AN ANALYSIS OF THE ENVIRONMENTAL CHANGES IN THE BHARATHAPUZHA RIVER BASIN, SOUTHERN INDIA

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1. Introduction

Rivers are considered as an open ecological system, which play a major function in integrating and organizing the landscape, and moulding the ecological setting of an area. The dynamism of the free-flowing rivers for long have challenged and fascinated humans and are a cradle of human civilization. The economic value of river basins could be in billions of dollars (Schuyt, 2005) if it could be reasonably estimated. However, rivers and streams are among the most human affected ecosystems in the globe and exceedingly exploited (Neilson et al., 2005) for water, energy and transportation by its stake holders.

The genesis and development of the modern human civilization is believed to have happened in the banks of various global river systems. The Egyptian, Mesopotamian, Chinese and Indus valley civilizations were developed respectively in the basins of the rivers Nile, Tigris–Euphrates, Yangtze-Yellow, and Indus during different geological time scales. Most of the important and highly populated cities of the present day are also located along river banks.

The growing human population started exploiting rivers by various ways as the nomadic life of the race transformed to a more settled one. The story of exploitation continued more intensively and expansively during the 19th and 20th century when agriculture revolutions required more irrigation, to cater the growing needs of the geometrically progressing population. Dams for irrigation and energy production in the upper catchments and nutrient enrichment due to extensive inorganic agriculture practices and consequential algal bloom became an issue for several rivers during this time (Varghese, 2009). Industrial revolution still exacerbated the situation with wastes of various kinds; as a rule, rather than exception, rivers are ultimate discharge points for effluents and to dump other wastes including domestic and municipal waste water. Several authors studied the hydrology of the river basins by focusing the water quality and runoff; studies conducted by Riedel et al., 2000; Gupta and Chakrapani, 2005; Sileika et al., 2006; Quadir et al., 2007; Raj and Azeez, 2009a are some among them.

Recent statistics show a spread of human populations over all the continents and presently 41% of the human population resides along river basins under extreme water stress (Bates et al., 2008; CBD, 2005). Since 40% of the world agriculture output purely depends on irrigation (Fischer et al., 2006), water impounded in reservoirs has quadrupled since 1960 (Millennium Ecosystem Assessment, 2005).

Water being of foremost importance to life in general, river basins and the flood plains have very valuable wetland ecosystems providing abode to numerous biologically diverse species. Degradation of these ecosystems till date has resulted in the extinction or near extinction, of about 20% of the world's 10,000 fresh water species (CBD, 2005). According to the Millennium Ecosystem Assessment report (2005) the world's fresh water ecosystems are reported to be the area of highest species extinction and several species in this zone fall among the list of threatened species.

Untoward variation in climate is one of the determining factors to the health and status of the world's fresh water resources. Drastic and adverse fluctuations in climatic conditions are likely to have a direct influence on fresh water resources. The global surface temperature is reported to have gone up by 0.74˚C since 1906 and the warming was more rapid during the last 50 years (Bates et al., 2008). The India Meteorological Department (IMD) also reports a 0.913˚C hike in temperature in 2009 than the 1961-1990 average (IMD, 2010). However, due to the lack of climate stations and availability of historical climate datasets there is a huge lacuna in documenting the global river flow related to climate change. Sea water intrusion is yet another major crisis observed in most of the river basins particularly those with low physiographic aspects, which will affect the water quality and well being of the ecosystems in a larger perspective. Sea level rise was observed at a rate of 1.7 ± 0.5 mm/yr for the 20th century is reported (Bates et al., 2008). There are notable studies on meteorology and its relation with the hydrology of the basin, (Yin et al., 2000; DeWit et al., 2007).

Land use change along the catchment of rivers affects the entire river system by altering the river runoff and ground water flow (Calder, 2000; Zade et al., 2005; Tijiu and Xiaojing, 2007; Xu et al., 2007) in general and by changing input of water, light, allochthonous materials into the system more precisely (Nilsson et al., 2003; Strayer et al., 2003). During the last couple of decades the world has been witnessing drastic land use changes (Zhu et al., 2008). Many studies have been conducted in this regard to investigate the effect of changes in land use on river basins around the globe; Xiaoming et al., 2007; Galster et al., 2007; and Bhaduri et al., 2000, are some among them.

Most Indian rivers are important from a mythological and cultural perspective. The sanctity bestowed on these rivers is a reflection of their importance to the local society. The rivers of India are broadly grouped into four classes according to their location and topography: Himalayans, Deccan, Coastal, and rivers of inland drainage basins. The three big rivers, Indus, Ganges, Brahmaputra and their network of tributaries in the Indo-Gangetic plains constitute the Himalayan river systems. The Deccan rivers include the west flowing Narmada and Tapti and east flowing Mahanadi, Krishna, Pennar and Cauvery river networks. The Coastal rivers include the small river networks along the coastal belt that spread across the eastern and western side of the peninsula. The small rivers of Rajasthan are known as the inland drainage rivers. These rivers draining into salt lakes or the desert are highly dependent on rainfall and largely ephemeral. The rivers of India could be also classified as major, medium and minor on the basis of catchment size (Jain et al., 2007); the class 'major rivers' includes those with catchment area > 20,000 km^2, 'medium rivers' included those with catchment area between 2000 and 20,000 km^2, while 'minor rivers' are those with Catchment area < 2,000 km^2.

The state of Kerala, located at the southwest corner (8.5˚-11˚ N and 76˚-77˚ E) of the Indian peninsula is unique in its physiography with an undulating terrain bounded by the Western Ghats on its eastern side and the Arabian Sea on the west. The Western Ghats reach more than 1500 meters in elevation and the coastline of Kerala is 580 km long. The State has 44 rivers with an average length of 64 km. This includes medium rivers Periyar (244 km), Bharathapuzha (209 km), Pamba (176 km) and Chaliyar (169 km). The network of their tributaries and distributaries cover almost 74% of the total surface area of the state. The average rainfall of the state is 3000mm and the total annual yield from all the 44 rivers to the state is 70,323 MCM (http://www.kerenvis.nic.in). However Nair (2008) states that Kerala's per capita water availability lies far below the more arid states of India such as Rajasthan and Maharashtra.

Studies reveal that there is a general declining trend in annual rainfall in the whole state (Soman et al., 1998; Kumar et al., 2004; Krishnakumar et al., 2009), and some of the studies reported local aberrations and decline in annual rainfall from different parts of the state (Soman et al., 1998; Raj and Azeez, 2010b). Unsustainable exploitation of natural resources in the basin and untenable encroachment of the river course and basin areas are the probable grounds for drying rivers in the state. Extensive mining of sand and clay have interfered with the flow regime of many tributaries, while imprudent and unhygienic disposal of wastes add to the quantum of degradation of the river courses (Raj and Azeez, 2010a).

Although Kerala has a rich river network, studies documenting the environmental status of these rivers are very rare. The present study was carried out on the Bharathapuzha river basin. The river is the water source for a human population of 4.6 million (Census, 2001a, b, c, and d) residing in five administrative districts, namely Malappuram, Thrissur and Palakkad districts of Kerala and Coimbatore and Tiruppur district of Tamil Nadu. There are eleven irrigation projects and several check dams in the river basin for 493064 ha of cultivated land (CWRDM, 2004; Ravi et al., 2004). However, the basin remains poorly studied with respect to important base line information. In this context the present study was under taken with the following objectives:

- Investigate the morphometric characters of the river basin,
- Analyze the land use changes that happened in the basin during last three decades
- Examine the meteorological status of the river basin,

- Study the quality and quantity of surface water in the river course, and
- Examine major factors influencing the river discharge in the basin.

The work is presented in the thesis as per the following structural organization:

Chapter 1: Introduction - provides a general background of the study

Chapter 2: Study Area - describes the Bharathapuzha River basin, geography, geology, and ecology. The chapter also gives a narration of the demography, history and major ecological threats in the basin.

Chapter 3: Morphometry - presents the geomorphology and drainage characteristics of the basin.

Chapter 4: Land use changes - discuss the land use changes in the river basin during the last three decades, with special emphasis on the urbanization and deforestation.

Chapter 5: Meteorology - gives an account of the rainfall and temperature changes in the basin.

Chapter 6: Surface water quality - discusses the spatio-temporal variation in the surface water quality of the river.

Chapter 7: Basin related factors influencing discharge in the river - examines various factors influencing and/or governing the discharge in the basin.

Finally, the salient findings of the study are briefed in the summary part of the thesis – Chapter 8.

2. Study Area, the Bharathapuzha River basin

2.1. Introduction

The Bharathapuzha River basin is the second longest river and the largest among the 41 west flowing river basins in the state of Kerala in Southern India. According to the classification by Jain et al., (2007), the river is considered as a 'medium' sized river. This west-flowing river lies between 10˚ 25' to 11˚15' N and 75˚ 50' to 76˚ 55' E. The Bharathapuzha watershed commences in the depression formed by the Palakkad Gap, the 30 km discontinuity in other wise continuous mountain range, the Western Ghats (Figure.2.1.). The river originates from different parts of the Western Ghats, as small brooks and rivulets which later joins to form 4 major tributaries, Chittur River, Kalpathi River, Gayathri River and Thootha River (Figure.2.1). These tributaries later as they flow down to the west join at different places and form the Bharathapuzha River at Parali and flows further west and debouch into the Arabian Sea at Ponnani on the Malabar coast. The Bharathapuzha River is also known as the Ponnani river or Nila river, especially among literary circles, and the population residing along the coastal region. The surface water potential of the basin is 7478 million m^3 of which the total utilizable yield is 4146 million m^3 (CWRDM, 1991). A recent study by Sarunjith and Sanjeevi (2007) shows the Bharathapuzha estuary is vulnerable to tsunami waves.

2.2. Bharathapuzha Drainage system

The total length of the Bharathapuzha River is 209 km. The area of the basin extends to 6186 km^2 of which 4400 km^2 lies in the Kerala state and the remaining area falls within the state of Tamil Nadu. The basin covers 1/9th of the total area of the state of Kerala.

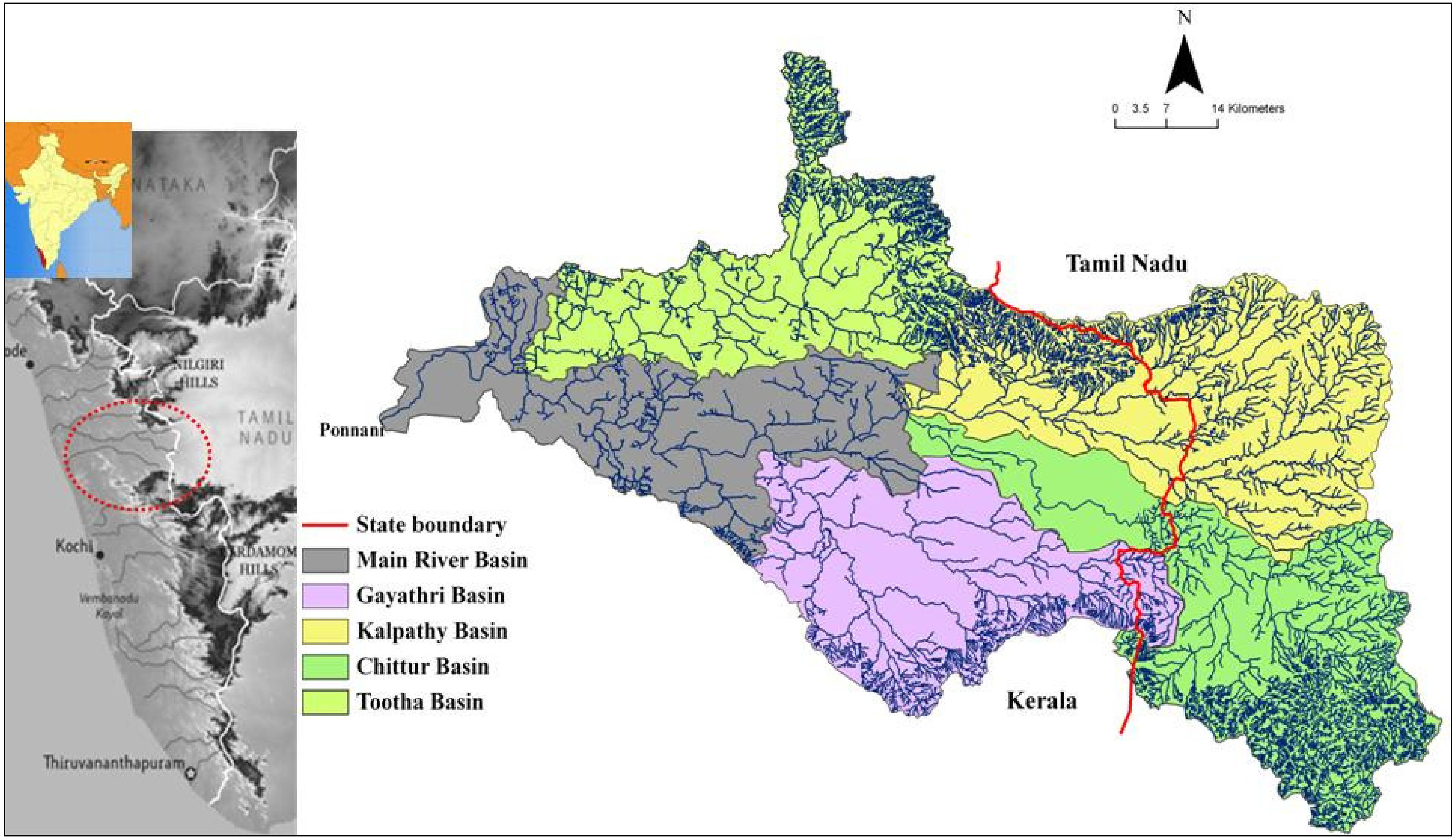

Figure 2.1 Bharathapuzha river basin Geographic location

Of the four tributaries, the most distant one, the Chittur River originates from different parts of the Anamalai hills. This sub-basin covers 1314.71 km^2. The Aliyar dam, Thirumoorthy dam and the Chitturpuzha irrigation project are located in this basin. The major tributaries are Palar, Uppar, Nallar and Aliyar. Small rivulets originating from Arasiammalmalai hills, Pichchimalai hills, and Kadatrimalai hills join and form the Palar River which flows north-westward and receive Nallar, another tributary flowing in the north-east direction from the Anamalai hills, and get in to the Aliyar River. The Aliyar River originates from the Anamalai hills as small tributaries. The Uppar River is another small rivulet that confluences with Aliyar. The Aliyar on crossing the Kerala border becomes the Chitturpuzha River which then flows westward and joins the Kalpathi River at Parali. The catchment of the Chitturpuzha River lies in the Coimbatore and Tiruppur districts of Tamil Nadu, and Palakkad district of Kerala. It flows through Chinnapudur, Vettaikkaranpudur, Anamalai, Amparampalayam, Chittur, and Tathamangalam. Chitturpuzha River is also known as Kannadi or Amravati (Figure.2.2).

The Kalpathipuzha River is the second largest sub-basin of Bharathapuzha River, its tributaries flow from the Bolampatti block reserve forest (RF), Chenat Nair RF and part of the Coimbatore plains. The major sub-tributaries of Kalpathipuzha are Korayar, Varatar, Walayar and Malampuzha. The small rivulets flowing through various parts of Coimbatore plains join together to form Korayar River, which confluences with Varatar, another stream originating from the western aspect of the Coimbatore plains and then flow further north-west through the Palakkad plains. Near Kanjikode, the Walayar River originating from Walayar RF in the Western Ghats and from western side of the Coimbatore plains confluence with the Koryar River; from there the river flows towards further north-west and joins the Malampuzha River, originating from different parts of the Chenat Nair RF and the Bolampatti block RF, to form Kalpathi River. Kalpathi River then takes a south- west direction and flows further to join the Chittur River at Parali and forms Bharathapuzha River. Thus during its course the Kalpathi River flows through Chettipalayam, Pollachi, Muttur, Kalpathi, Olavakkode and some part of Palakkad municipality. The Malampuzha irrigation project and the Walayar irrigation projects are located in Kalpathi River basin (Figure.2.3.).

Originating from different parts of Nelliyampathi RF and the adjoining hills of Anamalai RF, the Gayathripuzha River forms a network of streams over a watershed area of 1085 km^2. The rivers Mangalam, Ayalurpuzha, Vandazhipuzha, Meenkara and Chulliyar are its major tributaries. The Meenkara River is originating from the western and northern side of the Anamalai RF and flow westwards forming Gayathripuzha River at Muthalamada. The river then takes a bend towards the south and near Kambrattuchola it merges with Chulliyar River, originating from various hills located north to Thekkady RF. From here onwards the river flows westward. The river Ayalurpuzha beginning from the Nelliyampathi RF joins Gayathripuzha River near Kallepadam. On its course it joins the Mangalam River, which originates as Thiplikayam thodu, Kumbancheri thodu, Vattappara thodu and those small streams flowing through Vadakkancheri from Nelliyampathi RF. The Gayathripuzha River then flows north-west and confluences with the main river Bharathapuzha at Mayannur. On its course towards the main river, the Gayathripuzha River flows through places like Kollengode, Nenmara, Alathur, and Pazhayannur. Four irrigation projects are located in the basin namely the Meenkara river project, Mangalam project, Pothundy project, and Chulliyar project (Figure.2.4.).

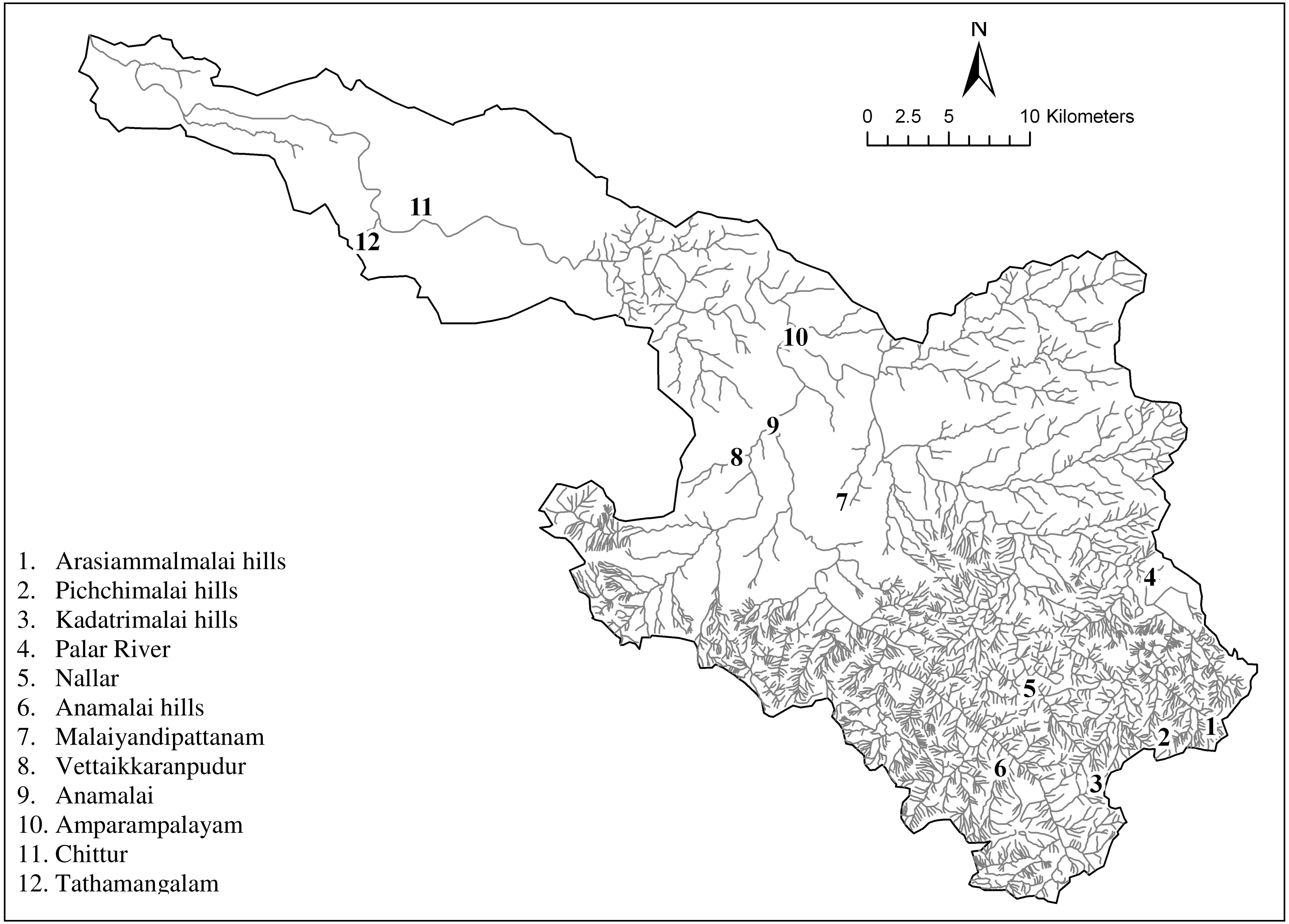

Figure 2.2 Drainage network of Chittur River sub-basin

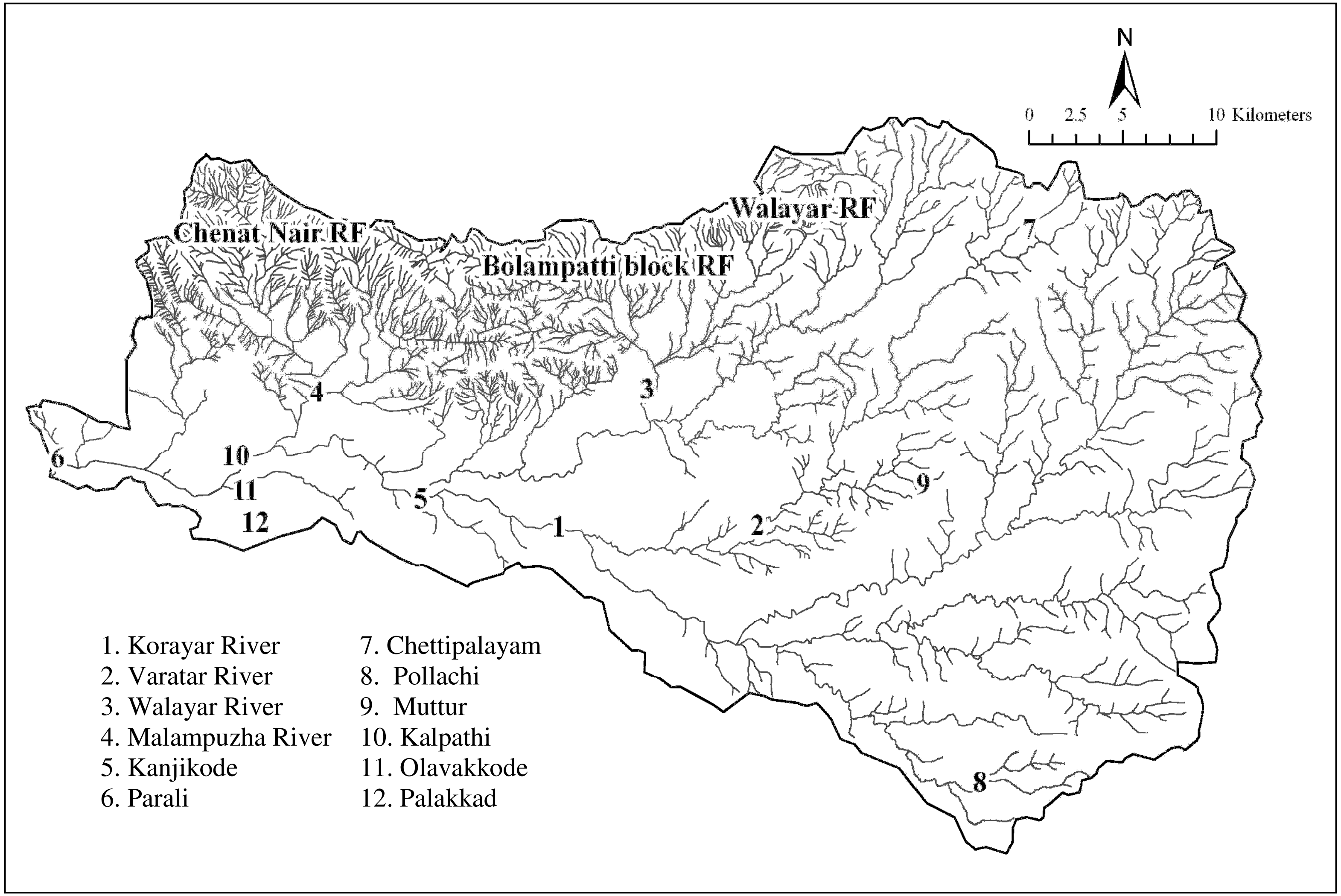

Figure 2.3 Drainage network of Kalpathipuzha River sub-basin

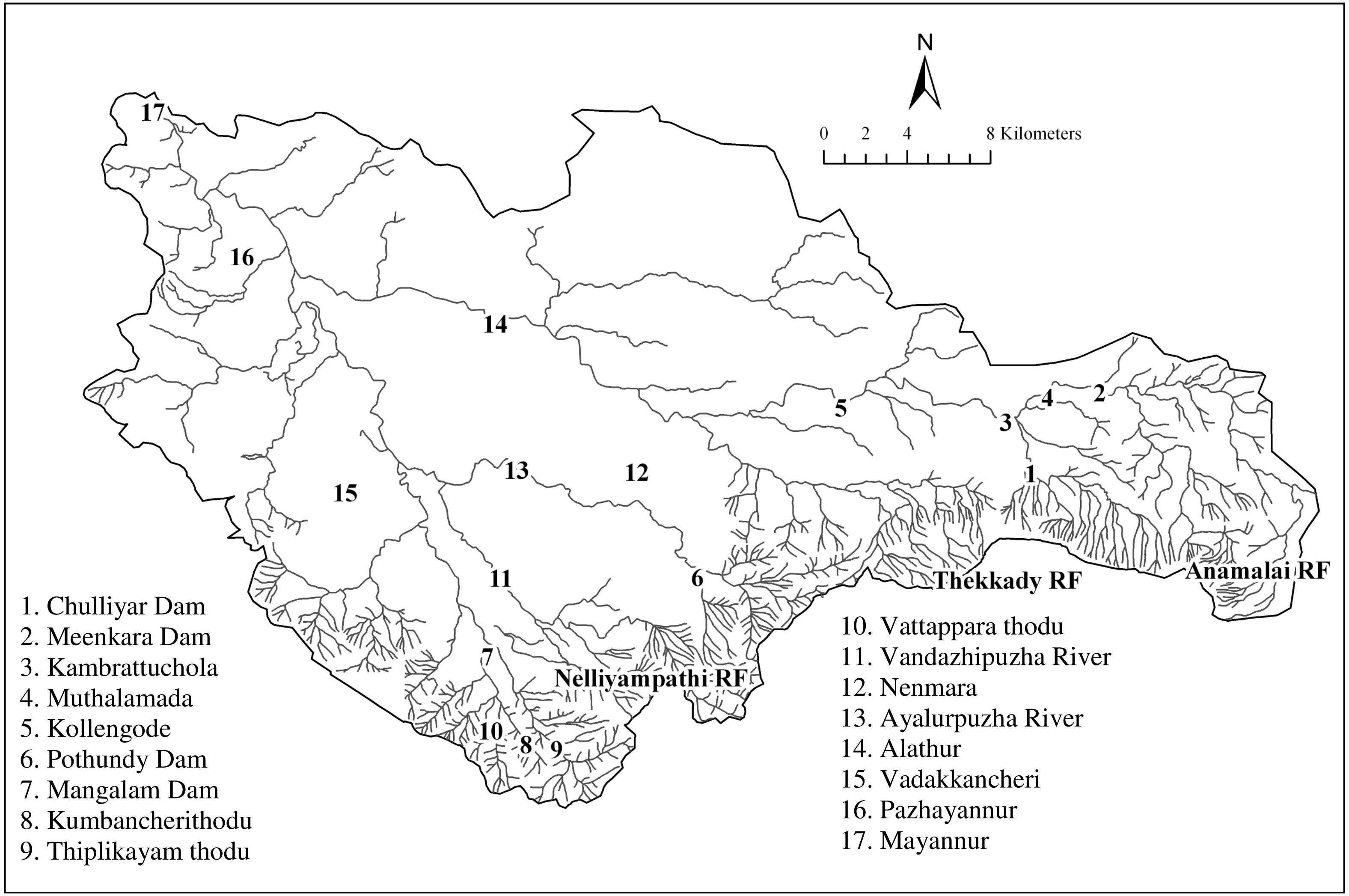

Figure 2.4 Drainage network of Gayathri River sub-basin

Thootha River basin forms the smallest sub-basin in the Bharathapuzha drainage network systems. It originates from various parts of Silent Valley National Park, Muthikkulam RF and Siruvani RF in the Western Ghats. Thootha River has four major tributaries, River Kunthi, Kanchirapuzha River, Nellipuzha River and Thuppanadupuzha River. Its watershed spreads over an area of 1015.3 km^2 (Figure.2.5.). River Kunthi is originating from higher elevation (2383 m) and travels through the high altitudinal rainforest at Silent Valleys for its major course. The river takes a south ward direction and merges with the Kanchirapuzha River and forms the Thootha River. During its journey towards Kanchirapuzha, the river Kunthi joins with several other small streams originating from the Silent Valley RF. The Nellipuzha River another tributary originates from the Muthikkulam RF and the Kanchirapuzha River originates from the Siruvani later joins with the Thootha River. The Thootha River takes a further south-east turn and joins with the Thuppanadupuzha River at Karimpuzha. The streams forming the river Thuppanadupuzha begin from western side of the Chenat Nair RF. After reaching Karimpuzha, the Thootha River bends westwards and some times in the south- west direction and flows through Elamkulam, Natyamangalam, Thiruvegappura, and Pulamanthole. The Thootha River, other wise known as the Pulamanthole River then flows towards the south-west and discharges into the main river the Bharathapuzha at Koottakadavu near Pallippuram. The Thootha River basin is relatively less harnessed among all other sub-basins and perhaps the rain forests in the upper reaches help maintain a minimum flow in the river throughout the year (Raj and Azeez, 2009a).

