater (wells or springs). Despite all these positive factors, the condition of Kerala is precarious with regard to drinking water potential. Even though the state receives heavy rainfall, the shortage of drinking water is alarming during summer months, and then the only source is groundwater.

Sustainable development of groundwater needs an understanding of its occurrence, availability, current usage and potential for future development. Different land forms like structural hills, pediments, buried pediments, valleys, valley fills etc., play a vital role in groundwater occurrence and movements. In crystalline rocks the extent of weathering and fracture characteristics decide the groundwater conditions. Crystalline rocks posses fractures and other discontinuities, which facilitate storage and movement of fluids through them. Discontinuities like faults, dykes etc. act as barriers to groundwater flow. The main flow paths in fractured rocks are along joints, fractures, shear zones, fault and other discontinuities. Porosity, permeability, grain size, lithification of the sediments, sedimentary structure and texture are the factors controlling the storage and movement of groundwater in sedimentary areas.

Dug wells are the major ground water extraction structures in Kerala. Almost every household has a dug well on which people are dependent for drinking and other domestic purposes (CWRDM, 1995). There are more than 40 lakhs of open wells in Kerala. About 30 lakhs of wells are being used to cater to domestic water needs. After 1980 there has been large scale development of bore wells by the State Groundwater Department as well as private agencies. More than 60% of the population of Kerala depend on these wells for drinking water (Vinayan, 2009). These wells are facing several problems such as lowering of ground water table, localised quality problems due to fluoride, iron, salinity etc. and microbiological contamination. Over exploitation of ground water takes place in various places due to uncontrolled withdrawal as well as inadequate recharge.

In the present groundwater scenario of Kerala, the regular monitoring of ground water levels is important. Ground water resource evaluation is done by the analysis of water level data being collected from the observation well network. Annual ground water recharge, draft and stage of development in Kerala is being estimated block wise by government departments. These are categorized into over-exploited, critical, semi-critical and safe based on the studies, by the Central Groundwater Board (CGWB) and Groundwater Department, Government of Kerala (CGWB, 2012). Strategies for groundwater recharge and management is to be implemented to cater to the future ground water demand in areas demarcated as over exploited, critical and semi-critical categories.

The watersheds or drainage basins should be the unit for better understanding of the hydrologic system as well as accurate assessment of the available resources (Narasimha Prasad et al., 2013, Arun et al., 2014, Sreeja et al., 2015). Over the past three decades, remotely sensed data have been increasingly used in groundwater studies (Jackson and Mason 1986, Star and Estes 1990, Baker and Panciera 1990, Sreedevi et al. 2005, Dinesh Kumar et al. 2007; Narasimha Prasad et al., 2013; Arun et al., 2014, Sreeja et al., 2015). For groundwater evaluation it is necessary to integrate data on various characteristics like topography, lithology, geology, lineaments, structures, depth of weathering, extent of fractures, slope, drainage patterns, etc. The use of remote sensing techniques in combination with geospatial systems aid in integrating these data sets in a very convenient manner, thereby facilitating quick decision support (Dinesh Kumar et al. 2007; Narasimha Prasad et al., 2013; Arun et al., 2014, Sreeja et al., 2015). In this context, the present study has been taken up with catchment as the unit in the Karamana river basin. The basin has the distinction that it hosts Thiruvananthapuram, the capital city of Kerala.

Occurrence of groundwater

All the water which occurs below the ground surface is called subsurface water. As per the degree of saturation, two zones can be broadly identified, i.e. the zone of aeration (vadose zone) and zone of saturation (phreatic or groundwater zone). In the vadoze zone, the intergranular space is only partially filled with water and the remaining space is being occupied by air. The zone of saturation is fully occupied with water. The water table is the upper surface of the saturated zone. Hydrogeologists are primarily interested phreatic water, being the main source of water supply.

The zone of aeration and zone of saturation are separated by a water table or phreatic surface, which is under atmospheric pressure. The water table will be very close to the ground surface in areas of intensive recharge. It can be even several hundred meters deep in arid regions. Fluctuations in the water table indicate changes in groundwater storage, either due to natural reasons or due to anthropological activity. Therefore, the monitoring of water table is of importance for the effective management of water resources. The main source of water to wells and springs is from atmospheric precipitation.

Hydrological classification of geological formations

Geohydrological characteristics of the subsurface formations determine the occurrence and movement of groundwater. The lithology, texture and structure influence the hydrological characteristics of natural rock formations. The geological formations are classified into four categories according to their porosity and permeability.*(i) Aquifer:* It is a geological formation which is highly porous, permeable and saturated with water. Unconsolidated sedimentary formations like gravel and sand are excellent aquifers. Fractured igneous and metamorphic rocks and carbonate rocks with cavities also form good aquifers. *(ii) Aquiclude:* A formation, which has high porosity but very low permeability like, clays and shales. *(iii) Aquifuge:* It is a formation, not porous as well as permeable like massive igneous and metamorphic rocks. *(iv) Aquitard:* Formations having insufficient permeability to make it a source of water supply but allows interchange of groundwater in between adjacent aquifers due to gravity. They serve as semi-confining layers. e.g. silt, shale and kankar.

HYDROGEOLOGICAL CONDITIONS

Groundwater Occurrence

The Karamana river basin is characterised by the outcrops of crystalline rocks of Archaean age in the eastern part and is overlain by sedimentary formations ranging in the age from Miocene to Recent along the western coast. Based on the water bearing properties, the entire district can be broadly classified into crystalline formation (Deep aquifers) and sedimentary/laterite formations (Shallow aquifers). The crystallines which include khondalites, charnockites, migmatites and intrusives occur from shallow or deep levels, with or without fractures. Whereas sedimentary formations comprise the (1) Recent alluvium that occur along the coastal plain and in the valleys and are mainly composed of sand and clay (2) Tertiary formation such as Warkali, Quilon and Vaikom beds and (3) laterites which occur as a capping over crystallines (CGWB, 2012). The river basin is covered by phreatic, semi-confined and confined aquifers. In the coastal/river alluvium, laterite, weathered and fractured rock, groundwater occurs under phreatic condition. In deep seated fractured crystalline rocks, groundwater occurs under phreatic or semi-confined or confined conditions.

Shallow Aquifers

The sandy formation in the coastal region and along the river courses forms one of the shallow aquifers in the study area. Groundwater occurs mainly under unconfined condition. Dug wells of 1–2 m diameter are used to extract groundwater. These open wells are constructed using cement rings to prevent the collapse of the sandy formation. The total time required for full recovery in dug wells in the coastal belt has been estimated as 67 to 742 minutes (CGWB, 2012). This means that the dugwells can be safely pumped after every 1 to 12 hours depending on the recovery rate. The discharge of the wells is in the range of very low to 6.91 lps (liters per second) and transmissivity value ranges from 69.76 to 232.4 m^2/day (CGWB, 2012).

The lateritic formations in the midland and in some high land regions are another shallow phreatic aquifer in the Karamana river basin. Laterite constitutes a potential aquifer because of its high porosity and permeability. However the groundwater drains off easily from this aquifer after the monsoon, particularly along the hills and slopes. Large diameter dugwell of 2–6 m is the typical groundwater extraction structure in this region. As laterites are generally stable, no protective lining is usually provided. Dug wells are usually pumped at discharges between 110 and 200 lpm (CGWB, 2012). Dugwells in laterite also sustains pumping of 2 to 4 hours duration during November to January, but during Feb–May, it sustains for 30 to 60 minutes only. In most of the cases, the full recovery takes place within 10 to 12 hours. However, there are cases where time required for full recovery varies between 12–96 hours depending on the initial saturated thickness and also the clay content in the laterites.

The weathered rock constitutes one more, shallow phreatic aquifer in the midland and highland regions of the study area. The weathered rock is covered by soil and/or laterites followed by lithomargic clay. The weathered zone is thick in valleys and plateau regions and thin along slopes and hill tops. Large diameter dugwells are the typical Groundwater extraction structures. However, because of the caving-prone lithomargic clay zone, it is essential that these wells have to be protected by lateritic brick lining or concrete rings, cast in-situ with weep holes for groundwater to enter the well. Discharge from wells tapping this zone varies between 58 and 67 lpm.

Deep Aquifers

The weathered rocks are underline by hard rocks such as khondalites and garnetiferous gneisses. The hard rocks are fractured at various depth horizons and in some places occur even just below the weathered rock. Such fractures normally occur along lineaments, which are basically weak zones in hard rocks. The aquifer lacks primary porosity and hence occurrence and movement of groundwater is controlled by development of secondary porosity in joints, fissures, etc. Bore wells are the typical groundwater extraction structures. Because of relatively poor water transmitting property of the fractured aquifer, dug-cum-borewells are also used at places to extract groundwater. Depending on the thickness and permeability of the overlying lithomargic clay, the groundwater will be under phreatic or semi-confined or confined condition in these fractured crystalline rocks. The NNW, NE, NW fractures form potential zones for bore wells in the river basin. The bore wells in khondalites were in the depth range of 98–200 m bgl and the discharge ranges from 30 to 1200 lpm. Exploratory drilling revealed the presence of 5–7 aquifer groups within a depth of 200 m in the Karamana river basin (CGWB, 2012). The transmissivity ranges from 0.94 to 9.03 m^2/day. The wells in the garnetiferous-biotite gneiss were in the depth range of 170–200 m bgl and the yield ranges from 12–420 lpm. The transmissivity of the wells drilled in garnetiferous-biotite gneiss ranges from 0.54 to 16.84 m2/day. General hydrogeological details of the Karamana river basin is presented in Fig.31 and Table 20.

Depth to Water Level

Fifty observation wells were established in the Karamana river basin for this study. The data on depth to water level monitored during pre-monsoon, monsoon, and post-monsoon periods in the years 2014 and 2015 is taken into consideration, to understand the groundwater level fluctuation (Fig. 32). The lowest depth to water level (bgl) is found to be 0.18 m at Pulayanarkotta during the post-monsoon of 2015 and the deepest water level is found to be 36.20 m Peringamala during pre-monsoon of 2014. The spatial distribution of groundwater level fluctuation during the period of study is presented in Fig. 33.

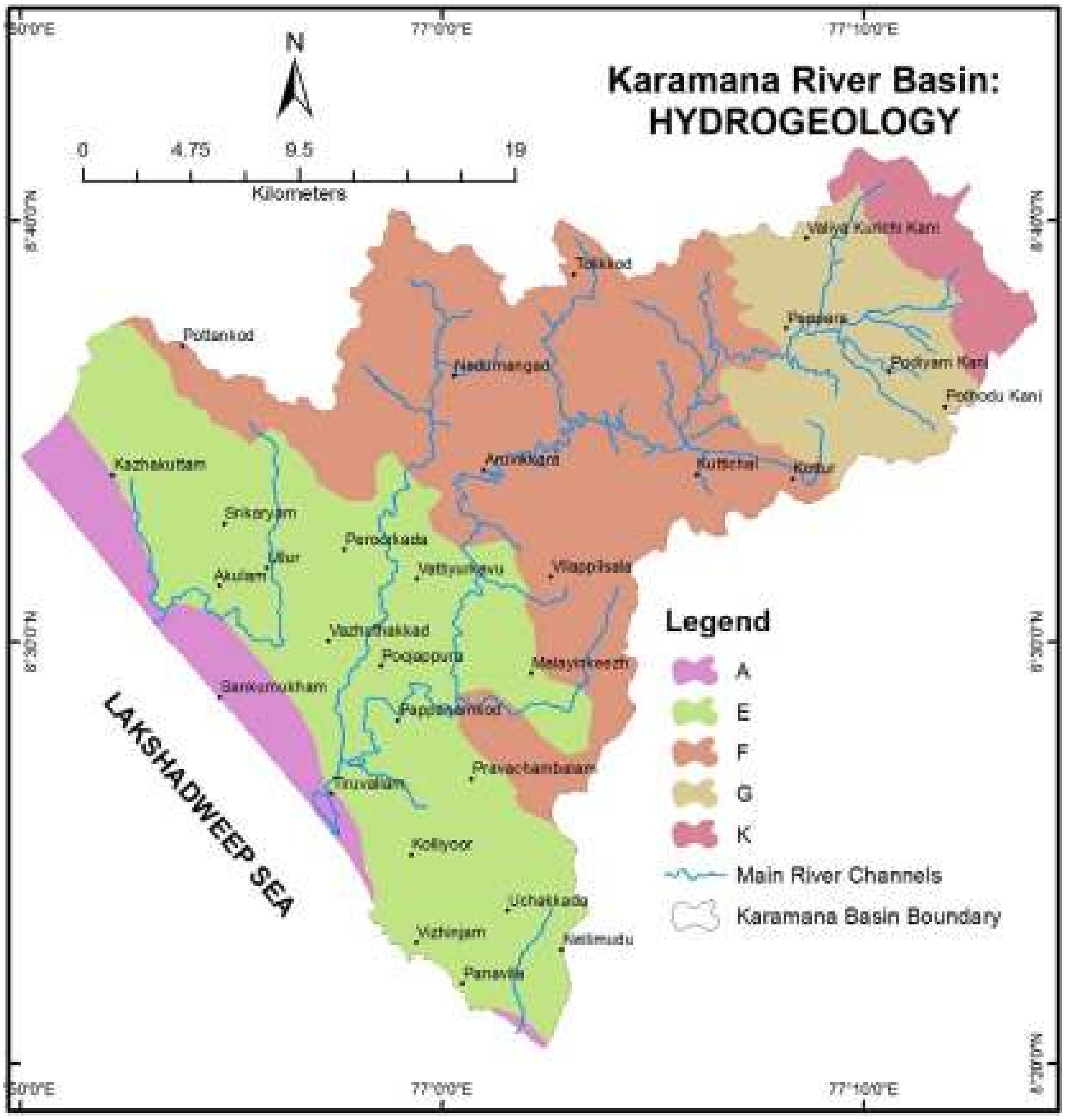


Fig. 31 Map showing general hydrogeology of Karamana river basin (Legend description is presented in Table 20).

Table 20 Description of Legend symbology

Code	Description of Legend Symbology
A	Coastal alluvium: Highly potential aquifer. It is suitable for open dug wells as well as filter point wells. The aquifer is continuous with intergranular porosity.
E	Midland area underlain by thick laterite, suitable for open wells. The aquifer is discontinuous with secondary porosity and fractures.
F	Area underlain by thin laterite / weathered zone. The aquifer is discontinuous with secondary porosity and fractures.
G	Foothills and highly undulating terrain. Aquifer discontinuous with secondary porosity.
K	Mountainous area, generally unsuitable for groundwater development. Fractures are seen but yield is limited.

Table 21 Groundwater levels in the Karamana river basin. All the values are in meters below ground level (m bgl). PRM- Pre Monsoon; MON- Monsoon; POM- Post monsoon.

Sl.No	Location	2014			2015		
		PRM	MON	POM	PRM	MON	POM
1	Pallipuram	3.01	0.77	1.90	2.36	0.96	0.35
2	Andukonam	6.99	5.05	5.09	5.86	5.57	5.30
3	Ariyottukonam	15.66	10.75	11.29	13.58	13.37	10.40
4	Pandalakkod	7.38	4.41	4.09	5.82	5.92	3.18
5	Chellamangalam	9.59	4.13	3.97	5.53	5.45	3.95
6	Pangappara	11.83	9.37	9.08	10.79	9.47	8.15
7	Kulathur	5.87	4.11	4.24	5.84	4.76	4.42
8	PulayanarKotta	0.95	0.25	0.35	0.53	0.42	0.18
9	Mannanthala	9.90	6.93	4.90	9.00	8.64	7.28
10	Nalanchira	1.09	0.97	1.18	1.38	0.70	0.67
11	Vanchiyoor	3.80	2.59	2.45	3.36	2.84	2.40
12	Sanghumukham	2.53	2.15	1.95	2.43	2.43	1.64
13	Veli	3.80	3.66	3.60	3.82	3.67	3.64
14	Thumpa	4.33	3.56	3.77	4.12	4.19	3.51
15	Valiyathura	2.65	2.57	2.36	2.63	2.70	2.07
16	Kovalam	3.93	1.98	2.45	2.77	2.43	1.75
17	Manakkad	2.85	1.70	1.65	2.51	3.03	1.25
18	Vellayani	3.14	2.62	2.55	2.98	2.65	2.07
19	Peringamala	36.20	36.02	34.57	31.49	34.25	27.80
20	Payattuvila	3.92	3.70	3.40	3.44	3.12	2.86
21	Punnakkulam	8.31	8.81	7.98	7.40	7.37	5.45
22	Azhimala	1.21	0.57	0.55	0.72	0.62	0.30
23	Mukkola	25.77	25.05	22.93	20.05	22.97	15.54
24	Madavurpara	3.60	2.55	2.63	2.98	2.79	2.05
25	Nemam	6.05	0.77	2.02	3.31	1.77	0.66
26	Peppanamkode	7.27	4.50	5.64	6.72	4.65	5.64
27	Vilavoorkal	3.12	2.07	2.04	2.90	2.28	0.48
28	Urootambalam	7.10	3.78	3.20	4.46	3.97	2.70
29	Killi	6.17	3.56	3.37	4.84	3.52	3.09
30	Poovachal	9.37	7.55	7.90	8.13	7.76	7.27
31	Kuttichal	7.68	6.50	7.25	7.21	7.50	5.70
32	Kottur	3.74	1.43	1.70	1.39	1.82	1.00
33	Aryanad	8.76	5.72	5.02	6.19	5.93	3.97
34	Keezhpallur	6.15	1.78	3.06	5.30	3.56	2.63
35	Mamala	10.04	7.37	7.30	8.88	7.77	7.85
36	Thokkode	4.87	3.11	3.45	4.28	3.75	3.65
37	Karakulam	6.40	2.00	2.93	5.70	1.97	1.67
38	Vattappara	1.97	1.05	1.15	0.98	1.04	1.03
39	Pazhakutti	1.23	0.40	0.53	0.44	0.49	0.33
40	Irinjayam	1.95	0.91	0.92	1.38	1.30	0.54
41	Panavur	1.45	0.77	1.16	1.45	1.10	1.01
42	Anad	6.50	2.83	3.20	6.07	1.85	1.10
43	Panackod	7.00	5.80	4.60	8.84	5.06	3.70
44	Puthukulangara	2.67	1.27	1.37	2.17	1.63	1.43
45	Mundela	9.10	5.47	5.20	6.39	5.93	1.75
46	Vellanad	4.90	1.12	2.15	3.20	1.88	1.13
47	Vilappilsala	12.51	9.93	9.84	9.24	10.28	6.20
48	Peyad	7.04	3.90	4.40	5.85	4.55	3.75
49	Malamugal	3.78	2.75	3.53	3.55	3.36	2.45
50	Nettayam	1.33	0.97	1.01	1.06	1.00	0.84

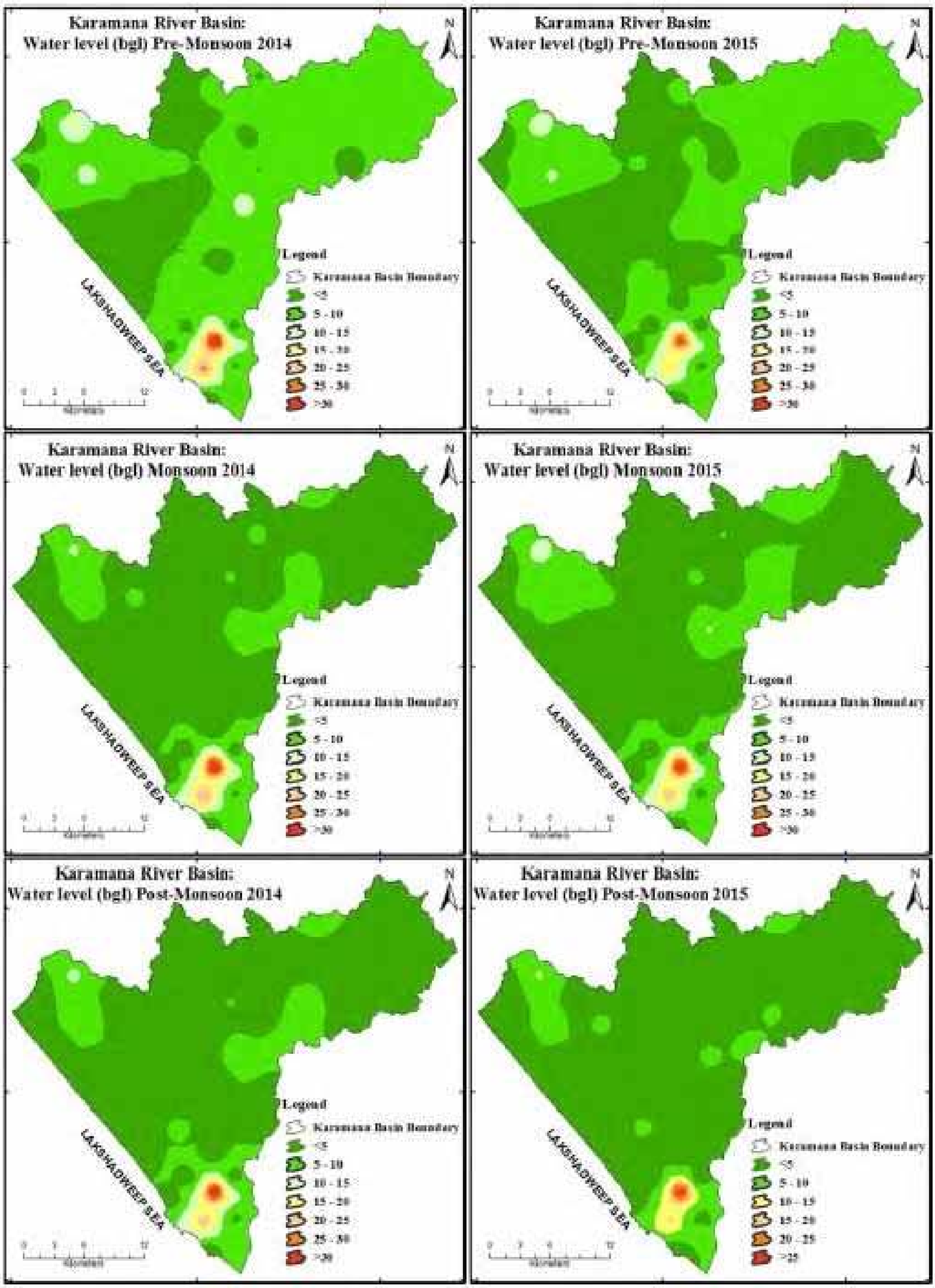


Fig. 32 Spatial distribution of groundwater level (m bgl) during 2014 and 2015

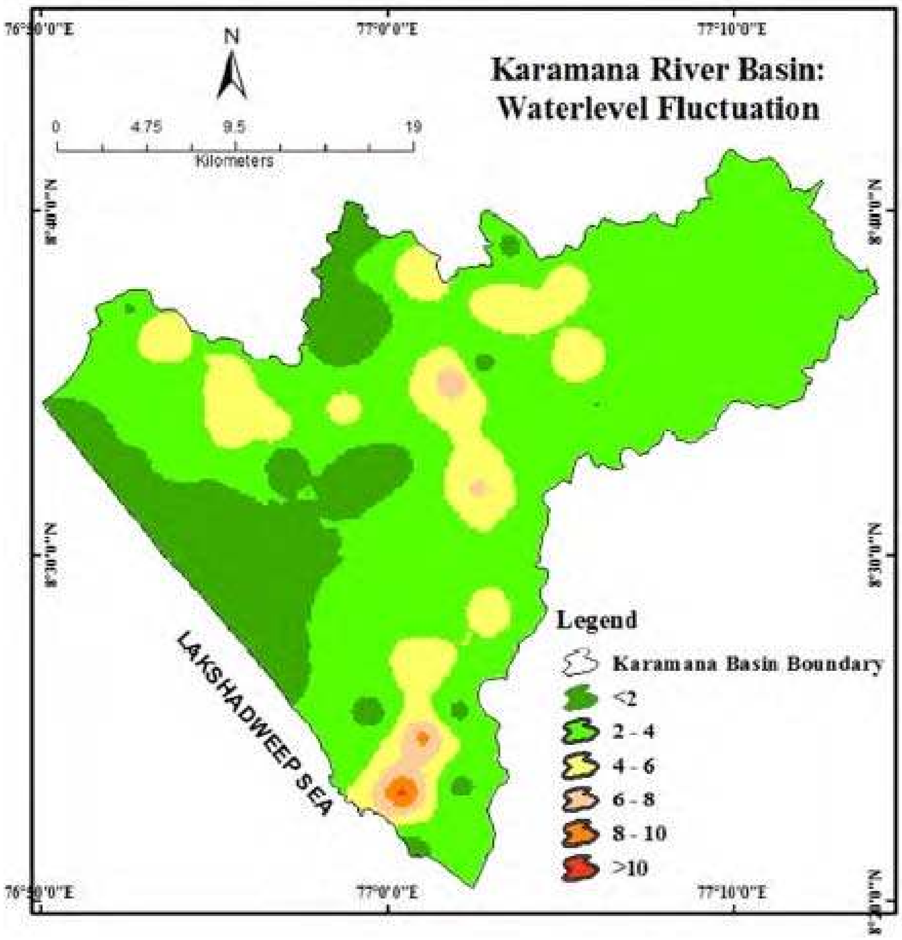


Fig. 33 Spatial distribution of groundwater fluctuation (m).

The analysis of the long-term water level reveals that the district does not face any severe groundwater availability problems. From the figures, it is clear that deeper water level of more than 20 m bgl is encountered in areas like Peringamala and Mukkola. The deeper water levels in these areas can be highly correlated with the physiographic set up of the area. These are the areas of occurrence of thick laterites and sandstones belonging to the Tertiary formations. Seasonal fluctuation indicates that in the major portion of the district, there is rise in water level in the range of 0–5 m except in a few isolated patches (CGWB, 2012). An analysis of the data shows that the depth to water level during pre-monsoon and post-monsoon is minimum in alluvium and maximum in laterites. This may be due to the fact that since alluvium occurs in the discharge zone, water level is shallow and fluctuation less. The high fluctuation shown by wells tapping laterite can be attributed to the cavernous and porous nature of laterite, by which it gets easily recharged by a heavy showers and due to the same porous nature water easily drains off from the aquifer as subsurface run off. The long term trend analysis (2002–2011) shows that the water level during pre- and post-monsoon indicates a rising as well as falling situation. Some of the wells in Trivandrum urban area show a decline in water level at a higher magnitude when compared to the previous decade. The post-monsoon period falling trend ranges from 0.0016 to 0.4975 m/year and rising trend ranges from 0.0079 to 0.2352 as observed by CGWB (2012).

Saturated Thickness

The data on pre-monsoon and post-monsoon depth to water level and the depth to bedrock in the Karamana basin has been used to obtain the respective seasonal saturated thickness. The lowland region has a saturated thickness of about 2–10 m during pre-monsoon and 6–13 m during post-monsoon. In midlands this varies between 0 (Dry) to 16 m and 0.8 to 17 m during pre-monsoon and post-monsoon respectively. In highlands pre-monsoon saturated thickness is 0 to 6 m and 0.3 to 8 m during post-monsoon.

Recharge and Discharge Areas

Recharge areas are those within which water enters an aquifer. In areas represented by phreatic aquifers, recharge occurs over the entire aquifer area, while in areas represented by confined aquifers, recharge area is limited to a large extend by the exposure of the aquifer at the ground surface to its subsurface connection with another aquifer or a body of surface water. The study area is entirely covered by phreatic aquifers and hence the whole area acts as recharge area. However due to the undulating topographic condition and the aquifer characteristics, groundwater tends to move towards down slope areas as subsurface flows. This creates water scarcity in the elevated areas and areas with steep slopes, mainly during summer period (Jan–May). Precipitation is the main source of recharge to groundwater in the study area.

Discharge takes place naturally and artificially. Natural discharge of groundwater takes place through evapotranspiration, spring flow, seepage to streams and leakage to other aquifers. Artificial discharge takes place through extraction of groundwater by manmade structures like dug wells, bore wells, etc.

Discharge of groundwater takes place naturally and artificially throughout the study area. All the streams in the basin are effluent in nature as evidenced by the flow of surface water even during the non-rainy months. The groundwater is also discharged through dug wells, bore wells, and filter point wells. In all the three physiographic zones, dug wells are being used as the main source of water for domestic purposes. This means that the entire study area acts as a discharge area also. However, the perennial nature and the height of water column available in the wells in different physiographic region varies. In general, midland and low land regions are favourable for groundwater exploration.