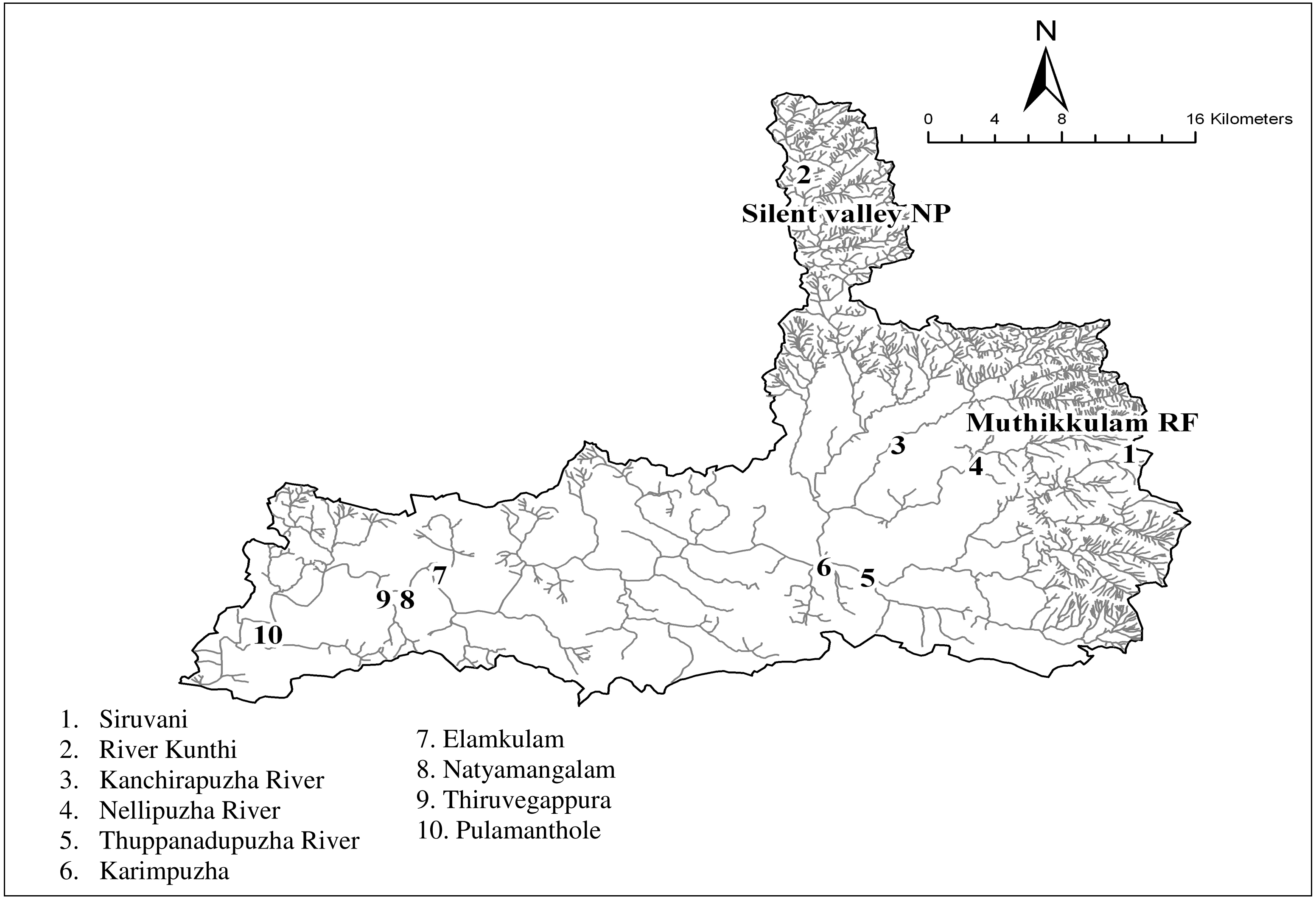

Figure 2.5 Drainage network of Thootha River sub-basin

2.3. Physiography

The Bharathapuzha river flows through three major physiographical zones i) the coastal belt/ lowland (<8 m), ii) the midlands (8-76 m), and iii) the highlands (> 76 m). A terrain analysis examining the elevation on each 5 km interval from the Parali, (where the main river starts) exhibits the gradual rise in the elevation towards, north, south and east as the distance increased, however towards west the trend is not uniform (Figure.2.6.). Considering the total area of the basin, 1/3rd of it falls under 'highlands', rest in the 'midland' and coastal zones (CESS, 2004). It is estimated that 85% from the highlands, 50% from the midland and zero percentage from the lowland contributes the total utilizable yield of the basin (CWRDM, 1991, Figure.2.7.).

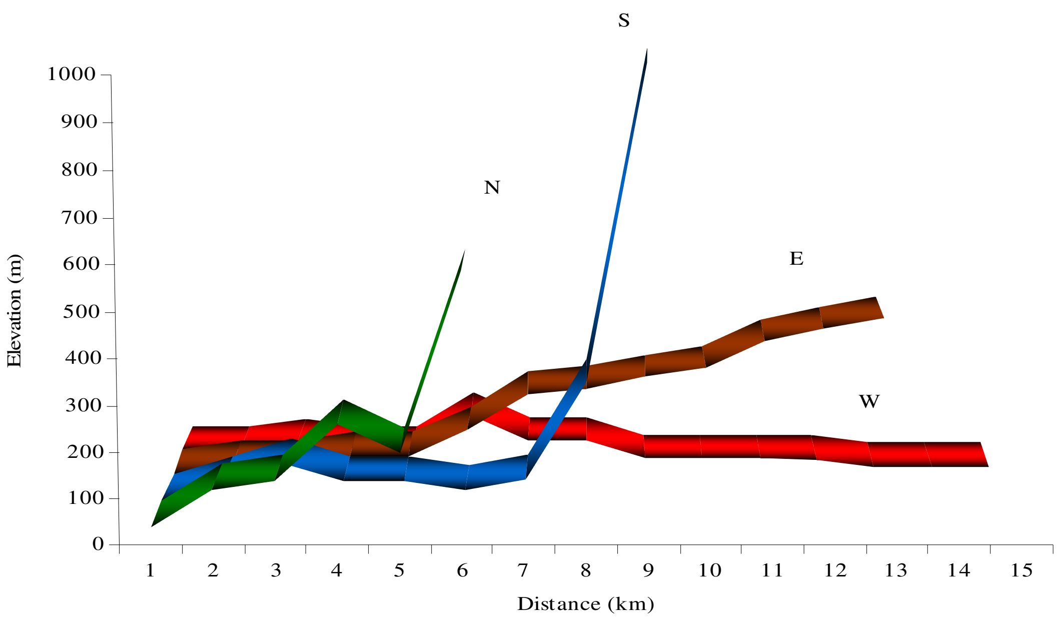

Figure 2.6 Elevation gradient in the Bharathapuzha River basin towards the four directions (N:North, E:East, W: West and S:South) from Parali

Rivulets from the forest of Silent Valleys, Muthikkulam, Siruvani, Nelliyampathi, and Anamalai of Western Ghats forms the Bharathapuzha River. A view of the River Kunthi at Silent Valley

Malampuzha dam. There are 11 dams in various sub-tributaries of the Bharathapuzha River basin. The Malampuzha dam and irrigation project is the largest one among all.

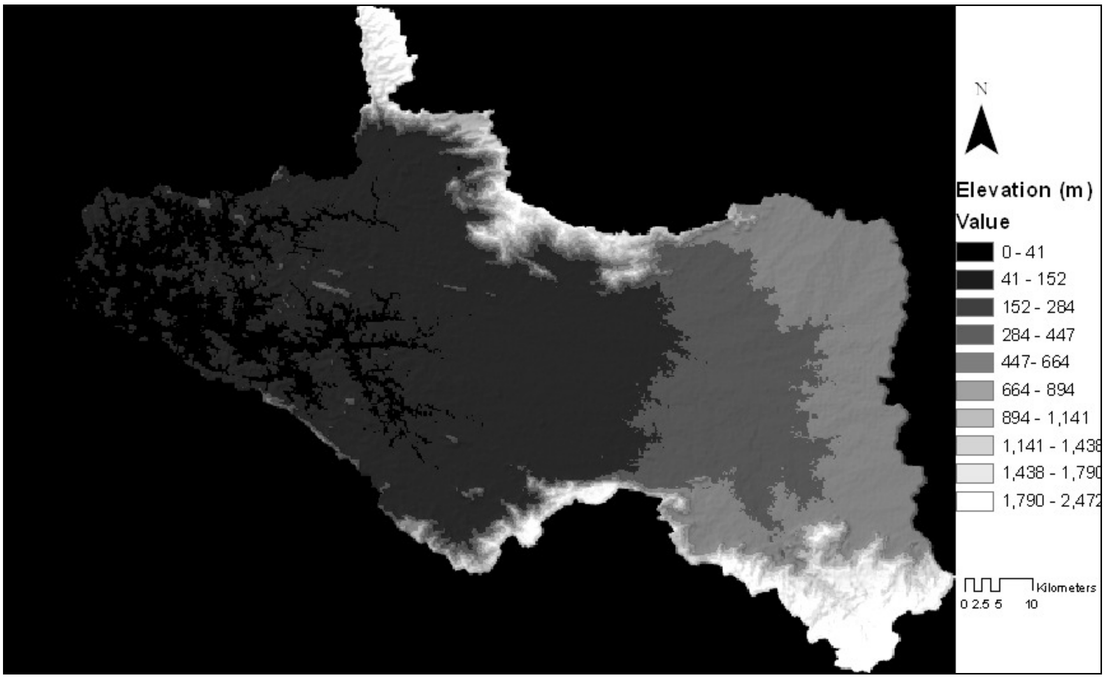

Figure 2.7 Elevation profile of the Bharatapuzha River basin

The highland regions in the basin includes the high mountain ranges of the Western Ghats, including the Anamalai regions, Nelliyampathi region, Bolampatti regions, the Silent valley, Siruvani, and Muthikkulam, and adjoining high valleys extending from western part of the Coimbatore covering the Palakkad plains in the Palakkad gap. The midland region is characterized by narrow valleys and small agricultural watersheds. Small lateritic mounds or hillocks bordering paddy fields and coconut groves are characteristics of the general physiography of these midlands. The coastal belt and the estuary regions of Bharathapuzha River are characterized by salt water navigable canal systems and coconut grooves. Bharathapuzha estuary other wise known as Purathur, lies in lowland area. The Purathur estuary is a common drain-out for Bharathapuzha River, Thirurpuzha River (at its north) and Kanchiramukku River (at its south) and it has a wider profile, susceptible for higher inundation. Recent bathymetric analysis reveals this estuary zone as having steeper slope at 5 and 10 m contours (Sarunjith and Sanjeevi, 2007). The estuary supports mangrove vegetation, one of the relic areas of this type of vegetation fast disappearing in the state for various market / developmental pressures (Azeez et al., 2004).

2.4. Geology

Geologists consider the Bharathapuzha River basin as a successor to a west flowing palaeo-river during the post Mio-Pliocene time (Jacob and Narayanaswamy, 1954; Subramanian and Muraleedharan, 1985; Vaidyanadhan, 1971). Vaidyanadhan (1971) as well as certain LANDSAT imageries, have also identified certain palaeo- river channels tending towards the east flowing Amravati River basin through the present day river course. The Bharathapuzha basin has a wide variety of geological formations including Archean crystallines, laterites and coastal sand and alluvium. The archean characterized by charnockites, garnet sillimanite gneisses (Khondalites), calc granulite and associated crystalline limestone, hornblende-biotite-gneisses, granites and quatzo-feldspathic gneisses, covers almost entire basin except the river mouth and the main river channel. At many places in the basin the crystalline are seen capped by laterites. The basic metamorphic bodies and acid intrusives are represented by pyroimite, amphibolites, dolerite, pegmatite, and quartz vein. Coastal sands and alluvium forms recent to sub-recent depositions / sediments at river mouth in the form of semi-consolidated and variegated tertiary sand stones and clay stones. The eastern boundary of the basin is characterized by deposition of Kankar, a product of chemical weathering of country rocks in dry and semi-arid climate (CESS, 2004) (Figure.2.8.).The basin has important records of seismic activity (D'Cruz et al., 2000). During 1341 and in 1900 significant earthquakes were reported from various part in the vicinity of the basin. The structural elements in the 'gap' region are consistent with a ductile shear zone (Palghat-Cauvery Shear zone), defined by a large E-W dextral oblique-slip component, which may have been associated with Proterozoic tectonic events (D'Cruz et al., 2000). Recently tremors were recorded from places like Vadakkancheri and Deshamangalam in the basin (John and Rajendran, 2008).

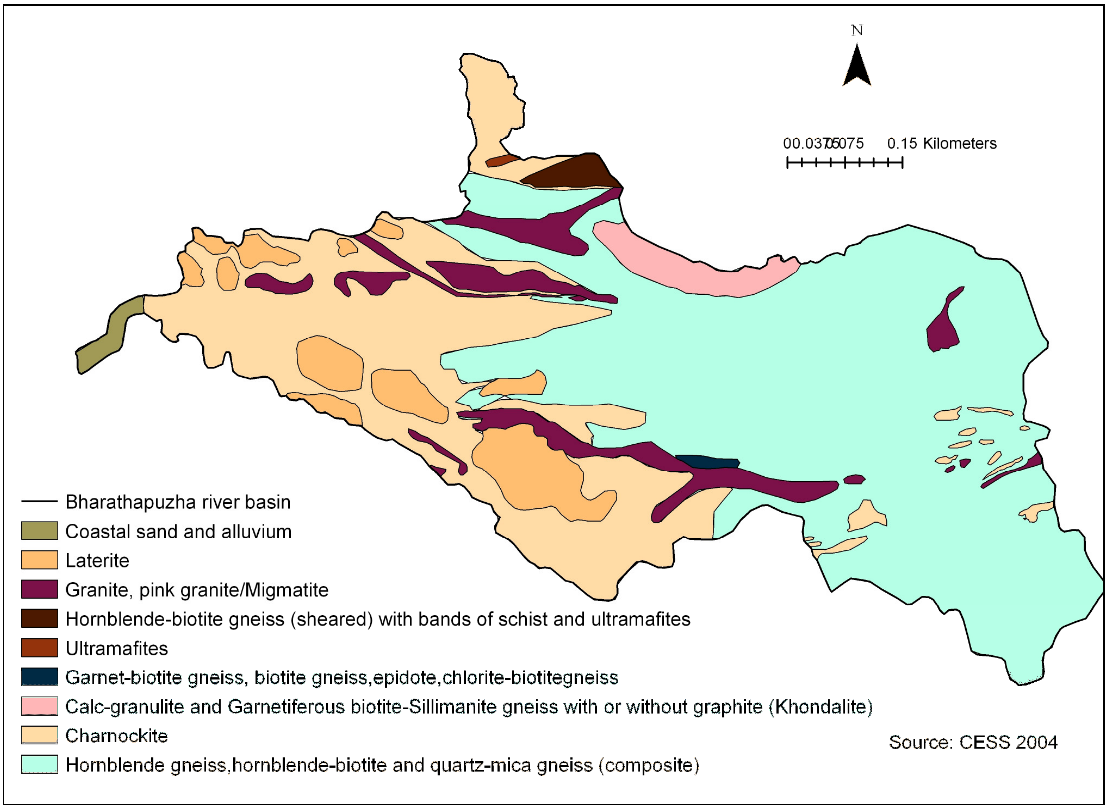

Figure 2.8 Geological set up - the Bharathapuzha River basin

2.5. Soil

Soil type of Bharathapuzha varies widely for each regions; the major soil type include laterite soil, brown hydromorphic soil, red sandy soil, black soil, forest loam and riverine alluvium. The lowland region including the coastal region is characterized by alluvial deposits, which texturally ranges from sandy loam to clay loam. Riverine alluvium is found concentrated in the flood plains of the river in the low and midlands. Lateritic soil forms the major soil type in the midland and highland regions of the basin. The small patches of brown hydromorphic soil also are found in the midland regions. Forest loam and black soil are very common in the highland regions in the Palakkad plains (GSI, 1976; CWRDM, 1991; CESS, 2004, Figure.2.9.).

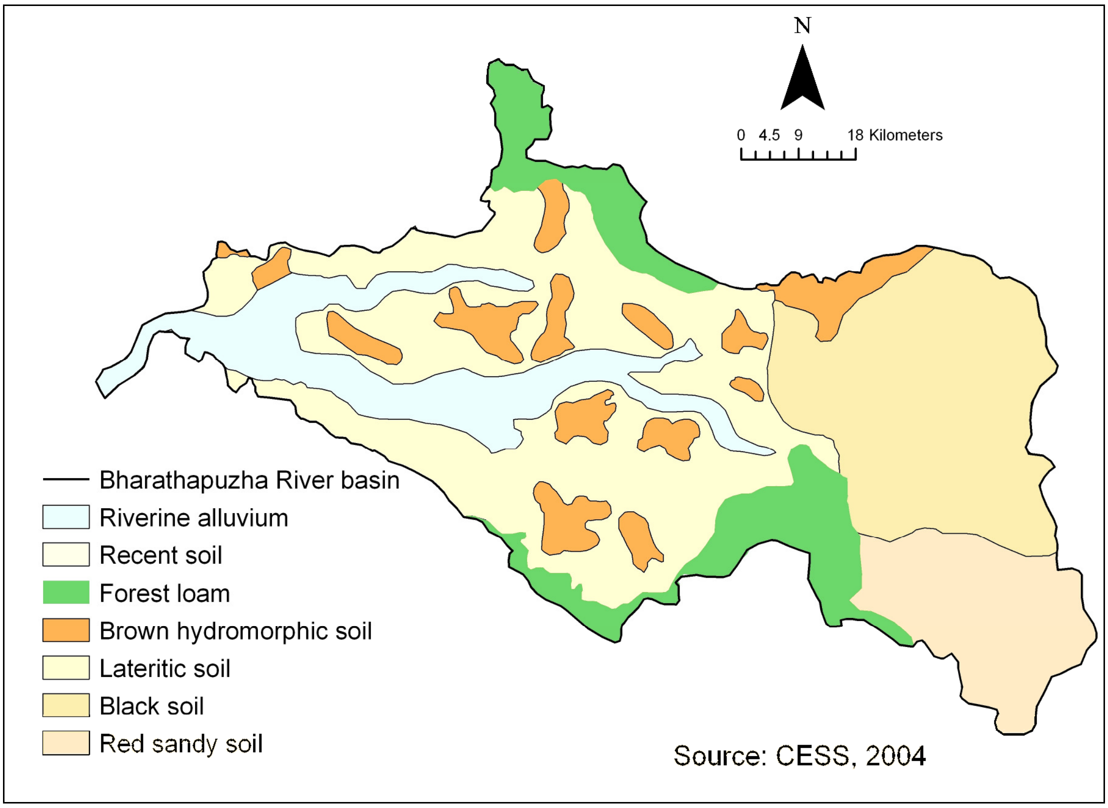

Figure 2.9 Soil Map – the Bharathapuzha River basin

2.6. Climate

Broadly the climate condition of the river basin is akin to the general climate of Kerala state; tropical monsoon with seasonally heavy rainfall and hot summer as per Koppen's climate classification (Nathan, 2000). However, its location in the Palakkad plains, in the Palakkad Gap, surrounded by high elevation mountain ranges of the Western Ghats, shapes the river basin to exhibit a relatively distinct climate realm from rest of the state of Kerala and South India. The wind flow, the rainfall, humidity and the temperature in the basin, is crucially influenced by the Palakkad Gap (Raj and Azeez, 2010b).The Chapter 3 gives a more detailed documentation of the matter.

2.7. Ecology

The basin abode various types of ecological systems; wetlands, various forest ecosystems including mangroves, high altitude grass lands, agriculture and urban ecosystems. Vast area of wetlands comprising of coastal wetlands, and freshwater wetlands forms home to a number of animal species and plant species. The fresh water system of the basin consists of both natural and manmade wetlands lying adjacent to reservoirs. Nearly 25% of the Bharathapuzha River basin is forested and these areas come under various protection regimes such as reserve forests, sanctuaries, national parks, etc. The forest type of the basin may broadly be classified in to wet evergreen, semi evergreen, moist deciduous and temperate shola forests. Documentation of the floral diversity of various parts of the basin has been done by various authors; documentation of the floral assemblage of Palakkad district by Vajravelu (1990), Silent Valley by Manilal (1988) are the important among them. Studies conducted from various part of the basin also record abundant floral assemblage in the river basin (Ayyar, 1939; Subramanyam, 1959; Subramaniyan 1966; Henry, 1963; Murugesan, 2003).

The faunal compositions of the river basin were also studied by various authors: Kumar (2001) studied the biodiversity in the main river between Lakkadi and Ponnani. He has recorded 24 species of zooplanktons, 13 species of molluscs, 61 species of fishes, 3 species of amphibians, 113 species of birds from the basin. The avifauna of Bharathapuzha river basin include near threatened species such as Darter (*Anhinga melanogaster*), Painted Stork (*Mycteria leucocephala*), Oriental White Ibis (*Threskiornis melanocephalus*), and Black-bellied Tern (*Sterna acuticauda*). Common otter (*Lutra lutra)* is also observed (Kumar, 2001) in some stretch in the basin. Sushama (2003) recorded 29 species of phytoplankton and 7 species of zooplanktons from various locations in the main river stretch, with distinct seasonal variation in the plankton population in all the locations. 10 species of crabs, 10 species of prawns, 13 species of molluscs, 150 species of fishes, 112 species of birds, two species of amphibians, two species of turtles, include one near threatened species were also recorded from the basin. The high altitudinal forest patches including the Silent valley National Park, Anamalai reserve forest, and Siruvani and Muthikkulam, in the upper reaches of the river are rich in floral and faunal composition (Nair, 1991; Arun, 2000; Das, 2008). The Bharathapuzha estuary at Purathur on the other hand is considered to be one of the locations in the migratory routes of many birds (Kurup, 1991).

2.8. Population

As mentioned earlier, the Bharathapuzha river basin extended to Tiruppur and Coimbatore districts of Tamil Nadu and Palakkad, Malappuram and Thrissur district of Kerala. The basin spreading through Coimbatore, Udumalpett, Palakkad, Mannarkkad, Chittur, Ottappalam, Thalappally, Chavakkad, Perinthalmanna, Tirur, and Ponnani taluks help in meeting the water needs of more than three thousand revenue villages directly or indirectly. According to 1981 census the basin had a population of 2 million people. During 2001 the population has grown up to 4.6 millions (Census, 2001a, b, c, and d). The denser areas in the basin are the 6 municipalities; Pollachi, Palakkad, Ottappalam, Chittur-Tathamangalam, Shoranur and Ponnani. While in the Tamil Nadu part of the river basin, the changes such as urbanization are mostly limited to certain locations, in Kerala such activities are wide spread and haphazard and urban agglomeration could be seen growing up all along flanking the river banks similar to all other parts of the state, which is more or less an extended urban sprawl.

2.9. History and culture

Menon (2008) states that in Kerala there is no evidence of Paleolithic human life and there are plenty of evidences for Neolithic habitations. However, Chandran (1997) observed that the human beings are known to live in many part of the basin since Paleolithic or Old Stone Age (before 12000 years BP). The basin had great influence on the early rulers of southern India including Pallavas, Cheras, Pandyas Rashtakutas and sultanate of Mysore. Since the basin commences right in the Palakkad gap that provided a major migratory route for the communities from the peninsular India to the south western land strip; the people’s movement must have directly influenced the cultural milieu of the basin. The river stretches right from the Palakkad gap to the Ponnani port, which was once a means of transportation for traders from different part of the world to the rest of India especially Tamil Nadu. It seems there was a ‘silk route’ through the Palakkad gap to the erstwhile Chennai from the yesteryear port of Muziris (believed to be located at a place called Pattanum south of the river Periyar, the longest river in the state of Kerala) on the western coast. Roman coins and jewels were discovered from various part of the basin. Buchanan (1807) profoundly narrated the river at different stages from its origin from various locations in the Western Ghats to its confluence at Ponnani.

2.10. Major ecological/ environmental threats

The river Bharathapuzha has been considered the epicenter for the modern culture of the state of Kerala tremendously contributing to the all round socio-cultural development of the state. However, unscientific, intuitive and haphazard developmental activities in the basin during the recent years contributed considerably to the deterioration of the health of the river. The survival of this unique drainage system in the Malabar coast now largely depends on the conservation measures that have to be implemented.

Indiscriminate sand and clay mining in various parts of the basin has been harshening the state of environment thorough out the river network and is considered to be the major environmental issue in the basin (Kumar, 2001). Study conducted by CESS (2004) also was alarming that if unscientific sand/clay mining persists in the basin it would question the future of this fluvial ecosystem. The report estimated that 640 m^3/ day of sand that could be taken out from the lower stretch of the river basin between Chamravattom and Thirunavaya only after or before the monsoon time. Due to the indiscriminate sand/clay mining in the river basin the flow regime of the river is considerably altered, especially in the stretch between Parali to Thirunavaya. Due to the change in flow various weed species grow extensively colonizing the expanse of the river in this stretch (Raj and Azeez, 2007). The land exposed as a result of sand mining are encroached by the locals to grow vegetables and other crops. The fertilizers used in these encroached cultivations are directly bringing in the process of eutrophication (Kumar, 2001). Illegal diversions of water for cultivations / plantations on the bank of the river also worsen the hydrological state of the river basin.

The river has 11 major dams in its basin and several check dams and subsurface dams / dykes irrigating 1 lakh hectares of area (Table 2.1; Figure. 2.11.). There are several small industries and vast stretch of agriculture area in the basin totally depending on the water resources of the river. Since it is an interstate river basin sharing the border between Kerala and Tamil Nadu, the water politics between the states is also very heartless to the basin by way of diversion and over exploitation in the upper reaches (Ravi et al., 2004).

Table 2.1**.** Dams and irrigation projects in the Bharathapuzha River Basin

Sl.No	**Project**	**Year of completion**	**River**	**Capacity (million m^3)**	**Command Area (Ha)**
1	Thirumoorthy	1967	Chittur	54.80	8029
2	Aliyar	1962	Chittur	109.43	16440
3	Upper Aliyar	1971	Chittur	33.19	12279
4	Chitturpuzha	1992	Chittur	Regulator	17300
5	Walayar	1959	Kalpathipuzha	18.87	3238
6	Malampuzha	1966	Kalpathipuzha	226.96	21045
7	Meenkara	1964	Gayathri	11.3	3035
8	Chulliyar	1970	Gayathri	13.70	2430
9	Pothundy	1971	Gayathri	43.89	5460
10	Mangalam	1966	Gayathri	24.67	3440
11	Kanjirapuzha	1995	Thootha	60	9720

Land use changes that happened in the river basin in the recent couple of years along with global climate anomalies also had their influence on the basin's hydrology. Deforestation and conversion of forest lands to plantations are very common story in various part of the basin (Chattopadhyay, 1985; Raj and Azeez, 2010a). Variation in the occurrence of climatic factors such as rainfall and temperature also noticed from different parts of basin (Soman et al., 1998; Raj and Azeez, 2009d and 2010b). Problems associated with urban sprawls in terms of waste disposal, encroachment and conversion of adjoining wetlands, of considerable ecological values as built-up area have lead to a plethora of issues that mar the environmental setup of the basin.

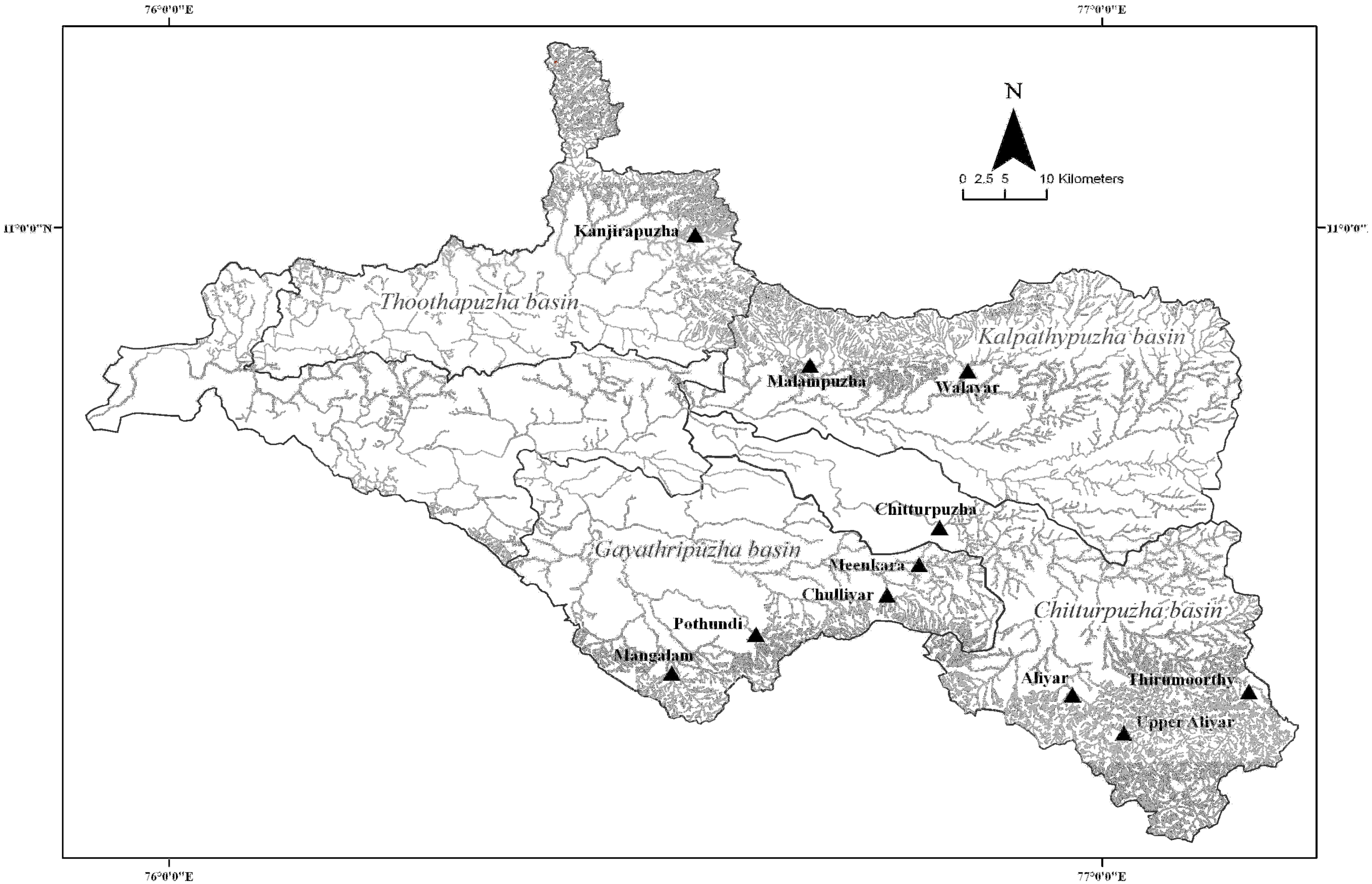

Figure 2.10 Location of major dams in the Bharathapuzha River basin

3. Morphometry and drainage pattern of the basin

3.1. Introduction

Morphometric analysis provides quantitative expression of the drainage basins, and is regarded as one important tool in hydrological analysis (Angillieri, 2008) providing simple and accurate measures to document the drainage systems (Mesa, 2006). Morphometric analysis brings out the basic characters on the geometrical and mechanical aspects of the river basin which in turn would be helpful in understanding the hydrology, sediment characteristics and landscape evolution of basins. The morphometric analysis examines linear and areal aspects of the drainage networks (Nag and Chakraborty, 2003). The basic steps involved in morphometric analysis are defining, measuring and analyzing the quantitative indices related to flow plane geometry and profile, and bed form of river basins.

Due to several anthropogenic pressures and global climate variations most of the world's fresh water flow regimes are under severe threat. Therefore documenting basin characteristics using morphometric techniques, well-known since early nineteenth century, are very valuable. The studies by Horton (1945), Strahler (1957 and 1964), and Schumm (1956 and1963) are well known works in the field. Studies conducted by Dade (2001), Singh et al., (2005), Sreedevi et al., (2005), Mesa (2006), Rao et al., (2006), Sarkar and Gundekar (2007), Rudraiah et al., (2008), Angillieri (2008), Thomas et al., (2010) are some of the recent studies. The recent studies make use of the potentials of Geographic Information System (GIS) and Remote Sensing (RS) as the most popular and effective tools to investigate the river morphometry and basin characters. The present study examines the morphometric characteristics of Bharathapuzha River basin using GIS and RS tools.

3.2. Methodology

Survey of India (SOI) topographic map series (58 A/4, A/8, A/12, A/16, E/4, B/1, B/5,B/9,B/13, B/2, B/6,B/10, B/14,F/2, B/11, B/15, F/3; 49 N/13, N/14) of scale

1:50,000 were taken as the base maps for delineation of Bharathapuzha River basin and its sub-basins. Land sat imageries available at (www.landcover.org) were also used for the morphometric analysis. The slope and relief of the basin were examined using digital elevation model data (DEM) available at www.asterdem.com. The stream order, stream length, mean stream length, stream length ratio, bifurcation ratios, mean bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, circulatory ratio and elongation ratio were estimated using standardized formulae (Table.3.1.). Arc GIS 9.3 and ERDAS IMAGINE 8.5 softwares were used for carrying out the study.

3.3. Results and discussion

As mentioned in the earlier chapter, the basin extends from the Western Ghats and the Palakkad gap at the east, narrowing down to the Arabian sea coast at the west. The four major tributaries of the Bharathapuzha River are Kalpathipuzha, Gayathripuzha, Thootha, and Chitturpuzha basins, all originating from the Western Ghats. The drainage pattern of the river Bharathapuzha is dendritic in nature, a pattern very common in areas with horizontal sedimentary rocks (Sreedevi et al., 2005). The areas under each sub-basin are given in the table.3.2. Kalpathy is the largest basin while Thootha forms the smallest among the four sub-basins. The perimeter, the total length of the drainage basin boundary of the whole Bharathapuzha River basin, is 1215.4 km. The perimeter among the sub-basins are in the order Chittur> Thootha> Kalpathy> Gayathri (Table.3.7). The basin length, the maximum length measured parallel to the main drainage line (Horton, 1945), was estimated individually for each of the sub-basins. The highest basin length was found in the case of Chittur basin followed by the Kalpathy, Thootha, and Gayathri basins.

The major portion of the midland and coastal region of the Bharathapuzha basin is characterized by rice paddies. A) Rice paddies in Palakkad and B) Chittur taluks

Table 3.1. Formulae adopted for computation of morphometric analysis of the Bharathapuzha River basin

Morphometric Parameters	**Formula**	**Reference**
Perimeter	Length of the watershed boundary	
Stream order	Hierarchical rank	Strahler, (1964)
Mean stream length (Lsm)	Lsm= Lu/ Nu Lu- total stream length of order u; Nu- total no. of stream segment of order u	Strahler, (1964)
Bifurcation ratio (Rb)	Rb = Nu / Nu + 1 Rb = Bifurcation ratio Nu = Total no. of stream segments of order 'u' Nu + 1 = Number of segments of the next higher order	Schumm, (1956)
Mean Bifurcation ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler, (1957)
Relief ratio (Rh)	Rh = H / Lb Rh = Relief ratio H = Total relief (Relative relief) of the basin (km);Lb = Basin length	Schumm, (1956)
Drainage density (D)	D = Lu / A D = Drainage density Lu = Total stream length of all orders A = Area of the basin (km^2)	Horton, (1945)
Stream frequency (Fs)	Fs = Nu / A Fs = Stream frequency Nu = Total no. of streams of all orders A = Area of the basin (km^2)	Horton, (1945)
Drainage texture (Rt)	Rt = Nu / P Rt = Drainage texture Nu = Total no. of streams of all orders P = Perimeter (km)	Horton, (1945)
Form factor (Rf)	$Rf = A / Lb^2$ Rf = Form factor A = Area of the basin (km^2) Lb^2 = Square of basin length	Horton, (1932)
Circulatory ratio (Rc)	$Rc = 4 * \pi * A / P^2$ Rc = Circularity ratio $\pi = 3.14$ A = Area of the basin (km^2) P^2 = Square of the perimeter (km)	Miller, (1953)
Elongation ratio (Re)	$Re = 2\sqrt{(A / \pi)}\ Lb$ Where, Re = Elongation ratio A = Area of the basin (km^2) π =3.14; Lb = Basin length	Schumm, (1956)

Determining the stream order is one of the early steps in study of drainage basin. The stream ordering was done following Strahler (1964). The main river is of 7th order and among the four basins while river Chittur fall in 7th order all others fall in 6th order (Table 3.2.). The number of streams gradually decreases as the stream order increases following the Horton's first law (Figure.3.1.), which states that the number of streams of different order in a given drainage basin tends closely to approximate an inverse geometric ratio. Physiography and structural condition of the basin are the important factors influencing the number and order of the streams.

Table 3.2. Stream order in the Bharathapuzha River basin

Basin	Basin area (km^2)	Stream order	No of streams of respective stream order						
			1	2	3	4	5	6	7
Bharathapuzha	6102.34	7	5628	1321	324	70	19	5	1
Chittur	1314.71	7	2162	494	115	22	6	2	1
Kalpathy	1390.16	6	1198	291	73	18	5	1	-
Gayathri	1084.69	6	633	165	44	8	3	1	-
Thootha	1015.3	6	1325	296	72	17	5	1	-

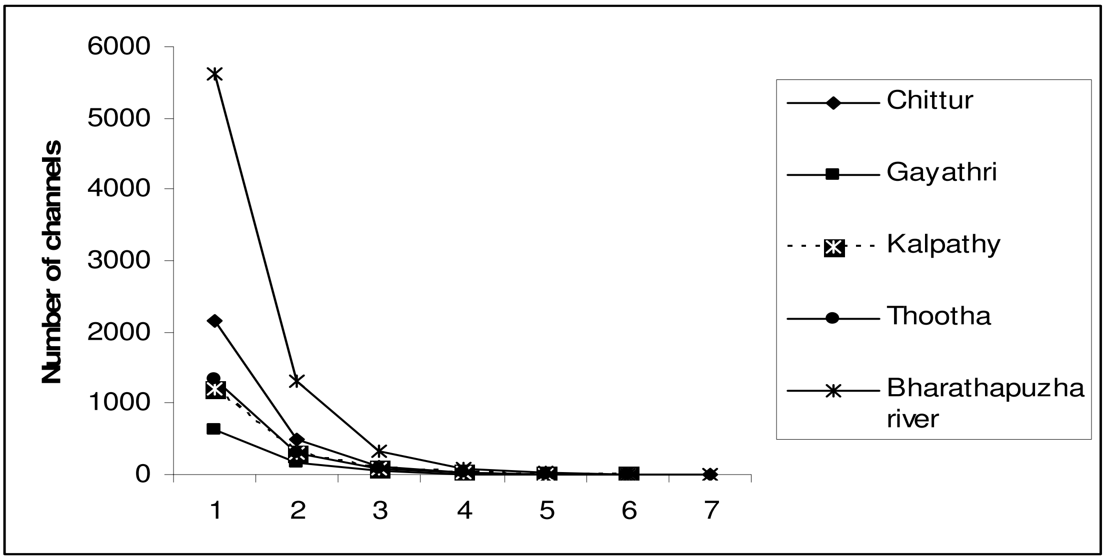

Figure 3.1 Relation ship between stream order and number of streams in Bharathapuzha River basin

Table 3.3. Stream length of Bharathapuzha River basin

Basin	**Order wise stream Length (km)**							**Total (km)**
	1	**2**	**3**	**4**	**5**	**6**	**7**	
Bharathapuzha	3884.8	1469.7	906.9	433.5	248.7	144.1	166.2	7253.8
Chittur	1329.2	429.0	237.1	84.2	66.0	40.2	70.3	2256.0
Kalpathy	929.0	392.6	279.1	134.2	61.0	14.2	--	1810.1
Gayathri	522.9	234.5	137.2	87.3	55.5	27.2	--	1064.7
Thootha	803.8	241.8	183.5	91.2	66.1	62.5	--	1449.0

Table . 3.4. Stream length ratio of Bharathapuzha River basin

Basin	**Stream length ratio**					
	2/1	**3/2**	**4/3**	**5/4**	**6/5**	**7/6**
Bharathapuzha	0.4	0.6	0.5	0.6	0.6	1.2
Chittur	0.3	0.6	0.4	0.8	0.6	1.8
Kalpathy	0.4	0.7	0.5	0.5	0.2	--
Gayathri	0.5	0.6	0.6	0.6	0.5	--
Thootha	0.3	0.8	0.5	0.7	1.0	--

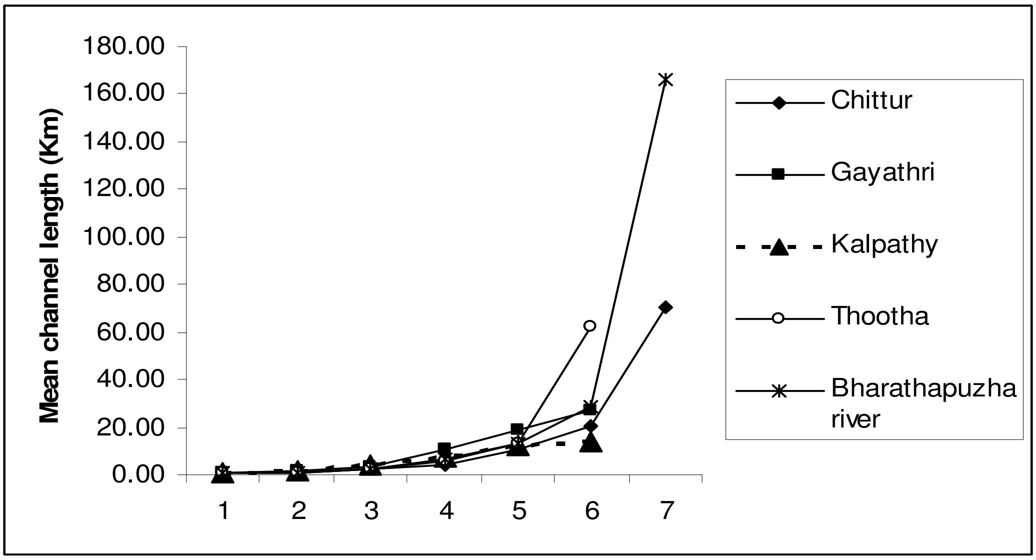

Figure 3.2 Relationship between mean channel length and stream order in Bharathapuzha River basin

Using the topographic maps, lengths of all the streams in the basin falling under different stream orders were measured (Table.3.3.) and as is expected the total stream length of each segment increases with the increasing stream order (Figure.3.2., see Table.3.5 for mean stream lengths of each tributaries). This indicates the decrease in the slope in the basin's terrain, it becoming more flattening and tending towards the coastal belt from the higher elevation Western Ghats. It is also observed that the stream length characteristic of the basin follows Horton's second law, which states that the average length of streams of each of the different order in a drainage basin tends closely to reach a direct geometric ratio (Horton, 1945; Chow, 1964). Mean stream length (Lsm, the ratio of the total number of stream segment of a particular order to the total stream length of the same order) is believed to be a distinctive property of a river channel relating the drainage network components and its associated basin surfaces (Strahler, 1964). The stream length shows an abrupt increase in 4^{th} and higher order for the main river as well as all the tributaries, indicating the pressure exertion from the structural elements especially slope and high amount of rainfall (Thomas et al., 2010). Study conducted by Thomas et al (2010) in Muthirapuzha river basin located south of the Bharathapuzha River basin in the Western Ghats show similar pattern in mean stream length ratio. This characteristic of Bharathapuzha River basin indicates that the geologic evolution of the basin is more or less according to the geologic erosion laws with homogenous characteristics of weathering (Nag and Chakraborty, 2003). The stream length ratio of the drainage system was calculated as the ratio between total stream lengths of the order to total stream length of its next order (Horton, 1945). The stream length ratio of the main stream of the river ranges from 0.38 to 1.15. The stream length ratios of all the four tributaries were also found varying considerably (0.30 to 1.75, Table.3.4.). The stream length ratio of Bharathapuzha River basin and its sub-basins were found to show anomalous variation. This could be explained as the down stream extension of the higher order stream or upward extension of tributaries or inception (Thomas et al., 2010). The change in the mean stream length ratio is an indicator of the changes in the slope and topography, which in turn determine the age of the basin (Rudraiah et al., 2008). The stream length ratio is also reported to be vital in explaining surface flow discharge and determining sedimentation stage of the basin (Sreedevi et al., 2005).

The Bifurcation ratio (Rb) is an adimensional parameter, derived as the ratio between the numbers of streams of any given order to the number in the next lower order (Schumm, 1956). This is considered to be an important parameter that articulates the degree of ramification of the drainage network (Mesa, 2006) and an indicator of the geological condition of the basin (Strahler, 1957). At the level of whole basin and sub-basins, the bifurcation ratio ranges from 2 to 5.50 (Table.3.6.) that can be ascribed to mountainous or highly dissected basin areas (Horton, 1945). However, as suggested by Chow (1964), these values may indicate that the area is not influenced powerfully by geological structures. The closeness in mean bifurcation values among the basins on the other hand shows the similarity in the geological set ups (Thomas et al., 2010). Present analysis of bifurcation ratio in Bharathapuzha River basin is not following the hypothesis of Giusti and Schneider (1965). According to them the bifurcation ratio is inversely proportional to the stream order. This is perhaps due to the influence of the relief. Relief is the altitudinal difference between the maximum and minimum elevation points in the basin. The relief ratio (Rh), another adimensional ratio is derived from the relief of the basin, calculated as the ratio between basin lengths to the total relief of the basin (Schumm, 1956). It is an important factor indicating the denudational characteristics of the basin. Normally the relief ratio is inversely proportional to the drainage area of the basin (Gottaschalk, 1964). However, in the case of Bharathapuzha River basin no inverse relationship could be found between the relief ratio and the drainage area of the basin (Table. 3.7.).

Table 3.5. Mean Stream length of Bharathapuzha River basin

Basin	**Mean Stream length (km)**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Bharathapuzha	0.69	1.11	2.80	6.19	13.09	28.81	166.17
Chittur	0.61	0.87	2.06	3.83	11.01	20.12	70.30
Kalpathy	0.78	1.35	3.82	7.46	12.21	14.16	
Gayathri	0.83	1.42	3.12	10.91	18.51	27.15	
Thootha	0.61	0.82	2.55	5.36	13.22	62.50	

Table 3.6. Bifurcation ratio and mean bifurcation ratio of Bharathapuzha River basin

	Bifurcation ratio (RL)						**Mean Bifurcation**
Basin	**1/2**	**2/3**	**3/4**	**4/5**	**5/6**	**6/7**	
Bharathapuzha	4.26	4.08	4.63	3.68	3.80	5.00	4.24
Chittur	4.38	4.30	5.23	3.67	3.00	2.00	3.76
Kalpathy	4.12	3.99	4.06	3.60	5.00		4.15
Gayathri	3.84	3.75	5.50	2.67	3.00		3.75
Thootha	4.48	4.11	4.24	3.40	5.00		4.24

Table 3.7. Relief and elongation ratio of Bharathapuzha River basin

Basin	**Perimeter (km)**	**Basin length**	**Relief ratio**	**Elongation ratio**
Bharathapuzha	1215.4	133	17.90	0.66
Chittur	273.5	78	30.00	0.52
Kalpathy	211.1	63	31.52	0.67
Gayathri	194.6	56	19.89	0.66
Thootha	251.3	58	37.79	0.62

By definition drainage density (D) of a basin is the total length of the streams of all orders per drainage area (Horton, 1945). Drainage density is believed to be highly influenced by environmental factors such as climate, infiltration capacity of the area, rock type, relief, vegetation cover, surface roughness, and runoff intensity. The drainage density of the Bharathapuzha River basin was 6.06. Among the four sub-basins of the river, highest drainage density was found in Chittur sub-basin and lowest in the case of Gayathri sub-basin (Table.3.8.). The higher drainage density of the Bharathapuzha basin suggests the role of undulating terrain with knolls and depressions here and there, while in the sub-basins it indicates highly permeable sub soil, with moderate vegetative cover as suggested by Rudraiah et al. (2008) for Kagna river basin, Karnataka, India.

Stream frequency (Fs) of a basin is defined as the ratio between total number of segments cumulated for all the orders within a basin and the basin area (Horton, 1945). Regarding the stream frequencies of the Bharathapuzha basin and its sub-basins, Chittur sub-basin have highest number (Table 3.8.) followed by Thootha sub-basin. The stream frequency appears to be correlated well with relief factor and slope of the area. The provenance of Chittur and Thootha sub-basins are in the high altitudes in the Anamalai reserve forest and Silent Valley National park respectively.

Drainage texture (Rt) is the total number of stream segments of all the orders to the perimeter of that basin (Horton, 1945). The drainage texture of a basin have direct relation with climate, rainfall, vegetation cover, rock and soil type, infiltration capacity, and relief and stage of development (Smith, 1950). It is considered to be one of the prime features of the basin geomorphology. Weak rocks devoid of vegetative cover produce fine texture, while rocks which are hard and with vegetative cover produce coarse texture. Sparse vegetation in arid climate causes finer texture than in humid regions. Smith (1950) have classified five different drainage textures related to various drainage densities as i) very coarse (below 2), ii) coarse (2-4), iii) moderate (4-6), iv) fine (6-8) and v) very fine (8 and above). The highest value for drainage texture was found in the case of Chittur basin indicating 'very fine' nature of the drainage system; in Gayathri basin the texture was found to be 'moderate' (Table.3.8.).

Form factor, (Rf) the ratio of the area of the basin to the square of basin length (Horton, 1932), for the basin and all its sub-basin (Table.3.8.), were more or less very close to each other, except in the case of the Chittur sub-basin. The Chittur sub-basin on the other hand is a narrow basin with relatively less number of drainage networks.

Table 3.8. Drainage density, texture ratio, form factor and circulatory ratio of the Bharathapuzha River basin

Basin	**Drainage density**	**No of streams**	**Stream frequency**	**Texture ratio**	**Form factor**	**Circulatory ratio**
Bharathapuzha	6.06	7368.00	1.21	6.06	0.34	0.05
Chittur	1.72	2802	2.13	10.24	0.22	0.22
Kalpathy	1.30	1586	1.14	7.51	0.35	0.39
Gayathri	0.98	854	0.78	4.39	0.35	0.36
Thootha	1.43	1716	1.69	6.83	0.30	0.20

Circulatory ratio (Rc), that can be expressed as the ratio of the basin area to the area of a circle with same perimeter as the basin (Miller, 1953), is more influenced by length, frequency, and stream gradients of various orders than slope condition and drainage pattern of the basin. According to Sreedevi et al (2005) it is a significant ratio indicating the dentritic stage of the basin. In all the sub-basins of Bharathapuzha basin the circularity ratio were found ranging from 0.20-0.39 showing the basin to be more elongated than circular (Table.3.8.) and indicate the relative youth stage of the river network. And the low value of circulatory ratio of the basins indicates their elongated shape and that is clearly due to its location in the Palakkad Gap in the Western Ghats. The elongated shape of the Bharathapuzha River basin and its sub-basins can be visualized well by measuring the elongation ratio (Re). It 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). The elongation ratio of the basin as well as sub-basin level of Bharathapuzha River basin is shown in the table.3.8. Since water lag of a basin can be determined from its elongation ratio, it is a necessarily important feature to be determined prior to any programs to harness river flow for any developmental activities.

3.4. Summary

Baseline morphometric information at a sub-basin level is essential to develop appropriate strategy for sustainable, socially acceptable, ecologically benign and economically viable development of a river basin. The present study was carried out in the relatively less studied Bharathapuzha River basin the second longest river in the state of Kerala, India. The drainage pattern of the Bharathapuzha River basin is dentritic. The mean stream length of the river was found ranging 0.69 to 166.17 km, among different stream orders. The drainage texture of the basin falls under 'fine' category. The elongation and circulatory ratios shows the elongative nature of the basin. The basin stretching to the Palakkad Gap in the Western Ghats with unique geological characteristics greatly influences the morphometry of the river basin. Other features such as slope, relief, and environmental factors such as rainfall also had considerably contributed to the basin morphometry. Documentation of the morphometric characters can be well utilized for conservation and sustainable management of the River basin and also is essential to develop appropriate strategy for socially acceptable, ecologically benign and economically viable development of the river basin.

4. Land use Land cover changes in the basin

4.1. Introduction

Landscape changes, transformations and conversions, are largely results of various pressures on ecosystems and have been progressing in concert with human settlements. All the natural areas including forests, grasslands, wetlands, and shores around the globe often underwent diverse kinds of transformation and conversion in varying degrees. The triggering factors for landscape changes may be biophysical, technological, institutional or economical (Joshi and Gairola, 2004, Jingan et al. 2005, Zhao et al. 2006). Understanding the spatial and temporal changes in land use and land cover (LULC) is one of the effective ways to analyze the current environmental status of an area. Urbanization, a major cause of land use changes and land conversions (Turner et al., 1993), has made natural habitats vulnerable to unpredictable and long lasting changes that may later challenge the very existence of the valuable ecosystems that offer known and unknown precious ecosystem goods and services.

It is obvious that the world is on a shift from predominantly rural based society to urban. At present in North America, Europe and Latin America more than 70% of population has become urban and in the case of Asia and Africa the figure would be around 40%. According to the Population Reference Bureau (2007; www.prb.org), by 2030 more than 60% of the whole world's population will be urban. During the last three centuries nearly 1.2 million km^2 of forests and woodlands, 5.6 million km^2 of grasslands and pastures have been converted into other types of land use globally, and the cropland areas in the world has increased sharply to 12 million km^2 during the same time span (Ramankutty and Foley, 1999). However, the sole blame for such changes and urbanization could not be totally placed on population increase since large proportion of the humankind still remains homeless and with deplorable purchase power to meet their day-to-day survival requirements.

As far as a river basin is concerned, the spatio-temporal changes in land use in its basin have a direct influence on its hydrological realm (Wilk and Hughes, 2002). Currently fresh water resources in several parts of the globe is facing severe crisis in availability due to unsustainable water use aggravated by the unpredictable and unforeseen changes in the global and local climate. The climate change coupled with urbanization and rampant alterations in land use in the basins made most of the world's fresh water flow regime under severe pressure and change. Deforestation and conversion of water logged wetlands in to built-up areas directly affects the ground water recharging capacity and natural water flow regimes.

Remote Sensing and GIS have been widely applied to understand the LULC changes and is considered to be a powerful tool to document the spatio-temporal changes of an area for the purpose of conservation and management of natural habitats (Long et al., 2007; Guler et al., 2007). The multi-spectral satellite images provide satisfactory spectral resolution which in turn offers a reliable means to diagnose LULC changes. Change detection generally employs one of the two basic methods: pixel-to-pixel comparison and post-classification comparison (Jaisawal et al., 1999). The post classification method compares two or more separately classified images of different dates (Pilon et al., 1988; Fung and Zhang, 1989).