As explained above, a clear cut demarcation of recharge and discharge zones in the present study area, is not possible. However an attempt has being made to demarcate recharge and discharge zones based on topography and water level data from the dug wells. Grid deviation method (Biswas and Chatterjee, 1967) has been adopted in preparing the grid deviation water table map. This is done by computing average water level for the river basin and finding the deviations of mean water level in the individual location. The deviations have been shown as positive zone denoting recharge area and negative zone denoting the discharge area.

The grid deviation water table map for the Karamana river basin is shown in Fig. 34. The positive zone lies in the upstream area denoting higher elevation, mostly seasonal wells, good for artificial recharge and water level fluctuation is expected to be higher. The negative zones lie in the lower reaches indicating higher groundwater potentiality, lower water level fluctuation and is generally good for perennial wells. Any stress imposed over the recharge zone may result in more lowering of water level upstream to it.

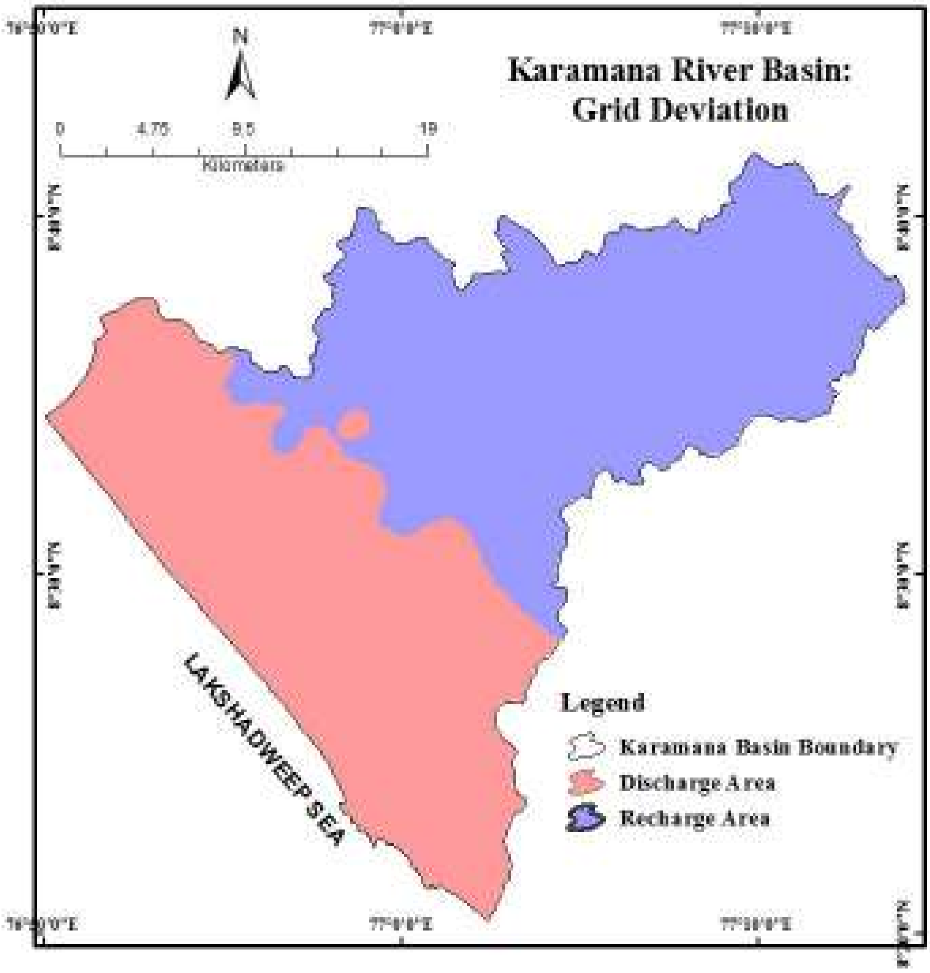


Fig. 34 Grid deviation map showing the discharge and recharge areas.

CURRENT STATUS OF GROUNDWATER DEVELOPMENT

As part of the present study, well inventory was carried out in selected sample areas of about 1 sq.km each representing different physiographic regions such as coastal lowland, lateritic midland and crystalline high land of Karamana river basin. This study was carried out to arrive at estimates of density, usage, growth pattern etc. of different types of wells. The three sample areas investigated in Karamana river basin are located in Pachallur (lowland); Mundela (midland) and Kottur (highland) areas.

Groundwater Extraction Structures

Groundwater in Karamana river basin is extracted through large diameter dugwells tapping shallow phreatic aquifers in alluvium, laterite and weathered formations. Borewells are being used to tap the deep fractured aquifers in crystalline rocks. Filter point wells are also being used to tap the groundwater from the coastal alluvial aquifers. In Karamana river basin, the depth of open wells varies from 1.5 to 7.0 meters in alluvial formation, 2.5 to 16 meters in laterite formation and 20 to 36.2 meters in areas where sandstone with lignite intercalations overlain by laterites, depending on the topography and overburden thickness. The diameter of the wells in Karamana river basin varies from 0.8 to 3.0 metres with an average diameter of 1.2 metres in alluvial formation and 1.25 to 5.0 metres with an average diameter of 2 metres in laterite formation. The depth of borewells ranges between 30 and 200 metres below ground level.

At present most of the dugwells in the midland region are partially penetrated with bottom of the well touching the clay zone or weathered zone. Because of this, wells dry up or they will have very little water column during peak summer period. Though there is scope for further deepening of these wells upto the hard rock, because of either excessive cost of construction involved to penetrate the clay zone and also to protect it from caving, or lack of knowledge, these wells are not fully developed. Wherever, the dug wells meet with the hard rock at the bottom of the well, the same can be further developed by blasting of the hard rocks. Dug-cum-bore wells can also be developed in the midland region by drilling a bore to a depth of 30 to 40 metres from the bottom of the dug wells. However, in both the above cases where blasting or drilling in the hardrock is concerned, site specific investigations are required before taking up the development or rejuvenation of existing wells (Narasimha Prasad, 1997).

Density of wells

The density of dug wells in Karamana river basin is considerably high due small land holdings (less than 1 hectare) and each family has its own well. In the river basin, the analysis of well inventory data shows that on an average in 1 sq.km area there will be typically 281 dug wells in lowland, 224 dug wells in midland and 92 dugwells in highland region. The analysis also indicates that in 1 sq.km area, about 85% of the wells are exclusively used for domestic purposes. Less than 10% are found to be exclusively used for irrigation purposes (Table 22). The density of dug wells, even if it is extrapolated to the other areas, remains more or less constant for the entire basin.

Table 22 Details of dug well inventory in Karamana river basin

Region	Density of wells/Km^2	Number of Dug wells for different uses				Ener gized wells	Av. Pumping Duration(in minutes)
		Domestic	Irrigation	Both	Unused		
Lowland (Pachallur)	281/sq.km	247	14	20	-	213	20-30
Midland (Mundela)	224/sq.km	172	18	34	-	188	20-30
Highland (Kottur)	92/sq.km	78	5	9	-	77	20-30

Details of wells for different uses have helped in estimating the draft from different types of wells in 1 sq.km in the study area. These results have been suitably averaged and extrapolated to get the draft within the Karamana river basin. The growth of dugwells during 1950–2015 is about 4 fold (Fig. 35). As the construction of bore wells on a larger scale was started only during the early part of 1980 in the study area, the growth trend of these wells has not been worked out.

Energised Wells

In Karamana river basin about 80% of the dug wells and 100% of the bore wells are fitted with energized pumps. More than 90% of these wells are fitted with pumps of less than 2 HP and these wells are mostly pumped for 20–30 minutes in a day (Table 22). Most of the energized wells are used for domestic purposes. Only very few wells are used for irrigation or irrigation-cum-domestic purposes. Irrigation through pumping of wells, in the basin, is for coconut, arecanut, banana and other plants grown within the house compound.

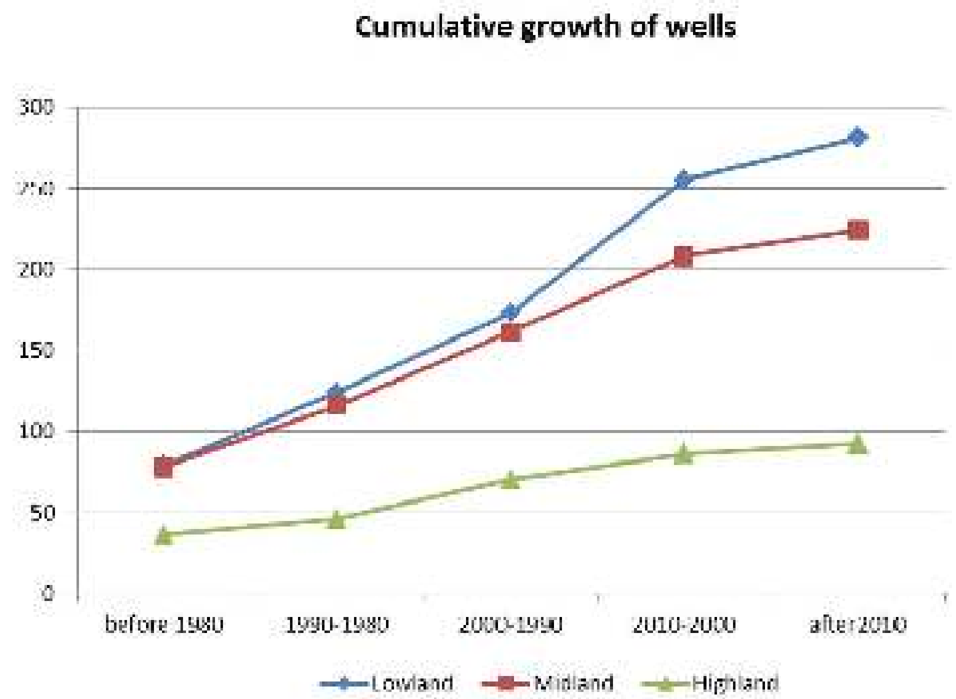


Fig.35 Growth pattern of dug wells in Karamana river basin

Groundwater Draft

Based on the results of the well inventory, the groundwater draft from different types of wells has been estimated for Karamana river basin. Considering an average of 5 person per well using 100 litres of water each per day throughout the year, the total groundwater draft per well will be about 180 m^3 per year. Considering about 1500 litres of water extracted per day from each well for irrigating garden and plantation crops within the house compound during non-rainy days, total groundwater draft per well will be 270 m^3 per year.

In areas having less than 20% slope, the average density of wells is 250/sq.km in the Karamana river basin. In areas having greater than 20% slope, the average density of wells is 92/sq.km. 80% of the wells are exclusively for domestic purpose and 5% of the wells are exclusively for irrigation purpose. Considering the above assumptions the draft from the wells for domestic purpose is 25.54 Million cubic meters (MCM)/year and for irrigation is 2.37 MCM/year in the Karamana river basin. Thus the total groundwater draft in the river basin is 27.91 MCM/year.

GROUNDWATER ASSESSMENT AND SCOPE FOR DEVELOPMENT

Groundwater assessment for Karamana river basin involving extraction of annual groundwater availability, computation of stage of groundwater development and categorisation for future groundwater development as per recommendations of report on "Groundwater

Estimation Methodology-1997" of the Ministry of Water Resources, Government of India, are presented in this section. The groundwater assessment unit for the basin comprises of the total river basin area. Portions having slope less than or equal to 20% have been demarcated and groundwater assessment made only for such portions. In this basin, surface water irrigation is practiced, mainly from Peechi and Chimony Irrigation project through its canal systems. A groundwater year is divided into monsoon season (June–September) and non-monsoon season (October–May), and groundwater assessment is made separately for these two seasons for the basin and the annual values are obtained as the sum of estimates for the two seasons.

Annual Groundwater Availability

The area in which ground slopes are less than or equal to 20% within the Karamana river basin is 531 sq.km. Groundwater assessment is made only for this area. Substituting 2600 mm for the normal (long term average) rainfall and 7% for the rainfall–recharge factor for laterites, the rainfall recharge in an year is estimated as 96.64 MCM by the rainfall–infiltration factor method. Substituting 2.37 MCM for the groundwater draft for groundwater-based irrigation and 25% of the applied water contributing to recharge by return flow, the recharge due to return flow from ground water based irrigation is computed as 0.59 MCM. Substituting 96.64 MCM for rainfall recharge, 0.59 MCM for return flow from groundwater irrigation, 38.66 MCM for base flow, the net annual groundwater availability is estimated as 58.57 MCM. Assessment of 531 sq.km feasible area of the Karamana river basin with average water level fluctuation of 3.07m and specific yield for laterite as 3% results annual groundwater availability of 48.91 MCM, employing water table fluctuation method. Hence these two methods resulted estimation of ground water availability within a range of ±20%, the rainfall infiltration method is considered for further calculations.

Gross Groundwater Draft

Present annual groundwater draft for drinking and domestic water supply and groundwater irrigation are 25.54 MCM and 2.37 MCM respectively. Hence annual gross groundwater draft for all uses is 27.91 MCM. Assuming a population growth of 3% per year and assuming that the percentage growth of groundwater development for drinking and domestic uses is same as the population growth, the allocation for drinking and domestic water supply up to the next 25 years can be estimated as 48.84 MCM.

Categorization for Future Groundwater Development

Substituting 58.57 MCM for the net annual groundwater availability and 27.91 MCM for the gross annual groundwater draft, the stage of groundwater development is computed as

47.65%. Both pre-monsoon and post-monsoon water levels do not show any significant declining trend. Consequently the Karamana river basin can be categorized for future groundwater development as 'SAFE'.

Groundwater Potential

Integrating all the gathered information such as geology, geomorphology, drainage, slope, lineaments, aquifer parameters, ground water level fluctuation and saturated thickness, the Karamana river basin has been classified into different groundwater potential zones viz VERY HIGH, HIGH, MODERATE and LOW using overlay analysis tools in Geographical Information System. The criteria employed for delineating these ground water potential zones are summarized in Table 23. This can form the base map for the concerned authorities to take necessary decisions as well as actions for the future groundwater development in this basin (Fig.36). Valley fills, pediments and moderately dissected plateaus of the basin are found to be favourable geomorphic units for groundwater exploration and development, whereas structural hills, residual hills, residual mounds, and linear ridges are poor groundwater potential zones. Hydrogeomorphology, lineament and slope play vital roles in the occurrence and movement of groundwater in the study area. This integrated hydrogeological study revealed that the downstream portion of the Karamana river basin is categorised as very good to good groundwater potential zone whereas the eastern portion of the basin is categorized as of poor to moderate groundwater potential. It is estimated that about 30% of the basin comes under the very high to high category in terms of groundwater potential, while the remaining area comes under the moderate to poor category.

Table 23 Criteria for demarcating groundwater potential

Category	**Criteria**
VERY HIGH	Alluvial formation, valley region, low drainage density, High lineament density, Flat to gentle slope (<5%), Depth to water table (DTW) at 1 to 3 m below ground level (bgl), and availability of water throughout the year (Perennial).
HIGH	Low land or valley portions in the Lateritic midlands areas covered by lateritic soil, low drainage density, High lineament density, Having flat to gentle slope (<5%), and availability of water throughout the year (Perennial)..
MODERATE	Lateritic formations in midland region, low to moderate drainage density, moderate lineament density, slope between 5% to 20%, and availability of water throughout the year (Perennial) and possibility of salinization.
LOW	Laterites or hard rocks in the highland region with more than 20% slope, high drainage density, low lineament density, seasonal water availability and possibility of salinization.

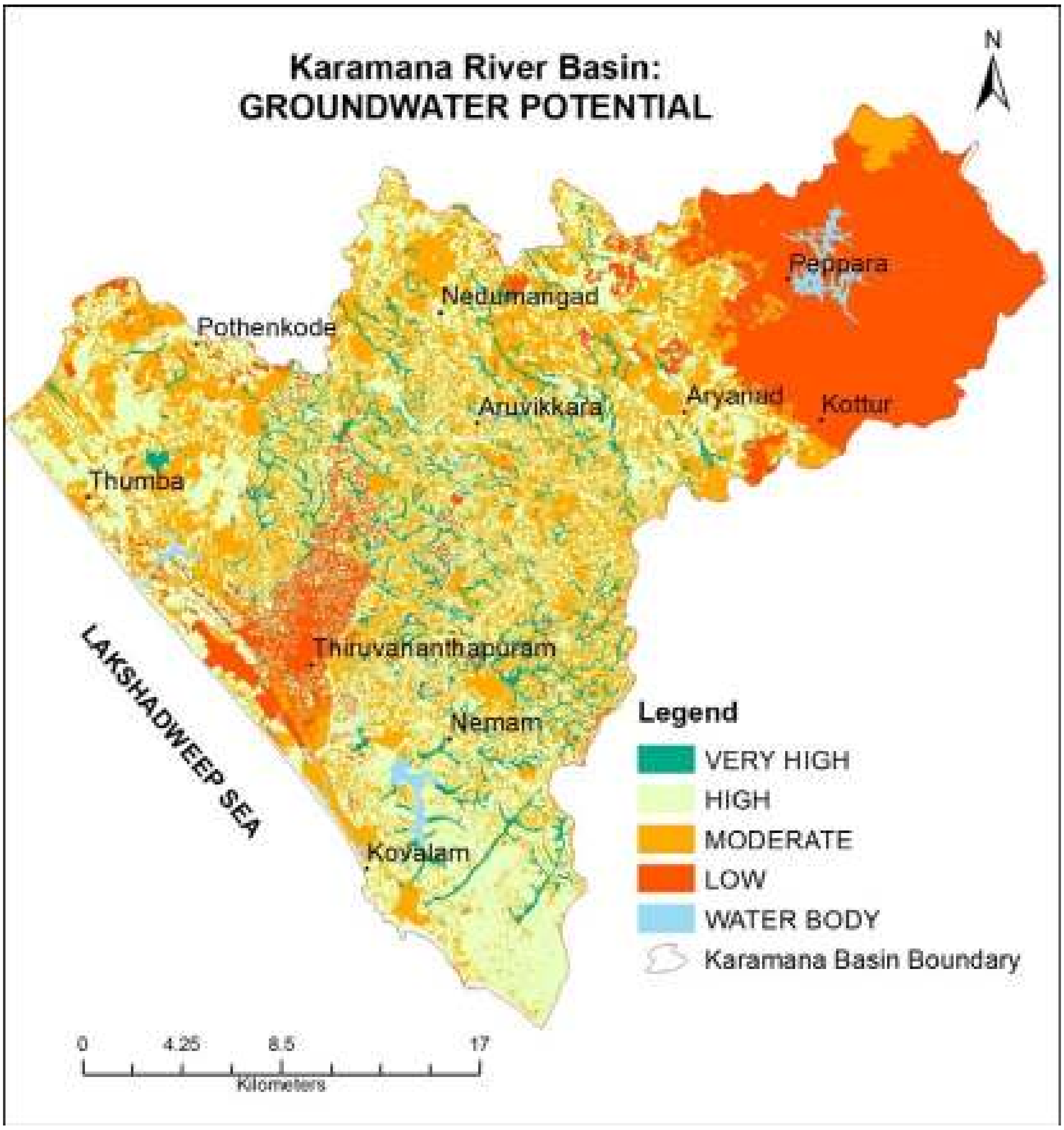


Fig. 36 Groundwater potential zones of Karamana river basin

GROUNDWATER RECHARGE AND CONSERVATION

Groundwater recharge is the replenishment of an aquifer with water from the land surface. In contrast to natural recharge (which results from natural causes); artificial recharge is the use of water to replenish artificially the water supply in an aquifer. Artificial recharge is a process by which excess surface-water is directed into the ground to increase infiltration, to replenish an aquifer. It refers to the movement of water through man-made systems from the surface of the earth to underground water-bearing strata where it may be stored for future use. Artificial recharge (sometimes called planned recharge/ managed aquifer recharge) is a way to store water underground in times of water surplus to meet demand in times of shortage.

The goal of artificial recharge is to convey water to the saturated zone. A combination of field, laboratory, analytical, and simulation methods generally are used to develop an understanding of the hydro-geological system as a basis for predicting potential consequences. Optimisation techniques may be coupled with predictive models of ground-water flow and other processes to create an effective tool for planning and management of artificial recharge projects. Pre-project and long-term monitoring of key aspects of a flow system is an essential part of a successful management plan.

Monitoring of hydraulic conditions prior to and during an artificial recharge project is an essential part of a management plan. Measurement of the performance after implementation is clearly one goal of a monitoring programme. A second goal is to provide the information needed for future improvement of predictive modelling capabilities and adjustment of optimisation constraints. Artificial recharge can be a valuable component of a groundwater management and conjunctive use strategy, for long-term reliability of groundwater supply, improvement of basin water quality, and for banking of water.

This entails evaluation of the dynamics of groundwater flow and basin recharge, and consideration of options for artificial recharge techniques that can be used. A primary concern is the identification of basin compartmentalisation or impermeable layers within the aquifer that inhibit recharge to the basin aquifers. Also important are concerns about chemical mixing of surface waters and native groundwater, hydrological variability within the aquifers, and the nature of probable migration of recharged water. Different sources of surface-water, together

METHODS OF ARTIFICIAL RECHARGE

Artificial recharge methods can be classified into two broad groups (i) direct methods, and (ii) indirect methods.

Direct Methods

(a) Surface Spreading Techniques

The most widely practised methods of artificial recharge of groundwater employ different techniques of increasing the contact area and resident time of surface-water with the soil so that maximum quantity of water can infiltrate and augment the groundwater storage. Areas with gently sloping land without gullies or ridges are most suited for surface-water spreading techniques. Flooding, Ditches and Furrows, Recharge Basins, Run-off Conservation Structures such as Gully plugs, bench terracing, Contour barriers and percolation tanks, Stream-channel Modification and Surface Irrigation are the major techniques in this category.

(b) Sub-Surface Techniques

When impervious layers overlie deeper aquifers, the infiltration from surface cannot recharge the sub-surface aquifer under natural conditions. The techniques adopted to recharge the confined aquifers directly from surface-water source are grouped under sub-surface recharge techniques. Injection Wells, Gravity-Head Recharge Wells, Connector Wells, Recharge pits like canal trench and contour trench, Recharge Shafts, etc are the commonly employed sub-surface techniques.

Indirect Methods

(a) Induced Recharge

It is an indirect method of artificial recharge involving pumping from aquifer hydraulically connected with surface-water, to induce recharge to the groundwater reservoir. In hard rock areas, the abandoned channels often provide good sites for induced recharge, that under favourable hydro-geological situations, the quality of surface-water generally improves due to its path through the aquifer materials before it is discharged from the pumping well. **Pumping Wells** hydraulically connected to an aquifer through the permeable rock material of the stream-channel; **Collector Wells** are horizontal wells in areas where the phreatic aquifer adjacent to the river is of limited thickness can get more induced recharge from the stream; **Infiltration Gallery**, which is a horizontal perforated or porous structure (pipe) with open joints, surrounded by a gravel filter envelope laid in permeable saturated strata having shallow water table and a perennial source of recharge are the common examples of induced recharge.

(b) Aquifer Modification

These techniques modify the aquifer characteristics to increase its capacity to store and transmit water. With such modifications, the aquifer, at least locally, becomes capable of receiving more natural as well as artificial recharge. Hence, in a sense these techniques are artificial yield augmentation measures rather than artificial recharge measures. **Bore Blasting** is suited to hard crystalline and consolidated strata. **Hydro-fracturing** is a recent technique and is a process whereby hydraulic pressure is applied to an isolated zone of bore wells to initiate and propagate fractures and extend existing fractures. The water under high-pressure break up the fissures cleans away clogging and leads to a better contact with adjacent water bearing strata.

(c) Groundwater Conservation Structures

The water artificially recharged into an aquifer is immediately governed by natural groundwater flow regime. It is necessary to adopt groundwater conservation measures so that the recharged water remains available when needed. **Groundwater Dams / Underground Barriers** is a sub-surface barrier across stream that retards the natural groundwater flow of the system and stores water below ground surface to meet the demands during the period of greatest need. **Fracture-Sealing Cementation Technique** can be employed in many hard rock areas, where the groundwater circulation to deeper levels is governed by shear, fault or fracture. The boreholes located on such zones prove productive but due to dissipation of the limited storage along preferred flow planes, in case of adverse topographical situation.

ARTIFICIAL GROUNDWATER RECHARGE IN THE STUDY AREA

Technological developments in well construction and pumping methods have resulted in large-scale exploitation of groundwater. In many areas, due to the vagaries of the monsoon, due to the lack or scarcity of surface-water resources, dependence on groundwater has increased tremendously in recent years. Thus, given the possibility of the available groundwater resources to be over-exploited in these areas, it is essential that proper storage and management of available groundwater resources be instituted. Replenishment of groundwater by artificial recharge of aquifers is essential, as the intensity of normal rainfall is grossly inadequate to produce any moisture surplus under normal infiltration conditions. Techniques such as canal barriers, construction of percolation tanks, and of trenches along slopes and around hills, et cetera, have been used for some time, but have typically lacked a scientific basis (e.g., knowledge of the geological, hydrological and morphological features of the areas) for selecting the sites on which the recharge structures are located. Suitable areas for implementation of ground water recharge measures in the study area are marked in Fig. 37, which comes under <20% slope category as well as >3m depth to water level. 47% of the river basin area is suitable for implementing groundwater recharge measures. High slopes increases landslide proneness with respect to recharge of water. At the same time, less than 3m to water level areas may tend to be water logged due to induced recharge and thus are not recommended for artificial recharge schemes. Recommendations on possible structures in suitable locations requires extensive hydrological investigations and hence, are not attempted in the present study.

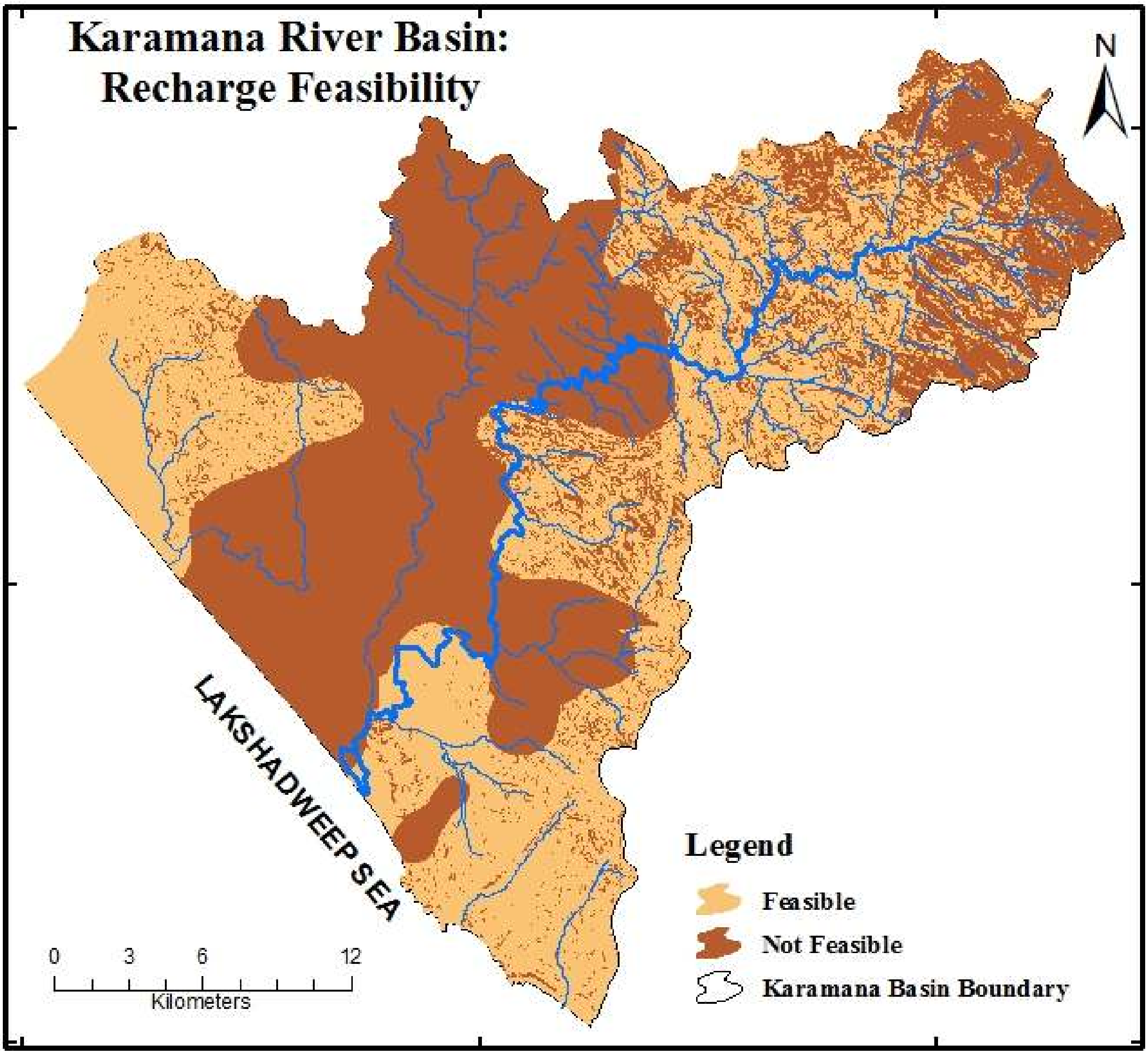


Fig.37 Groundwater recharge feasibility status of the Karamana River Basin.