In India, large-scale landscape alterations happened just after the independence (www.iipsenvis.nic.in). In this phase 'development' was conceived to be the process of bringing in all possible types of land under plough. Ecological goods and services of the various types of ecosystems and lands were perhaps of little concern or unknown to the policy makers and advocates of development. Conservation of ecosystems and species was practically unheard of in practice and its natural areas particularly the forests and wetlands experienced wide spread conversions and modification. Changes have happened both in the plains as well as at higher elevations. The Himalayas (Joshi and Gairola, 2004) and North east India (Lele and Joshi, 2008) and Western Ghats are the three major regions in the country that experienced extensive landscape changes (Chandrashekara, 2005; Venugopal, 2004; Jha et al., 2000; Negi et al., 1999), while these are the two major biodiversity hotspots in the country (Gunawardene et al., 2007) and vital for the environmental, social and cultural setup of the country.

The state of Kerala, flanked by the Western Ghats on its east, is well known for its unique pattern of development characterized by high level of socio-economic development. Human resource have been the major asset in the state and non-resident Keralites have been channelizing in large amount of money to the state primarily to support their families back at home (Raj and Azeez, 2009b). The flow of foreign currency (recently to the tune of 30-40000 crores per annum) into the state has promoted building construction in the state. Profuse landscape changes in Kerala have happened during the last few decades. Towards the later half of the last century the land use changes were highly associated with the socioeconomic developments that happened in the state such as Land Reform Act (1971) which assured release of huge landholding to the public at large from the hold of feudal landowners (Mahesh, 2000, Gopikuttan and Kurup, 2004), although the land reforms is blamed to have deprived the tribes and other underprivileged of their land holdings. The break down of joint families to the growing culture of nuclear family and high population density coupled with high foreign remittance to the state increased the demand for housing resulting in the process of land conversion becoming more precipitous. In this context the present study was undertaken to evaluate the LULC change happened in Bharathapuzha River basin during 1973-2005, assuming that the changes in the LULC could have profoundly affected the health of the river basin.

4.2. Methodology

The LANDSAT TM data, with a pixel resolution of 30 meter, were collected for 1973, 1990 and 2005 for the whole basin from Global Land Cover Facility (www.glcf.umd.edu).Data before, after and in between these years were found not available. The basin area was delineated using the Survey of India (SOI) topographic map series (58 A/4, A/8, A/12, A/16, E/4, B/1, B/5,B/9,B/13, B/2, B/6,B/10, B/14,F/2, B/11, B/15, F/3; 49 N/13, N/14) of 1:50,000 scale. Geometric correction and ground truthing were carried out by field surveys using Global Positioning System (GPS, model Garmin 12), and ancillary data from topographic maps and Google Earth images. Supervised classification requires training sets as the reference signature. On the basis of these training sets the whole population of pixels is classified. We used Arc GIS 9.3 and ERDAS IMAGINE 8.5 for the entire study.

4.3. Results and discussion

The satellite data has been classified in to six major classes (agriculture, natural vegetation, plantation, roads, urban centers and water bodies) and accordingly the land use changes in the Bharathapuzha river basin during the time span of 1973-2005 were examined (Figure.4.1.). During the early period (1973-1990) of the study in the basin land under natural vegetation cover (44%) dominated followed by area under agriculture. During the second half of the study period land under urban centers became important (32%) followed by the area under plantation. The area under agriculture remained almost same (26%), while the area under natural vegetation cover declined to considerably lower proportion in the total area of the basin. In 2005, the area under urban centers remains as the major land use type in the basin, followed by agriculture at the second position. In over all, the area under the natural vegetation cover consistently showed a trend of decline. On the other hand the positive growth trend of urban centers in the basin was observed during the whole period (Table.4.1.).

The natural vegetation cover in the basin shows a drastic decline during the first half of the study period; however it remained almost unvarying during the next half (Figure.4.2.). While the agricultural area in the basin was found remaining to be unchanged during the first half of the study period, it showed a notable fall during the next half (Figure.4.3.). On the other hand, area under plantation and under water resources showed a steep increase during the period 1973-1990. During the next half (1990-2005) a steep decrease was seen in these land use types (Figure.4.4 and Figure.4.5.). The urban area in the basin showed a consistent increase thorough out the study period (Fig.4.6.). The area under road that remained more or less invariable during the early period rose during the later stage of the study (Figure.4.7.).

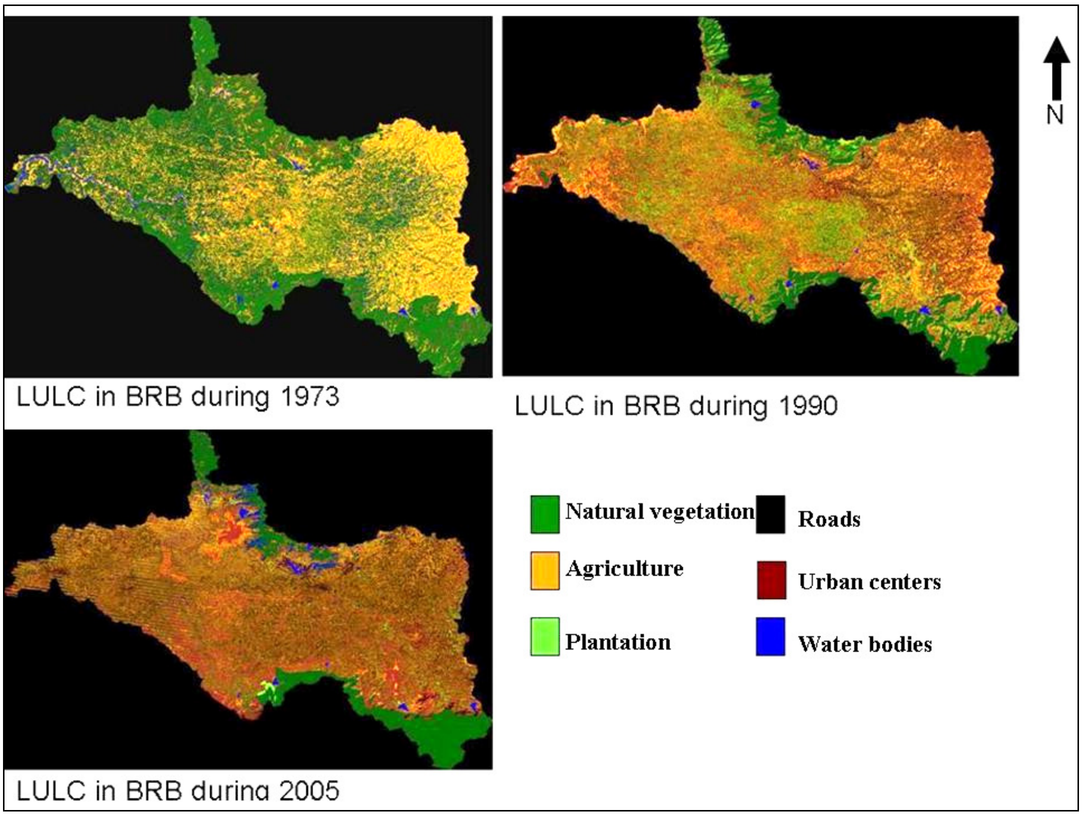

Figure 4.1Temporal variation in LULC in Bharathapuzha River basin generated from LANDSAT TM 1973, 1990, and 2005.

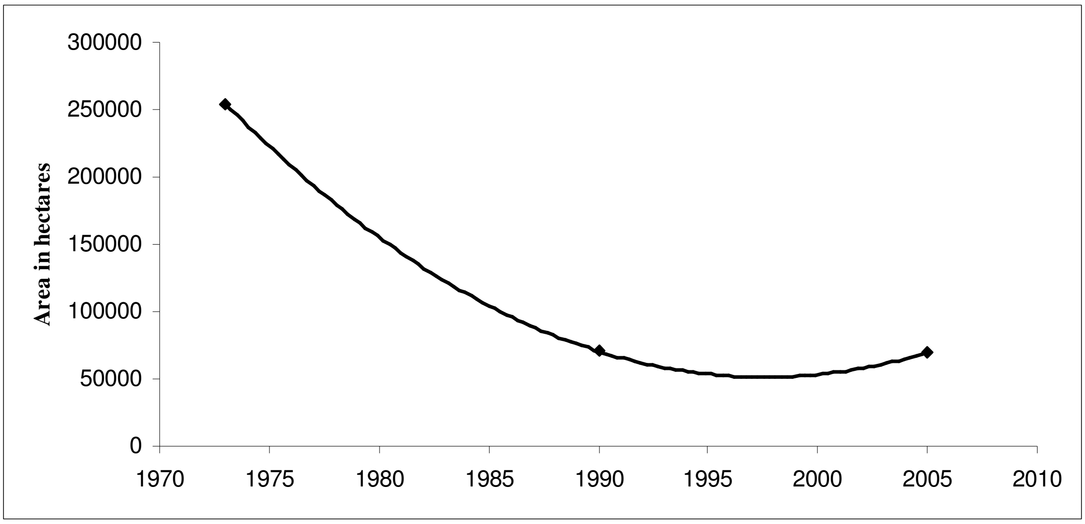

Figure 4.2 Natural vegetation cover change in Bharathapuzha River basin during 1973-2005

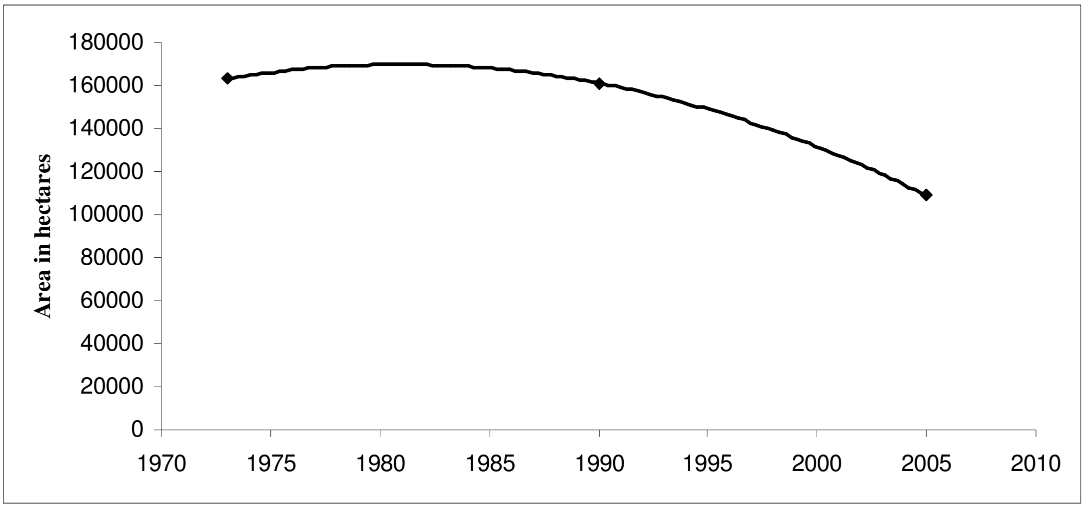

Figure 4.3 Area under agriculture in Bharathapuzha River basin during 1973-2005

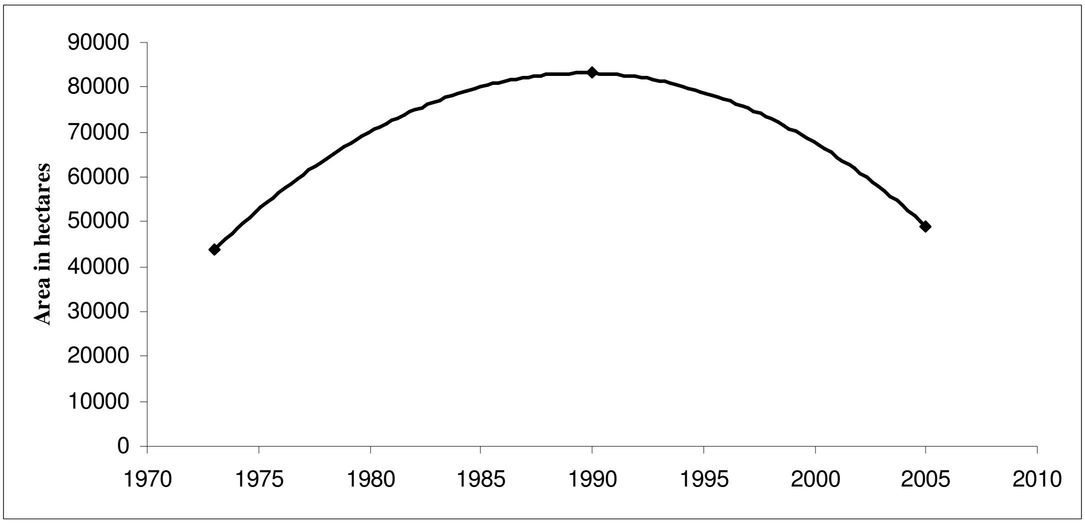

Figure 4.4 Change in the area under plantation in Bharathapuzha River basin during 1973-2005

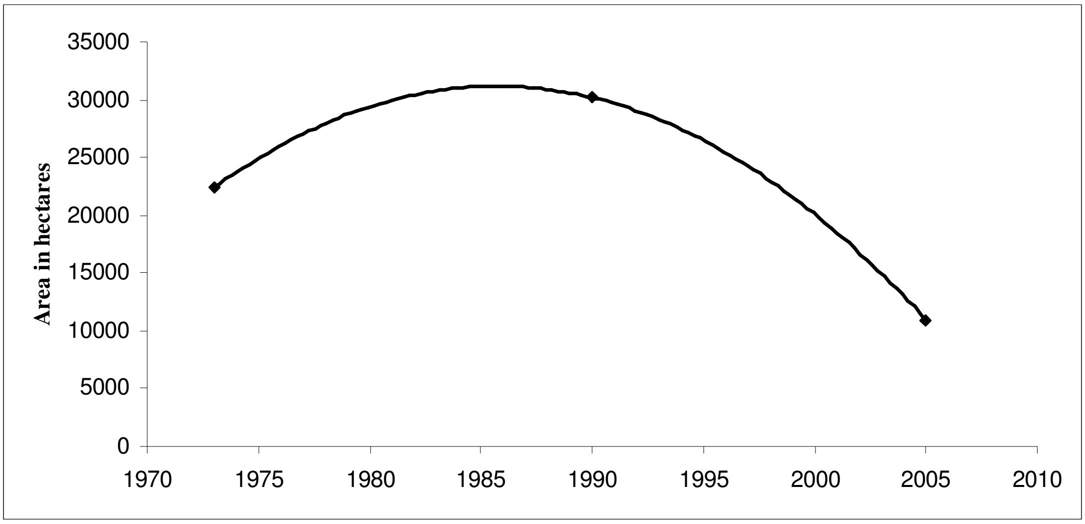

Figure 4.5 Change in the area under water bodies in Bharathapuzha River basin during 1973-2005

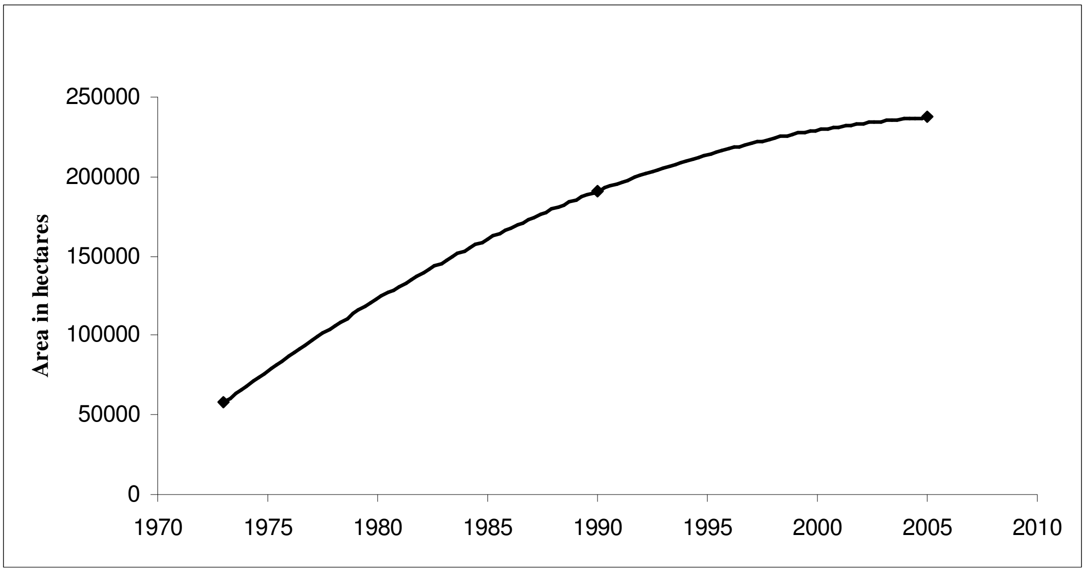

Figure 4.6 Change in the urban areas in Bharathapuzha River basin during 1973-2005

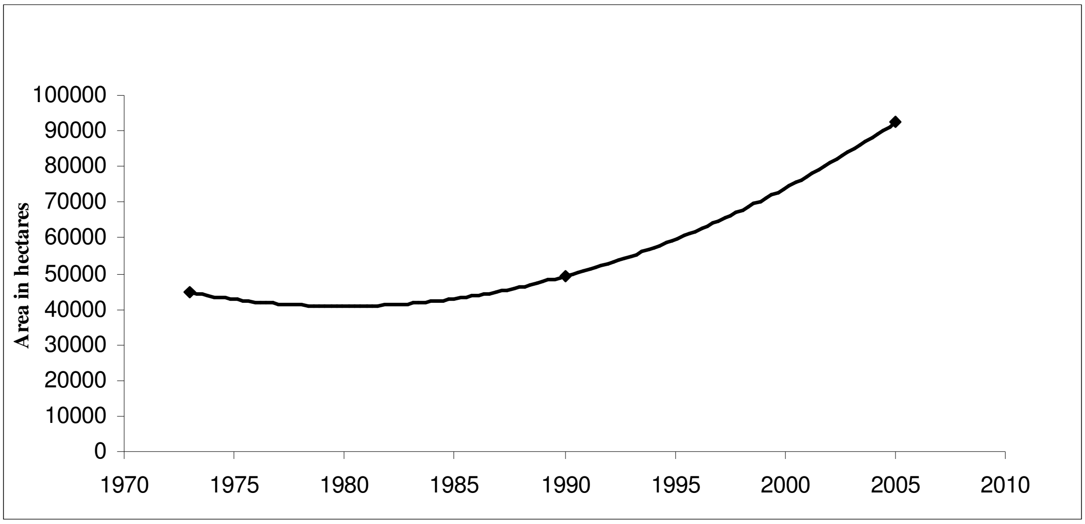

Figure 4.7 Area under roads in Bharathapuzha River basin during 1973-2005

The decrement in the area under natural vegetation during 1973-1990 in Bharathapuzha River basin can be attributed to the forest loss reported in the state (~5000 hectares annually). The study conducted by Jha et al. (2000) reported comparatively higher deforestation rate in Palakkad district from rest of the areas in the state. One of the major factors that promoted natural vegetation loss in the Bharathapuzha River basin is the spread of area under plantation. It is reported that during 1951-2000 the area under rubber plantation has increased by 627% and that of coconut by 106% in the state (Kumar, 2005). During a time span of mere one year (1970-71), 117% increase was reported in rubber and coffee plantation in the state (Nossiter, 1982). Presently, rubber plantations cover about 18% of the total agricultural land and 11% of the total geographical area of the state (Chattopadhyay and Chattopadhyay, 1997). These expansions happened mainly in the highland areas of the basin, since those areas were lesser inhabited earlier than the midland and lowland areas of the state and large chunks of lands were under feudal landowners. The conversion of wetland agriculture to more profitable (at that time) plantation crops particularly coconut and arecanut was also started during the same period due to the socio economic shifts that happened in the country as well as in the state (Eapen, 1999; Raj and Azeez, 2009c).

According to George and Chattopadhyay (2001) the deforestation in the state is mainly due to infrastructure development, such as roads, hydroelectric and irrigation projects, and other institutional amenities. The reduction in the natural vegetation in the Western Ghats is also associated with the implementation of Hydro Electric Projects (Meher-Homji, 1991; Pandurangan and Nair, 1996; Soman, et al., 1998). Hydroelectric projects apart from their direct impact on natural vegetations promote much higher collateral damages by way of opening up access to remote wilderness areas (Azeez et al., 1999). The Kanjirapuzha irrigation project in the Thootha puzha sub-basin has happened during the period. The initial growth and later decline in area under plantation can be correlated with the social, political and economical shifts in the state as well as in the country. During the early nineties with the liberalization of the country's economy the planters and agriculturists in Kerala faced huge financial crisis with the crash in the market price of their product (Sunil, 2007). For example, import of coconut oil for industrial uses and its culinary cheaper substitute the palm oil from East Asian countries was a blow to coconut farmers, while freely available and cheap spices and allies and rubber was a blow to other farmers.

Table 4.1. Total land cover (in %) as a proportion to the total area, and the net change during the study period

	1973	1990	2005	Change (%) during 1973-1990	Change (%) during 1990-2005	Change (%) during 1973-2005
Agriculture	27.84	27.54	19.15	-0.30	-8.39	-8.69
Natural vegetation	43.43	12.07	12.28	-31.36	0.21	-31.15
Plantation	7.46	14.20	8.64	6.74	-5.56	1.18
Roads	7.61	8.40	16.24	0.79	7.83	8.62
Urban centers	9.83	32.63	41.76	22.80	9.13	31.93
Water resources	3.82	5.16	1.93	1.34	-3.23	-1.89

The sharp out growth in urban centers in the basin in the initial years is associated with the declining natural vegetation area and in the later years to the decline in areas under agricultural wetlands. According to 1981 census the basin had a population of 2 million people, which has increased to 4.6 millions in 2001(Census of India, 2001a, b, c, and d). Deforestation processes in other parts of the state also are found correlated with population growth and infrastructure development (Chattopadhyay, 1985). During the late 90s wetland agriculture and even plantations crops was loosing their attractiveness in the basin which was also the case in various other parts Kerala (Mahesh, 2000; Raj, 2003; Raj and Azeez, 2009c). According to Eapen (1999) urban agglomerations or out growths were rare in Kerala till 1981 while later their number have been almost doubling every decade. The recent census shows that 25% of the total population of the state comes under urban category, much closer to the national statistics (27.8%). Meanwhile people were also abandoning their agriculture / plantations due to inadequate returns. However, the sudden rise in the real estate market attracted lots of people to invest money in building construction as well in tourism ventures (Raj and Azeez, 2009b). For the high demand for building construction largely residences, many of the low lying lands at various locations nearby in the main river as well as its tributaries are getting converted.

A rapid growth in real estate business was observed in the state since late nineties (Raj and Azeez, 2009b). The declaration of the 8th Five Year Plan during 1998 by the central government that assured private support for 'national housing and habitat development policy' gave it a further drive. Significant changes in the laws and regulations, including the Urban Land (Ceiling and Regulation) act by the central government and amendment to the National Housing Bank (NHB) act provided attractive climate for foreign investments further pushing up the real estate growth (Joshi, 2006). The rapid development in retail, entertainment sectors, financial institutions, information technology centers and the boom in the tourism sector all enhanced the growth rate. More over the Kerala Land Reform Act (1971) acted towards abolishing matrilineal system of joint family and development of nuclear families (Sushama, 1996). This resulted in the growth of nuclear families and housing units outpacing the population growth in the state. Statistics shows the state is still having a high demand for houses; demand always doubling as the year passes. Since the real estate sector is believed to provide much higher annual return on investment, ranging 10-12%, compared to other investments (Mahurkar and Senthil 2004), it attracts the resident and non resident Keralites more or less equally. The growing demand for real estate investment is reflected in the bench mark price for land fixed by the state government in March 2010, that reaches up to Rs. 50 lakhs per cent (~ Rs. 10000/ sq feet, reaching up to the rate in some of the well developed cities) in certain areas an incredible level of land cost.

Real estate is also believed to be a safe long term investment among all sections of the society who has additional surplus income to save. Moreover, it is highly lucrative for the middlemen and the promoters of real estate ventures who boost up the market value of land. Conversion of wetlands to households is a usual practice in Kerala. Most of the agriculture belts of Palakkad have got legally converted as housing plots prior to the Land acquisition (amendment) bill (2007). The new 'Regulatory Framework for Conservation of Wetlands' (2008) by the central government also does not affirm the future of rice paddies, an ecosystem of its own supporting a range of species and offering a range of ecological services, as it deter filling up wetlands for other uses.

No notable increase could be seen in the area under road during the first half of the study period however towards 2005 the area has almost got doubled. This may be very well attributed to the conversion of agriculture lands to built-up parcels. Urbanization always involve growth of infrastructure; buildings, roads, communication facilities etc. At present the road density in Bharathapuzha River basin is only 16.24 km / 100 km^2 and is apparent to grow rapidly in the coming years. In the state of Kerala the road network is growing up in rapid pace connecting in fact all the individual houses/ residences, although the roads are not much improved in terms of their quality. The road density of the over all state is 374.9 km /100 km^2, much higher than the density in the Bharathapuzha River basin and far ahead of the national average (74.9 km/100 km^2). Road development is the single most critical factor that opens up any ecosystem or traditional rural setup for rapid changes. Infrastructure development demands considerable lands to be divested from its former / original use and from ecologically important area to an ecologically insignificant one.

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Recent analysis of the river basin shows the change in climate particularly rainfall (Raj and Azeez, 2010b; Raj and Azeez, 2009d). Similarly our analysis on the historical discharge at various stations along the river course shows a statistically significant decrement in the total amount of water flow in the river Bharathapuzha. The present study in this context is documenting the significant physiographic changes happening in Bharathapuzha River basin during the last three decades. The study along with all other related works on the river basin is emphasizes the need for a scientific management plan for the sustainable development of the Bharathapuzha River basin, keeping guard of its ecological setup, environmental resources and ecological services.

4.4. Summary

The present study attempts evaluating the LULC changes in a highly vulnerable medium sized river basin located in a high population density area India, the Bharathapuzha river basin with the aid of LANDSAT thematic layers from 1973 to 2005 time periods. The study could find extensive changes in the LULC in the basin; 31% depletion in the natural vegetation cover and 8.69% depletion in wetland agriculture area were seen in the basin during the period. On the other hand the urban spread in the basin increased by 32%. The present study accentuate that the pattern of change in the basin more or less conforms to such changes happening all over the state of Kerala.

5. Meteorology of the basin

5.1. The rainfall

5.1.1. Introduction

Climate change is a well debated issue in recent times and possibly one of the gravest global challenges in the present century. It is well known that the earth climate have seen radical changes in a geological time scale and at least four glacial epochs or ice ages. However, since the last century it has been found that the earth's climate has been changing notably, at a faster pace and the changes are expected to continue. Evidences of changes are striking in the environment as the increase in global and regional temperatures and perceptible changes in the hydrologic cycles in many parts of the world including India (Goswami et al., 2006). Manifestation of such global scale variations can be observed as fluctuations in the normal display of any local climatic features. Rainfall is an important such feature, understanding the trends and changes of which will help to resolve uncertainties (Singh and Sontakke, 1999) and provide knowledge base for decision making on a broad series of local issues related with agriculture, industry, irrigation, generation of hydroelectricity and other human activities (Singh, 1998). Spatio-temporal trend analysis of rainfall has a vital role in different engineering and managerial strategies such as watershed / river basin development and management (Burguen˜o et al., 2004).

Annual trend in rainfall pattern has been examined extensively by different researchers from various parts of the world. Odekunle et al. (2005) and Eltahir (1992) in Africa, Burguen˜o et al. (2004) in Spain, Smith (2004) in Australia, Bidin and Chappell (2006) in Malaysia, Shen et al. (2007) in China, Ashley et al.(2003) and Haylock et al. (2006) in USA, are a few among such studies. Similarly monsoonal rainfalls in India has been explored on its general occurrence (Rajeevan et al., 2006, Gadgil and Joseph, 2003, Rajeevan, 2001), its predictability (Venketesan et al., 1997; Pai and Rajeevan 2006; Ratnam et al., 2007; Raju et al., 2007; Goswami and Gauda 2007), and its regional fluctuations and variations (Mohapatra and Mohanty, 2007; Simon and Mohankumar, 2004; Arora et al., 2006; Ghosh and Mujumdar, 2006). Recent studies by Ramesh and

Goswami (2007) reported the shrinking of the Indian summer monsoon in terms of total rain days as well as in total area of rainfall.