There are several tanks in the study area and the recharge of tanks can be high, provided the tank bottom was maintained by removing accumulated sediment and debris prior to the annual monsoon. Infiltration was aided by a connector well linking the phreatic, alluvial aquifer for most of the water supply schemes adjacent to the river channels in the study area. Surplus groundwater from the floodplain aquifers of the rivers are also utilised as water sources. Spreading methods, using techniques such as spreading channels, recharge pits and ponds, are found to be more economical and are part of the agricultural practices in the study area.

Watershed management practices adopted by the Government and the farmers to minimise soil loss in erosion also contribute to groundwater recharge. Check dams store surface-water during portions of the year, but also encourage infiltration into the surface aquifers, providing a threefold benefit to communities (i.e., prevention of soil loss, provision of water for livestock watering and human use, and groundwater recharge).

Sub-surface dykes can be effective in augmenting, infiltration channels and ponds. Coastal aquifers are highly porous and drain to the coastal zone, the rapid outflow of recharged water to the sea is expected and did not make artificial recharge a viable proposal. Periodic maintenance of artificial recharge structures is essential because infiltration capacity is rapidly reduced because of silting, chemical precipitation, and accumulation of organic matter. Roof top rainwater harvesting for conservation of water can be an effective method for the study area. The excess water from the collecting structure can be routed to existing wells for groundwater recharge.

Artificial recharge of ground water should be licensed and controlled by competent authorities according to specific requirements laid down in an appropriate permit system that should be flexible to adapt to site-specific conditions. Authorisation for artificially recharging the aquifer should be granted only if the hydro-geological situation, environmental condition and the recharge-water quality permit injection, percolation or infiltration of water by artificial means into aquifers for storage and retrieval. Appropriate measures should be taken to combat saline water encroachment into coastal aquifers even though it is not observed in the groundwater regime of the study area. In such areas, special regulations for ground-water abstraction should be enforced to avoid over-pumping and the resultant lowering of the ground-water table.

WATER QUALITY

The chemical composition of natural water derives from atmospheric, soil and rock sources (Arun, 2006). The relative contribution from each of these sources is a function of climate, modified increasingly by human activity, both directly or indirectly. The solute behavior of water is complex with respect to its role as a transporting medium. Water is a powerful solvent and distinguished source of chemical energy. Natural water chemistry deals mainly with liquid-solid, and liquid-gas reactions occurring in dilute solutions. Water in chemical reactions, may be involved in two ways – may act as a solvent in the solution process, or may engage in a chemical reaction. Most of the reactions in natural environment are usually irreversible under normal temperature and pressure conditions, so equilibrium will not be reached. These reactions are incongruent generally, since most minerals can be considered to react rather than dissolve when in contact with water.

In addition to these, the introduction of chemical constituents from point and non-point sources is a problem, as an essential life supporting agent. The differentiation of source contributions of chemical ingredients of water is extremely important in designing strategies on fresh water resources management. Therefore, an attempt has been made in this chapter to evaluate the water quality and hydrogeochemical processes in the Karamana river basin, which cater to the major freshwater requirements of Thiruvananthapuram district.

CHEMICAL COMPOSITION OF WATER IN THE STUDY AREA

The following section deals with chemical composition of the ground water as well as surface water samples of the Karamana river basin. Chemical composition of water conventionally include pH, total dissolved solids (TDS), conductivity, hardness, major cations like Ca, Mg, Na, K etc, and anions like HCO_3, SO_4, Chloride etc. The solute content of groundwater is a function of the chemistry of water percolating through soil profile and, chemical interactions occurring between and within the aquifer. Rock type of the region has a profound role in controlling ground water composition in addition to the type and intensity of weathering and the residence time of water in each geological formation (Raji and Alagbe, 2000; Arun, 2006).

The concentrations of various physico-chemical parameters estimated in this investigation for the surface water samples are furnished in Table 24 and the sample points are presented in Figure 38. The physicochemical parameters analysed for the water samples collected from 50 observation wells (Fig. 39) of the Karamana river basin are presented in Table 25 and their variations is depicted as figures in concerned sessions.

Fig. 38 River water sampling locations.

Fig. 39 Ground water sampling locations.

Table 24 Physico-chemical parameters in the river water samples of the Karamana river basin (M-Monsoon;NM-Non-monsoon)

Sl.No	Location	pH		ConductivityµS/cm		Alkalinity mg/l		Hardness mg/l		Ca mg/l		Mg mg/l	
		M	NM	M	NM	M	NM	M	NM	M	NM	M	NM
1	Peppara	5.44	5.61	25.20	55.00	17.20	21.50	26.02	12.01	5.61	6.42	2.92	1.36
2	Tholikkod	5.27	5.50	59.60	94.50	27.95	34.40	24.02	22.02	5.61	12.84	2.43	2.23
3	Aryanad	5.50	5.41	35.30	28.90	21.50	27.95	16.01	16.01	4.01	4.81	1.46	2.72
4	Nedumangad	6.01	5.58	101.80	130.80	32.25	38.70	26.02	32.03	8.82	27.28	0.97	1.15
5	Aruvikkara	5.08	5.38	52.30	37.80	23.65	23.65	14.01	14.01	4.01	9.63	0.97	1.06
6	Karakulam	5.65	5.46	103.90	129.20	34.40	43.00	24.02	34.03	8.02	9.63	0.97	5.92
7	Kulasekharam	5.26	5.58	43.30	53.20	25.80	32.25	10.01	86.07	4.01	3.21	0.00	20.12
8	Killippalam	5.59	5.74	121.70	195.20	40.85	47.30	34.03	48.04	13.63	22.46	0.00	6.21
9	Karamana	4.59	5.60	40.70	79.50	25.80	51.60	28.02	38.03	10.42	24.07	0.49	3.39
10	Thiruvallam	4.34	6.27	101.80	7070.00	36.55	64.50	30.02	24.02	9.62	3.21	1.46	5.05
11	Chappath	5.40	5.59	138.10	252.00	38.70	25.80	42.03	36.03	16.03	24.07	0.49	2.90
12	Punthurapozhi	5.76	6.29	375.00	12870.0	43.00	88.15	52.04	18.01	11.22	4.81	5.83	3.20

Sl.No	Location	Na mg/l		K mg/l		HCO_3 mg/l		Cl mg/l		SO_4 mg/l		TDS mg/l	
		M	NM	M	NM	M	NM	M	NM	M	NM	M	NM
1	Peppara	2.16	2.41	0.87	1.32	20.98	26.23	2.64	0.88	1.24	2.30	16.13	32.40
2	Tholikkod	6.40	7.96	1.84	4.58	34.10	41.97	4.40	8.79	2.28	12.00	38.14	65.90
3	Aryanad	3.22	3.70	1.26	1.90	26.23	34.10	5.27	5.27	1.16	1.90	22.59	21.49
4	Nedumangad	9.71	9.80	3.47	3.56	39.35	47.21	8.79	7.91	5.28	5.60	65.15	80.32
5	Aruvikkara	5.11	4.16	2.44	2.65	28.85	28.85	6.15	8.79	4.96	7.80	33.47	25.37
6	Karakulam	10.15	8.66	3.42	6.71	41.97	52.46	8.79	9.67	3.68	22.50	66.50	85.97
7	Kulasekharam	3.61	5.44	1.75	3.67	31.48	39.35	1.76	9.67	5.08	9.70	27.71	39.79
8	Killippalam	8.72	10.30	4.63	4.70	49.84	57.71	7.03	20.22	15.36	9.30	73.82	129.34
9	Karamana	2.96	25.92	1.90	4.94	31.48	62.95	4.40	48.35	6.48	21.80	26.05	47.45
10	Thiruvallam	8.82	1125.75	2.82	51.25	44.59	78.69	10.55	1968.07	16.08	61.20	67.25	4524.80
11	Chappath	13.26	32.96	4.76	2.60	47.21	31.48	16.70	53.63	7.64	18.60	88.38	163.28
12	Punthurapozhi	46.23	1822.00	5.58	71.00	52.46	107.54	78.25	3190.06	17.84	63.30	253.31	8236.80

The correlation coefficients between various physico-chemical parameters of the surface and groundwater samples of the study area are furnished in Tables 26 and 27 respectively and their spatial distribution in the study area are presented as maps. The following sections present a brief description of the results of the present study.

pH

pH values in the surface water samples of the study area varies between 4.3 and 6 (av. 5.32) during monsoon and 5.38 and 6.29 (av. 5.68) during non-monsoon seasons. The lowest pH value is recorded at Thiruvallam and the highest at Punthura Pozhi. Increased pH values are observed in the non-monsoon period throughout the study area (Fig. 40). The pH values of well water samples range from 4.18 (Killi) to 7.80 (Vanchiyur) during monsoon season and the average pH in the well water samples of the study area is 6.05. In non-monsoon season the pH values range between 4.24 (Mukkola) and 7.53 (Pazhakutti) with an average of 6.10. Most of the well water samples exhibit pH values outside the prescribed limit of BIS (6.5-8.5). Spatial distribution of pH shows an increasing trend towards the southern part of the study area (Fig. 41). Compared to the surface water samples (monsoon, 5.32 and non-monsoon, 5.68), the ground water samples of the study area show high pH values.

Conductivity

The conductivity of the surface water ranges from 25.2 µS/cm to 375µS/cm (av. 99.89 µS/cm) during monsoon and 28.90 µS/cm to 12870 µS/cm (av. 1749.67 µS/cm) during non-monsoon. Very high values of conductivity are observed at Thiruvallam (7070 µS/cm) and Punthura Pozhi (12870 µS/cm) during non-monsoon and this can be attributed to sea water ingression through the river channel. Reduced freshwater inflow through the river channel also induces saline water ingression from the sea, enhanced by the tidal influence.

Table 25 Physico-chemical parameters in the groundwater samples of the Karamana river basin (M-Monsoon; NM-Non-monsoon)

Sl. No	Location	pH		Conductivity µS/cm		Alkalinity mg/l		Hardness mg/l		Ca mg/l		Mg mg/l	
		M	NM	M	NM	M	NM	M	NM	M	NM	M	NM
1	Pallipuram	5.35	5.71	345.00	158.80	71.78	27.04	102.90	40.03	35.27	9.62	3.66	3.89
2	Andurkonam	5.25	5.24	88.60	84.70	15.22	22.88	10.46	14.01	4.01	4.01	0.11	0.97
3	Ariyottukonam	5.97	6.04	147.00	99.50	13.58	20.80	9.28	14.01	3.21	3.21	0.31	1.46
4	Pandalakkod	5.68	6.18	136.80	100.10	25.22	21.96	32.03	16.01	12.02	5.61	0.45	0.19
5	Chellamangalam	6.21	6.27	326.00	288.00	56.26	93.60	51.04	82.07	20.81	28.05	0.45	2.92
6	Pangappara	5.86	4.85	285.00	199.90	32.98	27.04	52.05	48.04	8.82	6.41	2.43	7.78
7	Kulathur	6.13	5.97	565.00	411.00	53.25	45.76	83.12	100.08	29.66	32.86	2.20	4.37
8	Pulayanarkotta	6.38	5.60	519.00	469.00	77.60	97.76	112.21	110.09	43.28	31.26	1.00	7.78
9	Mannanthala	6.31	5.32	297.00	251.00	65.96	43.68	59.04	32.03	20.81	10.42	1.70	1.46
11	Vanchiyoor	7.81	5.89	455.00	389.00	91.18	81.12	85.18	112.09	29.66	40.08	2.70	2.92
13	Veli	7.19	6.72	515.00	201.00	75.66	156.00	111.90	360.29	36.07	108.21	5.30	21.87
14	Thumba	7.34	6.68	362.00	441.00	44.62	60.32	94.08	112.09	32.06	41.68	3.40	1.94
15	Valiyathura	6.95	6.49	1304.00	973.00	116.40	187.20	201.92	270.22	72.91	75.14	4.80	19.44
16	Kovalam	6.49	7.31	326.00	433.00	48.50	52.00	37.67	68.05	8.82	4.81	3.80	13.61
18	Vellayani	5.15	4.47	82.10	115.90	9.70	12.48	9.01	14.01	0.80	2.40	1.70	1.94
19	Peringamala	5.08	5.25	78.30	185.10	9.70	79.04	20.02	44.04	2.81	10.42	3.16	4.37
20	Pavanthuvila	4.99	4.34	90.70	95.70	9.70	10.40	12.01	14.01	2.40	4.01	1.46	0.97
21	Punnakkulam	5.09	4.36	33.70	37.60	7.76	104.00	5.00	10.01	2.00	2.40	0.00	0.97
23	Mukkola	4.82	4.24	61.90	76.80	15.52	12.48	24.53	10.01	9.79	4.01	0.02	0.00
24	Madavurpara	5.74	5.35	273.00	124.60	34.92	18.72	51.24	14.01	18.21	4.81	1.40	0.49
25	Nemam	6.10	7.51	353.00	670.00	64.02	58.24	59.69	80.06	17.63	25.05	3.80	2.43
26	Pappanamkode	5.94	6.96	145.00	116.60	27.60	37.44	40.99	38.02	12.81	8.82	2.19	1.46
27	Vilavoorkal	5.90	6.05	177.00	95.30	29.10	31.20	24.02	16.01	8.82	6.41	0.49	0.00
28	Uroottambalam	6.49	6.46	120.40	57.40	15.52	18.72	7.01	12.01	0.80	4.01	1.21	0.49
29	Killi	4.18	5.09	161.20	100.00	7.76	8.32	4.37	12.01	1.60	2.40	0.09	1.46
30	Poovachal	6.47	5.86	61.80	51.10	17.46	20.80	3.17	20.02	1.20	4.01	0.04	2.43
33	Aryanad	6.16	6.24	133.70	101.00	13.58	20.80	6.58	20.02	2.40	6.41	0.09	0.97
34	Keezhpalur	5.28	6.50	32.50	34.90	7.76	8.32	14.49	10.01	5.80	2.40	0.00	0.97
36	Thelikode	4.88	6.25	26.80	24.10	11.64	12.48	20.68	8.01	8.20	2.40	0.05	0.49
37	Karakulam	5.58	5.98	311.00	528.00	25.22	24.96	36.03	50.04	9.62	16.03	2.92	2.43
38	Vattappara	6.58	7.01	470.00	508.00	151.32	160.16	154.44	160.13	59.62	48.09	1.35	9.72
39	Pazhakurri	7.49	7.53	409.00	272.00	143.56	39.52	122.82	82.07	43.24	27.25	3.60	3.40
40	Irinjayam	6.89	5.11	463.00	379.00	69.84	45.76	82.07	16.01	26.45	4.81	3.89	0.97
41	Panavur	5.32	6.45	118.30	245.90	25.22	49.92	26.09	56.04	7.21	20.04	1.96	1.46
42	Anad	5.35	6.73	78.70	72.40	17.68	21.96	32.03	12.01	8.02	3.21	2.92	0.97
43	Panackod	6.59	6.75	137.60	153.80	25.22	35.36	22.02	30.02	4.81	10.42	2.92	0.97
44	Puthukulangara	6.99	6.53	198.20	234.00	29.10	18.72	42.05	36.03	11.62	10.42	3.16	2.43
45	Mundela	5.19	6.38	31.60	64.50	11.64	10.40	25.50	10.01	5.80	2.40	2.19	0.97
47	Vilappilsala	6.37	7.12	191.20	158.80	19.84	33.28	22.75	36.03	8.00	9.62	0.67	2.92
48	Peyad	5.88	6.61	491.00	504.00	9.70	26.92	36.13	60.05	8.82	16.03	3.50	5.86
49	Malayinkil	6.68	6.85	161.70	152.50	23.28	24.96	16.24	34.03	5.61	7.21	0.54	3.89
50	Nettayam	5.90	7.00	86.70	118.80	25.22	60.32	17.59	46.04	5.61	17.65	0.87	0.49

Table 25 Continued… (M-Monsoon; NM-Non-monsoon)

Sl. No	Location	Na mg/l		K mg/l		HCO_3 mg/l		Cl mg/l		SO_4 mg/l		TDS mg/l	
		M	NM	M	NM	M	NM	M	NM	M	NM	M	NM
1	Pallipuram	26.90	20.00	2.34	1.50	87.57	32.99	42.99	25.91	52.40	13.87	265.00	147.00
2	Andoorkonam	12.61	11.70	0.24	2.00	18.57	27.91	9.00	13.40	4.00	5.41	76.70	74.20
3	Ariyottukonam	23.91	14.40	2.49	2.70	16.57	25.38	26.99	17.87	3.80	5.57	124.00	88.20
4	Pandalakkod	11.47	11.70	5.21	2.30	30.77	30.45	15.00	17.87	9.90	5.22	116.00	85.60
5	Chellamangalam	35.50	22.70	1.50	2.10	68.64	114.19	58.98	22.33	11.20	6.51	238.00	208.00
6	Pangappara	36.66	37.60	1.24	1.80	40.24	32.99	51.99	40.20	68.30	5.67	210.00	180.00
7	Kulathur	32.40	27.90	1.02	1.63	64.97	55.83	41.99	42.88	15.90	52.11	408.00	292.00
8	Pulayanarkotta	28.53	37.90	1.74	2.55	94.67	119.27	25.99	58.96	94.40	22.71	593.00	358.00
9	Mannanthala	30.76	39.30	1.14	1.60	80.47	53.29	56.99	46.45	7.10	5.67	224.00	188.00
11	Vanchiyoor	30.29	33.80	1.54	1.50	111.24	98.97	24.99	28.59	12.50	38.47	552.00	278.00
13	Veli	45.51	332.00	5.19	17.00	92.31	190.32	45.99	491.34	66.20	51.86	382.00	1500.00
14	Thumba	25.10	40.50	2.97	4.00	54.44	73.59	45.99	58.07	15.50	36.97	266.00	335.00
15	Valiyathura	43.42	85.50	1.03	2.85	142.01	228.38	96.97	111.67	70.70	49.04	948.00	680.00
16	Kovalam	40.04	59.00	1.58	1.21	59.17	68.44	56.98	67.00	9.60	25.65	255.00	329.00
18	Vellayani	15.89	20.50	0.08	1.00	11.83	15.23	20.99	49.13	6.00	7.02	71.30	103.00
19	Peringamala	4.19	12.20	0.06	2.14	11.83	96.45	6.00	26.80	9.40	5.57	104.00	274.00
20	Payattuvila	11.32	13.60	1.47	5.10	11.83	12.69	13.00	31.27	7.60	5.52	80.00	86.90
21	Punnakkulam	10.14	16.54	0.26	0.20	9.47	126.88	16.00	26.80	0.80	5.22	29.60	32.70
23	Mukkola	10.15	19.20	0.25	0.20	18.93	15.23	13.00	22.33	3.66	2.96	59.00	55.40
24	Madavurpara	15.73	20.40	1.88	1.60	42.60	22.84	21.99	23.23	4.47	3.11	71.30	107.00
25	Nemom	28.38	124.00	1.65	0.90	78.10	71.05	24.99	151.87	16.90	5.78	261.00	499.00
26	Pappanamkode	18.69	15.10	1.42	6.00	33.67	45.68	28.00	15.19	3.80	5.01	121.00	104.00
27	Vilavoorkal	21.35	11.20	1.02	5.50	35.50	38.06	33.00	11.61	4.70	3.86	151.00	81.30
28	Uroottambalam	20.59	11.20	1.92	2.20	18.93	22.84	17.00	8.93	3.10	2.96	105.00	49.50
29	Killi	15.17	19.30	0.02	3.30	9.47	10.15	17.00	25.01	0.84	4.58	146.00	90.20
30	Poovachal	8.84	8.60	3.09	4.10	21.30	25.38	6.00	10.72	0.30	3.75	55.50	53.50
33	Aryanad	18.39	16.00	0.62	4.20	16.57	25.38	19.00	16.08	1.50	4.51	111.00	90.00
34	Keezhpalur	4.90	3.60	0.01	4.00	9.47	10.15	7.00	3.57	2.50	5.08	25.40	30.10
36	Thalikode	3.59	4.80	0.01	0.02	14.20	15.23	7.00	18.00	2.47	4.22	20.10	20.10
37	Karakulam	50.91	56.50	1.51	1.80	30.77	30.45	59.99	93.80	4.04	4.40	239.00	390.00
38	Vattappara	29.97	37.50	2.84	0.50	184.61	195.40	40.99	53.60	5.90	4.58	307.00	382.00
39	Pazhakutti	17.67	23.30	1.49	1.60	175.14	48.21	25.99	29.50	3.33	19.04	307.00	214.00
40	Irinjayam	42.09	55.00	1.88	12.50	85.20	55.83	44.99	84.87	3.43	9.26	306.00	310.00
41	Panavur	12.34	23.50	0.09	5.50	30.77	60.90	15.00	29.48	4.20	6.56	95.50	203.00
42	Anad	12.13	12.70	1.39	5.60	21.57	30.45	22.00	8.93	1.31	4.65	68.50	64.00
43	Panacode	18.47	18.50	2.18	2.70	30.77	43.14	19.99	16.08	2.99	10.15	109.00	117.00
44	Puthukulangara	19.80	32.20	1.84	1.20	35.50	22.84	29.99	42.88	2.60	8.21	155.00	180.00
45	Mundela	2.98	7.80	0.01	5.30	14.20	12.69	8.00	15.19	1.40	5.01	22.60	55.20
47	Vilappilsala	12.24	22.30	0.08	1.90	24.20	40.60	14.00	22.33	3.00	8.54	161.00	134.00
48	Peyad	8.21	89.00	0.77	2.10	11.83	32.64	27.99	116.13	5.50	6.20	368.00	360.00
49	Malamugal	16.90	20.00	0.63	5.50	28.40	30.45	14.00	26.80	2.09	13.11	137.00	128.00
50	Nettayam	9.29	9.20	1.08	2.10	30.77	73.59	7.00	12.51	1.60	5.98	66.90	100.00

Slightly higher values are reported from Chappath (252 µS/cm), Killipalam (195.2 µS/cm), Karakulam (129.2 µS/cm) and Nedumangad (130.8 µS/cm) during non-monsoon season. This may result from the combined effects of domestic waste discharges as well as insufficient river water flow during non-monsoon season. Spatial variation of conductivity along the channels of the Karamana river shows an increasing trend downstream (Fig. 42). The Killiyar tributary records comparatively higher conductivity values and exhibit a progressive increase downstream. The conductivity values of the study area are similar to that of the Neyyar reservoir (31 µS/cm) reported by Sureshbabu et al. (1998).

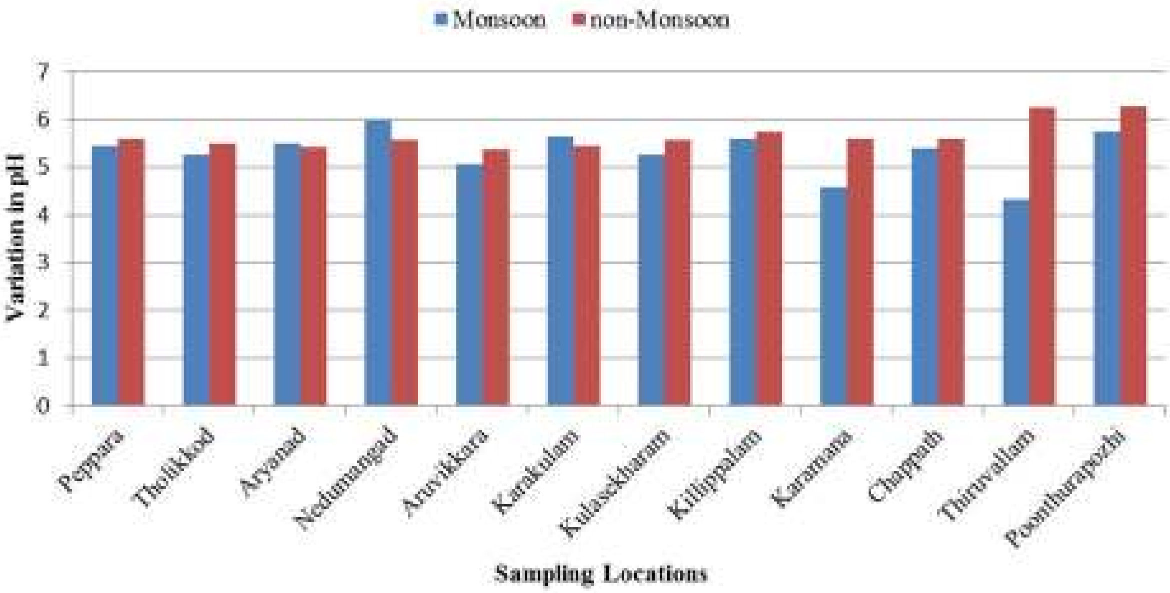


Fig. 40 Variation of pH in river water samples.

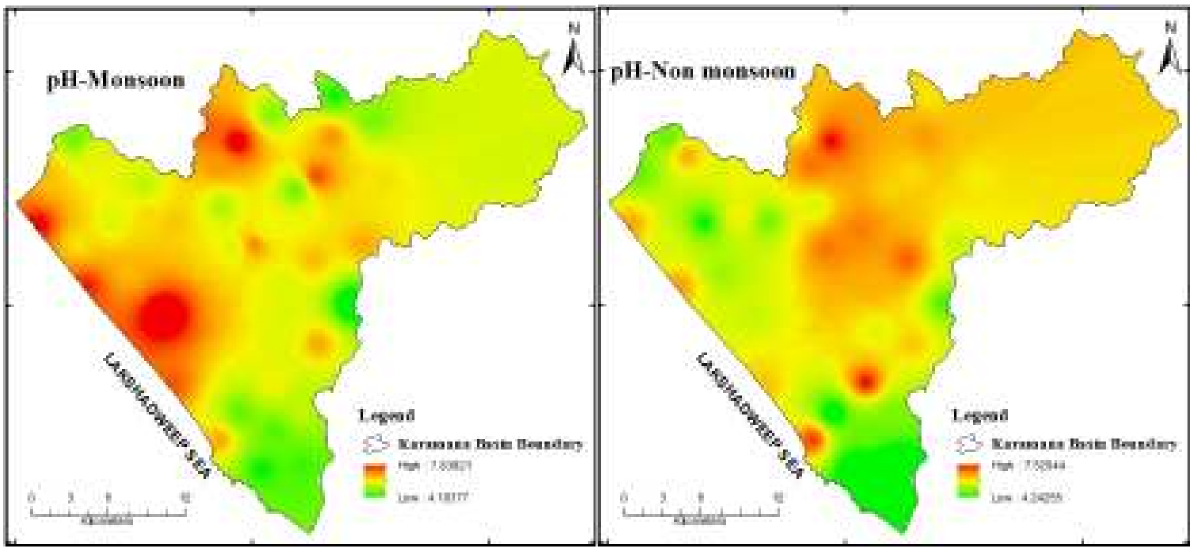


Fig. 41 Spatial variation of pH in ground water samples during Monsoon and Non-monsoon seasons

The conductivity of the ground water ranges from 26.8 µS/cm to 1304 µS/cm (av. 253.87 µS/cm) during monsoon and 24.1 µS/cm to 973 µS/cm (av. 1749.67 µS/cm) during non-monsoon. Higher conductivity values in the coastal reaches (Valiyathura) of the study area points to ground water pollution, mostly from anthropogenic sources (Fig. 43). Lower conductivity values observed in the eastern portions are attributed to high precipitation coupled with high rates of infiltration and low degree of weathering. The surface water samples exhibit markedly low conductivity (except the stations Thiruvallam and Poonthura pozhi) with respect to the ground waters.