Kerala is almost the entry point of the summer monsoon rainfall in Indian subcontinent. The rainy seasons in Kerala are the South west monsoon (June-September) and North east monsoon (October- November). In the state the pre monsoon months (March - May) are characterized by major thunderstorm activity, and the winter months (December- February) are marked by low clouding and low rainfall (Ananthakrishnan et al., 1979). Several studies examined the monsoonal rainfall of Kerala; Parameswaran (2001), Fasullo and Webster (2003), Joseph et al. (2004), and Guhathakurta (2005), documented general characteristics and pattern of monsoon in Kerala. Simon and Mohankumar (2004) using multivariate statistics explored the spatial variability in the occurrence of rainfall in the state.

Recent studies (Soman et al., 1998; Kumar et al., 2004; Krishnakumar et al., 2009) reported spatial and temporal variations in Kerala's annual rainfall. Nevertheless, little is known about the local scale rainfall trends in the state (Raj and Azeez, 2010a), though it is vital for an agriculture based economy, with largely rain fed irrigation systems. The present study focuses on the general trend analysis of rainfall in Bharathapuzha river basin of Kerala state.

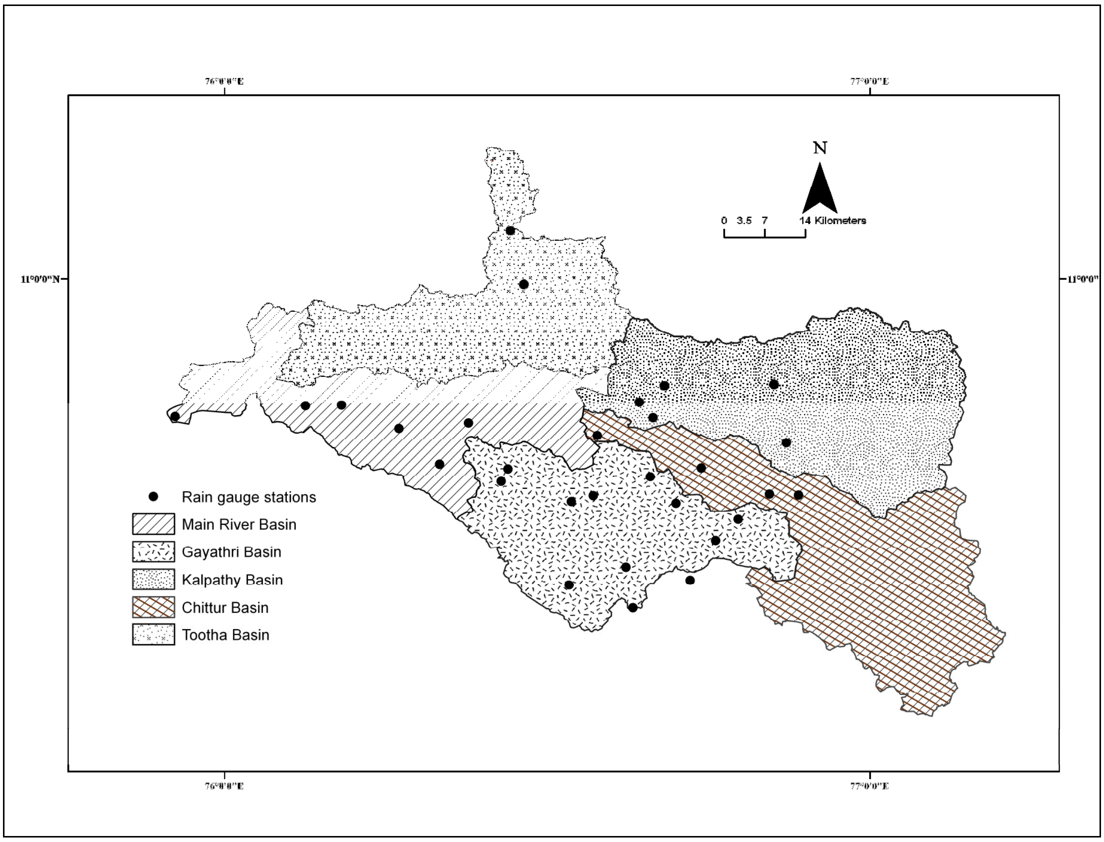


Figure 5.1.1 Location of rain gauge stations in the Bharathapuzha River basin

5.1.2. Methodology

To estimate the general trend in annual rainfall, monthly rainfall data of 34 years (1968-2002) from 29 rain gauge stations located in the basin (Figure.5.1.1) were collected from the Department of Irrigation (Government of Kerala Thrissur), Kerala Engineering Research Institute (KERI, Peechi) and Regional Agricultural Research Station (RARS, Pattambi). The average inter station distance between these rain gauge stations falls in a high correlation level as reported by James et al. (1986).The pooled data were then analyzed for various fundamental statistics such as mean (Normal), standard deviation (STDEV) and Coefficient of variation (CV, Table.5.1.1.). Time series of data was also examined for different temporal changes. Trend line and its significance were checked using *t* test statistics. The data was categorized according to Ananthakrishnan et al. (1979) in to four rain seasons; the South west monsoon (June-September), the North east monsoon (October- November) the pre monsoon months

(March - May) and the winter months (December- February). Temporal changes in the seasonal and annual rainfall were also analyzed by Man-Kendall rank correlation statistics (t), since it is among the most suitable statistical test for a long period of data (Basistha et al., 2007; Krishnakumar et al., 2009). Moreover it is a robust statistical tool for analyzing non-parametric climate data sets. The value of t can be used as the basis of a significant test by comparing it with

$$\boldsymbol{Tt = 0 \pm tg\sqrt{[4\,N + 10/9N\,(N - 1)]}}$$

where, *tg* is the desired probability point of the Gaussian normal distribution. *tg* at 0.01 and 0.05 were considered as the points for significance. The trend line fitted to the data was analyzed using Student *t* test to verify the results obtained from Man-Kendall statistics. In order to visualize the occurrence of events in a broad time scale, wavelet analysis was performed on the time series of rainfall data since the analysis is well known for its multi resolution analytical capabilities and for a broad insight to the periodic occurrence of climate processes (Jianhua et al., 2009; Nicolay et al., 2008; Sonechkin and Datsenko, 2000). A series of time scale analysis were conducted by taking symmlet as the basic wavelet. I used ‘Sym8’ as the operational wavelet function, and decomposed and reconstructed the average annual rainfall time series at three time scales, i.e., 16-years, 8-years and 4-years. Daily rainfall data collected from India Meteorology Department (IMD) for 34 years were examined for first rain event, and total number of rain days with the help of Man-Kendall rank correlation statistics (*Tt*). Rainfall of 0.2mm was taken as the minimum threshold value (Singh, 1998) to consider a rain day for data analysis. The entire rainfall events have been counted in Julian days numbering 1 to 365. SPSS 10 Software package and MATLAB 7.5 were used for carrying out all the statistical analysis.

Table 5.1.1. Rainfall statistics in Bharathapuzha River basin; the average rainfall (Normal), standard deviation (STDEV), coefficient of variation (CV), and %of contribution towards annual rainfall is also given.

Month	**Rainfall (mm)**			
	Normal	**STDEV**	**CV (%)**	**% to annual rainfall**
January	3	9.4	295	0.2
February	7	11	160	0.4
March	15	18.4	122	0.8
April	72	45	62	3.9
May	122	70	57	6.7
June	441	167.2	37	24.1
July	525	175	33	28.7
August	342	108	32	18.7
September	153	92	60	8.4
October	203	78.4	38	11.1
November	116	78	67	6.3
December	24	33	137	1.3
Annual	1828	456.4	25	100.0
Pre monsoon	189	84	44	10.3
South west	1318	391	29	72.1
North east	285	109	38	15.6
Winter	31	32	105	1.7

5.1.3. Results and discussion

5.1.3.1. Annual rainfall

Considering the whole 34 years of rainfall data, the average annual rainfall in the Bharathapuzha river basin is 1828 mm with a standard deviation of 456.4 mm. Among the months, while July receives the highest rainfall (525 mm) which accounts for 29% of the total annual rainfall in the basin, January receives the lowest (3mm). Among the four seasons of rainfall, the highest was during the South west monsoon season (1318 mm with a standard deviation of 391mm) followed by North east and pre monsoon seasons (Table.5.1.1.). The historical rainfall examined as units of five years class of annual rainfall in the basin also shows the prominence of rainfall during South west monsoon (Table.5.1.3.). Mann-Kendall test shows a significant decrease in the annual rainfall in the river basin (Table.5.1.2; Figure.5.1.2.). The study conducted by Krishnakumar et al. (2009) also revealed decrement in the annual rainfall on Kerala. Additionally, in the wavelet analysis a significant periodic change in a 16 years cycle

(R^2 =1) is observed, compared to 4 and 8 years (R^2 =0.08; Figure.5.1.3.). The decrement in rainfall in the region could alter the hydrology of the basin and its overall ecological setup. In the recent decades severe drought and dearth of water was reported from the basin (CWRDM, 2004). The decrement in the total rainfall may be a manifestation of the global climate change, perhaps leveraged on to by local changes.

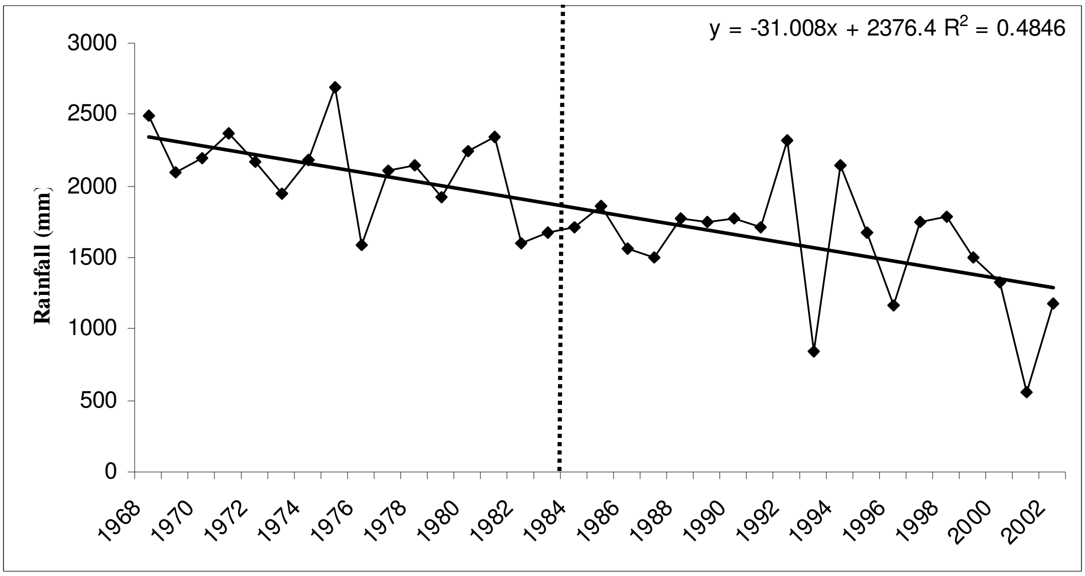


Figure 5.1.2 Annual rainfall trend in Bharathapuzha River basin, the dotted lines represents one cycle of event generated from wavelet analysis

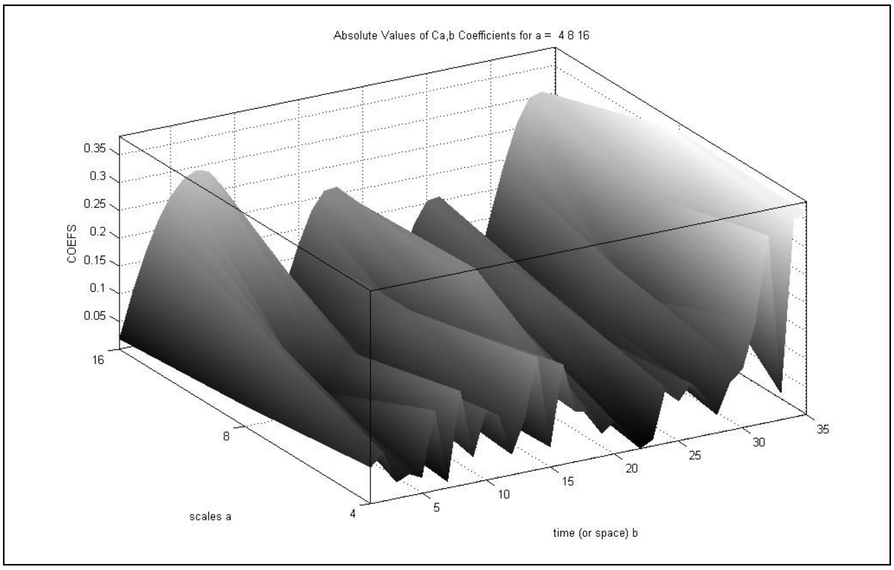


Figure 5.1.3 Wavelet for 3 time scales of rainfall; 4 years, 8 years, and 16 years

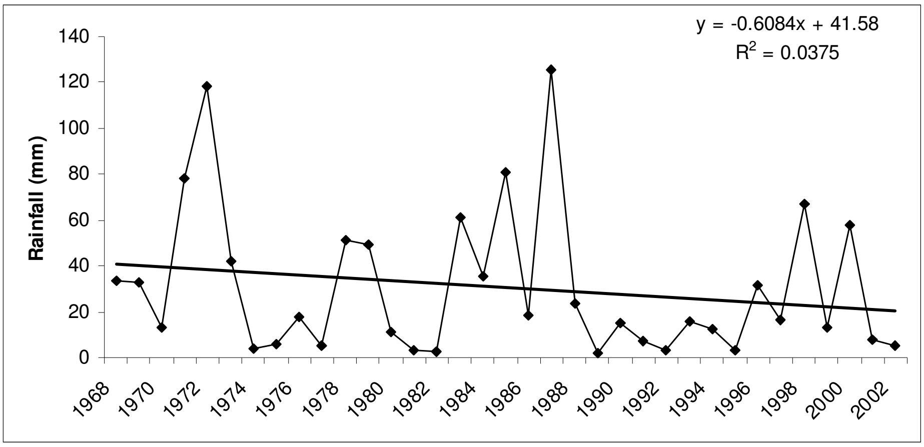


Figure 5.1.4 Rainfall trend during winter- Bharathapuzha River basin

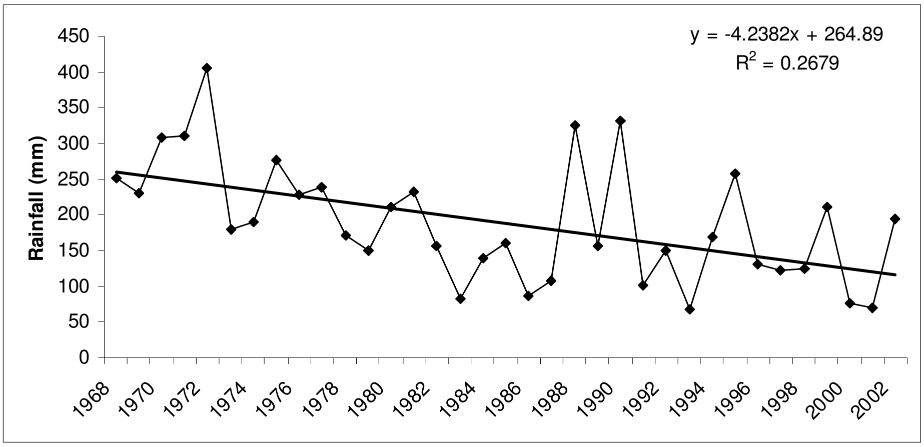


Figure 5.1.5 Rainfall trend during Pre monsoon-Bharathapuzha River basin

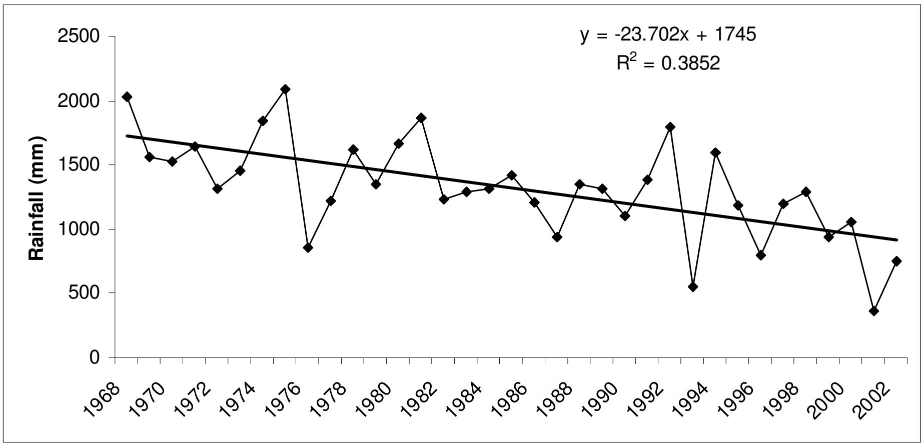


Figure 5.1.6 Rainfall trend during South west monsoon- Bharathapuzha River basin

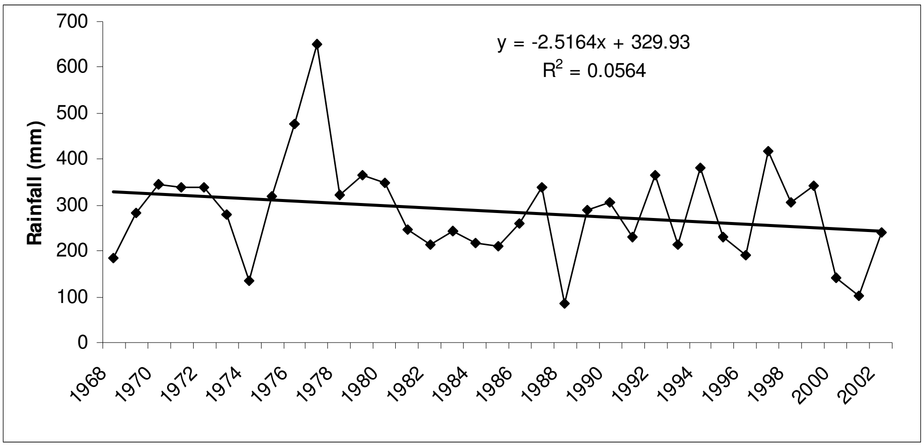


Figure 5.1.7 Rainfall trend during North east monsoon -Bharathapuzha River basin

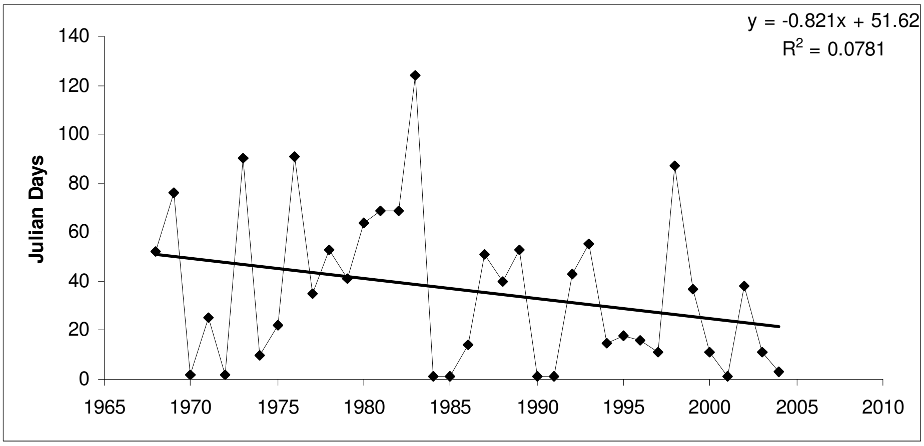


Figure 5.1.8 Occurrence of the first rainfall in Bharathapuzha River basin during the period of study

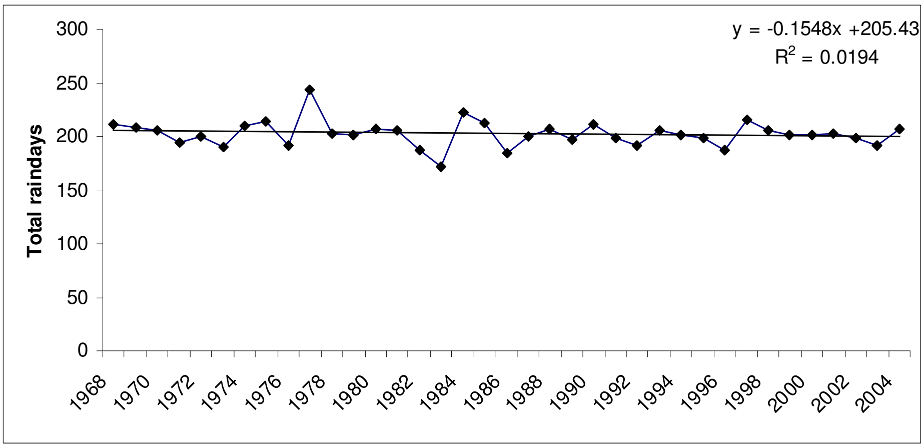


Figure 5.1.9 Variation in number of total rain days in Bharathapuzha River basin

5.1.3.2. Seasonal and monthly rainfall

The characteristic of seasonal and monthly rainfall of the basin is studied using Mann Kendall statistical analysis (Table.5.1.2.). The winter rainfall (Figure.5.1.4) does not indicate a statistically significant declining trend (Table.5.1.2.). This observation trend do not conform to the findings of Krishnakumar et al. (2009) for the entire state where in a trend of increasing winter rainfall was seen. The pre monsoon rainfall (Figure.5.1.5.) shows a significant decrease during the study period. It is also found that the pre monsoon rainfall is negatively correlated with the February rain. Study conducted by Kumar et al. (2004) reported that the pre monsoon peak of rainfall occur about seven pentads prior to the onset of monsoon over Kerala.

Table 5.1.2. Mann-Kendall's statistical analysis of rainfall characteristics

Rain	Coefficient
January	0.038
February	0.067
March	-0.068
April	-0.159
May	-0.154
June	-0.067
July	-0.165
August	-0.183
September	-0.091
October	0.109
November	0.066
December	-0.067
Winter	-0.101
Pre monsoon	-0.423**
South west monsoon	-0.428**
North east monsoon	-0.129
Annual rainfall	-0.496**
Rain days	-0. 150
First rainday	-0.088

** Significant at 0.01 level

Table 5.1.3. Contribution (in %) of the seasonal rainfall to the total annual rainfall

Season	1968-1973	1974-1979	1980-1985	1986-1991	1992-1997	1998-2002
Winter	2	1	2	2	1	2
Pre monsoon	13	10	9	11	9	11
South west monsoon	72	71	77	72	72	69
North east monsoon	13	18	13	15	18	18

The South west monsoon (Figure.5.1.6.) also shows a significant (p= 0.01 level) negative trend. The decreasing trend in south west monsoon rainfall over Kerala is also reported by other researchers (Kumar et al., 1992; Guhathakurta and Rajeevan, 2007). Joseph and Xavier (1999) observed a strong decreasing trend during last 100 years in the monsoon depression frequency. Since the South west monsoon contributes major share of the total annual rainfall the decrement, if consistent in the coming years, will have huge impacts on the general hydrology of the basin and the agriculture.

Table 5.1.4. *t*-test significance for linear equations to verify the Man-Kendall's statistics

Rainfall	**Linear equation**	**Calculated *t***
Annual	y = -31.008x + 2376.4	**0.4846
Pre monsoon	y = -4.2382x + 264.89	**0.2679
Southwest	y = -23.702x + 1745	**0.3852
Northeast	y = -2.5164x + 329.93	0.0564
Winter	y = -0.6084x + 41.58	0.0375

** Significant at the 0.01 level

The study conducted by Soman et al. (1998) reported decrement in the North east rainfall in the region. In the present situation although the rainfall during North east monsoon (Figure.5.1.7.) tends to decrease, its decline is not statistically significant. Rainfall in any individual months shows any significant change. However there is a trend of increase in rainfall during the months of January, February, October and November. On the other hand the rest of the months show a decreasing trend. In a year July, June and August are the major rain giving months in the basin and the analysis shows a decrease in trend in the rainfall (Table.5.1.2.) during these months. The *t*-test statistics, (Table.5.1.4.) indicated that South west, pre monsoon and annual rainfall trends in Bharathapuzha basin to be significant at 0.01 levels.

In the basin the occurrence of first rain day was found advancing and the total number of effective rain days as decreasing as the year progresses (Figure.5.1.8.; 5.1.9.and Table.5.1.2.). However both the events show no statistical significance. However, in the Palakkad Gap, in the eastern part of the basin a significant advancement in the first rainfall and a decrement in the total number of effective rain days is already reported (Raj and Azeez, 2009d). The advancement of first rain day may be possibly due to the temperature changes happening in the ocean during the late spring or in the early winter period which can bring about the convection current necessary for monsoon (Fasullo and Webster, 2003, Ramesh and Goswami, 2007). Local temperature hikes, subsequent lifting of air mass and attraction of moist laden colder air parcels from the western sea could also be perhaps added reasons.

The variation in the rainfall pattern of the basin has to be viewed in the context of global climate change. An increase in surface air temperature of about 1°C over Indian peninsula has been reported by Dash et al. (2007). The area surrounding the river basin is highly subjected to anthropogenic pressures such as deforestation (Meher-Homji 1991), and urbanization. In states like Kerala large-scale landscape changes, including flattening of several hillocks, are happening at a fast pace for various social, economic and cultural reasons. Studies conducted by Chattopadhyay (1985) has shown remarkable extend of land use change in some part of the basin. Our study on the land use/land cover changes are also highlight the notable changes happened during the last couple of decades in the basin (See Chapter 4 for further details)..

5.1.4. Summary

Knowing the variations in the general rainfall pattern of a river basin is vital to understand the hydrological cycle and water budget of the basin. The present study examined the general rainfall pattern in the Bharathapuzha river basin using monthly rainfall data for 34 years collected from 29 rain gauge stations. Mann-Kendall's rank correlation statistics and wavelet analysis were used to examine the trend of rainfall. The study revealed significant changes in annual, pre monsoon and South west monsoon rainfall in the study area. No significant decrement could be seen in the North east monsoon. The decrement in the annual rainfall could have a negative impact on major water input to the basin and the hydrologic realm of the basin. These changes are expected to seriously affect the irrigation and hydro electric projects in the basin, which will indirectly affect the agriculture productivity in future.

5.2. Changes in temperature in the Basin

5.2.1. Introduction

Global warming and its impact on life on earth have been of great concern among intelligentsia of various occupations; scientists, economists and decision makers since the later half of the 19th century. The idea of global warming was first put forth as early as 1896. However, it took almost a century to reach Kyoto in 1997 to shape a protocol among nations to deal with the future climate shocks (Raj and Azeez 2009e). The Kyoto protocol was plagued by various impediments, major producers of green house gases like USA declined to ratify the protocol and to abide by the restrictions paused on green house gas emission by the protocol. Recently in Copenhagen another summit has happened; but the summit more or less failed to reach at an effective binding control measures. A number studies have been under taken on various aspects of climate, to examine and cross examine the global as well as local climatic anomalies. According to Bates et al. (1995) the global mean surface temperature has increased by 0.3 to 0.6ºC since late 19th century. The overriding paradigm of development along with population explosion that happened during the last century had a perilous effect leading to the warming of the globe.

Urban or agriculture heat islands, and urban growth pressures, ocean dynamics, emission of green house gases and atmospheric aerosols are some of the identified major anthropogenic pressures (Tonkaz and Cetin, 2005), with varying degrees of influence that leads to the rise in global temperature. The general temperature variation has been examined by several authors (Yilmaz et al., 2009; Schrier and Jones, 2008; Lee and Shon, 2007; Sala et al., 2000) and the periodicity of temperature changes during the twentieth century could be summed up as three periods of alternate warming and cooling. During the first half of the century up to 1940s the land surface temperature increased by 0.6°C with a deviation of ±0.3°C, followed by thirty years of cooling period (1940 to 1970), and a second warming trend beginning at about 1970 (Smadi, 2006).