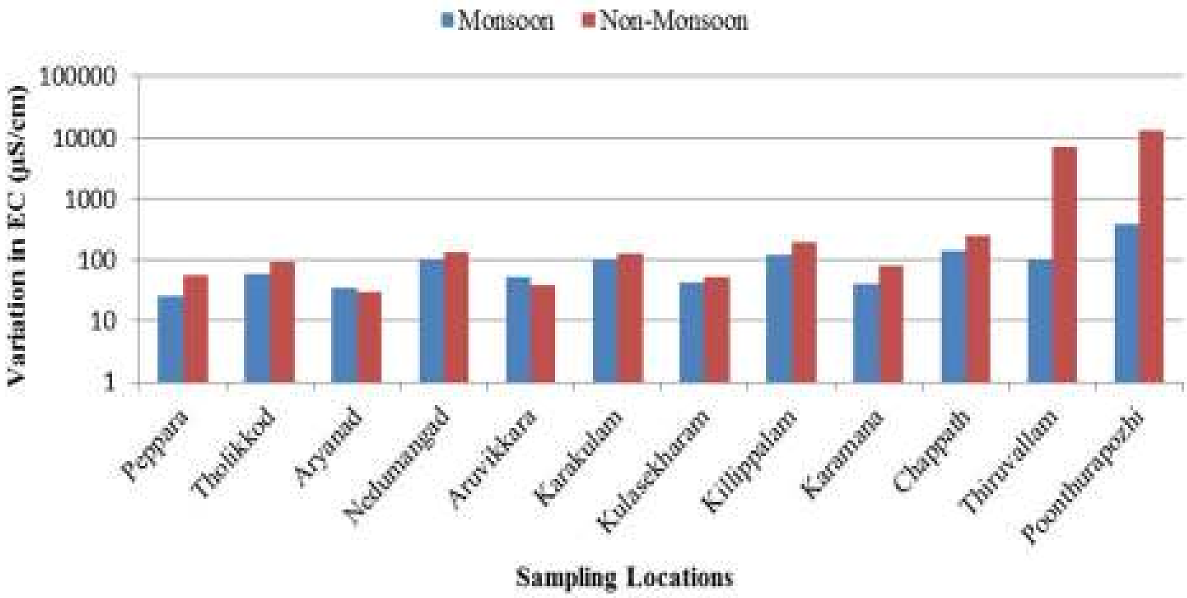


Fig. 42 Variation of EC in river water samples

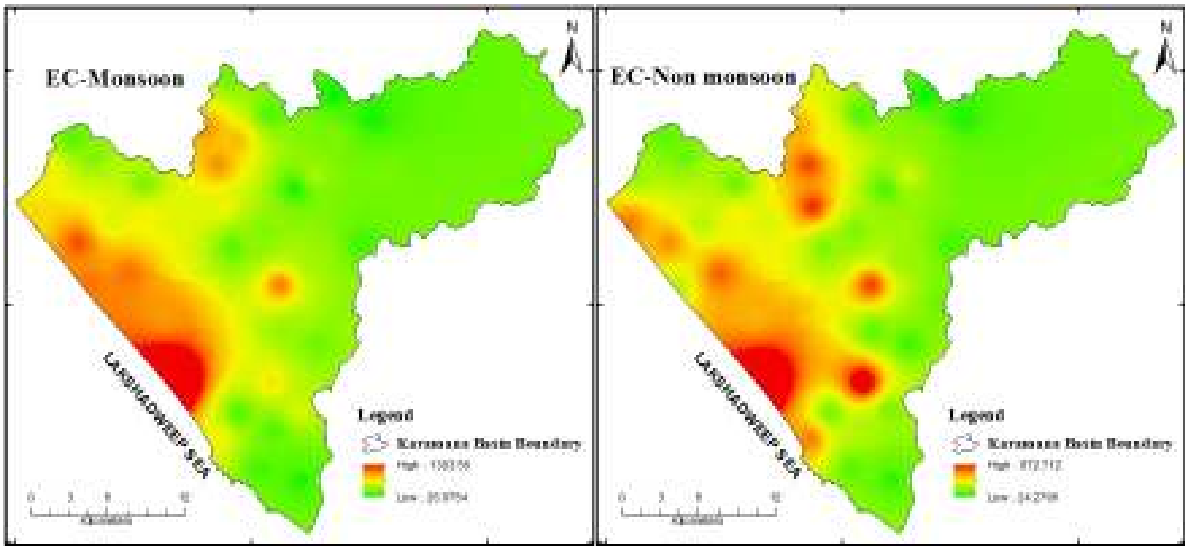


Fig. 43 Spatial variation of EC in ground water samples during Monsoon and Non-monsoon seasons.

Alkalinity

In the study area, the alkalinity values of groundwater samples range from 8.3 mg/l at Keezhpallur to 187.2 mg/l at Valiyathura (av. 46.4 mg/l) during non-monsoon and from 7.76 mg/l at Keezhpallur to 151.32 mg/l at Venkod (av. 39.21 mg/l) during monsoon seasons (Fig. 45). In the river water samples alkalinity ranges from 21.5 mg/l (Peppara) to 88.15 mg/l (Poonthura pozhi) with an average of 41.57 mg/l during non-monsoon and from 17.2 mg/l (Peppara) to 43.0 mg/l (Poonthura pozhi) with an average value 30.64 mg/l during monsoon seasons. Irrespective of the seasons, the settlement areas show comparatively high alkalinity values than that of the forest areas. The alkalinity shows an increasing trend in the downstream side, during both seasons. Comparatively higher alkalinity values exhibited by ground water in the study area may be attributed to the rock–water interaction processes. According to Saxena (1994) alkalinity is imparted more by the presence of CO_2, suggesting the fact that decay of organic matter is the prominent activity elevating alkalinity in natural waters. It is also important that alkalinity resulting from naturally occurring ions like CO_3 and HCO_3 are not considered as a health hazard for drinking purposes (NAS, 1974).

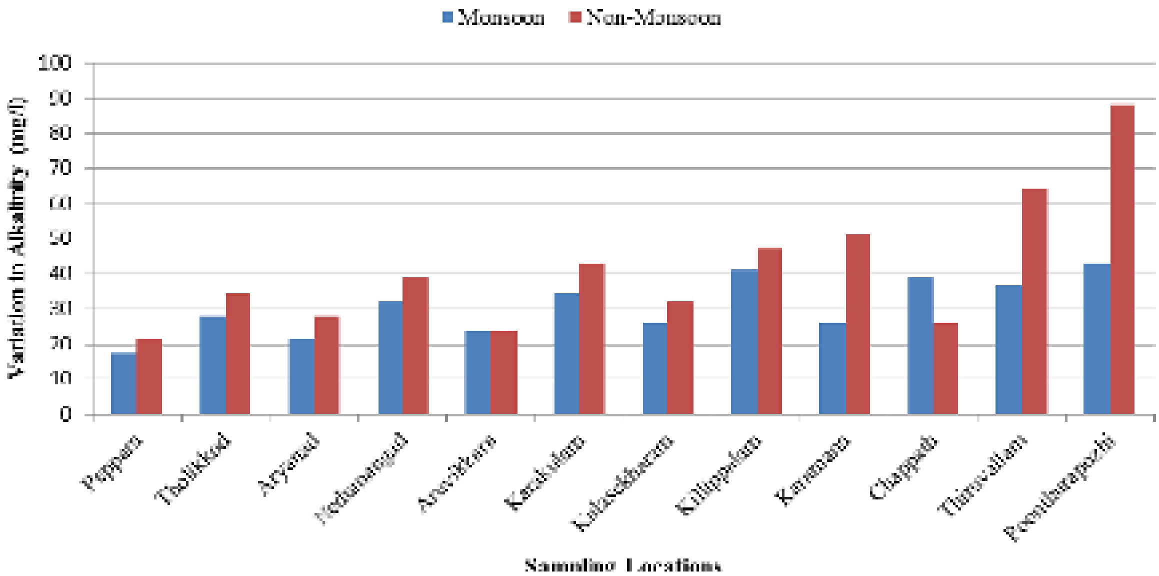


Fig. 44 Variation of Alkalinity in river water samples

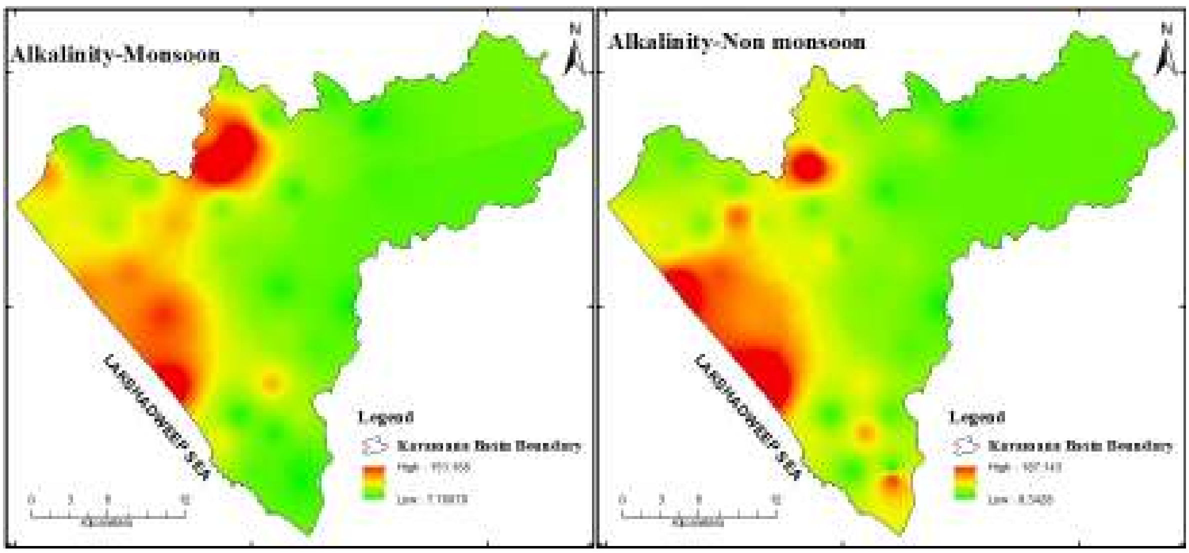


Fig. 45 Spatial variation of Alkalinity in ground water samples during Monsoon and Non-monsoon seasons

Table 26 Correlation matrix for river water samples of Karamana river basin

Monsoon

	Temp	pH	EC	TDS	HCO_3	Cl	SO_4	Ca	Mg	Na	K
Temp	1.0000										
pH	-0.0501	1.0000									
EC	-0.2662	0.3466	1.0000								
TDS	-0.2734	0.3357	0.9994	1.0000							
HCO_3	0.0484	0.1821	0.7695	0.7510	1.0000						
Cl	-0.3741	0.2923	0.9657	0.9733	0.5892	1.0000					
SO_4	-0.2275	-0.1514	0.7239	0.7150	0.8139	0.6220	1.0000				
Ca	0.1493	0.0527	0.5166	0.4951	0.7923	0.3576	0.6311	1.0000			
Mg	-0.1473	0.2360	0.6798	0.6985	0.1478	0.7986	0.2685	-0.0412	1.0000		
Na	-0.2928	0.3481	0.9898	0.9936	0.6792	0.9891	0.6495	0.4155	0.7555	1.0000	
K	-0.1133	0.3670	0.8327	0.8143	0.9383	0.6785	0.7340	0.7899	0.2146	0.7559	1.0000

Non Monsoon

	Temp	pH	EC	TDS	HCO_3	Cl	SO4	Ca	Mg	Na	K
Temp	1.0000										
pH	0.5707	1.0000									
EC	0.5251	0.9080	1.0000								
TDS	0.5254	0.9079	1.0000	1.0000							
HCO_3	0.5636	0.8617	0.8786	0.8786	1.0000						
Cl	0.5366	0.9211	0.9983	0.9983	0.8783	1.0000					
SO4	0.5043	0.9033	0.9091	0.9092	0.8827	0.9240	1.0000				
Ca	-0.1090	-0.2658	-0.3988	-0.3992	-0.1349	-0.4085	-0.3114	1.0000			
Mg	0.3659	0.0283	-0.0662	-0.0655	0.0067	-0.0623	-0.0101	-0.5176	1.0000		
Na	0.5357	0.9210	0.9983	0.9983	0.8779	1.0000	0.9241	-0.4082	-0.0632	1.0000	
K	0.5480	0.9331	0.9902	0.9903	0.8944	0.9956	0.9468	-0.4118	-0.0422	0.9956	1.0000

Table 27 Correlation matrix for groundwater samples of Karamana river basin

Monsoon

	Temp	pH	EC	TDS	HCO_3	Cl	SO_4	Ca	Mg	Na	K
Temp	1.0000										
pH	0.0215	1.0000									
EC	0.1402	0.5448	1.0000								
TDS	0.1571	0.5588	0.9891	1.0000							
HCO_3	-0.1346	0.6598	0.7253	0.7011	1.0000						
Cl	0.0900	0.4763	0.8412	0.8355	0.5978	1.0000					
SO_4	0.2538	0.2778	0.6195	0.6363	0.4252	0.4807	1.0000				
Ca	-0.0159	0.5718	0.8564	0.8305	0.9112	0.7012	0.5941	1.0000			
Mg	0.0969	0.5168	0.6003	0.6053	0.4755	0.5817	0.3915	0.4889	1.0000		
Na	0.1280	0.5812	0.7211	0.7156	0.6289	0.8399	0.5596	0.6132	0.5423	1.0000	
K	0.0855	0.5642	0.2735	0.2468	0.4174	0.3326	0.2582	0.3828	0.3223	0.4666	1.0000

Non Monsoon

	Temp	pH	EC	TDS	HCO_3	Cl	SO_4	Ca	Mg	Na	K
Temp	1.0000										
pH	0.1081	1.0000									
EC	0.4060	0.3156	1.0000								
TDS	0.5070	0.2643	0.9495	1.0000							
HCO_3	0.4330	0.1918	0.6070	0.6944	1.0000						
Cl	0.4149	0.1808	0.3393	0.9490	0.5182	1.0000					
SO_4	0.6952	0.2402	0.5468	0.7252	0.6172	0.5830	1.0000				
Ca	0.6019	0.3015	0.5905	0.8980	0.8256	0.7710	0.8262	1.0000			
Mg	0.5004	0.2208	0.5631	0.8314	0.7454	0.7186	0.7240	0.7892	1.0000		
Na	0.4423	0.2281	0.3789	0.9514	0.5294	0.9927	0.5947	0.7788	0.7307	1.0000	
K	-0.0218	0.1801	-0.0760	0.5428	0.1797	0.6169	0.3300	0.3885	0.3176	0.5902	1.0000

Hardness

Hardness exhibits wide regional as well as seasonal fluctuations in the study area. Further, the non-monsoon values are generally higher than that of monsoon values. The hardness values in groundwater range between 8.01 mg/l at Tholikode and 360.3 mg/l at Veli (av. 55.2 mg/l) in non-monsoon and 3.17 mg/l at Poovachal to 201.92 mg/l at Valiyathura (av. 46.73 mg/l) in monsoon. In river water hardness values range between 12.01 mg/l at Peppara and 86.07 mg/l at Kulasekharam (av. 31.69 mg/l) in non-monsoon and 10.01 mg/l at Kulasekharam to 52.04 mg/l at Poonthura pozhi (av. 27.19 mg/l) in monsoon. In general, the hardness value of surface water increases progressively downstream (Fig.46).

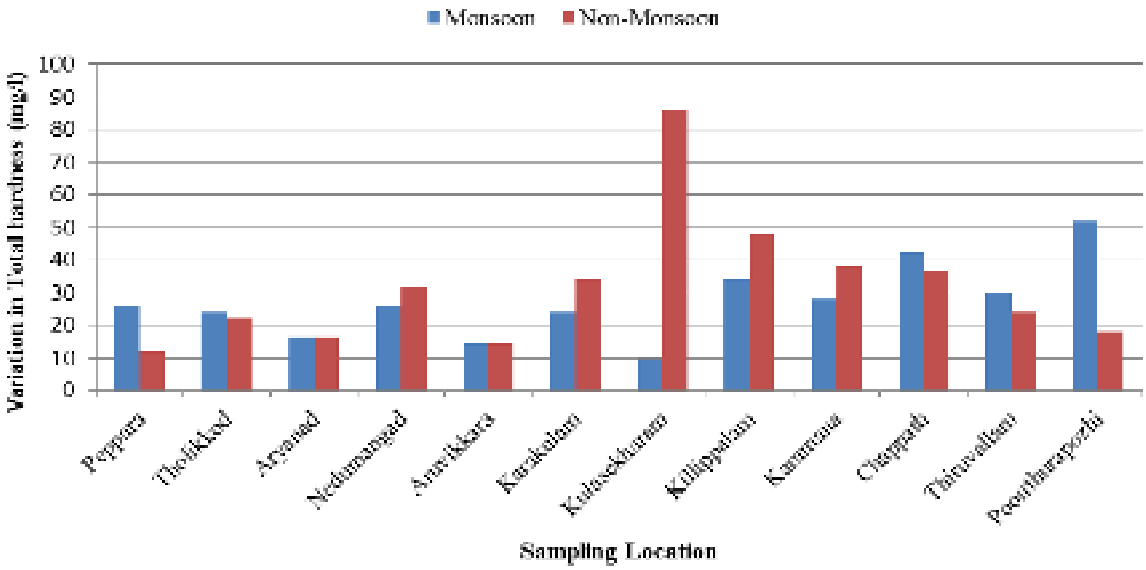


Fig. 46 Variation of Hardness in river water samples

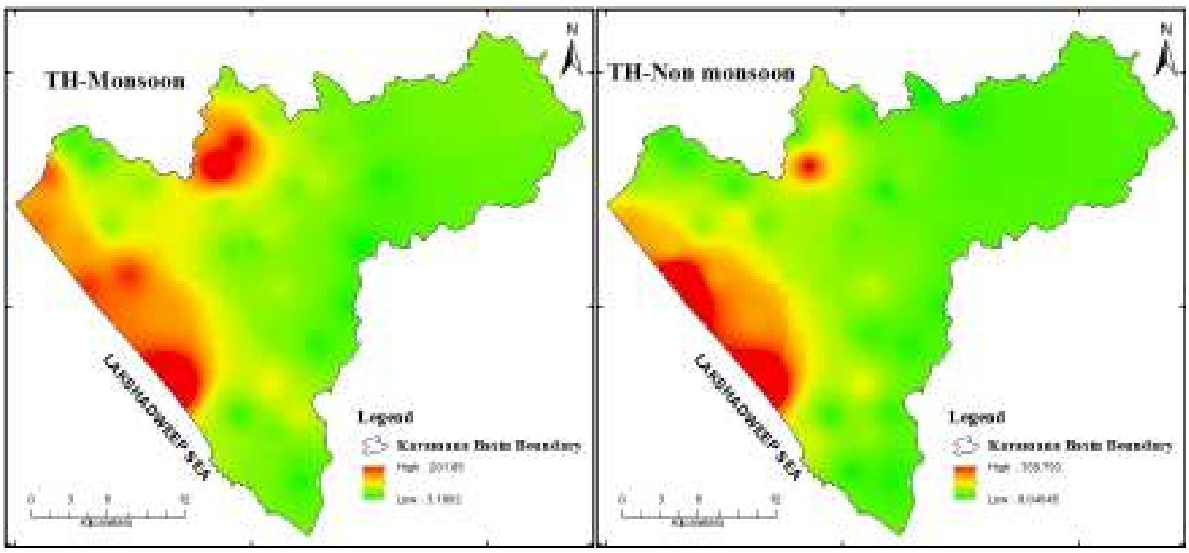


Fig. 47 Spatial variation of Hardness in ground water samples during Monsoon and Non-monsoon seasons

Compared to the groundwater environment, the river water shows lower hardness values in both the seasons and this clearly indicates that the ground waters acquire appreciable quantities of carbonates and bicarbonates in dissolved form during their movement through the aquifer system of the study area. The upper reaches exhibit decreased hardness values than that of coastal reaches in both the seasons (Fig. 47).

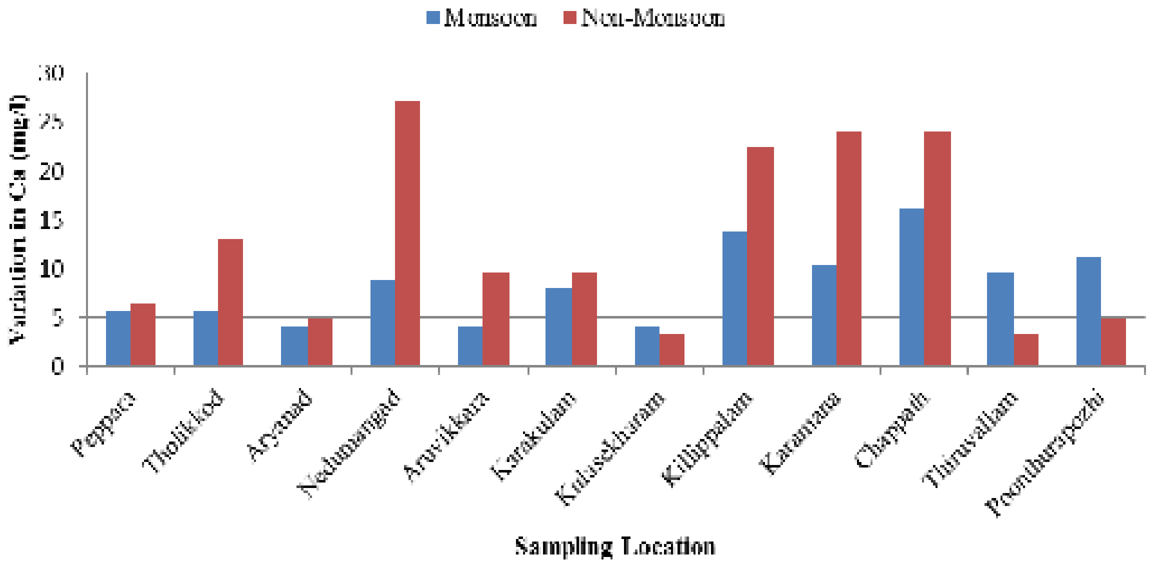


Fig. 48 Variation of Calcium in river water samples.

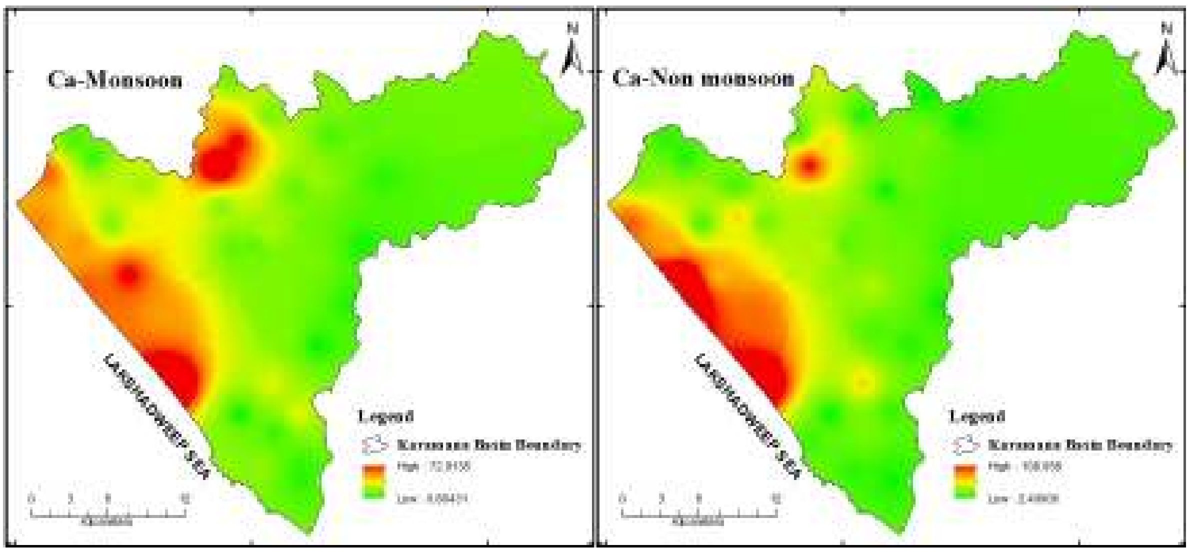


Fig. 49 Spatial variation of Calcium in ground water samples during Monsoon and Non-monsoon seasons

Calcium and Magnesium (Ca and Mg)

In the groundwater environment of the study area Ca records an average concentration of 16.4 mg/l (range: 2.4–108.2 mg/l) in non-monsoon and 15.63 mg/l (range: 0.87–72.94 mg/l) in monsoon (Fig. 49). Ca content in the river channels varies from 3.21 mg/l to 27.28

mg/l (av. 12.7 mg/l) during non-monsoon and 4.01 mg/l to 16.03 mg/l (av. 8.42 mg/l) during monsoon. Ca concentration in the study area exhibits marked fluctuation, both seasonally and regionally. In both the seasons an increasing trend exists in the downstream reaches (Fig. 48). This indicates that the streams in the lower part of the study area contribute more Ca than the upper part streams.

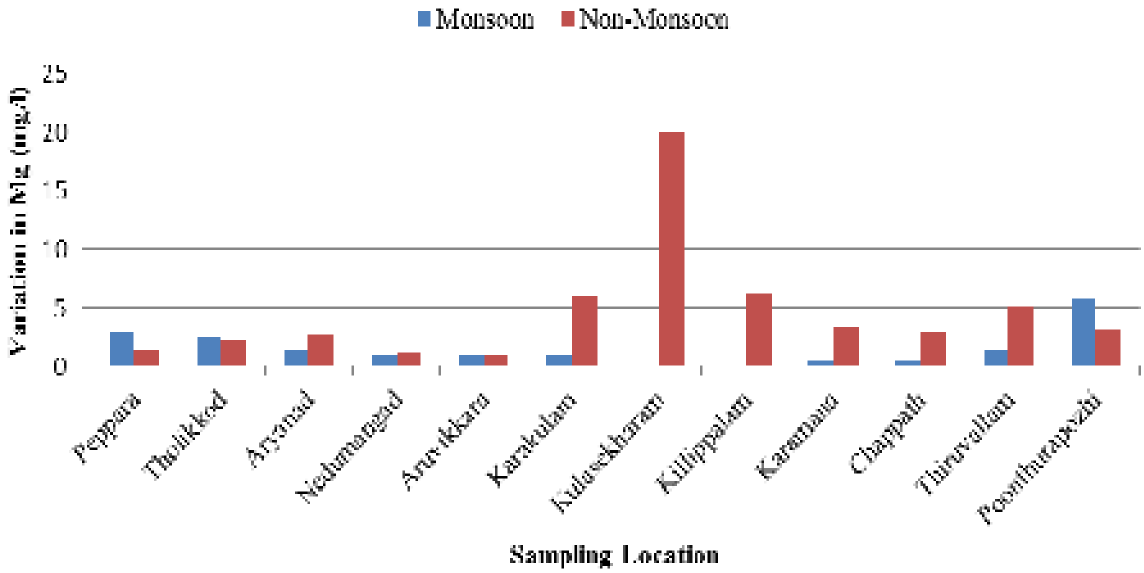


Fig. 50 Variation of Magnesium in river water samples

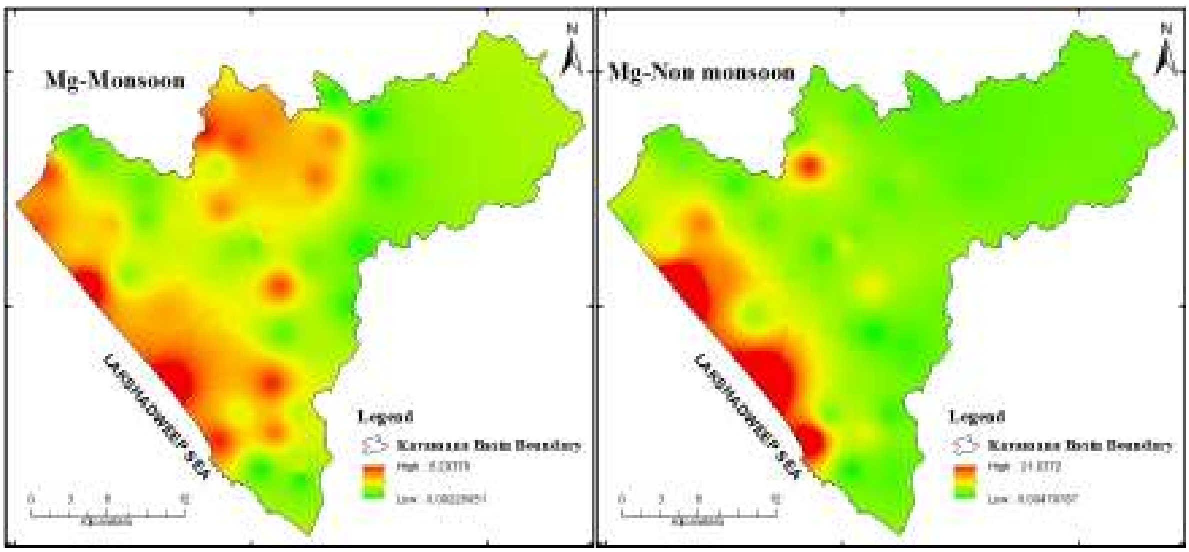


Fig. 51 Spatial variation of Magnesium in ground water samples during Monsoon and Non-monsoon seasons

The Mg content in the groundwater of the study area varies from below detectable limit (BDL) to 21.9 mg/l (av. 3.05 mg/l) in non-monsoon and from BDL to 5.30 mg/l (av. 1.87 mg/l) in monsoon. Mg content in the river channels varies from 1.06 mg/l to 20.12 mg/l (av. 4.61 mg/l) during non-monsoon and BDL to 5.83 mg/l (av. 1.50 mg/l) during monsoon.

The settlement areas exhibit elevated Mg values than the forested areas irrespective of the seasons. Mg shows highly significant positive correlation with alkalinity and hardness during both the seasons. Mg occurs in lower concentrations in the study area than Ca, but exhibits regional as well as seasonal fluctuations. Most of the samples show elevated Mg concentrations during non-monsoon than monsoon (Fig. 50 and 51). The concentration of these elements solely depends on the geological sources and chemical weathering process.

Sodium and Potassium (Na and K):

Na content in the groundwater ranges between 3.6 mg/l at Kizhpallur and 332 mg/l at Veli (av. 35.7 mg/l) in the non-monsoon and between 2.98 mg/l at Mundela and 45.51 mg/l at Veli (av. 20.58 mg/l) in monsoon. The average value of Na in the river channel is 252.92 mg/l in non-monsoon (2.41 mg/l–1822 mg/l) and 10.03 mg/l (2.16–46.23 mg/l) in monsoon. Very high Na values are recorded in Thiruvallam and Poonthurapozhi due to the sea water ingression during the non-monsoon season. Na concentration shows an increasing trend downstream and coastal reaches (Fig. 52 and Fig.53). Na exhibits significant positive correlations with K and TDS in the monsoon and non-monsoon seasons.

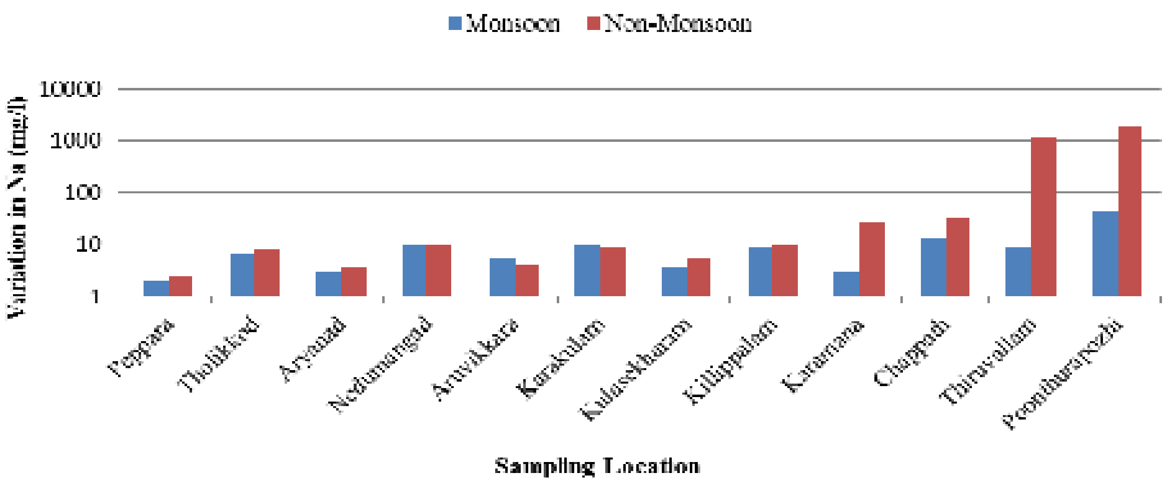


Fig. 52 Variation of Sodium in river water samples.

In the groundwater, K records an average concentration of 3.2 mg/l (range: BDL–17 mg/l) in non-monsoon and 1.30 mg/l (range: 0.01–3.21 mg/l) in monsoon. The river channels account for an average concentration of 13.24 mg/l (range: 1.32–71 mg/l) in non-monsoon and 2.90 mg/l (range: 0.87–5.58 mg/l) in monsoon. High values are recorded in the river channels and the maximum value is observed at Poonthura pozhi in non-monsoon as well as monsoon season. In both the seasons K exhibits strong correlation with conductivity, hardness, Ca and TDS. K exhibits the same trends (Fig.54 and Fig.55) as that of Na even though its concentration is generally lower than Na.

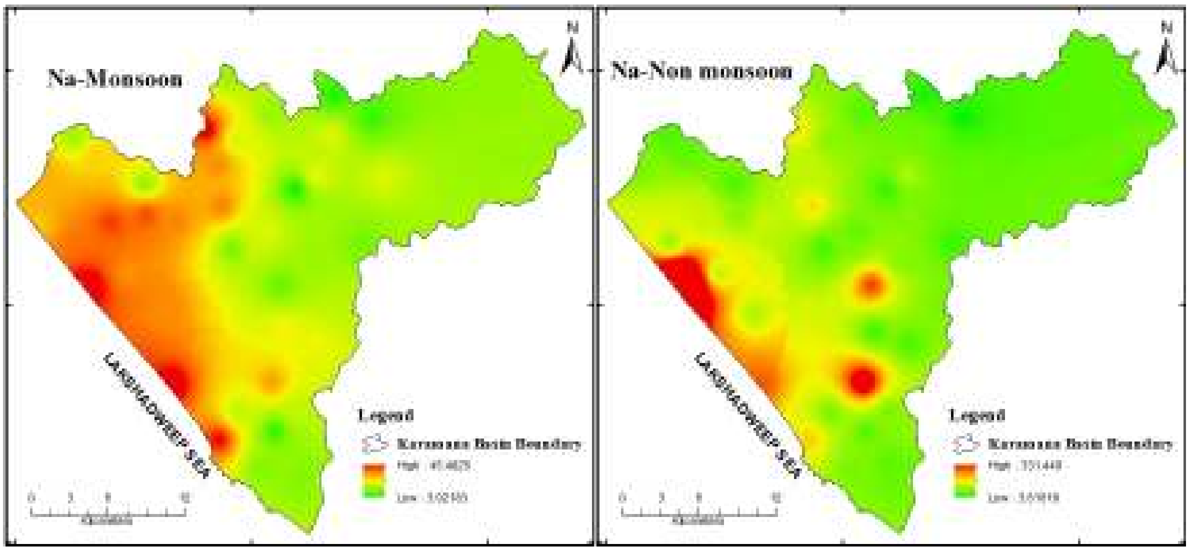


Fig. 53 Spatial variation of Sodium in ground water samples during Monsoon and Non-monsoon seasons

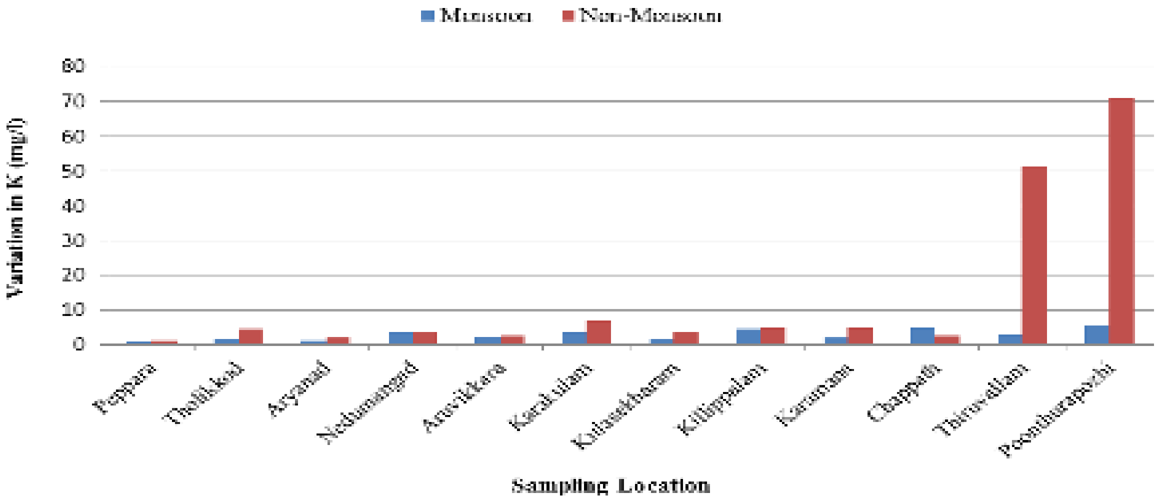


Fig. 54 Variation of Potassium in river water samples

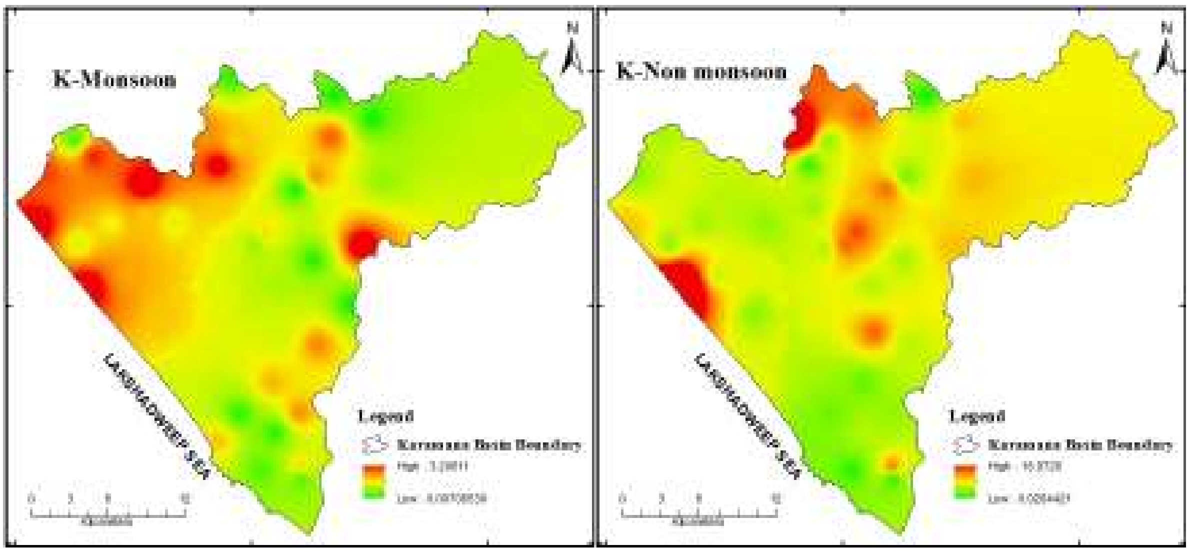


Fig. 55 Spatial variation of Potassium in ground water samples during Monsoon and Non-monsoon seasons

Carbonates (CO_3) and Bicarbonates (HCO_3)

The atmospheric CO_2 and rocks are the primary sources of carbonates and bicarbonates in water. The solubility of CO_2 in water decreases with increase in temperature as well as decrease in pressure. Water with CO_2 dissolves carbonate minerals in soil and rocks to bicarbonates. The alkalinity of water is caused by carbonates and bicarbonates along with hydroxides. Large amount of bicarbonate and alkalinity in water is undesirable in industrial use. Higher amount of carbonates and bicarbonates in drinking water can cause heart ailments and artery blockage (Sreela, 2009).

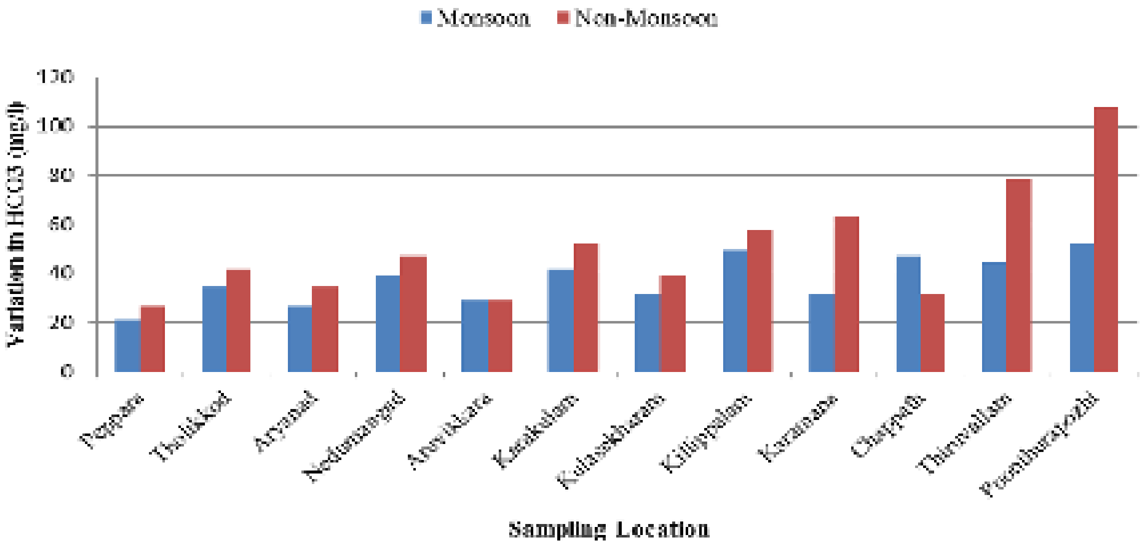


Fig. 56 Variation of Bicarbonate in river water samples.

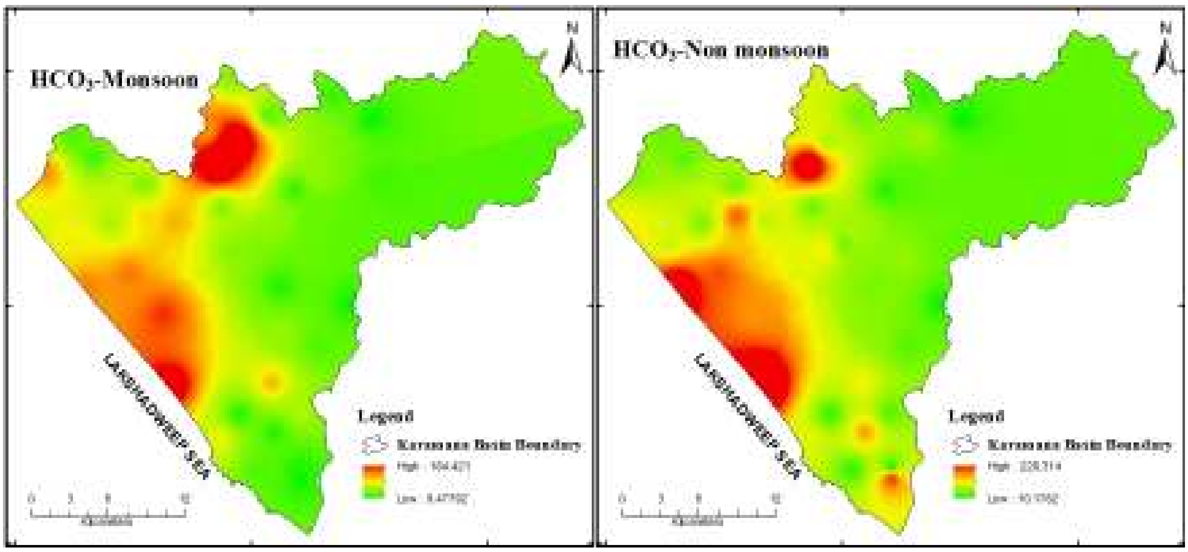


Fig. 57 Spatial variation of Bicarbonates in ground water samples during Monsoon and Non-monsoon seasons

Carbonates (CO_3) are not recorded for any of the surface as well as groundwater samples in the study area, mostly due to the acidic nature of water revealed by comparatively low pH values. Bicarbonate (HCO_3) is detected in all the groundwater samples in the study area and the minimum, maximum and average HCO_3 content in groundwater of the study area are 10.2 mg/l (Keezhpallur, Killi), 491.3 mg/l (Veli) and 48.4 mg/l respectively during non-monsoon season and 6 mg/l (Poovachal), 96.97 mg/l (Valiyathura) and 26.49 mg/l during monsoon. In the river environment average value of HCO_3 is 50.71 mg/l in non-monsoon (26.23 mg/l–107.54 mg/l) and 37.38 mg/l (20.98–52.46 mg/l) in monsoon. Maximum values are recorded in Poonthura pozhi irrespective of the seasons with a two-fold increase in non-monsoon (Fig.56). Samples from Vanchiyur, Valiyathura, Venkod and Pazhakutti exhibits a concentration >100mg/l of HCO_3 value in monsoon and in non-monsoon the samples from Chellamangalam, Pulayanarkotta, Veli, Valiyathura, Punnakkulam and Venkod exhibits >100 mg/l concentration. The coastal reaches of the study area exhibits high HCO_3 content (Fig.57) and all other portions show very low concentration.

Chloride

The minimum, maximum and average Cl content in groundwater of the study area are 3.6 mg/l (Keezhpallur and Killi), 491.3 mg/l (Veli) and 48.4 mg/l respectively during non-monsoon season and 6 mg/l (Poovachal), 96.97 mg/l (Valiyathura) and 26.49 mg/l during monsoon. The river channel samples account for an average Cl content of 444.28 mg/l during non-monsoon and 12.89 mg/l in monsoon. High values of Cl are recorded in the river samples of Thiruvallam (and Poonthura pozhi (3190.06 mg/l) in non-monsoon season. Cl values of the riverine samples exhibit wide regional fluctuations during both monsoon and non-monsoon seasons (Fig. 58). In general Cl shows an increase in concentration towards the coastal reaches of the study area. It is interesting to note that Cl exhibits an inverse relation with altitude – the high altitude zones record lower Cl values (Fig. 59). In general, Cl shows increased values in monsoon than non-monsoon within the study area. Higher Cl concentrations in the urbanised areas may be an indicator of pollution caused by urban, domestic and organic wastes, a feature also observed elsewhere (Ownbey and Kea, 1967). Cl is present in sewage effluents and farm drainages and remain unaltered even during the purification processes. Cl concentration of water from different sources is summarized in Table 28. Water from the study area falls within the surface water class, specifically in unpolluted river water category.

Table 28 Chlorides (Cl^-) in waters from various sources

Source	Chloride (ppm)
Rain water	2
Surface water	12
Unpolluted river water	Upto 15
Spring water	25
Deep well water	50
Drinking water	10-20
Weak sewage	70
Medium sewage	100
Strong sewage	Upto 500
Urine	4,500-5,000
Sea water	20,000

(Source: Klien, 1972)

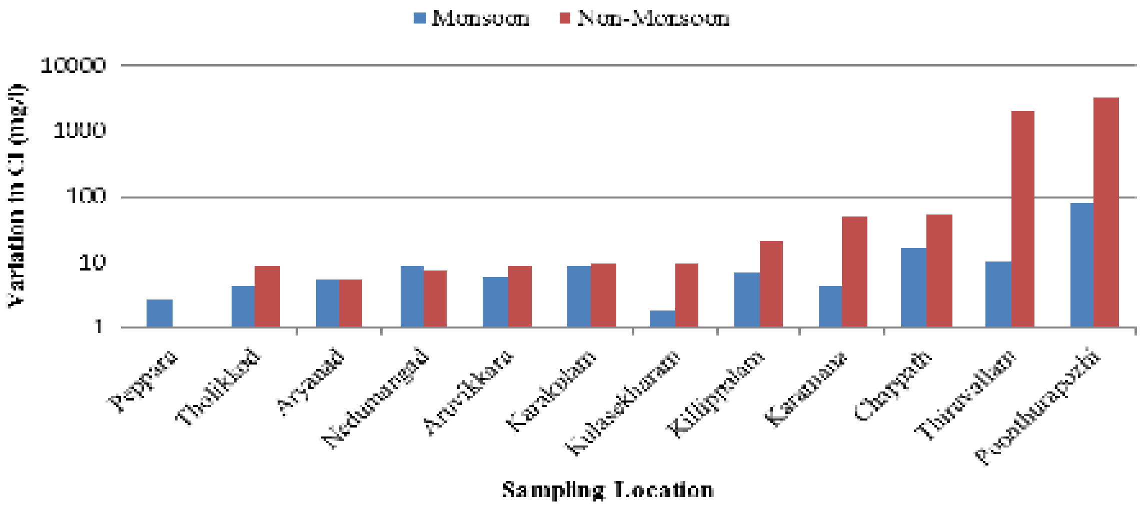


Fig. 58 Variation of Chloride in river water samples.

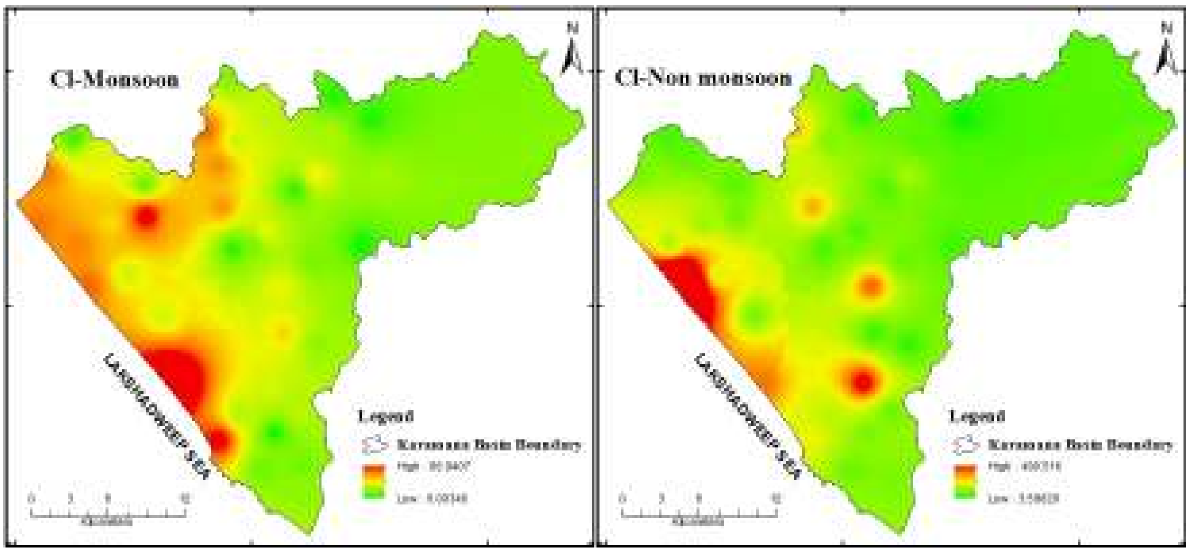


Fig. 59 Spatial variation of Chloride in ground water samples during Monsoon and Non-monsoon seasons

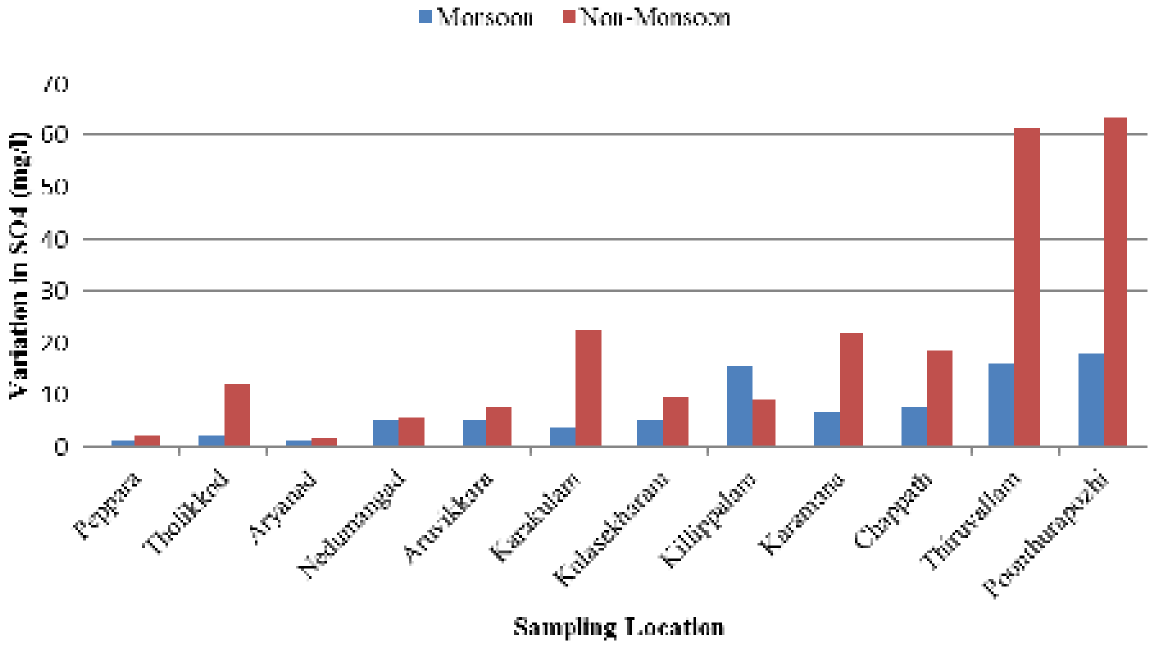


Fig. 60 Variation of Sulphate in river water samples.