The tropics are very vulnerable to warming and climate variations since the world's most populous and underdeveloped or developing countries are located in this strip. Being second most populous country in the world India is highly prone to climate changes and its implications. In the country the large proportion of the population that remains below the poverty line (Tendulkar, 2009) will be the worst sufferers. India is expected to be next most important green house emitters after China, in the coming years with its 7 to 8 % annual growth rate. Several studies have documented temperature variations in different parts of Indian peninsula (Dash et al., 2007; Tiwari, 2006; Gadgil and Dhorde, 2005; Kothawale and Kumar, 2005; Rao et al., 2004; De, 2001). It is reported that thousands of people in the country died every year due to the temperature fluctuations (Dow and Downing, 2007) or go through excruciating ordeal due to the changing climate. In the latest summer sun stroke and sun burns so far unheard of, has been widely reported in the news paper from Palakkad, the major city in the present study area, the Bharathapuzha River basin. Recently Dash et al. (2007) and IMD (2010) have reported rise in surface air temperature over the Indian peninsula. Nevertheless, studies on local temperature changes are relatively less in the Indian subcontinent. In a global context Peel et al. (2007) has also observed scarcity in temperature studies due to the very low number of temperature gauging stations.

The gridded temperature data available with India Meteorology Department (IMD) is a premier historic climate data used widely to study temperature anomalies (Gadgil, and Dhorde, 2005). Using the gridded data from the IMD, the present study examined the trend of temperature in the Bharathapuzha basin.

5.2.2. Methodology

The daily maximum, minimum and mean temperatures during the period 1969-2005, collected from the IMD, Pune, were used for the study. Temporal changes in the seasonal and daily temperature for the four seasons (Ananthakrishnan, 1979), the South west monsoon (June-September), the North east monsoon (October- November), the pre monsoon months (March - May) and the winter months (December- February) were examined using Mann-Kendall's rank correlation statistics (t) The value of '*t*' were used as the basis of a significant test by comparing it with

$Tt = 0 \pm t_g\sqrt{4}$ N+ 10/9N (N – 1) as mentioned earlier in this chapter regarding the analysis of rainfall. Similar to rain analysis, the points for deciding the significance for 't_g' in temperature analysis also were 0.01 and 0.05. The best fit trend line fitted to the data were examined using student '*t*' test to verify the results obtained from Man-Kendall statistics. The trend line fitted to the data was analyzed using Student *t* test to verify the results obtained from Man-Kendall statistics. To visualize the occurrence of events in a broad time scale, wavelet analysis was also performed. SPSS 10, MATLAB 4 were used for carrying out the statistical analyses.

5.2.3. Results and discussion

5.2.3.1. Variation in annual temperature

The variation in annual maximum (T max), minimum (T min) and mean (T mean) temperature and the standard deviation (STDEV), and coefficient of variation (CV) were estimated for daily, yearly, monthly and seasonal temperature for the 1969-2005 period. The mean annual temperature of the basin was found 24.3° C with a standard deviation of 0.3ºC (Table. 5.2.1.). Taking the whole period in to consideration, the mean annual, mean minimum and mean maximum temperature shows statistically significant increasing trend as the years proceeds (Table.5.2.1.). However, the temperature during 1969 was found warmer and it started decreasing and during 1971 the basin experienced the lowest temperature. During 1972 the temperature started rising. There after it shows a more or less an upward trend with bumps during the years 1983, 1987, 1998 and 2003. The highest annual temperature was observed during 1987 (Figure 5.2.1 A, B, and C). Further to this the wavelet analysis shows a significant periodic change in a 16 years time scale (R^2 =1) in the temperature trend in the basin (Figure.5.2.2.).

Table 5.2.1.General temperature (ºC) statistics of Bharathapuzha River basin

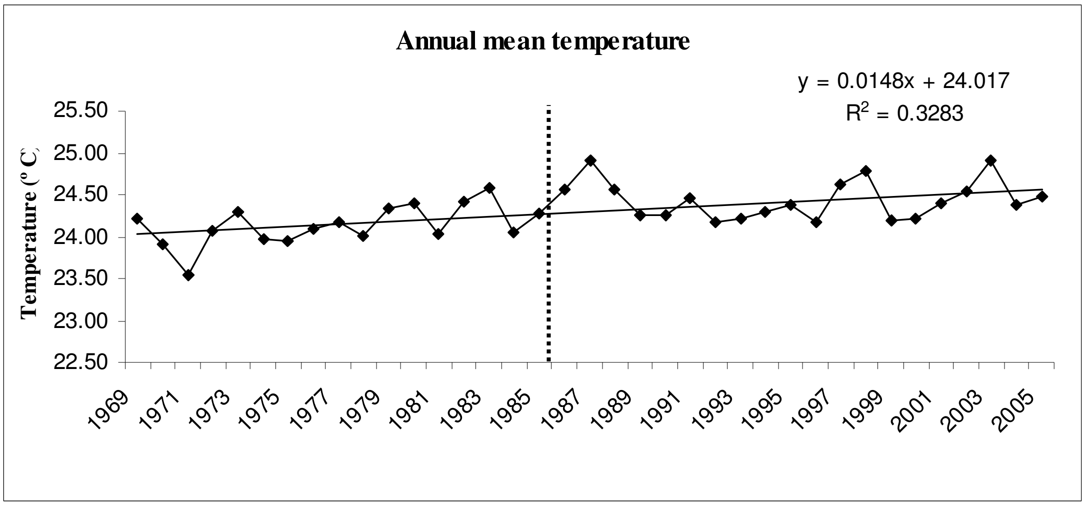
Month	**T max**	**T min**	**T mean**	**SD (º C)**	**CV (%)**
January	28.77	16.95	22.86	0.5	2.2
February	30.22	18.09	24.15	0.5	2.0
March	31.85	19.82	25.84	0.4	1.6
April	32.20	21.36	26.78	0.5	1.8
May	31.10	21.46	26.28	0.7	2.6
June	27.96	20.45	24.21	0.6	2.6
July	26.90	19.98	23.44	0.4	1.6
August	27.01	19.99	23.49	0.4	1.5
September	28.05	20.00	24.02	0.4	1.6
October	28.15	19.91	24.03	0.4	1.7
November	28.01	19.09	23.55	0.3	1.5
December	28.16	17.66	22.91	0.5	2.1
Annual	29.08	19.51	24.30	0.3	1.1
Winter	29.05	17.56	23.31	0.3	1.5
Pre-monsoon	31.72	20.88	26.30	0.4	1.5
SW monsoon	27.48	20.10	23.79	0.4	1.5
NE monsoon	28.08	19.50	23.79	0.3	1.4

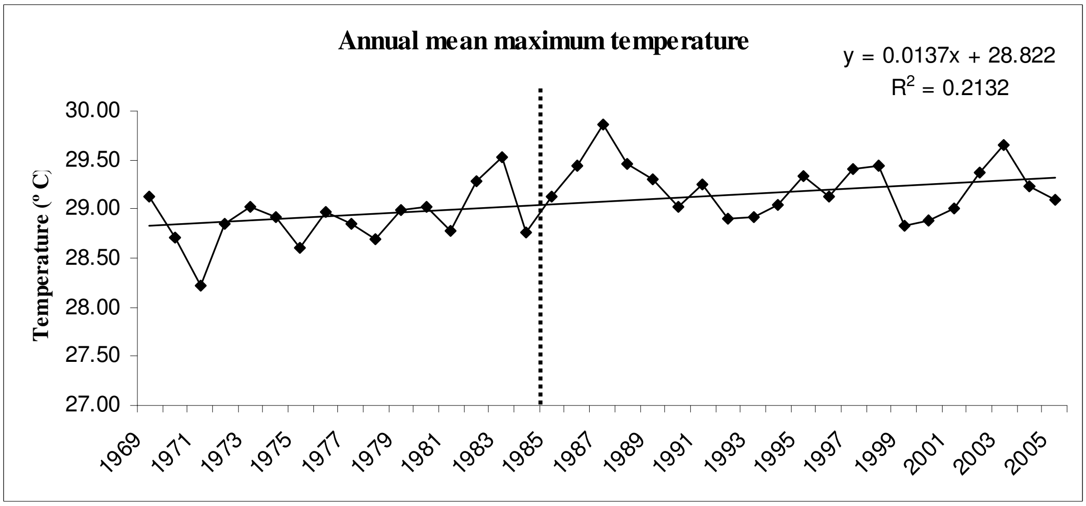
The annual mean temperature of the basin is directly influenced by the daily and monthly temperatures. The significant increment in the annual temperature is thus related with the significant increasing trend in the daily temperature during the study period (Table.5.2.2.). The monthly temperature during January, February, March, July, August, and September has obviously influenced the annual temperature hike. The historical data analysis on temperature revealed that there is a significant rise of 0.27 ºC in the annual mean temperature over the basin. The increasing trend in the annual temperature in the basin reflects the temperature rise of 1ºC reported from the peninsula during the last century (Dash et al., 2007). The study conducted by Zhaomei et al., (2001) observed the annual temperature change over the tropical region of the globe between Indian Ocean and Pacific Ocean by 0.6º C / 100 years. A study conducted by the IMD also reported a hike in the mean annual temperature of the state of Kerala by 0.5º C between 1961 and 2003 with a rise of 0.8º C in the mean maximum temperature and 0.2 º C rise in the mean minimum temperature (Kutty, 2008). The increase in the annual temperature in the state and particularly in the basin presumably will have a direct correlation with rainfall. It is found that the annual rainfall in the state shows a decreasing trend (Krishnakumar et al., 2009). Further an historical rainfall analysis of the basin also had shown a decreasing trend in annual rainfall.

Urbanization and increase in population could have a positive correlation with temperature of a place (Chung et al., 2004; Mohsin and Gough, 2009). The urbanization pressure is at a higher level in different parts of the basin. The old city centers such as Pollachi, Anamalai, Palakkad, Ottappalam, Shornur, Chittur and Ponnani are invariably facing high urbanization pressures. In addition to these, places like Pattambi, Mannarkkad, Alathur, Anagalakuruchi, Kottur, Vadasithur Kuttipuram and Pulamanthole have also become city centers developing in a fast pace.

5.2.3.2. Variation in seasonal temperature

The seasonal and monthly variations in temperatures was analyzed considering the four seasons; winter (January, February and December), Pre monsoon (March-May), South west monsoon (June- September) and North east monsoon (October- November). In the basin, during winter the mean temperature showed a statistically significant increasing trend. The temperature in the basin showed a hike of 0.54ºC during the study period. The trend of increase was also clear for the maximum and minimum temperatures (Table.5.2.3.). During 1969 the basin had high winter temperature that started decreasing and reaching a low temperature (22.65ºC) during 1972 and the trend persisted up to 1973 with comparatively cool winter. Afterwards, the temperature started rising reaching 23.54 ºC during 1979 followed by a moderate hot winter up to 1991. During the period of 1992-1993, the basin experienced very cool winter followed by a rise in temperature persisting up to the end of the study period. The basin observed a coolest winter during 1974 and hottest winter during 2004 (Figure.5.2.3.A, B, and C).





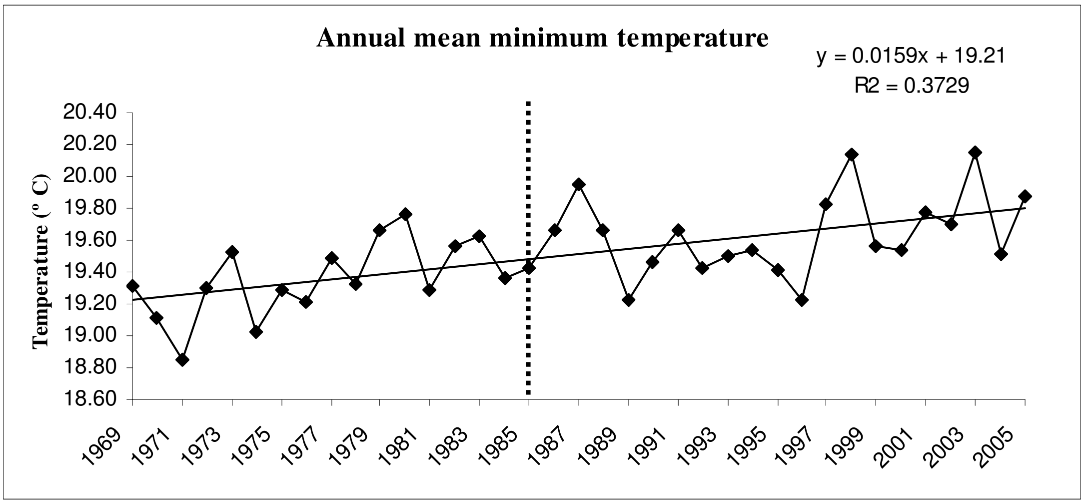


Figure 5.2.1 A, B, C; Annual (A) mean, (B) maximum and (C) minimum temperature in Bharathapuzha River basin, the dotted line represents the cycle of event generated from the wavelet analysis

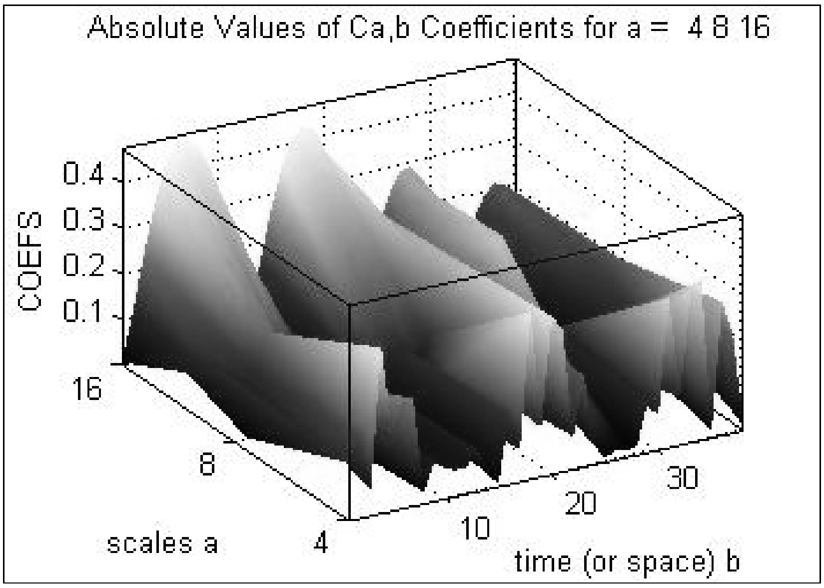


Figure 5.2.2 Wavelet analysis showing the annual mean temperature trend for different time scale in Bharathapuzha River basin

It is observed that the temperature during winter is found increasing globally (Mohsin and Gough, 2009). However the study conducted by Gadgil and Dhorde (2005) in Pune, a west coast city in Maharashtra, and the study conducted in Pattambi, a station located in the Bharathapuzha basin towards its lower stretches found not conforming to these observations.

Of all the four seasons, in the basin the pre monsoon has seen the highest range of temperature. The average pre monsoon temperature was 26.30 ºC with a SD of 0.4 ºC. Except in the case of the minimum temperature, no statistically significant trend of rise was seen in the case of either maximum or mean temperature in the basin during the pre monsoon (Table.5.2.1.). As the year proceeds pre monsoon temperature shows an alternating warm and cool cycle. The hottest pre monsoon was during 1998 and coolest during 1972 (Figure.5.2.4.A, B, and C).

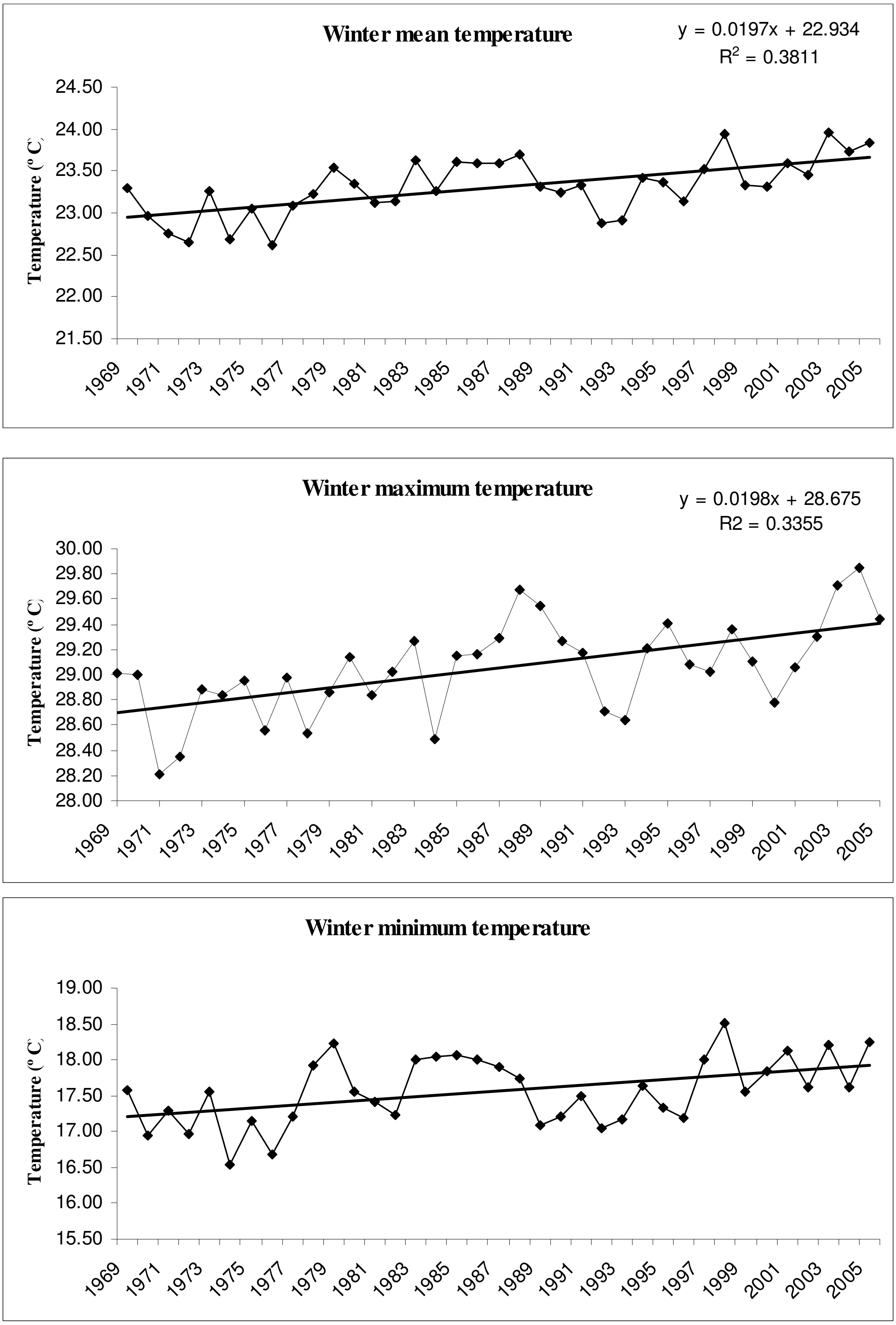


Figure 5.2.3 A, B, C Winter (A) mean, (B) maximum and (C) minimum temperature in Bharathapuzha River basin

The South west monsoon temperature in the river basin shows a significant increase during 1969-2005. The significant increase could be found in South west monsoon maximum, minimum and mean temperature. Initially during the beginning of the study the South west monsoon temperature shows an alternating rise and fall up to 1985. There after the temperatures shows a trend of rise (Table.5.2.2). A 0.4 ºC of rise was observed in South west monsoon temperature of the basin during the period of study. The highest South west monsoon temperature for the study period was seen during 1987 and the lowest during 1971 (Figure.5.2.5.A, B and C).

Table 5.2.2. Mann-Kendall's rank correlation statistics

Month	**T maximum**	**T minimum**	**T mean**
January	0.318**	0.328**	0.414*
February	0.277*	0.211	0.268*
March	0.188	0.298**	0.275*
April	-0.048	0.120	0.014
May	0.182	0.238*	0.202
June	0.155	0.230	0.179
July	0.322**	0.269*	0.329*
August	0.277*	0.339*	0.363**
September	0.243*	0.420**	0.356**
October	0.130	0.297**	0.202
November	0.154	0.223	0.299**
December	0.211	-0.027	0.143
Daily	0.310**	0.022	0.154*
Annual	0.317**	0.428**	0.404**
Winter	0.420**	0 .299**	0 .440**
Premonsoon	0 .094	0.250*	0 .158
South west monsoon	0.309**	0.326**	0.352**
North east monsoon	0.174	0.265*	0.303**

** Significant at level 0.01 and * at 0.05

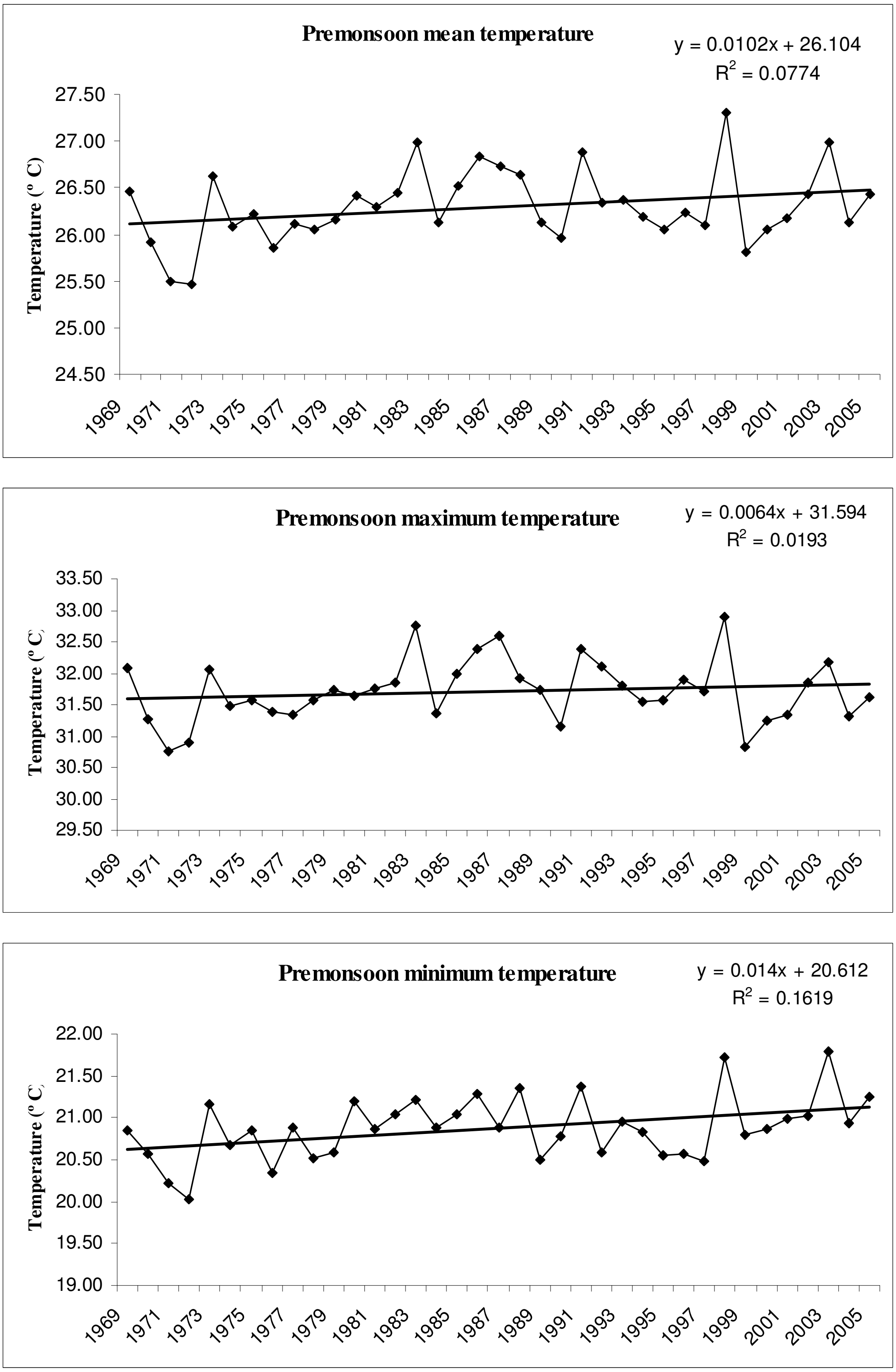


Figure 5.2.4 A,B and C Premonsoon (A) mean, (B) maximum and (C) minimum temperature Bharathapuzha River basin

The minimum and mean temperature during North east monsoon season in the river basin shows a statistically significant increasing trend. The temperature trend line of the season shows more or less persistent rise without much fluctuation. The analysis shows a rise of 0.19 ºC in North east monsoon temperature during the period of study. The maximum temperature recorded in the season was during the year 1987 and the minimum during the year 1971 (Table5.2.2; Figure.5.2.6.A, B and C). Student *t* test results confirm the Mann- Kendall's correlation results (Table.5.2.3.).

Table 5.2.3. Calculated *t* value from the linear equation

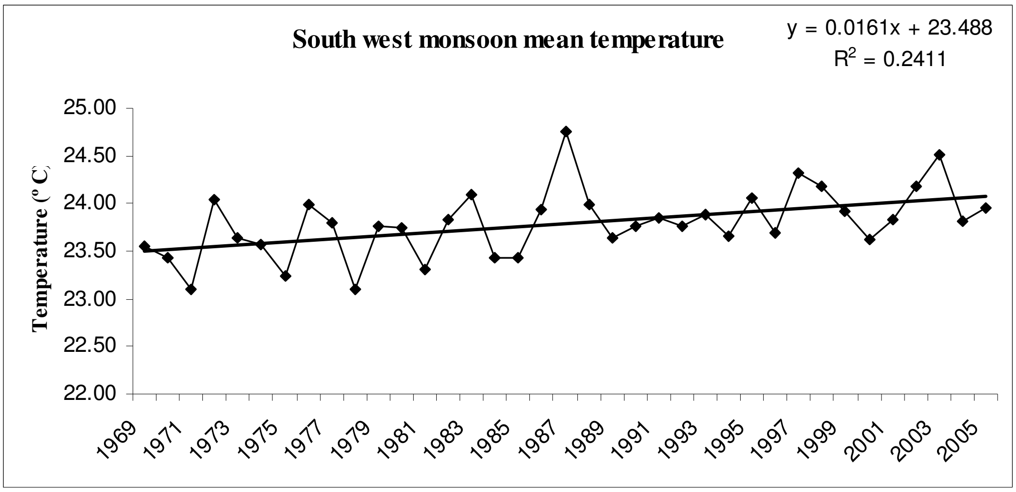
Season	**Calculated t**
Annual Tmean	0.3283**
Annual Tmin	0.3729**
Annual Tmax	0.2132**
Winter Tmean	0.3811**
Winter Tmax	0.3355**
Winter Tmin	0.2065**
Premonsoon Tmean	0.0193
Premonsoon Tmin	0.1619*
Premonsoon Tmax	0.0193
South west monsoon Tmean	0.2411**
South west monsoon Tmin	0.2459**
South west monsoon Tmax	0.1966**
North east monsoon Tmean	0.1805**
North east monsoon Tmin	0.1693*
North east monsoon Tmax	0.0784

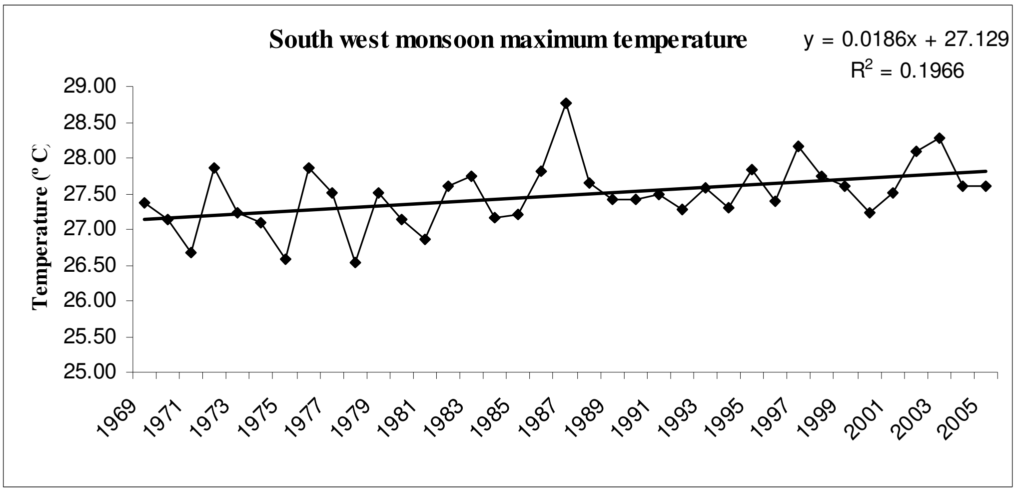
** Significant at level 0.01 and * at 0.05

Dash et al. (2007) have reported a rise of temperature during pre monsoon (0.3º C), and North east monsoon (1.1º C) all over the country. The present study also shows a significant increase of North east monsoon temperature and in the South west monsoon temperature. The rise in temperature during south west monsoon will have a huge impact on the agriculture in the region since most of the traditional rice cultivation crucially depends on the monsoon.

5.2.3.3. Daily and Monthly temperature variation

The analysis of maximum monthly temperature in the river basin shows an increasing trend for all the months except April. Significant increments in maximum temperature were observed in the months, January February, July, August and September. In the case of minimum temperature, the basin observed statistically significant rise in temperature during January, March, May, July, August, September and October. In December, the temperature, although tending towards a dip, the changes were not statistically significant. The mean monthly temperature shows a statistically significant trend of rise statistically significant for January, February, March, July, August, September, and November (Table.5.2.2.). The daily temperature of the basin shows a switching rise and fall through out the study period. Daily mean and maximum temperature shows a significant hike in the basin during the period of study (Table.5.2.2.).





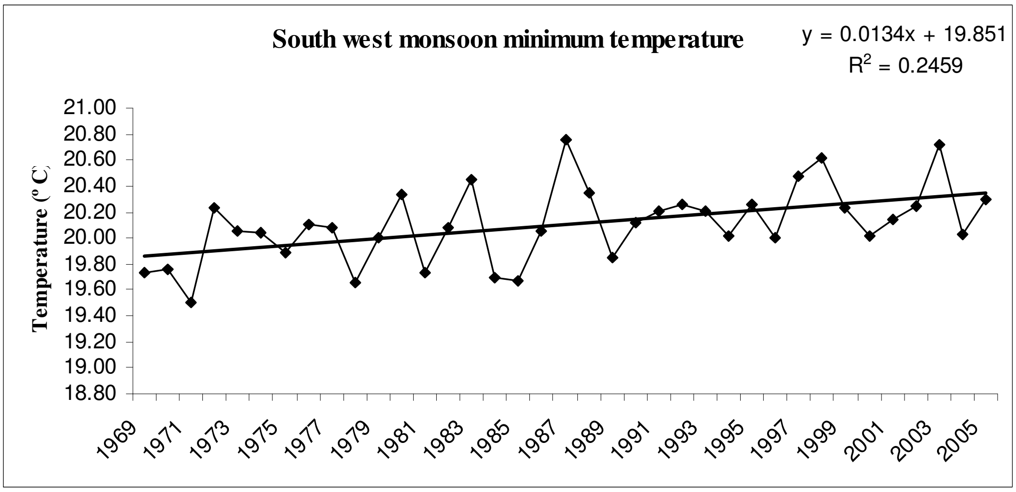
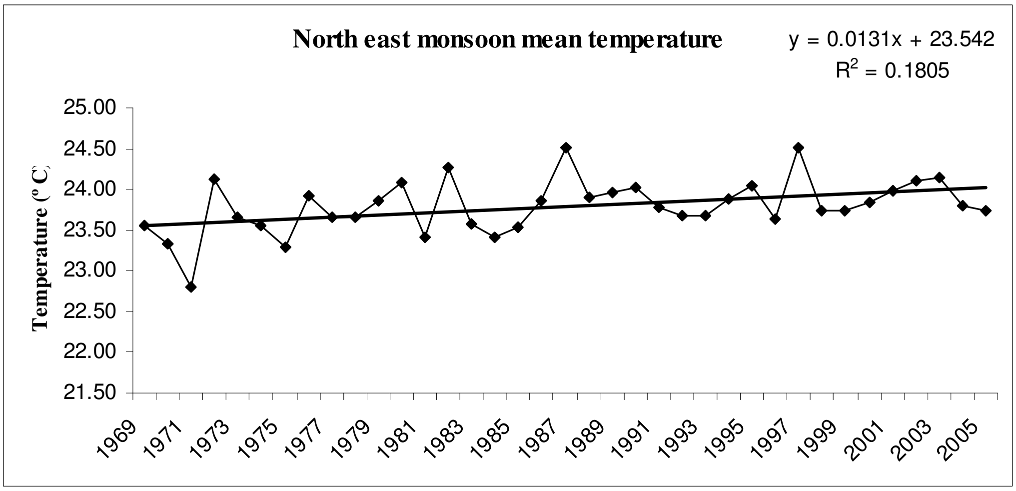
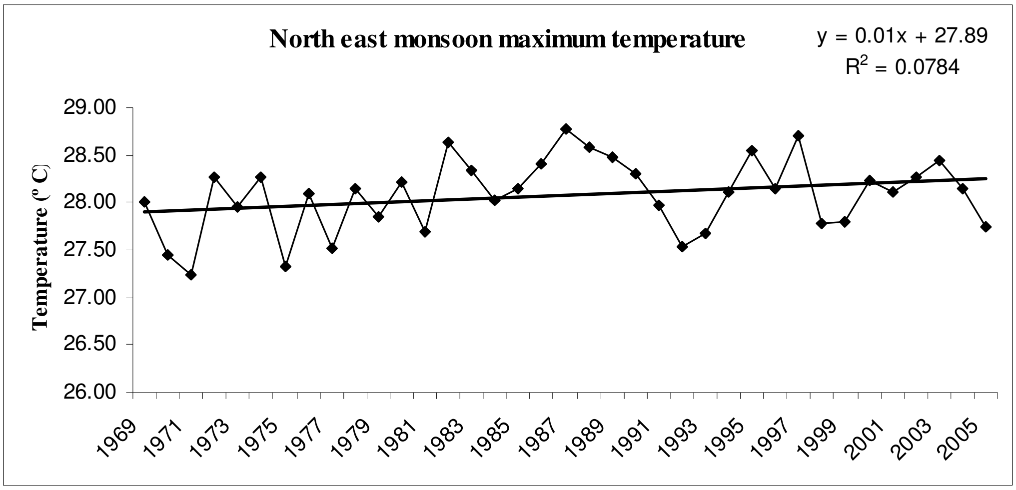


Figure 5.2.5 A,B and C South west monsoon (A) mean, (B) maximum and (C) minimum temperature in Bharathapuzha River basin





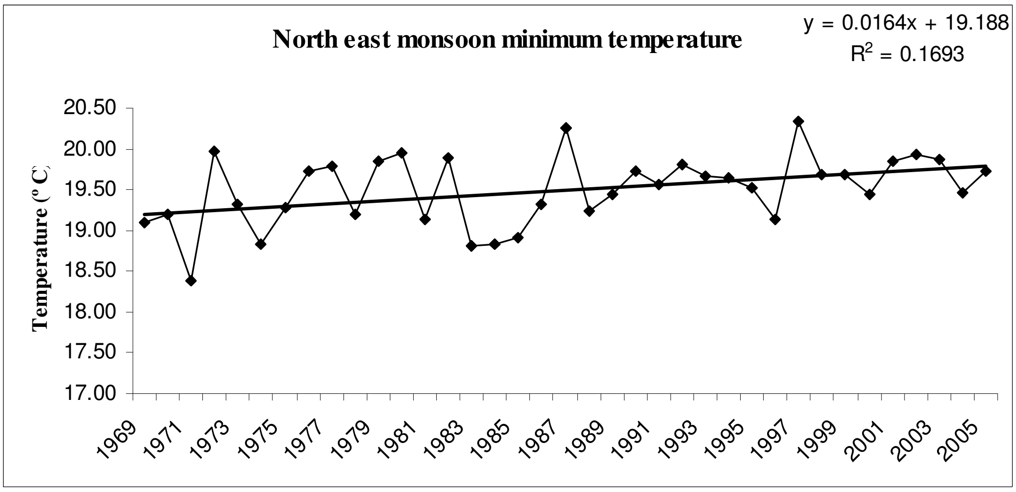


Figure 5.2.6 A,B and C North east monsoon (A) mean, (B) maximum and (C) minimum temperature in Bharathapuzha River basin

The observed temperature hike would have decisive impacts on the hydrology and biodiversity of the basin. The basin is regarded as the rice granary of the state of Kerala. The agriculture practices in the basin still to a large extend depend on the temperature and the monsoon rainfalls. The basin during the recent decades has under gone large scale deforestation due to the establishment of several dams in its pristine forest areas located in its upper catchments. It is noted that the extent of forest cover directly influences the local temperature and vise versa (Tiwari, 2006). Presumably those land use changes also must have played a great role in the temperature hike in the basin.

5.2.4. Summary

Local climate changes can be a manifestation of global climate changes perhaps exacerbated by local changes. Temperature variation per degree Celsius will have direct and indirect impacts on various natural resources and processes. The historical data analysis on temperature in the Bharathapuzha River basin revealed that there is a significant rise of 0.27ºC in the annual mean temperature over the basin. The wavelet analysis further shows a significant periodic change in a 16 years time scale (R^2 =1) in the temperature trend of the basin. Similarly significant hikes in temperature was observed during winter (by 0.54 ºC), South west monsoon (0.4ºC), and North east monsoon (0.19ºC). The rise in temperature in the basin can have direct implications on the basin hydrology, agriculture and biodiversity. Perhaps the recent drought conditions in the basin may be among its reflections.

*The content of the chapter forms research articles published / communicated in various research journals / edited volumes as given below.

1. Changing rainfall in the Palakkad plains of South India. *Atmósfera* 23:1, 81-88. 2010.
2. Historical analysis of the first rain event and the number of rain days in the western part of Palakkad gap, south India. Climate Change: Global Risks, Challenges and Decisions IOP Conf. Series: *Earth and Environmental Science*. 6 072046.
3. The general rainfall trend using the historical data: a case from the Palakkad plains of Kerala. In: *Climate Change, Biodiversity and Food Security in the South Asian Region* (Eds: Jerath N; Bhooj R; and singh G) Punjab State Council for Science and Technology, Chandigarh and United Nations Educational Scientific and Cultural Organization, New Delhi. Published by Macmillan Publishers India Ltd, New Delhi.
4. Trend analysis of daily temperature in Bharathapuzha river basin Kerala, India, communicated to *Current Science*.
5. Trend analysis of rain fall in Bharathapuzha river basin, Kerala, India. Communicated to *International Journal of Climatology*.

6. Variations in quality and quantity of surface water in the river system

6.1. Introduction

Rivers are the prime factors controlling the global water cycle and in the hydrologic cycle, they are the most dynamic agent of transport (Garrels et al., 1975). Rivers carry elements, in suspended or in dissolved form, from their source and deposit them sequentially at different locations based on their physicochemical nature. The suspended load in the river can act as sink for nutrients and other elements in certain cases and as source in certain other cases (Horowitz, 1995 & 1997; Gaur et al., 2005). In spite of their wide-ranging role in various natural processes, rivers are presently under severe threat due to various anthropogenic pressures (Singh and Singh, 2007). Monitoring the surface runoff of a river on a regular basis provides valuable information on the eco-hydrologic conditions of a river basin. Such data provide valuable insights into spatial and temporal variation in water quantity and quality, considered as simple measures of the health of a river. Such data are also a measure of the applicability of various water quality models and their reliability in predictions (Rode and Suhr, 2007).

The quality and quantity of surface water in a river basin is influenced by natural factors such as rainfall, temperature and weathering of rocks, and anthropogenic changes that curtail natural flow of the river or alter the hydrochemistry of the river. Rivers and streams are highly heterogeneous in spatial as well as temporal scales and several investigators have documented this heterogeneity focussing on the physicochemical dynamics of rivers. Variation in the quality and quantity of river water is widely studied in the case of several world rivers. Riedel et al. (2000) examined the spatiotemporal variation in trace elements in Patuxent river of Maryland, and Sileika et al. (2006) observed the variations in nutrient level in the Nemunas river of Russia. Schaefer and Alber (2007) studied Nitrogen and Phosphorous in Altamaha river of Georgia and Quadir et al. (2007) studied the Nullah Aik, a tributary of the river

Chenab. Gupta and Chakrapani (2005) studied the Narmada river basin, Kannel et al. (2007) the river Bagmati, and Sundaray et al. (2006) the Mahanadi basin. Compared to the northern rivers in India, the southern ones are less studied perhaps due to their lower size and discharge. The rivers in the peninsular India, barring the four Godavari, Krishna, Cauvery, and Thunga Bhadra, are largely of medium sized or small sized rivers according to the classification by (Jain et al., 2007). Most of the peninsular Indian west flowing rivers are highly seasonal in discharge and shorter in length although they form a crucial and effective water realm in their basin and major sources of sediment transport to the Arabian Sea (Gupta and Chakrapani, 2005).

Among the Indian rivers, those flowing through the Indo-Gangetic plains are most studied. Subramanian (1983) documented inconsistent down stream variations in river water chemistry. Singh and Singh (2007) and Mukherjee et al. (1993) documented the physical chemical and biological aspects of the Ganges River. Heavy metals such as Cr, Mn, Fe, Co, Ni, Cu, Zn, and Pb in the sediments of the Ganges river basin were analysed by Singh et al., (2002) and Purushothaman and Chakrapani (2007). Studies are also many on tributaries of the Ganges including the River Yamuna (Saxena et al., 2001; Dalai et al., 2004; Rode and Suhr, 2007), River Gomti (Gaur et al., 2005; Singh et al., 2005) and River Hindon (Jain and Sharma, 2002) documenting different physio-chemical aspects. Panigrahy and Raymahashay (2005) studied the Mahanadi basin, and Singh and Hasnain (1998) the Damodar basin. Down south of India, Avvannavar and Shrihari (2007) documented the water quality of River Netravathi flowing through Karnataka, and Jeevanandam et al. (2007) studied the hydro-geochemistry and ground water quality of the Ponnaiyar river basin of Tamil Nadu. Among the rivers of Kerala, Joseph (www.krpcds.org/report/Joseph%20M.L.pdf) prepared a status report of the Periyar river basin of Kerala. Sreedharan (www.krpcds.org/report/TPS.pdf) explored the Valapattanam river basin of Kerala with special emphasis on the ecology and socio cultural aspects.

The river Bharathapuzha as mentioned elsewhere is currently facing tremendous pressure due to encroachments, sand and clay mining, and illegal diversion of water.

However, the basin remains less examined regarding important base line information. The present study focuses on the spatiotemporal variation in water quality and quantity of the river.

6.2. Methodology

Attempts were made to collect historical data on water quality of the river from various sources. Data on water quality (for 10 water years, 1993-2003) and discharge could be procured from five river gauge stations maintained by the Central Water Commission (CWC, Government India). While discharge data for a much longer period were collected, to match with the period for which water quality data was available for the purpose of the present analysis, discharge data only for the 1993-2003 period were used. Thus the data represents five river gauge stations from where water quality data were made available. The stations were Amparampalayam, Pudur, Mankara, Pulamanthole and Kumbidi (Figure 6.1). Of these five stations, Amparampalayam lies in the Chittur river basin, a sub-basin located in the upper reaches of the Bharathapuzha basin. It is located in the downstream reaches of the river Aliyar, which has important dams across (Figure. 2.11.). Amparampalayam is the one and only river gauge station in the basin located in Tamil Nadu. The gauge station Pudur is located in the lower reaches of Chittur River. The station at Mankara near to the Palakkad town falls in the main river course. Pulamanthole on the other hand is located in the lower reaches of Thootha River. Kumbidi is the lowermost gauging station and it falls in the river course (Table.6.1.).

Multivariate statistical techniques like Hierarchical Cluster Analysis (HCA), and Principle Component Analysis (PCA) were used to segregate and examine the water quality data for 10 water years from 1993 to 2003. For spatiotemporal analysis, multivariate statistics is considered to be appropriate tool and a number of studies reveal its efficiency (Singh et al., 2005; Sundaray, 2006; Quadir et al., 2007). HCA is used to see the spatial variation in water quality as well as quantity among stations.

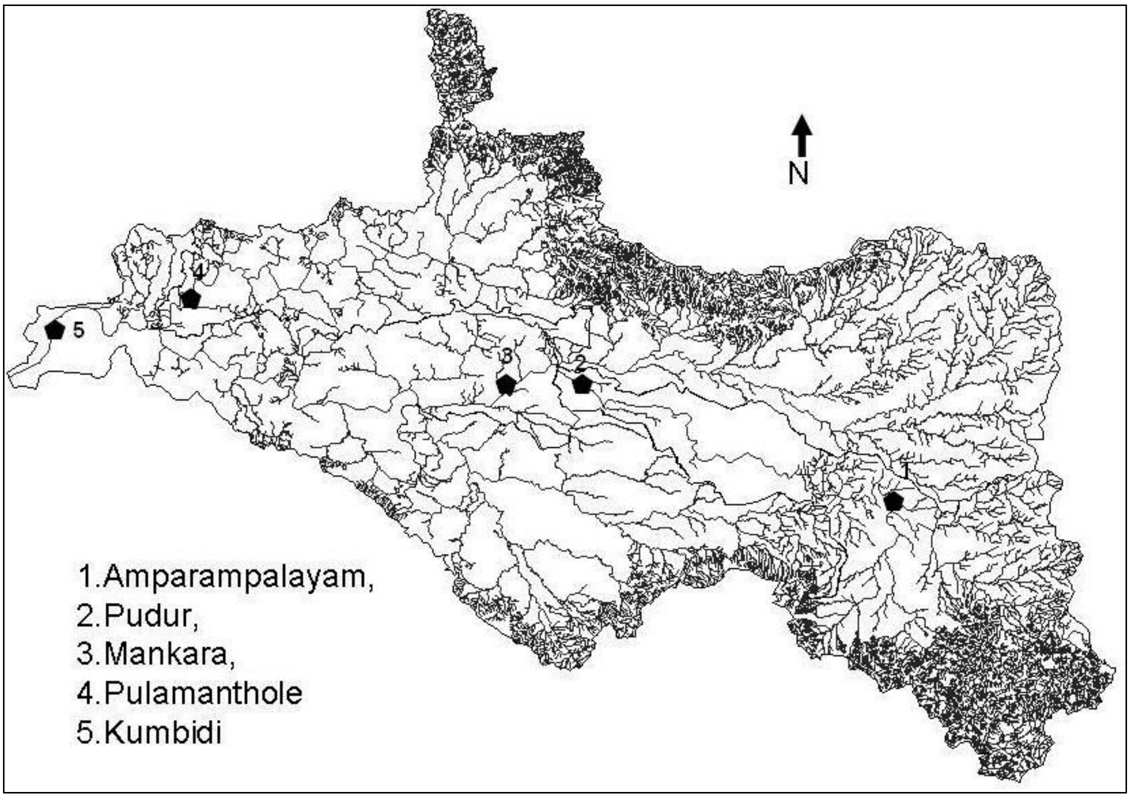


Figure 6.1. Location of river gauge stations in Bharathapuzha River basin

Table 6.1. River gauge stations

River gauge stations	Location	Tributary
Amparampalayam	10°37' N 76°56' E	Chittur river
Pudur	10°46' N/ 76°34' E	Chittur river
Mankara	10°44' N/ 76°28' E	Main river
Pulamanthole	10°53' N/ 76°11' E	Thootha river
Kumbidi	10°50' N/ 76°2' E	Main river

6.3. Results and Discussion

6.3.1. Variation in the river water discharge

The annual total discharge at the five river gauging stations in the basin varied considerably. The discharge also varied with seasons, the river getting its bulk supply of water from the monsoons. The average annual water discharge of the river at Kumbidi, the lowest location in the river course, was 3.94 cubic kilometres (km^3) varying between 3.40 and 10.83 km^3. Among the four tributaries of the Bharathapuzha, the highest average annual discharge was seen at Pulamanthole, located in Thootha River; 1.67 km^3. The lowest average discharge was seen at Pudur; 0.29 km^3 among the years (Table.6.2.). The high contribution from the river Thootha may be for the large stretches of comparatively less disturbed evergreen forests such as Silent valley, Siruvani and Muthikkulam on the upper reaches of the river basin. The forested area may be a significant factor for the consistently high discharge of water round the year. More over the basin apparently falls under "slightly disturbed area'' as per the classification proposed by Gordon et al. (1992). The richly forested area, apparently sponging the rain water (Liu et al., 2004; Tijiu and Xiaojing, 2007), enhance its retention, promote percolation and recharge of ground water, and permit gradual release to the river (Foley et al., 2007). Thick vegetation cover is also known reducing the evapotranspiration loss (Willis, 2002). However increase in evapotranspiration possibly induces rainfall as suggested by Calder (1998). It is felt that difference of opinion arises because of the locational and species wise specificities. Compared to other parts of the Bharathapuzha basin in Thootha River basin, agriculture is less extensive, illicit water diversion from the river basin low and urban pressure is much low. The people's movement in the eighties against the far-famed Silent valley hydro-electric project has put the area on a more eco-sensitive pedestal curtailing all untoward water harvesting projects coming up in the area. All other tributaries of the Bharathapuzha River are dammed up for irrigation projects and exploitation of water for agriculture and other human use is high.

The water discharge of the Bharathapuzha River is almost fully under the control of the monsoon rainfall. The monthly average discharge among the stations was found highest during June-July for all the four stations except Amparampalayam. In Amparampalayam, the peak-flow was during November-December period since the area receives more rainfall and subsequent runoff water during the northeast monsoon (Figure.6.2.).

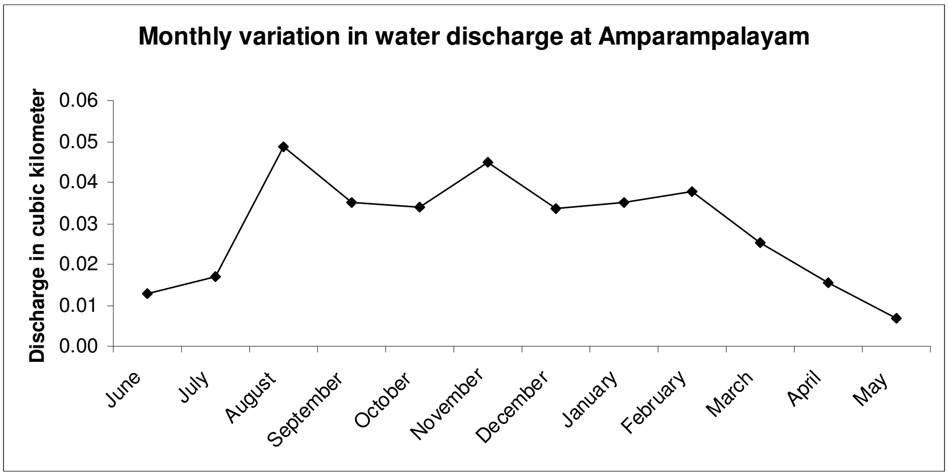
Weed infestation is common in the river bed. The main river at Mankara

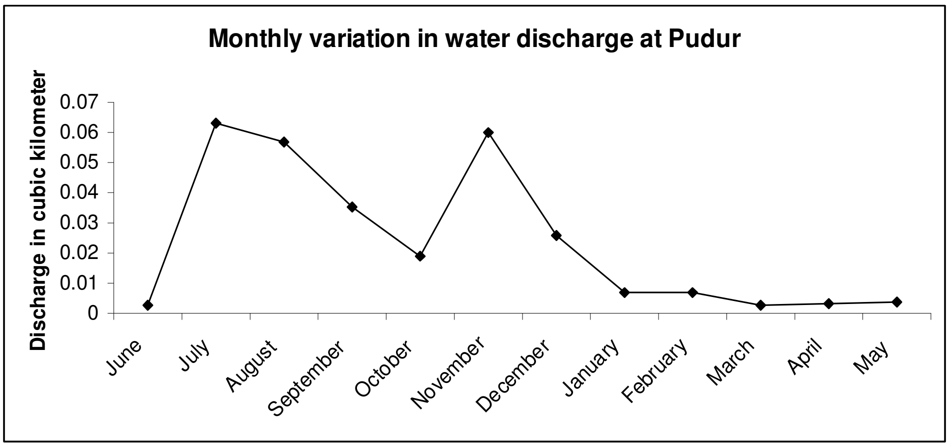
Illegal sand and clay mining is one of the growing environmental issues in the river basin. Heap of sand sacks stored in the river bed near Thrithala

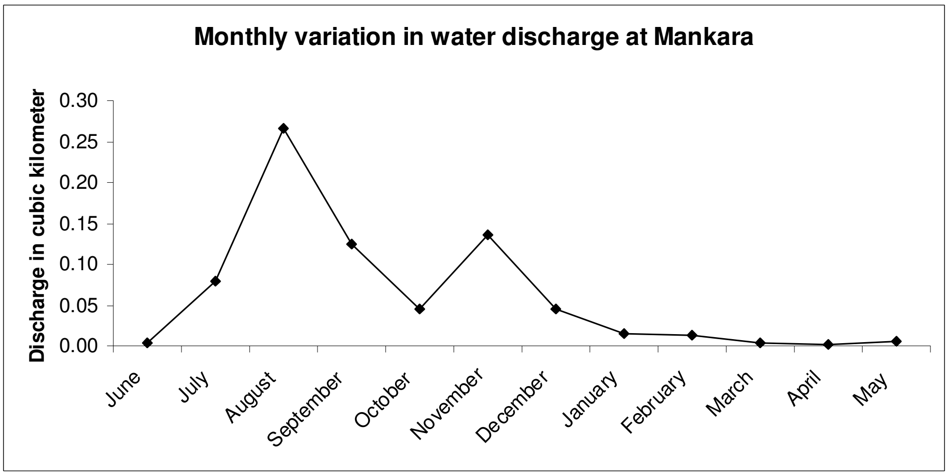
Table 6.2. Discharge profile at various stations in Bharathapuzha River

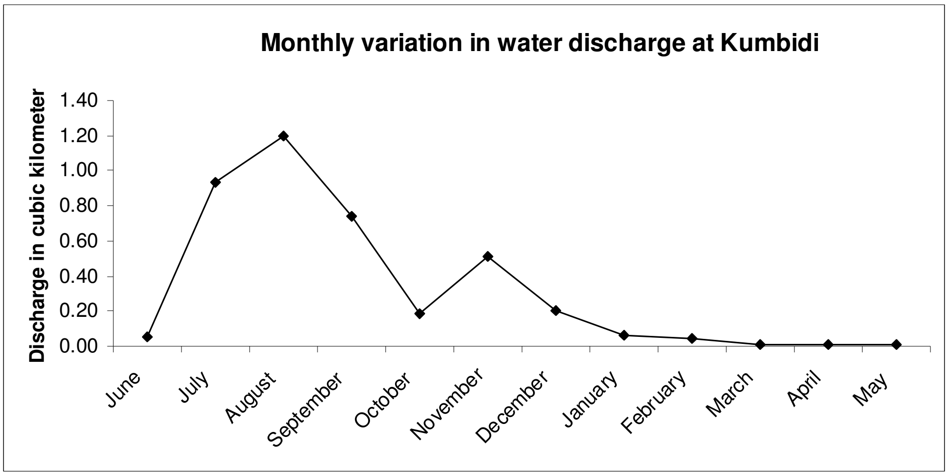
Station	Average discharge (km^3)	Lowest discharge (km^3)	Highest discharge (km^3)
Amparampalayam	0.35	0.06	0.75
Pudur	0.29	0.03	0.75
Mankara	0.74	0.05	1.72
Pulamanthole	1.67	0.11	3.00
Kumbidi	3.94	3.40	10.83

It is found that the monsoon contribute more than 90% of the total annual discharge in all the stations except the Amparampalayam. In the case of Amparampalayam, the monsoon discharge was only about 65% of the total discharge (Figure.6.3.). The discharge during non-monsoon at Amparampalayam, Pudur and Mankara is likely due to the discharges from the reservoirs located upstream in these tributaries; Aliyar dam controls water flow at Amparampalayam and Pudur, and Malampuzha dam and Walayar dam in the case of Mankara (Figure.2.11.). The influence of upstream dams in the river is highest in case of Amparampalayam, while such influence is lowest on the discharge at Kumbidi. The tributary significantly influencing the discharge at Kumbidi might be the river Thootha, where the forest patches at locations like Silent valley, the evergreen forest patch of 89 km^2, ensure consistent flow even in lean seasons, as observed else where by various authors (Foley et al., 2007; Ward et al., 2007; deLinhares et al., 2007). Though the tributary is also embanked by the Kanjirapuzha irrigation project in the Kanjirapuzha river, a tributary of the river Thootha (Nair, 1999), its influence is apparently lesser compared to the river Kunthi another sub tributary flowing from the Silent Valleys National Park.