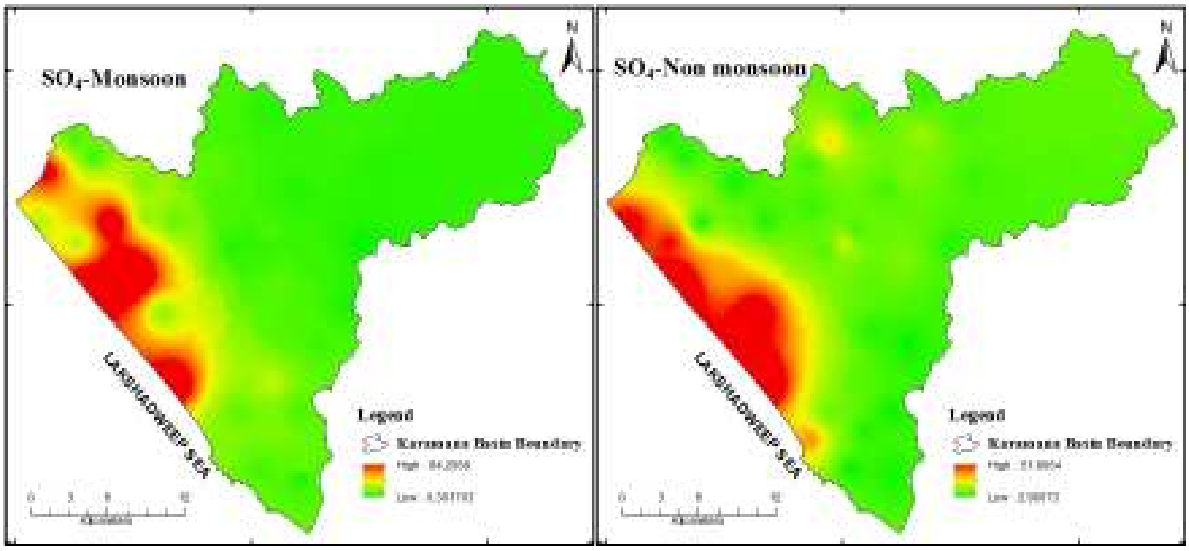


Fig. 61 Spatial variation of Sulphate in ground water samples during Monsoon and Non-monsoon seasons

Sulphate (SO_4)

In the river samples SO_4 content varies from 1.90 mg/l at Aryanad to 63.30 mg/l at Punthurapozhi (av. 19.67 mg/l) in non-monsoon and 1.16 mg/l at Aryanad to 17.84 mg/l at Punthurapozhi (av. 7.26 mg/l) in monsoon season. In the river environment the SO_4 values show an increasing trend downstream. Water from the downstream portions of the study area reveals comparatively high seasonal difference of SO_4 while towards upstream the variation diminishes to notable levels (Fig. 60). In the non-monsoon season the water samples show comparatively lower values without much variation in river environments. The SO_4 content in the groundwater samples of the study area varies from 3 mg/l at Mukkola and Uruttambalam to 51.9 mg/l at Veli (av. 11 mg/l) in non-monsoon and 0.30 mg/l at Poovachal to 94.40 mg/l at Pulayanarkotta (av. 13 mg/l) in monsoon season, respectively (Fig.61). The settlement area records high SO_4 values and this may be attributed to the high influx of sulphate ions/salts from agricultural lands, urban sewages and domestic waste discharges. Bathing and washing can also contribute significant amounts of SO_4 in river environments (Unni, 1996). Domestic sewages and industrial effluents, besides biological oxidation of reduced sulphur species, may add sulphur to water. SO_4 can cause gastrointestinal irritation along with excessive Na and Mg dissolved in waters (USEPA, 2000). Water with about 500 mg/l and above SO_4 concentration will have a bitter taste (ICMR, 1975).

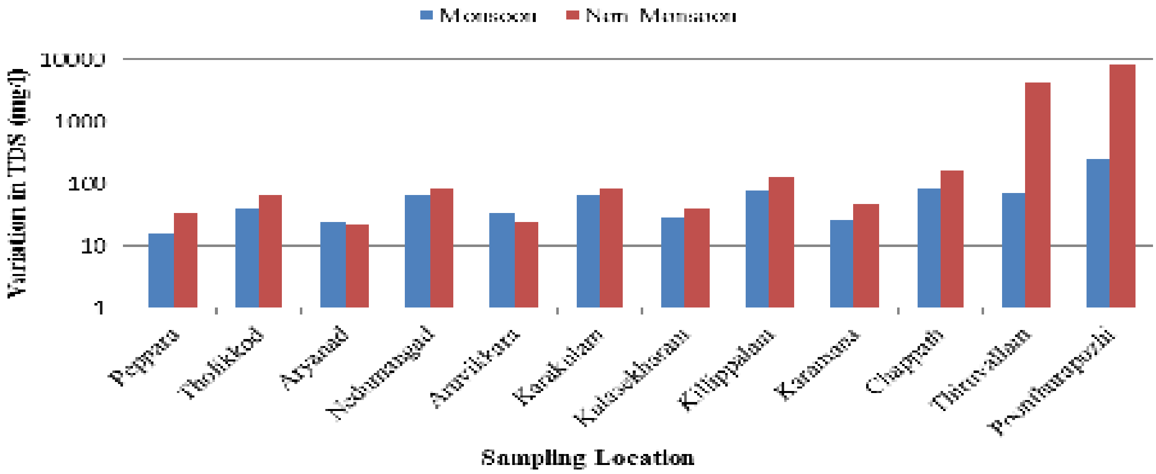


Fig. 62 Variation of TDS in river water samples

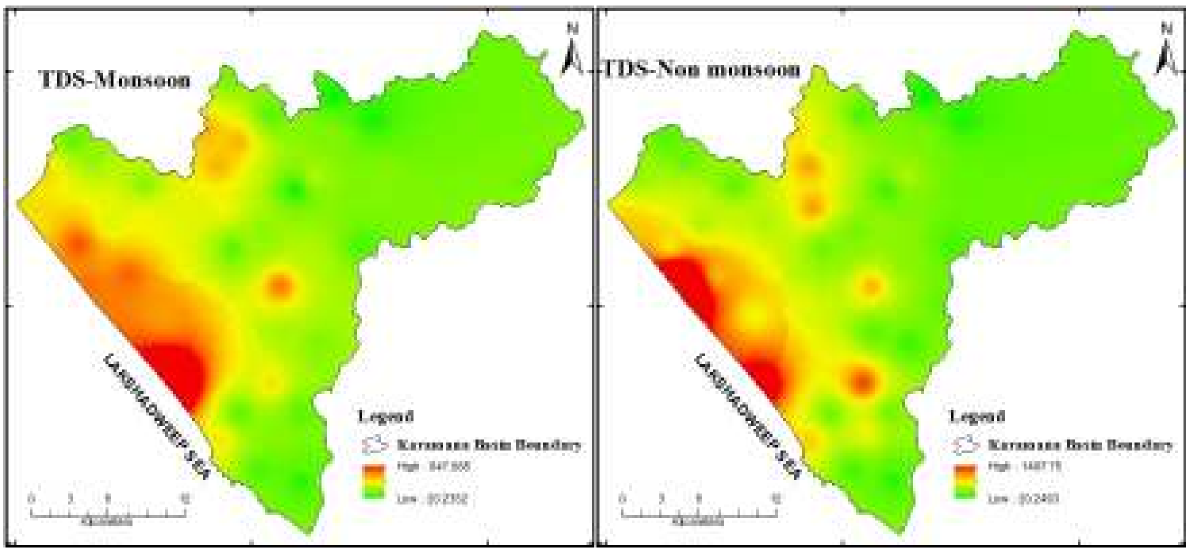


Fig. 63 Spatial variation of TDS in ground water samples during Monsoon and Non-monsoon seasons

Total Dissolved Solids (TDS):

The average TDS content in groundwater is 215.6 mg/l in non-monsoon and 190.27 mg/l in monsoon. The values vary between 20.1 mg/l (Tholikode) and 1500 mg/l (Veli) in non-monsoon and ranges from 20.1 mg/l (Tholokode) to 948 mg/l (Valiyathura) in monsoon. TDS concentration in the river channel environment varies between 21.5 mg/l (Aryanad) and 8236.8 mg/l (Punthurapozhi) in non-monsoon (Av. 1121.08 mg/l) and between 16.13 mg/l (Peppara) and 253.31 mg/l (Punthurapozhi) in monsoon (Av. 64.88 mg/l). TDS exhibits positive correlations with conductivity, hardness, and K in monsoon and non-monsoon seasons. Most of the river water samples in the study area exhibit reduced TDS content during monsoon period. In general, TDS shows an increasing trend towards coastal reaches during both monsoon and non-monsoon seasons. (Fig. 62). The higher concentrations of TDS reiterate the long residence of ground water within the aquifer systems of the area (Sathyamoorthy et al., 1993). Increased TDS levels can also be attributed to over exploitation and ground water lowering (Ballukraya and Ravi, 1999). TDS distribution exhibits a sympathetic relation with the conductivity of the samples (Fig.63). The surface water samples from the study area shows lower TDS values than the ground water samples (except the areas influenced by sea water ingression), which indicates the fact that the ground waters receive more dissolved solids from the aquifers of the study area, rather than atmospheric and other surficial sources. Based on Todd (1980), water quality can be classified based on TDS and the categories are presented in Table 29. Accordingly 100% of the samples are in fresh water category in monsoon season for the groundwater as well as river water. But in non-monsoon 2% of the groundwater and 17% of the river water falls under the brackish category. This may be attributed to insufficient freshwater flow in the river channels as well as leaching of salts from the coastal formation along with percolation of domestic sewage into the groundwater.

Table 29 TDS-based categorization of water (Todd, 1980)

TDS mg/l	Category	Ground Water		River Water	
		M	NM	M	NM
<1000 mg/l	Fresh	100%	98%	100%	83%
1000–10000 mg/l	Brackish	0%	2%	0%	17%
10000–1000000 mg/l	Saline	0%	0%	0%	0%
>1000000 mg/l	Brine	0%	0%	0%	0%

Table 30 Bacteriological status of river and groundwater samples of Karamana river basin . (Total Coliforms -TC;Faecal Coliforms - FC;Faecal Streptococci -FS)

		Non Monsoon			Monsoon		
Sl.No	**Location**	**TC**	**FC**	**FS**	**TC**	**FC**	**FS**
A)	***River water***						
1	Peppara	9	0	2	2	0	0
2	Tholikkod	23	9	29	9	2	5
3	Aryanad	11	3	17	4	1	6
4	Nedumangad	93	21	6	28	8	2
5	Aruvikkara	27	6	16	2	0	5
6	Karakulam	46	5	4	22	1	1
7	Kulasekharam	59	14	0	15	2	0
8	Karamana	41	7	11	17	7	3
9	Killippalam	37	9	0	12	5	0
10	Chappath	53	17	5	13	5	2
11	Thiruvallam	27	4	6	10	2	2
12	Poonthurapozhi	54	19	36	18	8	3
B)	***Groundwater***						
1	Pallipuram	49	14	13	12	4	2
2	Andurkonam	27	8	11	9	2	2
3	Ariyottukonam	42	6	9	7	1	1
4	Pandalakkod	31	13	11	13	5	2
5	Chellamangalam	47	10	9	11	3	4
6	Pangappara	23	8	14	8	2	2
7	Kulathur	36	9	15	7	4	3
8	PulayanarKotta	41	6	14	5	2	2
9	Mannanthala	42	8	17	9	1	4
10	Nalanchira	73	11	16	10	3	4
11	Vanchiyoor	28	6	13	5	3	5
12	Sanghumukham	17	2	6	4	2	1
13	Veli	21	8	11	7	2	3
14	Thumpa	36	10	1	9	1	0
15	Valiyathura	46	17	37	15	2	2
16	Kovalam	11	9	0	8	0	0
17	Manakkad	0	0	0	0	0	0
18	Vellayani	23	10	1	6	2	0

Table 30 Continued...... (Total Coliforms -TC; Faecal Coliforms - FC; Faecal Streptococci -FS)

		Non Monsoon			Monsoon		
Sl.No	**Location**	**TC**	**FC**	**FS**	**TC**	**FC**	**FS**
19	Peringamala	29	9	0	8	0	0
20	Payattuvila	0	0	0	0	0	0
21	Punnakkulam	39	11	6	10	3	0
22	Azhimala	68	19	0	16	4	0
23	Mukkola	42	13	8	12	2	0
24	Madavurpara	23	7	9	9	0	0
25	Nemam	27	10	8	12	3	0
26	Pappanamkode	0	0	0	0	0	0
27	Vilavoorkal	39	14	9	16	2	0
28	Urootambalam	0	0	0	0	0	0
29	Killi	4	0	0	0	0	0
30	Poovachal	23	8	6	9	0	0
31	Kuttichal	14	6	3	5	0	0
32	Kottur	42	18	11	14	5	2
33	Aryanad	4	0	6	0	0	0
34	Keezhpallur	16	5	8	6	0	0
35	Mamala	0	0	0	0	0	0
36	Tholikode	2	1	0	0	0	0
37	Karakulam	8	2	0	0	0	0
38	Venkod	0	0	0	0	0	0
39	Pazhakutti	63	11	0	10	2	0
40	Irinjayam	48	19	0	16	4	0
41	Panavur	2	0	32	0	0	0
42	Anad	47	7	1	6	0	0
43	Panackod	6	2	18	2	0	2
44	Puthukulangara	0	0	0	0	0	0
45	Mundela	2	0	0	0	0	0
46	Vellanad	16	6	1	4	0	0
47	Vilappilsala	11	3	0	2	0	0
48	Peyad	21	10	7	6	2	0
49	Malamugal	36	9	13	8	3	1
50	Nettayam	113	20	18	21	6	2

MICROBIOLOGY

Contaminants of feacal origin from humans and animals are often continually released into the soil and water environment. Microbiological studies in terms of Total Coliforms (TC), Faecal Coliforms (FC), and Faecal Streptococci (FS) were carried out in this study to get an idea about the microbial contamination of the water resources in the Karamana river basin and the unit is CFU (Colony Forming Unit).

Bacteriological studies reveal that all the water samples of the river environment show the presence of TC irrespective of the seasons (Table 30 and Fig. 64). TC accounts for an average content of 40 CFU/ml (range: 9–93 CFU/ml) in the river samples during non-monsoon and records 12 CFU/ml (range: 2–28 CFU/ml) in monsoon. In groundwater, the content of TC varies between ND and 113 CFU/ml (Nettayam) in non-monsoon and between ND and 21 CFU/ml (Nettayam) during monsoon (Table 30). In the groundwater environment 84% and 72% of the samples are microbiologically contaminated in non-monsoon and monsoon seasons respectively. In the river environment Nedumangad, Kulasekharam, Poonthurapozhi and Chappath records high content of TC during non-monsoon season. The Nedumangad station records the maximum value of TC i.e., 93 CFU/ml. The lack of sufficient flow in non-monsoon season may be the cause for this elevated content of TC in the river environment (Fig.65).

The feacal coliform (FC) content in the river water samples of the study area behaves almost similar to TC, but is not observed in some locations. The FC content of the study area varies from ND to 21 CFU/ml (Nedumangad) during non-monsoon and from ND to 8 CFU/ml (Nedumangad and Punthurapozhi) during monsoon. In the river environment Peppara records no FC during both the seasons and Aruvikkara records no FC during monsoon. Elevated FC values are observed in non-monsoon season and the reasons could be the presence of human settlement with low level of sanitary facilities. The reduced flow through the river during the summer may also aggravate the situation. In groundwater, the content of FC varies between ND and 20 CFU/ml (Nettayam) in non-monsoon and between ND and 6 CFU/ml (Nettayam) during monsoon. In the groundwater environment 78% and 54% of the samples are contaminated (Fig.66) by FC in non-monsoon and monsoon seasons respectively.

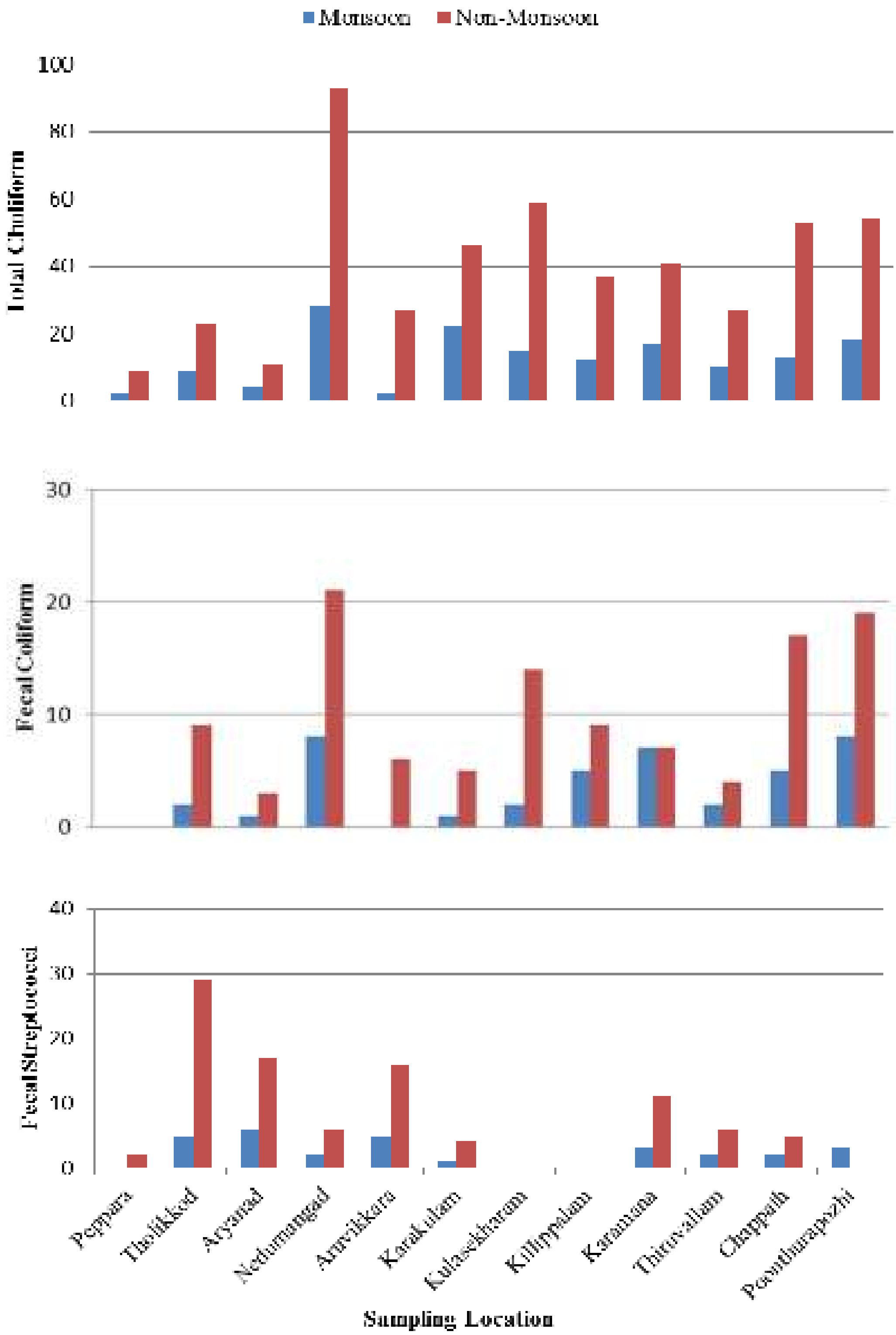


Fig. 64 Variation of microbiological parameters in river water samples

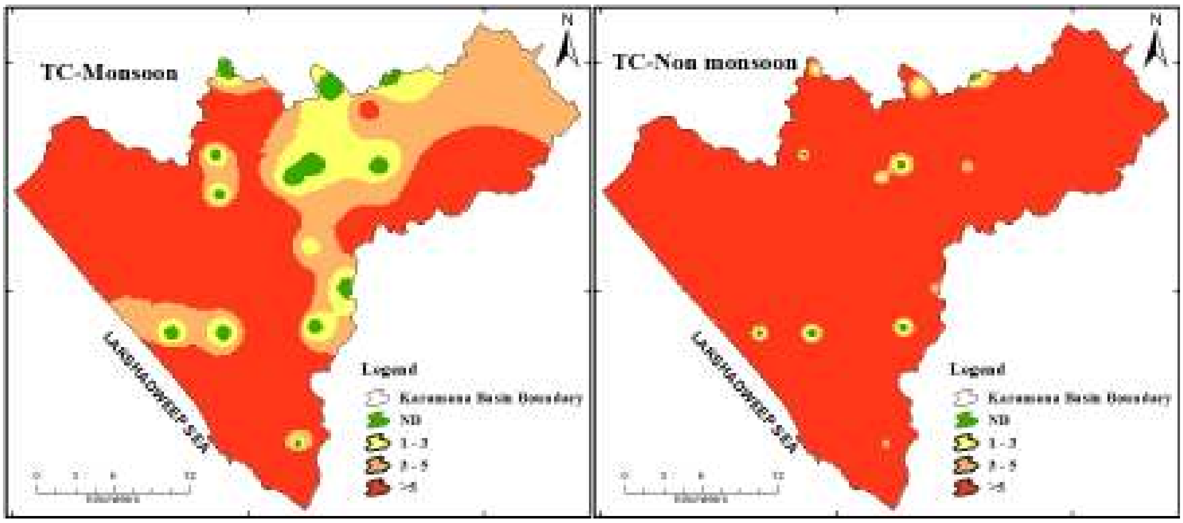


Fig. 65 Spatial variation of Total Coliforms in ground water samples during Monsoon and Non-monsoon seasons

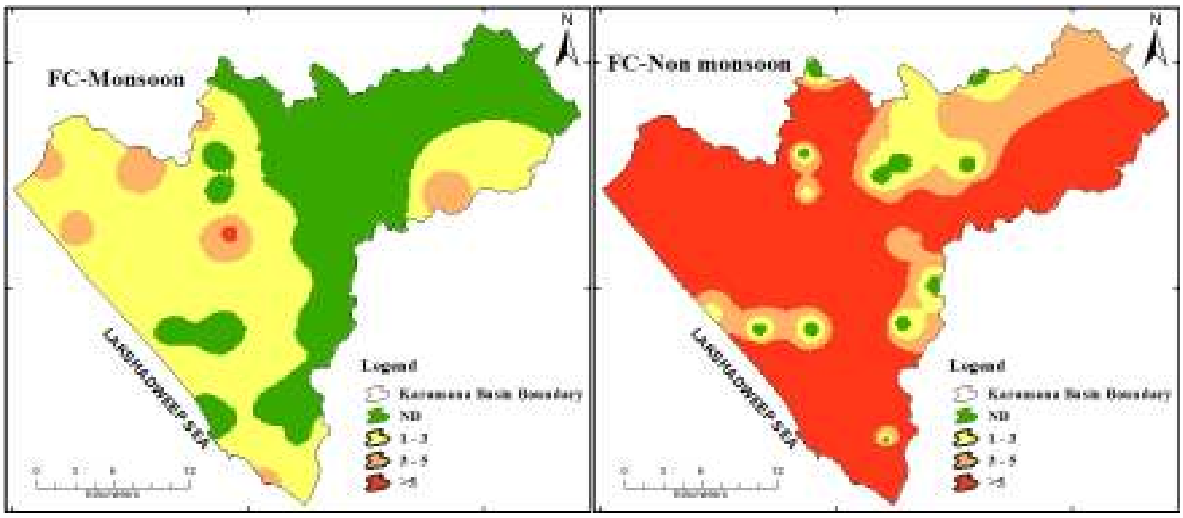


Fig. 66 Spatial variation of Feacal Coliforms in ground water samples during Monsoon and Non-monsoon seasons

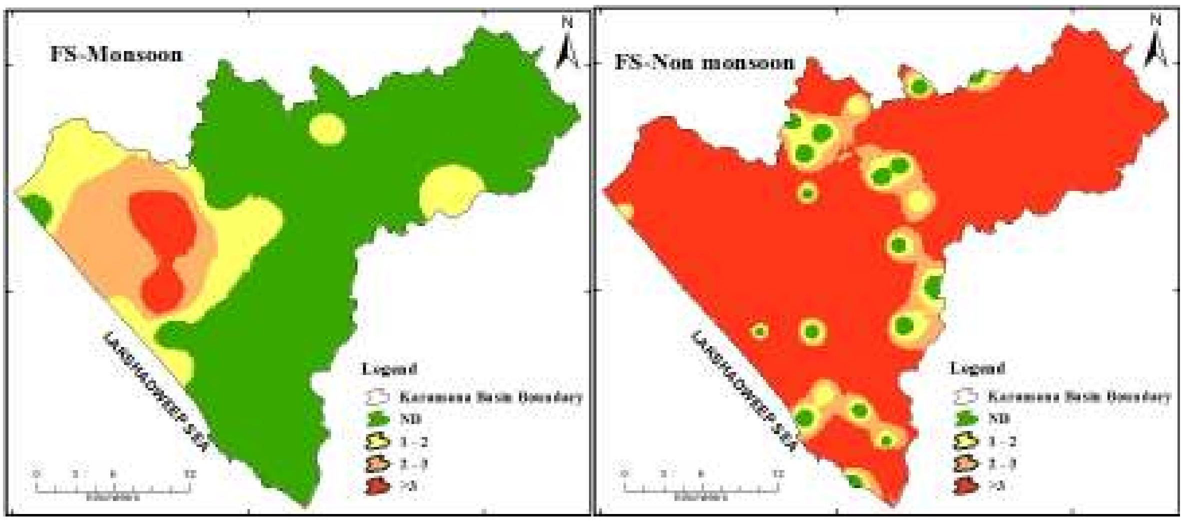


Fig. 67 Spatial variation of Feacal Streptococci in ground water samples during Monsoon and Non-monsoon seasons

The faecal streptococci (FS) content in the river water samples of the study area varies from ND to 36 CFU/ml (Punthurapozhi) during non-monsoon and from ND to 6 CFU/ml (Aryanad) during monsoon. In the river environment FS was not observed at Kulasekharam and Killippalam during both the seasons and Peppara during monsoon. Elevated FS values are observed in non-monsoon season. In groundwater, the content of FS varies between ND and 37 CFU/ml (Valiyathura) in non-monsoon and between ND and 5 CFU/ml (Vanchiyur) during monsoon. In the groundwater environment 66% and 36% of the samples are contaminated (Fig.67) by FC in non-monsoon and monsoon seasons respectively.

The contents of FC, TC and FS show elevated concentrations especially in the lower reaches of the study area (i.e. settlement area especially the northern coastal portions), which indicates the influence of anthropogenic activities in the downstream areas. Leach pits and sewage outlets are the sources, since the area is thickly populated. The elevated values are especially recorded in the coastal sand and alluvial aquifers and this may be attributed to higher permeability of the formation. The higher bacteriological concentration and microbial contamination of Karamana river was also reported earlier by GREENS (2003), Arun (2006) and KSCSTE (2010).

Table 31 Water quality status of Karamana river basin with respect to various standards. (M-Monsoon; NM-Non-monsoon)

Sl. No.	Parameters	WHO (2011)	BIS (1991)	Percentage of samples within limits				Percentage of samples exceeds the limits			
				River water		Groundwater		River water		Groundwater	
				M	NM	M	NM	M	NM	M	NM
1	pH	6.5-8.5	6.5-8.5	0	0	36	46	100	100	64	54
2	EC (µS/cm)	1500	--	100	83	100	100	0	17	0	0
3	TDS (mg/l)	500	500	100	83	98	96	0	17	2	4
4	HCO_3 (mg/l)	500	--	100	100	100	100	0	0	0	0
5	Cl (mg/l)	250	250	100	83	100	98	0	17	0	2
6	SO_4 (mg/l)	250	100	100	100	100	100	0	0	0	0
7	Ca (mg/l)	75	75	100	100	100	96	0	0	0	4
8	Mg (mg/l)	50	30	100	100	100	100	0	0	0	0
9	Na (mg/l)	200	--	100	83	100	98	0	17	0	2
10	K (mg/l)	12	--	100	83	100	96	0	17	0	4
11	TH (mg/l)	100	--	100	100	88	86	0	0	12	14

WATER QUALITY WITH RESPECT TO STANDARDS

An evaluation of water quality of Karamana river basin, with respect to WHO and BIS drinking water standards reveals that the concentrations of most of the physico-chemical parameters fall within the prescribed limits during the monsoon as well as non-monsoon periods, however, the pH of groundwater in both the seasons falls below the limit (64% in monsoon and 54% in non-monsoon; Table 31). EC, bicarbonates, sulphate and magnesium in all the samples fall within the standards during both the seasons. 14% of the samples are outside the limits during monsoon in terms of TDS and Total hardness. 30% of the samples in non-monsoon are also outside the standard value ranges in terms of TDS, Chloride, Calcium, Sodium, Potassium and Total hardness. In the river environment all the samples are within the prescribed limit during monsoon except the pH, which falls below the limits (acidic). In the non-monsoon season too pH falls outside the limit for all the samples. In non-monsoon samples from Thiruvallam and Punthurapozhi, high values of EC, TDS, Cl, Na and K are recorded due to sea water ingress. Proper treatment and disinfection is necessary for all the surface as well as groundwater of the study area for human usage.

According to the classification of water by Davis and DeWiest (1966), based on TDS (Table 32), 98% and 96% of the groundwater samples from the study area during monsoon and non-monsoon seasons, respectively, are in the 'desirable' category for drinking purposes. In both seasons 2% is under 'permissible' for drinking category. In the non-monsoon season 2% is categorised as 'useful' for irrigation. In the river environment 100% is in the 'desirable' category for drinking purpose during monsoon. But in non-monsoon 17% of the river samples fall in the 'unfit' category for drinking and irrigation and 86% is in the 'desirable' category for drinking purpose. The spatial distribution of these classes shows, low quality water samples were encountered at the coastal reaches, mainly due to salinity ingression to the river system.

Table 32 TDS-based classification of water by Davis and DeWiest (1966)

TDS mg/l	Category	Ground Water		River Water	
		M	NM	M	NM
<500 mg/l	Desirable for Drinking	98%	96%	100%	83%
500–1000 mg/l	Permissible for drinking	2%	2%	0%	0%
<3000 mg/l	Useful for irrigation	0%	2%	0%	0%
>3000 mg/l	Unfit for drinking and irrigation	0%	0%	0%	17%

Sawyer and McCarty (1967) classified water based on the hardness values and the details are presented in Table 33. In the river environment, 100% of the samples are in the soft category during monsoon and 92% are soft during non-monsoon. In the groundwater samples 80% are in the soft category and 4% are in hard category during both the seasons. During non-monsoon 2% records very hard category. 16% and 14% of the samples are in moderately hard category during monsoon and non-monsoon seasons respectively. The spatial distribution of the hardness classes in the Karamana river basin shows that, moderately hard and hard categories are observed in the coastal reaches especially in the alluvial formations.

Table 33 Water classification based on hardness (Sawyer and McCarty, 1967)

Total Hardness	Water Type	Ground Water		River Water	
		M	NM	M	NM
<75 mg/l	Soft	80%	80%	100%	92%
75–150 mg/l	Moderately Hard	16%	14%	0%	8%
150–300 mg/l	Hard	4%	4%	0%	0%
>300 mg/l	Very hard	0%	2%	0%	0%

WATER QUALITY INDICES

There are several water quality indices to categorise water sources with respect to its suitability for drinking, irrigation as well as industrial usage. Primarily these indices are a means to summarize large amounts of data into simple terms, evaluate and rank the quality of water bodies for various beneficial uses of water, like suitable or unsuitable (Willcox,1955; USSL, 1954; Doneen, 1964; Paliwal, 1972; Todd, 1959; Richards, 1954). The indices used for this study are Sodium Adsorption Ratio (SAR), Magnesium Hazard Ratio (MHR), Soluble Sodium Percent (SSP), Kelly's Ratio (KR) and Permeability Index (PI). The formulae used for calculation of these indices as well as the standard specifications are presented in Table 34.

Sodium Adsorption Ratio (SAR) was widely used for the classification of irrigation water as recommended by US Salinity Laboratory of the Department of Agriculture. The electrical conductivity and SAR are considered in determining the suitability of the water quality. High SAR values in irrigation waters lead to the development of Na hazards in soils. The variation diagram, known as US salinity diagram, based on electrical conductivity and SAR values enables quality rating of irrigation water. The degree to which water tend to enter cation reactions in soil can reasonably well be predicted by SAR. High values for SAR imply a hazard of Na replacing absorbed Ca and Mg, a situation ultimately damaging to soil structure (Hem, 1992).

The SAR values of riverine as well as groundwater samples are <10 during both the seasons and comes under the excellent category (Table 35 and 36). The SAR *versus* conductivity plots (Wilcox, 1955) of the surface as well as groundwater samples from the Karamana river basin are depicted in Fig. 68.

Table 34 Water quality indices and the standard specifications

Indices	**Formula (All values in epm)**	**Standard Specifications**
Magnesium Hazard Ratio (MHR)	$\frac{Mg\ x\ 100}{[Ca + Mg]}$	<50% - Suitable >50% - Unsuitable
Soluble Sodium Percent (SSP)	$\frac{Na\ x\ 100}{[Ca + Mg + Na + K]}$	<20% - Excellent 20-40% - Good 40-60% - Permissible 60-80% - Doubtful >80% - Unsuitable
Sodium Adsorption Ratio (SAR)	$\frac{Na}{\sqrt{Ca + Mg}/2}$	<10 - Excellent 10-18 - fair >20 - Poor
Kelly's Ratio (KR)	$\frac{Na}{[Ca + Mg]}$	<1 - Suitable 1-2 - Marginal >2 - Unsuitable
Permeability Index (PI)	$\frac{Na + \sqrt{HCO_3}}{[Ca + Mg + Na]}$	>75 - Excellent 25-75 - Good <25 - Unsuitable

Table 35 Water quality indices of river water samples of the Karamana river basin (M-Monsoon;NM-Non-monsoon)

Sl.No.	Location	MHR		SSP		Kelly's Ratio		SAR		PI	
		M	NM	M	NM	M	NM	M	NM	M	NM
1	Peppara	45.98	25.73	15.31	19.52	0.18	0.24	0.26	0.32	110.96	141.66
2	Tholikkod	41.50	22.15	36.72	29.57	0.58	0.42	0.80	0.76	135.38	100.44
3	Aryanad	37.34	48.06	30.45	25.77	0.44	0.35	0.50	0.47	173.07	145.55
4	Nedumangad	15.29	6.48	44.79	22.61	0.81	0.29	1.17	0.71	129.99	69.30
5	Aruvikkara	28.43	15.33	44.24	24.14	0.79	0.32	0.84	0.48	181.20	115.91
6	Karakulam	16.57	50.20	47.88	28.04	0.92	0.39	1.27	0.77	137.88	97.08
7	Kulasekharam	0.00	91.13	43.92	11.57	0.78	0.13	0.70	0.35	244.95	50.85
8	Killippalam	0.00	31.17	35.75	21.54	0.56	0.27	0.92	0.70	120.99	68.31
9	Karamana	7.10	18.75	18.67	43.21	0.23	0.76	0.34	1.85	122.85	82.17
10	Thiruvallam	19.89	72.06	38.98	77.32	0.64	3.41	0.99	5.17	125.89	122.18
11	Chappath	4.73	16.50	40.66	49.86	0.69	0.99	1.26	2.39	102.71	74.85
12	Punthurapozhi	45.98	32.17	65.93	61.16	1.94	1.57	3.94	2.23	96.35	163.66

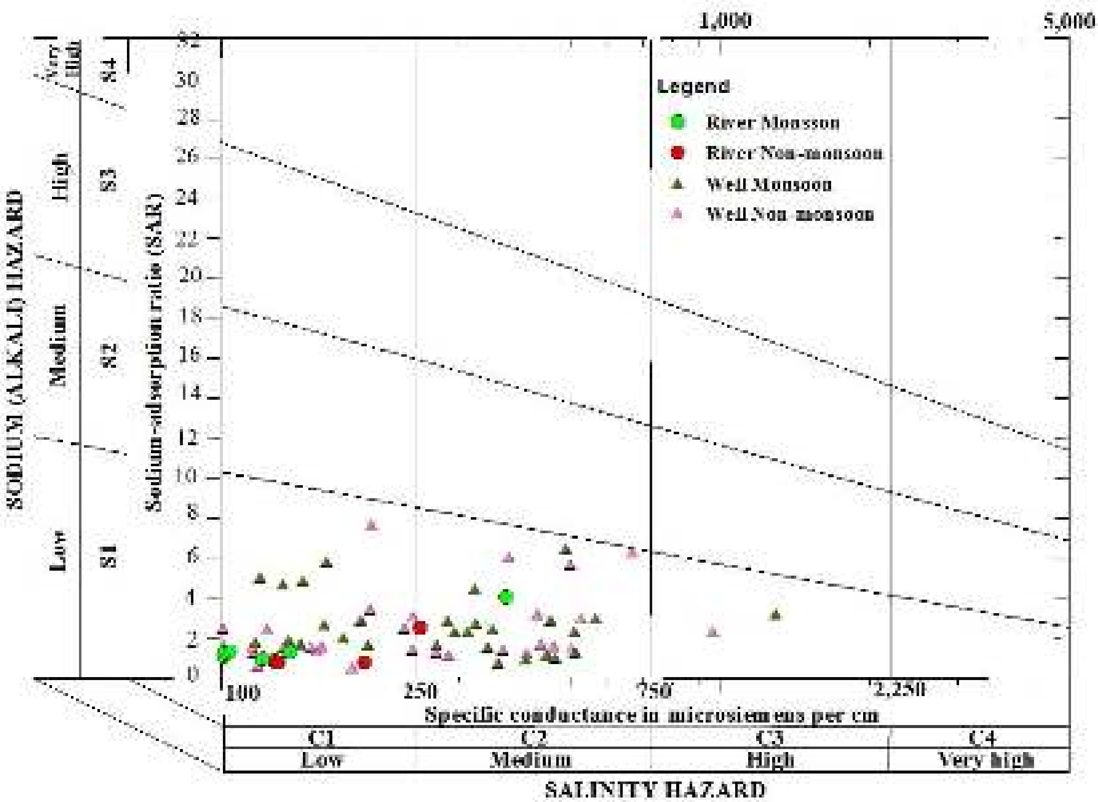


Fig. 68 Classification of water based on Conductivity and Sodium Adsorption Ratio (SAR) for the Karamana river basin

Table 36 Water quality indicesof groundwater samples of the Karamana river basin (M-Monsoon; NM-Non-monsoon)

SL No.	Location	MHR		SSP		Kelly's Ratio		SAR		PI	
		M	NM	M	NM	M	NM	M	NM	M	NM
1	Pallipuram	14.33	39.83	34.15	52.10	0.52	1.09	1.49	1.38	72.48	96.16
2	Andurkonam	4.30	28.42	67.41	64.49	2.07	1.82	1.89	1.36	153.29	150.25
3	Ariyottukonam	13.67	42.66	84.81	69.11	5.58	2.24	4.81	1.67	127.44	140.30
4	Pandalakkod	6.21	12.43	42.17	61.36	0.73	1.59	1.17	1.27	106.25	146.59
5	Chellamangalam	3.68	14.55	56.46	37.55	1.30	0.60	2.70	1.09	99.15	89.61
6	Pangappara	31.10	31.26	63.43	77.81	1.73	3.51	2.77	3.39	109.85	112.81
7	Kulathur	10.83	17.90	53.18	37.74	1.14	0.61	2.93	1.21	82.23	67.50
8	Pulayanarkotta	3.65	28.95	29.19	42.83	0.41	0.75	1.24	1.57	68.47	79.17
9	Mannanthala	11.79	18.64	50.75	72.74	1.03	2.67	2.24	3.02	98.64	112.53
11	Vanchiyoor	12.98	10.65	30.62	39.59	0.44	0.66	1.15	1.39	85.61	73.90
13	Veli	19.40	24.87	42.78	66.72	0.75	2.00	2.24	7.61	74.24	74.88
14	Thumba	14.81	7.08	19.49	43.98	0.24	0.79	0.66	1.66	59.91	71.41
15	Valiyathura	9.73	29.49	43.82	40.78	0.78	0.69	3.14	2.26	65.04	62.00
16	Kovalam	41.38	84.21	71.65	65.96	2.53	1.94	4.38	3.15	108.78	92.19
18	Vellayani	77.66	23.40	76.78	56.76	3.31	1.31	2.80	1.53	133.80	88.58
19	Peringamala	64.84	19.05	57.88	22.02	1.37	0.28	1.74	0.55	104.38	74.20
20	Payattuvila	49.83	27.93	75.30	67.52	3.05	2.08	2.98	1.57	120.70	119.60
21	Punnakkulam	0.00	3.60	86.83	24.60	6.59	0.33	4.17	0.68	138.62	73.93
23	Mukkola	0.33	0.00	38.73	80.63	0.63	4.16	0.89	2.64	108.23	128.89
24	Madavurpara	11.18	14.30	44.51	75.96	0.80	3.16	1.62	2.37	89.74	128.37
25	Nemam	26.09	6.95	52.16	78.15	1.09	3.58	2.38	6.21	97.54	93.79
26	Pappanamkode	21.86	21.33	46.71	53.94	0.88	1.17	1.59	1.24	95.03	125.04
27	Vilavoorkal	8.28	0.00	58.90	60.31	1.43	1.52	1.99	1.22	124.14	158.14
28	Urootambalam	71.29	16.68	86.96	66.93	6.67	2.02	4.98	1.40	139.01	151.02
29	Killi	8.42	49.91	90.65	77.79	9.70	3.50	5.74	2.42	132.73	115.61
30	Poovachal	5.17	49.81	84.34	48.34	5.38	0.94	2.71	0.84	230.36	131.74
33	Aryanad	5.78	19.86	86.58	63.50	6.45	1.74	4.61	1.56	141.40	122.37
34	Keezhpallur	0.00	39.83	36.89	43.97	0.58	0.78	0.63	0.50	122.60	158.57
36	Tholikode	0.96	6.08	16.85	24.02	0.20	0.32	0.26	0.36	113.73	81.52
37	Karakulam	33.18	8.26	57.31	63.39	1.34	1.73	2.28	2.92	99.44	81.62
38	Vattappara	3.58	9.21	21.18	38.10	0.27	0.62	0.95	1.42	65.54	79.93
39	Pazhakutti	12.00	8.33	21.91	42.38	0.28	0.74	0.88	1.22	75.76	79.58
40	Irinjayam	19.40	24.83	52.28	88.20	1.10	7.47	2.81	5.98	86.65	123.48
41	Panavur	30.80	10.66	54.26	47.67	1.19	0.91	1.71	1.36	116.59	94.29
42	Anad	37.34	33.11	39.84	69.71	0.66	2.30	1.06	1.59	95.77	158.91
43	Panackod	54.37	13.23	57.68	57.26	1.36	1.34	1.81	1.47	126.11	117.12
44	Puthukulangara	30.80	18.35	46.35	68.69	0.86	2.19	1.58	2.48	95.09	98.71
45	Mundela	38.17	39.83	16.55	62.97	0.20	1.70	0.27	1.07	102.37	147.65
47	Vilappilsala	12.06	33.21	68.15	57.38	2.14	1.35	2.89	1.62	112.23	105.66
48	Peyad	39.40	15.97	78.90	80.22	3.74	4.06	6.38	5.60	91.67	95.44
49	Malamugal	13.62	46.91	69.37	56.15	2.27	1.28	2.58	1.49	133.72	101.77
50	Nettayam	20.25	4.35	68.42	30.27	2.17	0.43	2.57	0.59	132.18	113.37

Most of surface water samples (i.e, except Thiruvallam and Punthura pozhi during non-monsoon) and all the ground water samples fall in the low salinity–low sodium (C1-S1) and medium salinity–low sodium (C1-S2) category. But, the ground water sample from Valiyathura falls in the high salinity low sodium (C3-S1) category. River samples at Thiruvallam and Punthura pozhi falls in the extremely high salinity, medium sodium (C5-S2). This clearly indicates the suitability of well water as well as surface water resources of the

Karamana river basin for irrigation purposes, except for the areas influenced by sea water ingression.

According to Magnesium Hazard Ratio (MHR), the groundwater from Kovalam during non-monsoon is in the unsuitable category and all the others are in suitable category. In monsoon the groundwater samples from Vellayani, Peringamala, Uruttambalam and Panackod are under the unsuitable category. In the riverine environment all the monsoon samples are in suitable category and in non-monsoon, samples from Karakulam, Kulasekharam, Thiruvallam and Punthurapozhi are found in unsuitable category.

As per the Soluble Sodium Percent (SSP) the categories are Excellent, Good, Permissible, Doubtful and Unsuitable. The particular percentages in monsoon and non monsoon are 7.14%, 19.05%, 38.1%, 21.43%, 14.29% and 0%, 19.04%, 28.57%, 45.24%, 7.14% respectively. In the riverine environment samples from Peppara and Karamana are in the excellent category during monsoon. In non-monsoon Kulasekharam and Peppara falls under the excellent category. According to Kelly's Ratio (KR) of the river samples 11 locations in monsoon and 10 locations in non-monsoon are in the suitable category. In groundwater 34% of the samples are in suitable category during both the seasons. In the river samples, all the samples are in excellent category as per Permeability Index (PI) during monsoon and in non-monsoon 67% of the samples are in excellent category and 33% in good category. In the groundwater samples, 72% and 70% of the samples are in excellent category during monsoon and non-monsoon seasons respectively. All other samples are in the category 'good'. According to these indices the quality of the freshwater resources in the study area varies widely in spatial as well as temporal scales.

FACTORS CONTROLLING WATER QUALITY

Karamana river basin exhibits marked seasonal as well as spatial variations in water quality parameters. The major sources of chemical constituents in natural waters are weathering, precipitation (i.e, from rain water) and anthropogenic activities. Monsoon discharge controls the seasonal water chemistry while basin characteristics and human settlements of the study area affect the spatial distribution of chemical constituents. The extent of chemical weathering is well reflected in the ground water than surface water. The water samples record marked seasonal variations in the case of physico-chemical as well as biological parameters. The non-monsoon values are higher than that of the monsoon values. At the same time, the water samples reveal high degree of seasonal as well as regional differences in the case of parameters like conductivity, Ca, Mg, Na, Cl, SO_4, etc. Thus, the overall changes in the water quality of the study area could be explained in the light of the natural and anthropogenic effects to which the region is subjected over the years. A detailed discussion of these causative factors is attempted in the following sections.

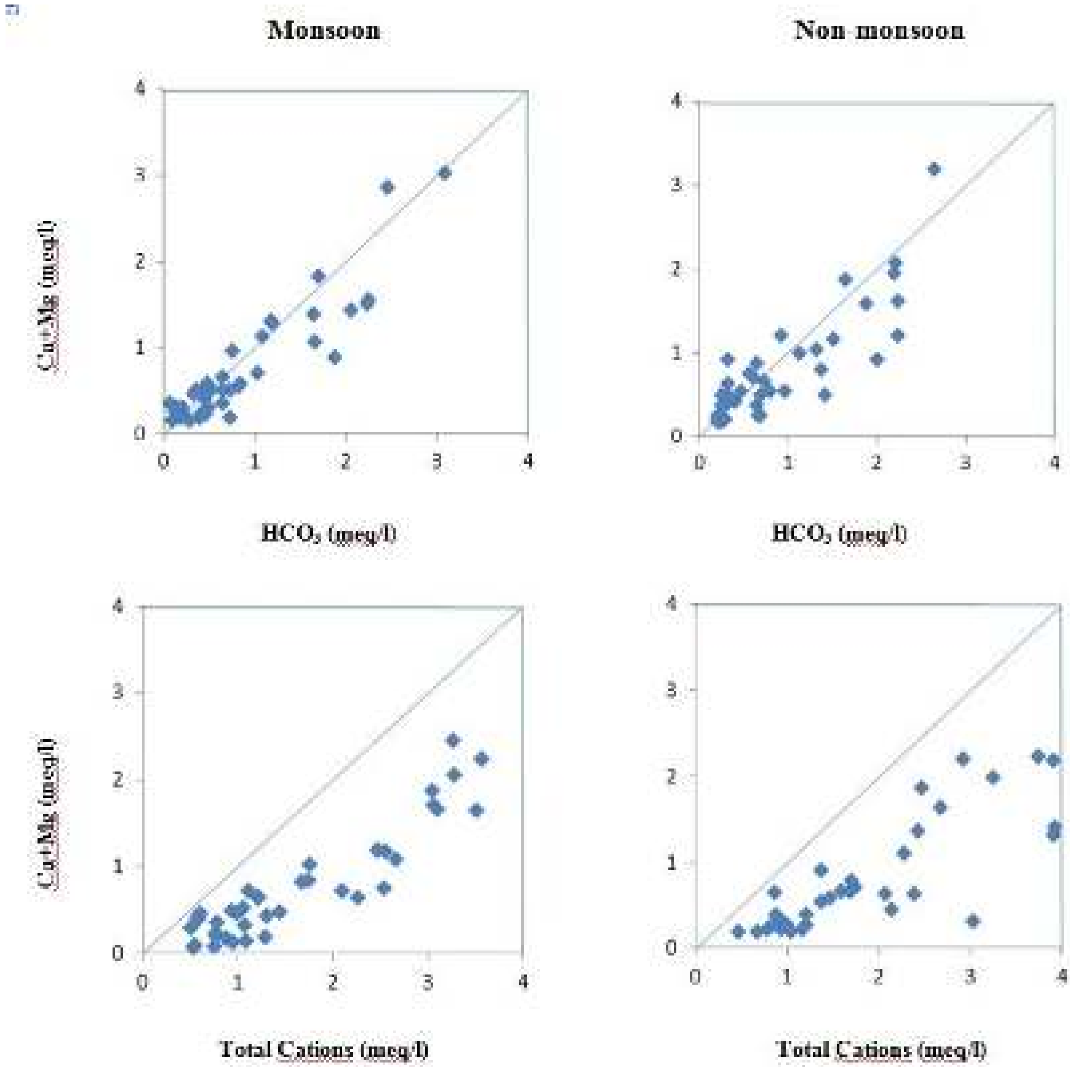


Fig. 69 Plots of Ca+Mg versus HCO_3 and Total cations during Monsoon and Non-monsoon seasons.

Natural factors

In high altitudes, the steep hydraulic heads force water to flow more quickly than low altitudes. In such cases water gets only minimal time to interact with weathered rocks as well as soils. This in turn contributes only minimum amount of dissolved constituents in natural waters (Hamilton et. al., 1993; Ator and Ferrari, 1997). There is probably a range of net effects – increased ionic concentrations due to erosion and potentially lower concentrations due to low residence time (Arun, 2006). Within the study area also samples in the high altitudes show low values of anions and cations than low altitudes. Researchers like Vitousek (1977) opined that the level of several ions including Cl decreases with increase in altitude.

The phenomenon could be explained in the light of the altitudinal variations in water balance, with increase in precipitation and decrease in evapo-transpiration at higher altitudes. Along with other ions Cl shows the decreasing trend with increase in altitude in the Karamana basin as discussed earlier, reiterating the observations made by Vitousek (1977).

Bivariate plots of Ca + Mg *versus* HCO_3 (Fig.69) show that the data points generally lie below the equiline. Though the (Ca + Mg)/HCO_3 ratios in both the seasons are close to unity, the ratio is comparatively high in monsoon than that of non-monsoon indicating that chemical weathering is predominant in the study area. The plots of Ca + Mg *versus* Total cations (Fig. 69) reveal that the points lie below the equiline in this case also with low equivalent ratios both in monsoon and non-monsoon seasons. The relatively high contribution of Na + K to the total cations indicates silicate weathering and/or contribution from soils derived from decomposition of feldspathic rocks (Walling, 1980; Das and Singh, 1996; Babu et al., 2003; Arun, 2006). The geology and tropical humid climate of the region are also favourable for chemical weathering.

To discriminate the effect of natural processes in changing water quality of the Karamana river basin, Gibbs (1970) graphic model has been attempted in which the ratios Cl/(Cl+HCO_3) and Na/(Na+Ca) are plotted against TDS concentration (Fig.70). By examining the proportions of individual ions, particularly Ca, Na, Cl and HCO_3 contained in a large number of river and lake waters, Gibbs (1970) could discriminate three major controls on chemical composition of natural waters. They are related to the source of solute load and are defined as, first, atmospheric precipitation dominance, secondly, soil and rock dominance, and, thirdly, evaporation – chemical precipitation dominance. They varied in importance according to the magnitude of annual precipitation or runoff.

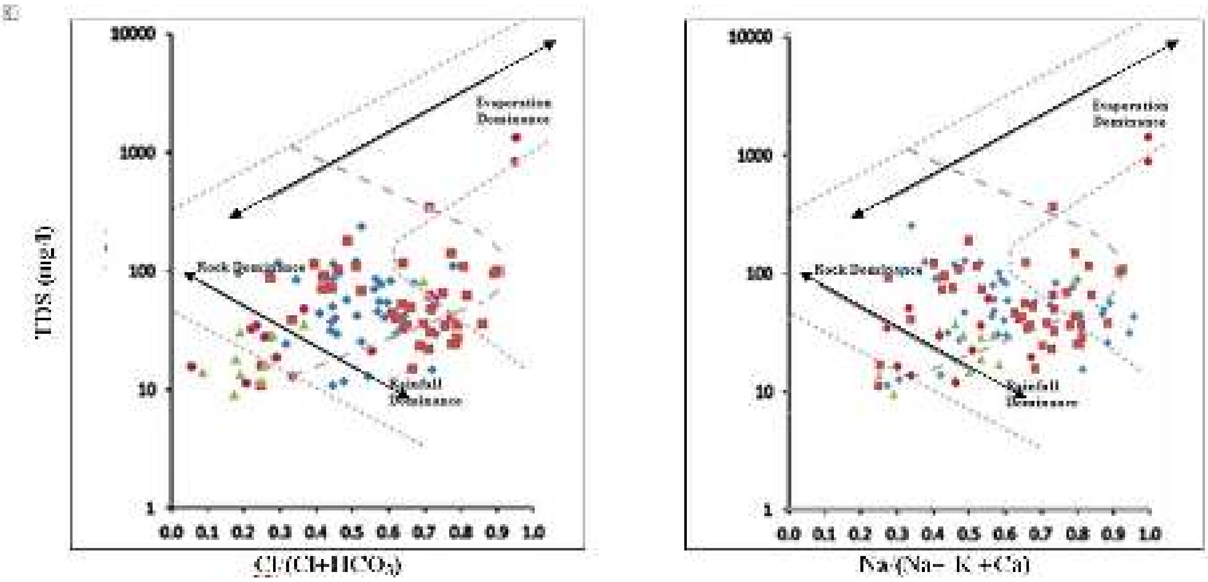
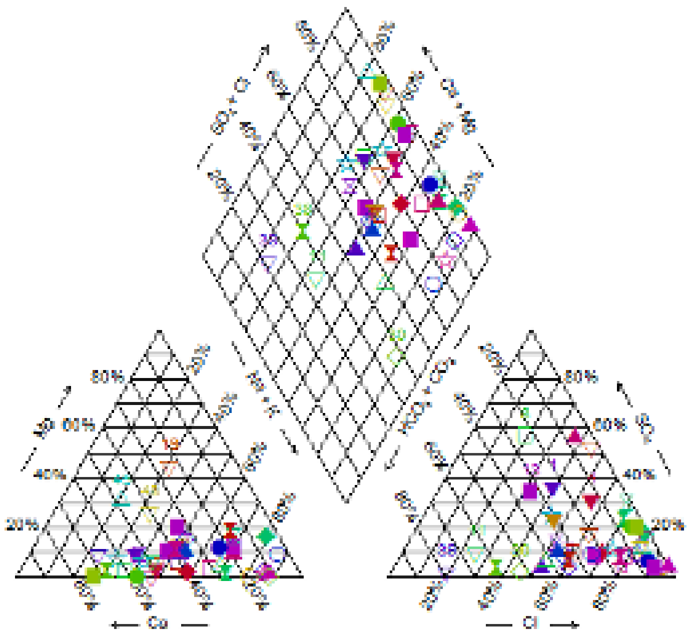


Fig. 70 Plots of total dissolved solids (TDS) against Cl / (Cl+HCO_3) and Na / (Na+K+Ca); (after Gibbs, 1970)

Waters of low salt concentration (20–30 mg/l and lower) are classed as being dominated by atmospheric precipitation sources and are therefore characterised by the major cation and anion being Na and Cl, respectively. Waters with very high salt concentrations (1000–2000 mg/l and higher) are influenced by processes of evaporation and subsequent precipitation, and their composition reflects the precipitation of $CaCO_3$ from solution, leaving Na and Cl as the dominant ionic constituents. Where rock and soil sources predominate, concentrations are intermediate and the water is characterised by dominance of Ca and HCO_3 ions. From Fig.70, it is clear that there is a large range in the proportions of these ionic constituents for a given total dissolved solid concentration, but the general pattern must be accepted as reflecting a major influence on the solute composition of stream water. Surface samples from the Karamana river basin fall in the field of precipitation dominance both in the monsoon and non-monsoon seasons with a slightly lower TDS values in the non-monsoon. More than 50% of the samples show greater than 30mg/l TDS in monsoon and this clearly indicates contribution from river catchments in changing its overall water chemistry. But in non-monsoon only 15% of the samples exhibit values greater than 30mg/l. In well waters, the TDS ranges from 40mg/l to 284mg/l with an average value of 255mg/l. The well water samples fall in the rock dominance field and show a continued trend in distribution especially with the non-monsoon surface water samples. It is a clear indication of the influence of ground water in the form of base flow in regulating the water chemistry.

An attempt has also been made here to find out the hydrochemical facies of water samples of the study area. For this the groundwater samples are plotted on the piper trilinear diagram (Piper, 1944). In monsoon, the water samples are in the category of Ca-Cl, Na-Cl, Na-SO_4, Ca-SO_4, Ca-HCO_3, Na-HCO_3 and Mg-SO4 types (Fig 71). The non-monsoon water samples the categories are, Ca-Cl, Na-Cl, Na-SO_4, Ca-HCO_3 and Na-HCO_3 types. The dominant species are calcium - chloride type and sodium - chloride type (Fig. 72). This peculiar suite of chemical facies also points to rock-water interaction that predominates in the non-monsoon.

Monsoon



Non monsoon

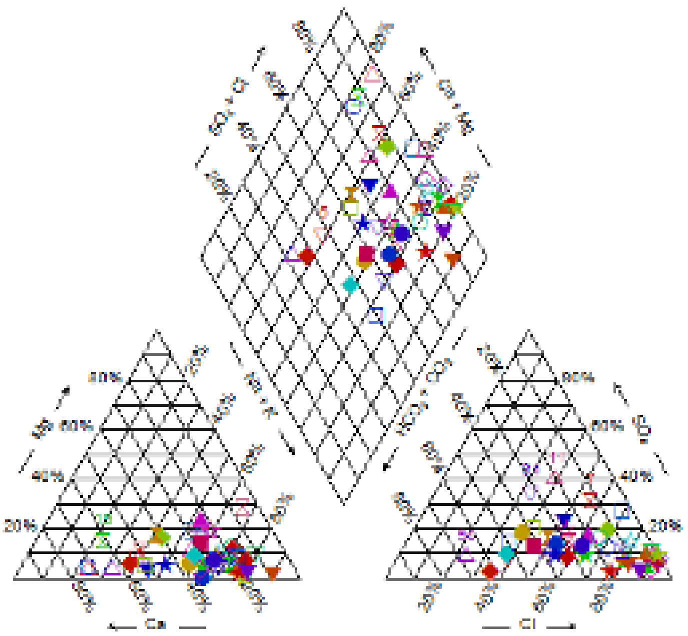
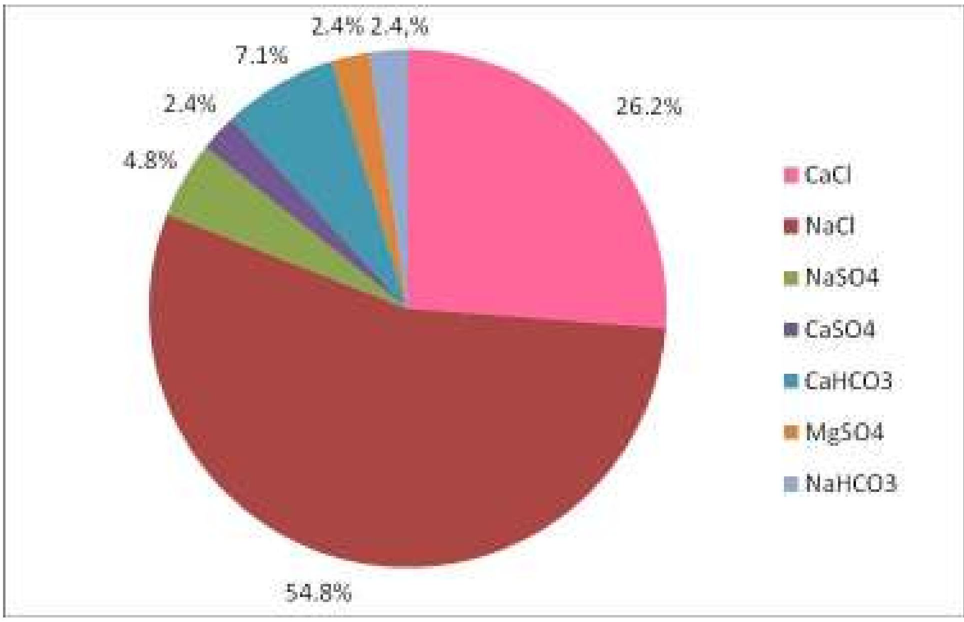


Fig. 70 Piper Plots for the water samples of the Karamana river basin.

Monsoon



Non-monsoon

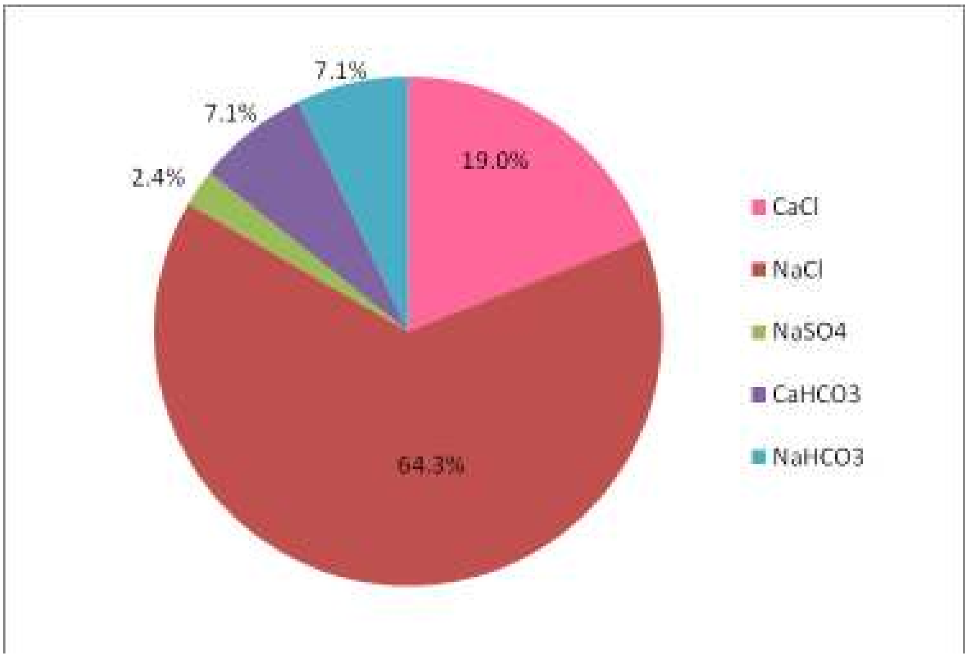


Fig. 72 Water types of Karamana river basin and its percentage distribution during Monsoon and Non-monsoon season.

Anthropogenic factors

A spatial evaluation of the water quality parameters in the Karamana river basin reveals that the coastal reaches and densely inhabited areas are contaminated by waste discharges from point and non-point sources. The study area is influenced significantly by domestic waste discharges from the settlement areas. Monsoon flood imparts marked changes in the water quality of study area. Dilution by monsoon discharges can also reduce the chemical constituents values to significant levels. And, the degree of increase is higher towards the downstream reaches. TDS shows an increasing trend towards coastal reaches. The higher concentrations of TDS is the combined effect of long residence of ground water within the aquifer systems of the area along with percolation of domestic sewage into the groundwater especially in coastal and riverine alluvium.

It is a fact that agricultural activities can directly affect the K and Ca concentrations in river waters (Drever, 1997). Chemical fertilizers, pesticides and animal wastes contribute these elements into the water environment (Poinke and Urban, 1985; Mehta et.al., 1990; Alymore and Kookana, 1993; Suresh et. al., 1994 and Arun, 2006). The increased SO_4 concentration in the lower reaches of the study area implies the degree of pollution from the highly populated and cultivated areas with in Karamana river basin. In addition to natural processes, a substantial quantity of SO_4 can also be released in the fluvial systems from the agricultural lands, oxidation of sulphide minerals in the sub-recent sediments exposed due to sand and clay mining, etc. Another important source of SO_4 is bacterial decomposition of organic matter.

In the study area along with other ions Cl shows a decreasing trend with increase in altitude. The fluctuating trend at the lower portions also suggests the input of Cl into the river as well as groundwater from anthropogenic sources. Common salt (NaCl) consumption for a person is approximately 5g per day and then, the total human consumption of NaCl in the study area is about 2920 tons per year. Therefore a substantial part of Cl can also reach the area through human sources as well.

The presence of microbial pathogens in the study area is established by concentration of TC, FC and FS in the riverine and groundwater environment. Proximity of leach pits to water sources and the release of untreated sewage to the surroundings are the main reasons for microbial contamination and proper disinfection practices should be mandatory for drinking purpose.

SUMMARY

The study area, the Karamana River Basin, is located between North latitudes 8°05' and 8°45' and east longitudes 76°45' and 77°15' and cover an area of 702 km^2. The Karamana river is a small mountainous river with main stream length of 68 km. Physiographically the Karamana river basin is characterized by – the coastal belt or lowland (between mean sea level and 7.5 m amsl) in the west, the midland region (7.5 – 75 m amsl) characterised by laterites in the central portion and the highland (>75m amsl) in the east comprising the foot hills and hill ranges of Western Ghats, covered by crystalline hard rocks. The average annual rainfall is 2600 mm and the rainfall ranges from less than 1400 mm in southwestern part to about 4200 mm in the northeastern portions.

The Karamana river basin falls partially or completely within the jurisdiction of 30 local bodies (28 grama panchayats, Nedumangad municipality and Thiruvananthapuram Corporation). The population of the area is about 16 lakhs as per 2011 census. The study area comprises a spectrum of land use classes, which include forests, forest plantations, mixed crops, agricultural areas, paddy lands and water bodies. The area contains mineral resources like tile and brick clays, crystalline rocks, construction grade sand, graphite and gem minerals like chrysoberyl. Mining and other anthropogenic activities along with natural hazards like landslides, flooding etc., pose severe environmental problems in the area. The study area hosts one of the important biodiversity hotspots in South India - the Peppara Wild Life Sanctuary (PWLS).

Geologically, the Karamana River Basin is composed mainly of crystalline rocks of Archaean age which includes khondalite, charnockite, garnet-biotite-gneiss with associated migmatites, pyroxene-granulite, calc-granulite and quartzite. All these rocks are intruded by a number of dolerite dykes in the midland regions. Thin and impersistent veins of pegmatites and quartz veins are also common. Sedimentary formation of Mio-pliocene age (Warkalli beds) occurs as detached patches unconformably overlying the crystallines, along the coastal tracts. In addition to these, patches of Quaternary deposits are seen in areas close to the river channels and coastal reaches. The Tertiaries and the basement rocks of the midland are extensively lateritised. Late Quaternary (Holocene) sediments represented by pebble beds, sand and clay deposits are encountered in the upper reaches of the study area.

About 80% of the area falls in the <300 m and 40% in <100 m altitudinal zones. Only 2.5% of the study area falls in the altitudinal category of >1000 m. Gently sloping (3 - 5%) to moderately steeply sloping (10 - 15%) classes cover a greater part (52.21%; 367 km^2) of the Karamana river basin. Nearly level (<1%) to moderately sloping (1-3%) classes constitute

6.83% (48 km^2) and occupy the lower part of the study area. Steeply sloping to very steeply sloping areas (287 km^2; 40.95%) are confined to high altitude zones.

The Karamana river basin have suffered intense tectonic activity, which is manifested in the form of dislocation of stream courses. The Karamana river drains mainly through khondalitic terrain. The river has incised into the planation surfaces and because of nearly uniform bedrock lithology, the channel pattern reflects structural control rather than lithologic inhomogenities. The NW-SE axial traces of nearly upright large-sca1e folds of gneissic foliation and banding are cut by the river. The change of course and the channel orientation are generally controlled by prominent fracture zones and joint planes. At Aruvikkara, the N-S course of the river is controlled by well-developed N-S trending vertical joints. In Karamana river basin the lineaments are dominant in the midland region, followed by highlands and coastal regions and the major lineament direction is NW-SE.

The stream order of Karamana basin is 6, indicating moderate stream discharge, channel dimension and size of the basin. More number of first order streams are observed in the hilly regions of the study area indicating complex terrain and less permeable bedrock lithology along with rugged topography and intensive channel erosion. The dissimilarity in the bifurcation ratio of various orders among the sub-basins of Karamana river basin is evidence for the control of tectonic activity on drainage development and the high values indicate young tectonic movements. Majority of the sub-basins have sinuous characteristics.

Drainage density of the sub-basins of Karamana river basin varies from 0.789 to 5.584 km/km^2. The drainage density has its highest value for the sub-basins in the highland terrain, which is associated with tectonism, highly resistant impermeable strata and high rate of precipitation. Low drainage density and stream frequency in coastal sub-basins is indicative of the gentle ground slopes, and greater rock-permeability, where the run-off is low and the infiltration is higher. Elongation ratios ranging between 0.461 and 0.751 in the study area, indicates very strong relief and steep slopes indicates moderately active tectonism. Elongated shape of the sub basins also indicates a young stage of evolution, caused by intense tectonic activity.

Basin relief of the sub-basins of the study area ranges from 87 to 1513 m and the high values are attributed to the palaeo and neotectonic activities. High basin relief, steeper hill slopes and higher stream gradients, decreases time of concentration of runoff inducing floods. It also indicates higher intensity of erosional processes in the basin as well as sediment load in the channels. The high ruggedness values observed for the upland sub basins imply that these are highly dissected basins with moderate to high relief and intrinsic structural complexity.

Most of the sub-basins in the study area show convexity in the lower portion of the hypsometric curve, due to uplift associated with folding or faults.

Granulometric analysis of the sediments of Karamana river basins reveals distinct features. Pebbles and granules show comparatively higher proportions in the river stretch where the gradients and local turbulence are higher. As the flow velocity increases, the finer sediments will be selectively entrained and deposited in the reservoirs leaving coarser particles upstream as lag concentrates. In addition to the natural processes, man-made obstacles like check dams, bridges etc., also impart marked effect on grain size distribution along and across the profile of the river. Unlike the river channels, the reservoirs are floored by muddy sediments. Phi mean increases (i.e., the actual size of the grain in mm decreases) downstream consequent to progressive decrease in the energy regime. The general decrease in grain size towards the direction of flow is attributed to combined effects of differential transport and abrasion. The changes in fluvial morphology and mean discharge of sediments seem to be the most important factors responsible for progressive decrease in the competency of river water in the study area.

Standard deviation varies from 0.58Φ to 5.84Φ in the fluvial sediments of the study area. The sorting improves significantly downstream. The improvement of sorting is attributed to differential transport of sediment particles. There is a tendency for sediment particles to assume normal distribution towards downstream. Such a tendency arises from the successive lagging behind of the larger particles whose presence imparts comparatively ill-sorted character to the sediments. Towards the reservoir sorting improves and the best sorted sediments are encountered in the river confluence zones with the reservoir.

The high positive skewness in the upstream reaches indicates that the sediments are predominantly of coarser grade. The very fine skewness of reservoir sediments is attributed to addition of silt and clay modes in the sediment population. It is evident that as the phi mean increases, the skewness decreases from very positive to near symmetrical and further changes to negative. As in the case of skewness, significant variations are observed in kurtosis values as well. The kurtosis values reflect fluctuations in the velocity of the depositing medium and are more pronounced in reservoirs than river channels.

Gravel, sandy gravel, gravelly sand, slightly gravelly sand and sand are the various sediment types encountered in the river channel. Sand dominates in the confluence zones of river with the reservoir. The reservoirs are floored by a suite of finer sediments - sandy mud, sandy silt, muddy sand, mud, clay and clayey sand.

The CM pattern worked out for the sediments reveals that the mode of transportation in the river channel is mainly rolling and partly by rolling and suspension. Uniform suspension and graded suspension are the chief transportational mechanisms in the reservoirs. ‘Pelagic suspension’ is noticed in Peppara reservoir near the impoundment.

The entire study area is covered by phreatic aquifers and hence may be considered to be completely recharge areas. However, due to the undulating topographic condition and the aquifer characteristics, groundwater tends to move towards down slope areas as sub-surface flows. As the groundwater is discharged through dugwells, borewells or filter point wells in all the three physiographic regions, the entire study area could also be considered as discharge area too. Lateritic and hard rock aquifers are hydraulically interconnected. However, the interference problem between dugwells and borewells depends on the extent by which the shallow and deeper aquifers are interconnected and also on the hydraulic property of the clay zone between the lateritic and fractured hard rocks.

In the Karamana river basin there are 281 dug wells in lowland, 224 dug wells in midland and 92 dugwells in highland region per km^2. About 85 % of these wells are exclusively used for domestic purposes. Less than 7% are found to be exclusively used for irrigation purposes.

In Karamana river basin about 80% of the dug wells and 100% of the bore wells are fitted with energized pumps. More than 90% of these wells are fitted with pumps of less than 2 HP and these wells are mostly pumped for 20-30 minutes a day. Most of the energized wells are used for domestic purposes.

Dynamic groundwater resource estimation for the Karamana river basin has been performed for the portions having <20% slope. The net annual groundwater availability is 58.57 MCM and the gross annual groundwater draft is 27.91 MCM. The stage of groundwater development in the study area is 47.65%. Both pre-monsoon and post-monsoon long term water levels do not record any significant declining trend and the stage of groundwater development is less than 70%. Hence, the Karamana river basin can be categorized for future groundwater development as ‘SAFE’.

Through integrated hydrogeological approach, using Geographical Information System, the downstream portion of the Karamana river basin is categorised as very good to good groundwater potential zones whereas the eastern portion of the basin is categorized as poor to moderate groundwater potential zones. It is estimated that about 30% of the basin comes under the very high to high category in terms of groundwater potential, while the remaining area comes under the moderate to low category.

Karamana river basin exhibits marked seasonal as well as spatial variations in the water quality parameters. In the settlement areas water is contaminated by the influx of liquid and solid wastes from domestic / urban centers. The anthropogenic contribution is significant during monsoon season compared to non-monsoon season. The monsoonal hike is not so prominent in the forest areas of the study area. The increased SO_4 concentration in the lower reaches of the study area implies the degree of pollution in the highly populated and cultivated areas within the Karamana river basin.

The plots of Ca + Mg *vs* HCO_3 reveal that chemical weathering is predominant in non-monsoon period. Gibbs plots reiterate the fact that precipitation has a direct control over the distribution of chemical signals in the fluvial environments of the study area. The well water samples fall in the rock dominance field indicating the role of chemical weathering and geological influence on the chemical constituents of groundwater.

In the settlement areas water is contaminated by the influx of sewage from domestic / urban centres. Considerable numbers of the groundwater samples are acidic in nature. 93% of the groundwater samples are bacteriologically contaminated. The presence of microbial pathogens in the study area is alarming, both in the riverine and groundwater environment. Proximity of leach pits to water sources and the release of untreated sewage to the surroundings are the main reasons for microbial contamination and proper disinfection practices should be mandatory for drinking purpose. In the non monsoon season, water in the river mouth regions shows high conductivity, salinity, Na and Cl values indicates sea water ingression due to reduced river flow.

To sum up, the terrain characteristics, morphometric parameters, the transportation and depositional mechanisms of the sediments, hydrogeochemical variability of certain major elements, groundwater conditions as well as water quality of the Karamana river basin have been brought out by the present investigation.

CONCLUSIONS

- The study area is composed mainly of khondalite suite of rocks capped at many places by laterite. Quaternary sediments are often observed in areas close to river channels.
- The granulometric characteristics as well as statistical parameters of the sediments of Karamana river basin generally depend on the flow pattern controlled by the gradient of the terrain.
- Morphometric analysis infers the control of tectonic activities on drainage development and indicates young tectonic movements.
- The high flow energy of the upstream reaches is capable of transporting sand and other finer particles downstream leaving gravel and other coarser particles as lag concentrates.
- The reservoirs retard the flow velocity and force water to deposit the particles in suspension upstream of the dam based on size and specific gravity.

- CM model reveals that particles in the river environment are transported mainly by rolling and partly by rolling and suspension. In reservoirs, the transportation processes are graded suspension and uniform suspension. Sediment collected from areas close to the Peppara dam behaves like those deposited from pelagic suspension. This is a clear indication of a turbulent-free depositional environment in the area.
- The stage of groundwater development in the Karamana river basin is 47.65% and can be categorized for future groundwater development as ‘SAFE’.
- Suitable areas for implementation of ground water recharge measures in the study area are demarcated, and 47% of the Karamana river basin area is suitable for implementing groundwater recharge measures. Roof top rainwater harvesting for conservation of water can be an effective method for the study area. The excess water from the collecting structure can be routed to existing wells for groundwater recharge.
- Contamination in water is several fold higher in the coastal reaches and downstream portions due to influx of considerable quantity of liquid and solid wastes of domestic / urban origin. The effect of contamination is severe during non-monsoon than monsoon period.
- Analysis of hydrochemical data using bivariate evaluation methods reveals that weathering and precipitation play a dominant role in controlling the major ion chemistry of the water resources.
- Water resources of the study area are excellent for irrigation purpose as per United States Salinity Laboratory (USSL) rating. Also, water is suitable for drinking purposes after eliminating the microbial pathogens through proper treatment.
- Salinity ingression in the coastal reaches of the river channel is at alarming levels during non-monsoon season, especially due to reduced river flow.

RECOMMENDATIONS

1. Every effort should be made to minimize waste discharges from urban / agricultural areas into Karamana river basin which is the drinking water source for the Thiruvananthapuram city and adjoining areas.
2. Steps are to be taken to promote the use of organic fertilizers to maintain agricultural productivity.
3. The activities that contaminate river systems like, bathing, washing, etc. should be strictly prohibited.
4. Sanitary facilities in the settlement areas should be improved and create awareness among the local people to conserve perennial water sources.
5. Proper disinfection should be done before using water for drinking purposes.
6. Periodic maintenance of recharge/conservation structures is essential in the study area to retain infiltration / capacity by reducing silting, chemical precipitation, and accumulation of organic matter.
7. Roof top rainwater harvesting for conservation of water should be promoted in the study area.
8. The choice of a particular artifitial recharge method should be governed by local topographical, geological and soil conditions; the quantity and quality of water available for recharge; and the technological-economical viability and social acceptability.
9. Arrangements should be made to monitor water quality of the area for taking timely and appropriate remedial measures.
10. Suitable measures should be formulated to arrest the saline water ingression through the river mouth.

OUTCOME OF THE PROJECT

- Thematic maps such as drainage, geology, hydrogeomorphology, hydrogeology, lineaments, water table, groundwater potential, etc are prepared in Geographical Information System. Thus the maps can be used even in the micro level planning process which would be very helpful for local to higher-level administrative processes.
- The status of quality and spatial availability of water resources in the Karamana river basin that has been reported in this work and the water resources management strategies evolved in this study can enable the framing of policies that stress on wise use of water in the Karamana river basin.
- Strategies/Recommendations for water conservation and management based on the spatial and temporal availability/demand evolved during the study can be implemented by local bodies to increase the water availability in the basin.

Publications

i. International Journals

1. Sreeja R., Arun P.R., Mahesh Mohan and Pradeepkumar A.P. (2015) Groundwater Potential of a Fastly Urbanizing Watershed in Kerala, India: A Geospatial Approach. International Journal of Engineering Research, Volume No.4, Issue No.10, pp : 578-581, ISSN: 2347-5013.

ii. Papers presented in Conferences

1. Sreeja R and Arun P.R. (2014), Grain Size Distribution of Fluvial Sediments in an Impounded River Catchment, Proceedings of the International Symposium on Integrated Water Resources Manangement (IWRM-2014), February 19-21, 2014, Kozhikode, Kerala. Vol. 1, pp. 795-803
2. Sreeja R., Arun P.R. and Pradeep Kumar A.P. (2015) Groundwater Potential of Killiyar Watershed, Thiruvananthapuram, Kerala: A geospatial Approach. Proceedings of the 27th Kerala Science Congress, scheduled to be held at Alleppy during 27-30 Jan 2015.

iii. Other Publications

1. Sreeja R (2017), Ph.D. Thesis submitted to Mahatma Gandhi University on "Sedimentology and Hydrogeochemistry of Karamana River Basin" during February, 2017.

SCOPE OF FUTURE WORK

This integrated study has provided the necessary foundation and paved the way for taking up further research on a wide range of applied aspects involving geomorphology, geology and water quality. Some of the aspects that has not been dwelt upon in the present study can be pursued in the future to build up on the existing knowledge gained from this study,

- In the present study, dating of the terraces of different levels is not attempted. Thermoluminiscence dating can provide an excellent relative chronology of the terrace sediments. It enables to establish a correlation between sedimentation episodes of fluvial systems and can throw light on the climatic cycles in the Quaternary age.
- To understand the tectonic evolution and palaeo-seismicity of the study area, 40Ar/39Ar dating of fault-related rock is very useful, since it is composed of friction-derived melt material interspersed with clasts and crystals from the host rock and is thought to be formed in response to seismic activity, meteoric impact, rapid tectonic faulting or landslides.
- Detailed hydrologic investigations are not attempted in this study. The hydrologic studies in detail can be useful for the modelling, designing and implementing site specific ground water recharge as well as conservation structures in the river basin.

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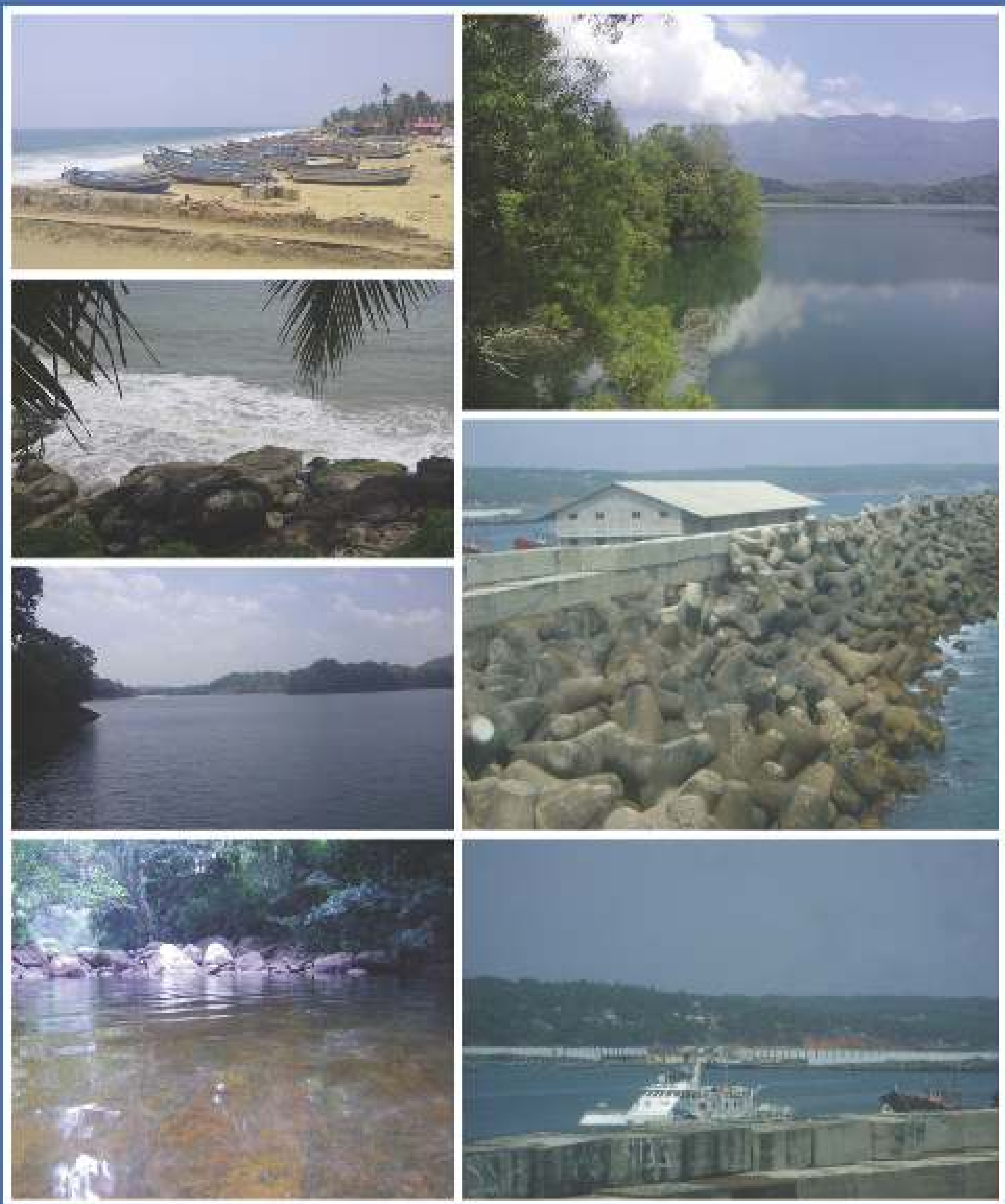

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