Monthly variation in water discharge at Amparampalayam
Discharge in cubic kilometer
0.06
0.05
0.04
0.03
0.02
0.01
0.00
June
July
August
September
October
November
December
January
February
March
April
May


Monthly variation in water discharge at Pudur
Discharge in cubic kilometer
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
June
July
August
September
October
November
December
January
February
March
April
May


Monthly variation in water discharge at Mankara
Discharge in cubic kilometer
0.30
0.25
0.20
0.15
0.10
0.05
0.00
June
July
August
September
October
November
December
January
February
March
April
May



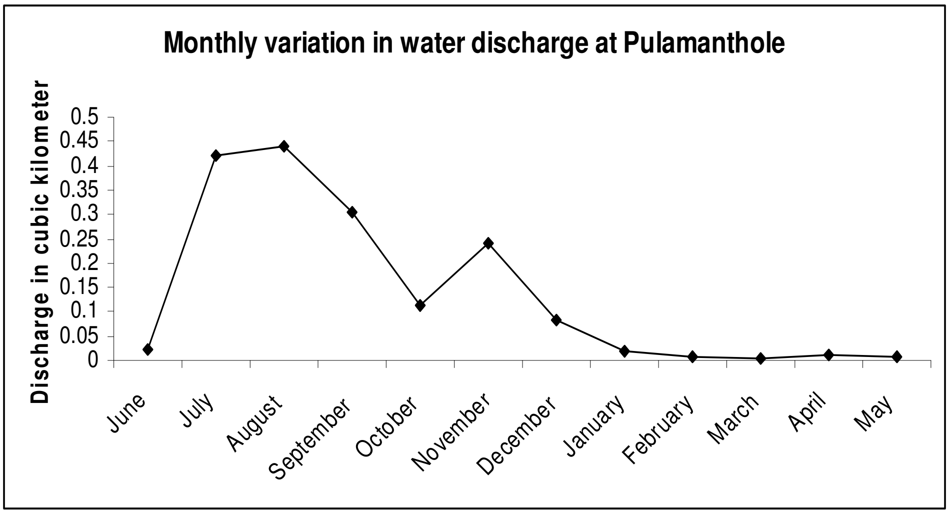


Figure 6.2 Monthly variation in water discharge at different gauge stations at Bharathapuzha River basin

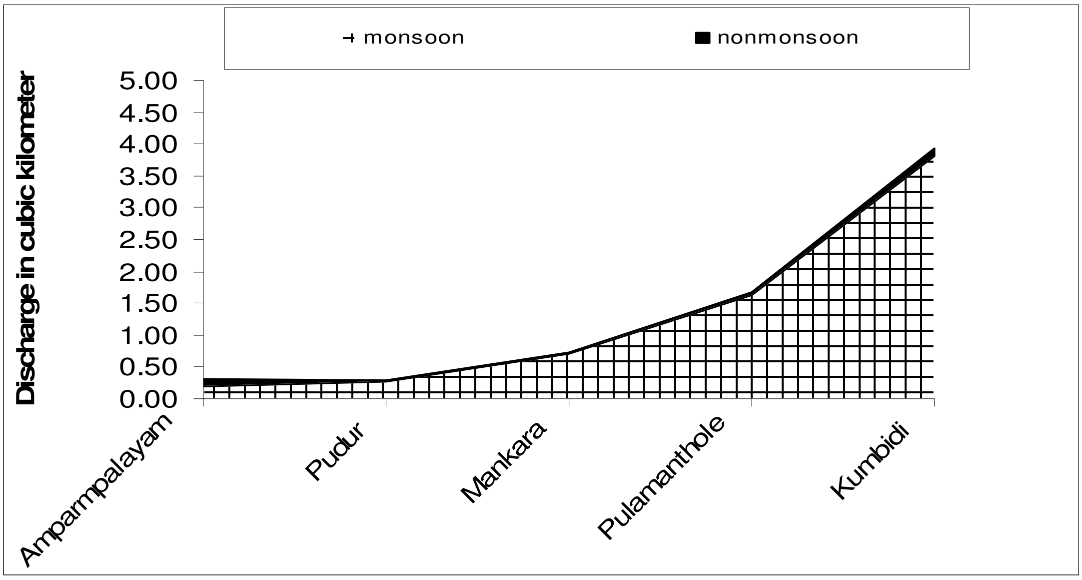


Figure 6.3.Influence of monsoon on river discharge at various stations in Bharathapuzha River

6.3.2. Variation in Water quality

As mentioned in earlier, Hierarchical Cluster Analysis was done (HCA, Figure.6.4.) to explore the spatial variation among different stations. HCA grouped the stations on the basis of similarities in water quality parameters. Among the five stations, the water quality of Amparampalayam, Pudur, Mankara and Pulamanthole were relatively similar while the water quality at Kumbidi was different from all others. This is possibly due to the mixing of water from all the other tributaries, and perhaps for local hydro chemical changes happening due to the mixing, Kumbidi being the lower most location along the river course. The likely seawater incursion in the area also may have its influence (CESS, 2004). The stations coming after high-level water regulations in the form of dams and dykes as in the case of Amparampalayam, Pudur and Mankara were found closer while Pulamanthole the only station with least number of dams upstream was found to lie aside from all other stations.

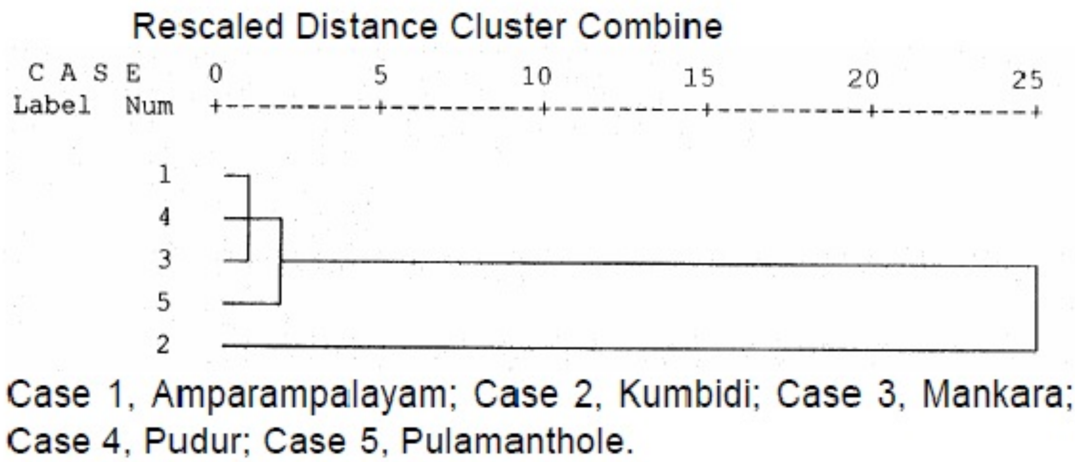


Figure 6.4 Dendrogram Showing Average Linkage between stations

Principal Component Analysis (PCA) was carried out on the whole data set on the chemical composition of the river water to identify the set of factors that could capture the variance of data set satisfactorily. The PCs with Eigen values > 1.32 were selected since the plot of Eigen values against the PCs further to the third PC 3 showed a trend of gradual tapering. On the first PC, the factor loadings for Ca, Cl, K, Na, Mg, PO4, and SiO_3 were high. On the other hand, Fe, NO_3, F, Al and NO_2 were having low factor loadings on the same PC. Fe, NO_3, F, and NO_2 had high factor loadings on the second PC (Table.6.3.). The elements assorted by each PC have been analyzed individually to know the trends in their spatial variation. The PC 1 elements Ca, Cl, K, Na Mg, PO_4 and SiO_3 showed clear variation in their total load (Kg/year) in water at each station, with their load being the highest at Kumbidi, the lower most station (Figure.6.5.) in the river course and close to the estuary. In the case of PC 2 elements Al, Fe, and F, the total annual load was high at Amparampalayam, the upper most station (Figure.6.5.). Regarding the concentration (in mg) of each element, variations among the stations are obvious (Table.6.4), although, there are considerable overlaps in the concentrations ranges.

The fluoride rich rocks such as Fluorspar (CaF_2), Cryolite (Na_3AlFPO_6), Fluorapatite (Ca_3 $(PO)_2$, Ca $(FCl)_2$ may contribute the fluoride in the Bharathapuzha water.

Upstream area of this station is known to be prone to flurosis. Further the early stretches of the command area of the Parambikulam–Aliyar project, an interstate project of contention regarding water sharing between the states of Kerala and Tamil Nadu lies in this stretch (Ravi et al., 2004). The range of chemical parameters in down stream water profile are modified by the diluting and concentrating effects of tributary inflows (Subramanian, 1983) or due to the specific physicochemical characteristics of an element or group that determine their persistence in the water column. For example, reactive elements like Fe is oxidised during its course down and probably gets settled en route. On the other hand, highly conservative element like aluminium does not move down long along the flow and may settled earlier, perhaps this is why aluminium is not seen in the down stream water.

Table 6.3. Factor loadings on the PCs for various water quality parameters of the river Bharathapuzha (Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. A rotation converged in 5 iterations)

	Principal Components		
Parameters	**PC 1**	**PC 2**	**PC 3**
Al	-0.02	0.44	-0.06
Ca	0.97	-0.01	0.09
Fe	-0.01	0.77	0.12
Cl	0.96	-0.03	0.02
CO_3	0.03	0.02	0.81
F	0.01	0.60	0.07
HCO_3	0.20	-0.01	0.00
K	0.95	0.02	0.07
Na	0.96	0.05	0.05
NH_4	0.07	0.02	0.80
NO_2	-0.02	0.54	-0.18
NO_3	0.00	0.74	0.44
PO_4	0.85	-0.08	-0.06
SiO_3	0.85	-0.01	0.02
SO_4	0.45	0.00	0.07
Mg	0.90	0.01	0.02

The higher annual load (Table.6.5.) in elements especially Ca and Mg chiefly arise from the ancient crystalline basement rocks of the Western Ghats. But it is also possible that effluents containing the residues from soaps and detergents (Quadir et al., 2007) cause local enrichment of the elements. Presence of PO_4 on the other hand is possibly from the agriculture run off and also due to other anthropogenic activity like excessive mining (Singh and Hasnain, 1998), although mining is not known to happen in the present study area. The high annual load in Cl, Na, and Mg is perhaps due to salt water incursion from the sea during the time of lean flow in the river. Nitrate and nitrite nitrogen also may be contributed by intensive fertilizer use in agriculture. Being the lower most location, the water flush out to the sea (Ward et al., 2007) at Kumbidi holds sand and sediments in higher level concentration. In the case of SiO_3, Na and K the increase in annual load is likely due to the association of these elements with clay (Dalai et al., 2004).

Table 6.4. Observed range in element concentration (mg) at different locations. (Mean values in bracket).

Element	Amparampalayam	Pudur	Mankara	Pulamanthole	Kumbidi
Ca	16-108.8 (46.43)	0-94.4 (45.14)	0-81.6 (33.35)	0-19.2 (10.63)	0-49.6 (18.81)
Cl	0-73.84 (16.53)	0-46.8 (19.29)	0-49.7 (18.72)	0-31.2 (10.30)	0-33.4 (13.21)
K	0-9.36 (2.76)	0.39-3.51 (2.15)	1.17-5.07 (2.30)	0.39-9.16 (1.28)	0.39-5.07 (1.59)
Na	0-70.84 (17.99)	1.38-40.02 (14.31)	5.06-30.36 (11.99)	0-47.39 (7.52)	2.53-19.09(7.94)
Mg	0.05-35.55 (9.71)	4.331.72 (9.78)	0-60.72 (1.81)	0.96-7.68 (2.13)	0.96-11.04 (4.16)
PO_4	0-2.6 (0.05)	0.04-5.55 (0.45)	0-8.73 (0.53)	0-1.45 (0.24)	0-0.97 (0.28)
SiO_3	20.7-104.4 (44.00)	0.69-68.31 (22.06)	18.1-121.4 (26.23)	8.09-59.34 (19.83)	10.07-68.31(22.07)
Al	0-79.47 (1.95)	0	0	0	0
Fe	0-0.2047 (0.07)	0	0	0	0-0.144 (0.0032)

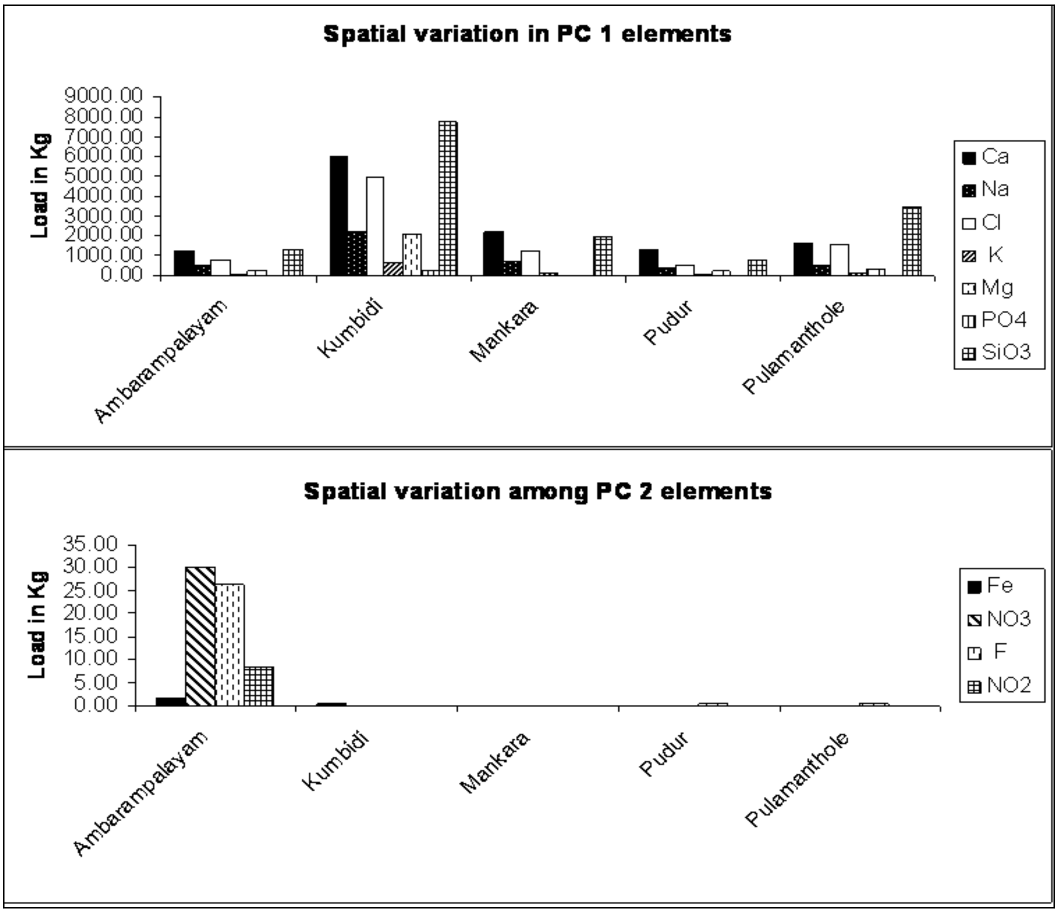


Figure 6.5 Spatial variation in PC 1 and PC 2 elements in Bharathapuzha River basin

Table 6.5. Average annual element loading (kg) at different stations

Element	**Amparampalayam**	**Pudur**	**Mankara**	**Pulamanthole**	**Kumbidi**
Ca	1098.69	3276.74	2227.52	4420.01	11331.81
Cl	1205.61	2421.87	1251.91	1401.47	4902.77
K	118.88	50.15	127.68	125.76	817.94
Na	698.72	376.59	700.30	488.67	5032.15
PO_4	2.01	18.65	42.60	33.88	224.29
SiO_3	1213.93	805.55	1964.72	3208.63	13482.54
Mg^{2+}	401.53	258.87	30.57	320.53	2986.05
Fe	5.23	0	0	0	0.2300
F	40.78	0	0	0	0
No_2	8.49	0	0	0	0
No_3	43.54	0	0	0	0
Co_3	29.14	68.87	22.86	0	11.46
NH_4	3.27	0.07	0	0	3.83

6.4. Summary

The study examines the spatiotemporal variation in water quality and quantity of Bharathapuzha river basin using multivariate statistical analysis tools PCA and HCA. The sub-basins varied notably in terms of river discharge, elemental concentration as well as elemental load. The average discharge of the river basin was 3.94 km^3 per year at the lower most station Kumbidi. The study identified distinct spatial variation in water chemistry. Spatial variations in the water discharge, water quality and elemental load can be due to the differences in land /substrate land cover characteristics and the reduction in forest cover in the catchments and presence of irrigation projects.

*This chapter was published as a research article entitled "Spatial and temporal variation in surface water chemistry of a tropical river, the river Bharathapuzha, India" in Current Science. 96:2, 245-251.

Urbanization in various part of the basin exerts great pressure to the river system. A view of the Palakkad town

There are resorts and tourist retreats flanking the river named after "Nila"; ironically many of them encroach upon the river bed of the dying river. An encroached construction in the river bed at Pattambi

7. Basin related factors and the river discharge

7.1. Introduction

There are growing concerns over the globe regarding the impact of anthropogenic pressure and the current climate changes over several natural resources, ecosystems and species. Rivers and wetlands that have enormous ecological value (Schuyt, 2005) are highly vulnerable to human induced as well as natural instant and gradual changes (Turner, 1991; Naiman et al., 2002). Human pressures and their manifestations on river systems are wide and varied. Local alterations, largely carried out with narrow objectives, and without much considerations of long term impacts, in the form of dams and dykes, diversion of the bulk of water flow for agriculture, industrial or human consumption, municipal waste disposal, embankment and encroachments to cater the various human needs or urbanization, and over exploitation of the river basin and river bed for sand and clay coupled with drought and local temperature hike adversely effect the sustainability of many world rivers (Dai et al., 2010; Changming and Xiaoyan, 2009; Tijiu , and Xiaojing 2007; Wilk and Hughes, 2002).

Measures to assess the health of rivers are debatable. Even so according to Changming and Xiaoyan (2009) continuous and consistent runoff, favorable riverbed and complete drainage system verifies the health of any river. In simple terms the river discharge plays a satisfactory indicator of the well being of the fluvial ecosystems. Apparently the river discharge being directly related with the hydrologic cycle of the basins is an integrated measure of the influence of climate, land cover, and human activities on the hydrologic cycle over a drainage basin (Sharma et al., 2000). Several river basins located across the globe are examined regarding the impact of the contemporary environmental changes on discharges. Fang et al. (2009) studied the Yellow river, China and appraised the direct influence of rainfall (50%) and anthropogenic activities (<50%) on the stream flow in the basin. Sharma et al. (2000) on Kosi river basin of Himalayan range revealed that anthropogenic pressure coupled with the global warming adversely affected the river discharge.

Studies on several river basins have documented the impact of damming on the natural discharge of rivers (Burke et al., 2009; Tukur and Mubi, 2002; Cowell and Stoudt, 2002) and on the natural profile of the river bed which indirectly affects the water discharge (Altaiee and Alhamdani, 1990). Land use / land cover in the basin especially in the upper reaches affects the flow pattern of the rivers, by influencing the sedimentation process and diversions in the natural flow regime (Yang et al., 2004). Expansion of agriculture in the basin is associated with unsustainable water diversions from the rivers. Encroachments in the river beds as well as the natural habitats in the river basins affect the hydrology of the basins (Nilsson et al., 2003).

Perhaps for the unsustainable and irrational water demands, the Bharathapuzha river critical as a support system for over 4.5 million people and more than four hundred thousand hectares of agriculture area, in recent decades is experiencing serious water scarcity sometimes even immediately after the monsoons. The present study attempts to examine the annual discharge in the river in relation with various anthropogenic and climatic parameters.

7.2. Methodology

To examine the trend in annual river discharge 37 years (1968-2005) of discharge data from twelve river gauge stations from the Irrigation department (Government of Kerala) and Central Water Commission (CWC) were used. Similarly the rainfall data and temperature data for the same time period were used (See chapter 5.)

The land use land cover changes in the river basin were examined as discussed in the previous chapter (Chapter 6.). Since continuous data on land use / land cover for the (LULC) basin is not available, I resorted to a method of gross approximation of the data on LULC; the land use land cover data of the three periods were used to extrapolate and estimate the data for the whole period of the study. Using linear regression methods, and using the best fit lines for the available data (Appendix. 1.), backward and forward extrapolations were made. For the unavailability of data from remote sensing or other sources of land use change data, this was the only logically and reasonably apt. Man-

Kendall rank correlation analysis was used to test the temporal changes in annual discharge, and its association with other factors.

Multiple regression analyses coupled with partial regression analyses have been carried out to find the most influential parameters that determine the river discharge and to find out the weight of each parameter on the annual river discharge. The multiple regression analysis could be regarded as a convenient and to a great extend robust tool to find the respective weights among two or more factors. It is also applicable in testing hypothesis as well as prediction or interpolating the relationships (Zar, 1999; Nawaz and Adeloye, 1999). It is assumed that both climatic and anthropogenic factors influenced greatly the discharge trend in Bharathapuzha river basin. The factors such as rainfall, rain days, maximum, minimum and mean temperatures were considered as the climatic factors while the land use / land cover changes in natural vegetation, water bodies, agriculture, plantation, urbanization, roads were considered as the anthropogenic factors. For generating unbiased results, the area under plantation and agriculture were merged together since the means of utilization of river water is same by both these factors. Thus the factors were classified in to two; those likely to influence the river discharge positively and those having a negative influence on it. It was assumed that rain days, rainfall, natural vegetation, roads and water bodies to be positively related with the river discharge and the temperature, urban area and agriculture area to be inversely related with discharge (Figure. 7.2.).

7.3. Results and discussion

It is interesting and useful to examine the annual trend of discharge of a river and the factors that influencing that. The data extending for almost four decade shows the average discharge in Bharathapuzha river basin to be 5.39 km^3 (STDEV±1.58). Man-Kendall rank correlation analysis shows a significant ($p<0.01$) decreasing trend in the discharge as the years proceeds (t= -0.604, Table.7.1, Figure.7.1). This decreasing trend in discharge has to be further examined to identify other determinant factors. The correlation analysis of various parameters on discharge shows a significant positive correlation ($p<0.01$) with rainfall and natural vegetation; ($p<0.05$ levels). Variables such as rain days and area under roads also show positive correlation, though not statistically significant (Table 7.2).

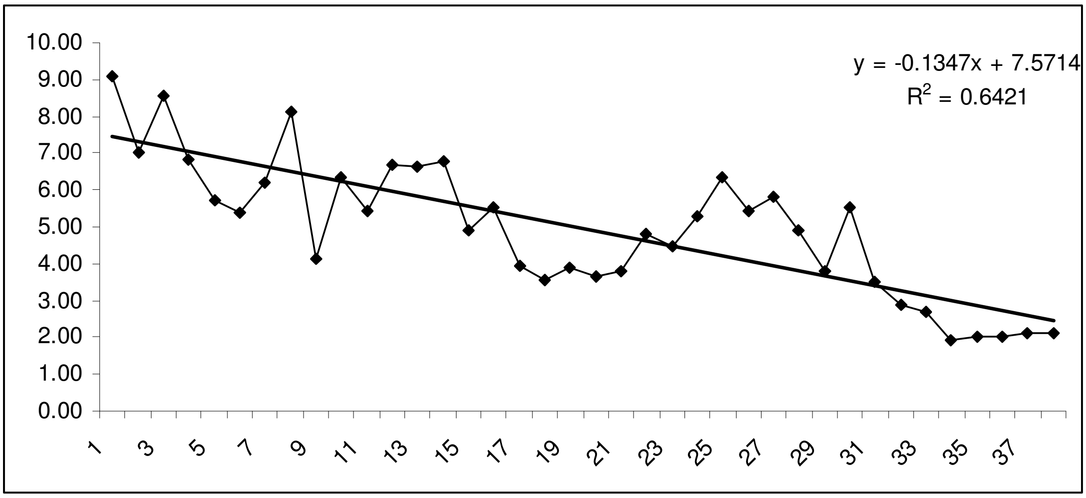


Figure 7.1 Temporal trend in annual discharge in the Bharathapuzha River basin

It is plain that rainfall acts directly on the river discharge (Pfister et al., 2000), save for the physical structures in the catchment altering its influence. Our study on seasonal fluctuation in the river discharge (Raj and Azeez, 2009a) also confirms the importance of rainfall on the river discharge. Alongside, the study on the general rainfall in the basin shows a statistically significant decreasing trend as the year proceeds (Figure.5.1.2.). The rain days on the other hand although tending positive with the river discharge, is not statistically significant (Table.7.1. and Figure.7.2.). Similarly the temporal trend analysis of rain days shows a decreasing trend in the total rain days (Figure.5.1.9.) in the basin. The study by Ramesh and Goswami (2007) also reported a decreasing trend in the effective rain days in the Indian subcontinent. The roads lead to diversion of water flow during rains; perhaps this is reflected in the result, as the roads show a positive relationship with the discharge, not statistically significant (Table.7.2.). A large study area would have helped us to elucidate this relation.

The area under water bodies ($p<0.01$), and the agriculture area ($p<0.01$ levels) shows a negative correlation with discharge. Other parameters such as maximum temperature (T max), minimum temperature (T min), mean temperature (T mean), and area under urban centre shows a negative relationship with discharge; nevertheless they are not statistically significant (Table.7.1.). The area under water bodies represents all the artificial water bodies such as dams, ponds in the basin. It is clear that the dams and other embankment reduces or curtail the natural flow in the river especially in the lower reaches. In the basin there are 11 such dams and irrigation projects (Table.1.1.). Of this Aliyar dam located in the Chittur basin is a part of the Parambikulam Aliyar Project (PAP), an interstate water diversion scheme utilizing the water resources of three river basins, viz, River Bharathapuzha, Periyar and Chalakkudipuzha, by Kerala and Tamil Nadu (Ravi et al., 2004). As a part of the existing administrative conflict in sharing the water resources between the states, the river water is believed to face diversion from its upper catchment, which is likely to have a negative impact on the total water discharge in the river basin (Sadasivan, 2003).

The discharge and the agriculture area in the Bharathapuzha river basin shows a statistically significant ($p<0.01$) inverse relationship (Table.7.2.). Switching forested area to agriculture uses will alter the river discharge due to the change in the vegetation type and will have a brief effect during the ground preparation stage such as ploughing, draining and felling (Hudson et al., 1997). The over exploitation of water and diversion for agriculture is a common practice in the Bharathapuzha basin (Kumar, 2001).

Table 7.1. Man-Kendall's rank correlation analysis showing the relation ship between discharge and other parameters

Variables	**Coefficient**
Rainfall	0.442**
Rain days	0.17
T max	-0.15
T min	-0.063
T mean	-0.103
Natural vegetation	0.277*
Water bodies	-0.459**
Roads	0.166
Agricultural area	-0.451**
Urban centers	-0.166

** Significant at 0.01 and*0.05 levels

Taking the above observations as the cue, a multiple regression model was attempted, anticipating that the discharge of the basin could be predicted using the above variables. While we used all the factors through a step wise and multiple regression exercise the result was the model equation given below.

Qw = 13879.29 + (-0.36*Aw) + (4.752*Rf)

Where Qw is the discharge, Aw denotes area under water bodies and Rf is the annual rainfall in the basin.

It can be noted that variables like maximum, minimum, and mean temperature, natural vegetation, area under roads, urban centres, agricultural area and total rain days were excluded due to their lower weight on the river discharge.

Table 7.2. Summary of the Multiple Regression model

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Change Statistics				
					R^2 Change	F Change	df1	df2	Sig. F Change
1	0.740	0.547	0.521	3091.44	0.130	10.085	1	35	0.00

Predictors: (Constant) Area under water bodies, Rainfall
Dependent Variable: Discharge

Table 7.3. Regression Model for predicting discharge in Bharathapuzha river basin

Model	Unstandardized coefficient		t	Significance	Partial correlation coefficient
	β	Std error			
Constant	13879.29	4218.85	11.62	0.002	
Area under water bodies (W)	-0.36	0.08	-4.35	0.000	-0.592
Rainfall (RF)	4.752	1.49	3.18	0.003	0.473

The regression model generated is highly significant (R^2= 0.521, Table.7.3.). The multiple regression analysis refined our result focusing only on two out of the ten factors. The area under water bodies (p=0.000, R^2= 0.400) and rainfall (p=0.003, R^2= 0.293) were found to be influencing factor.

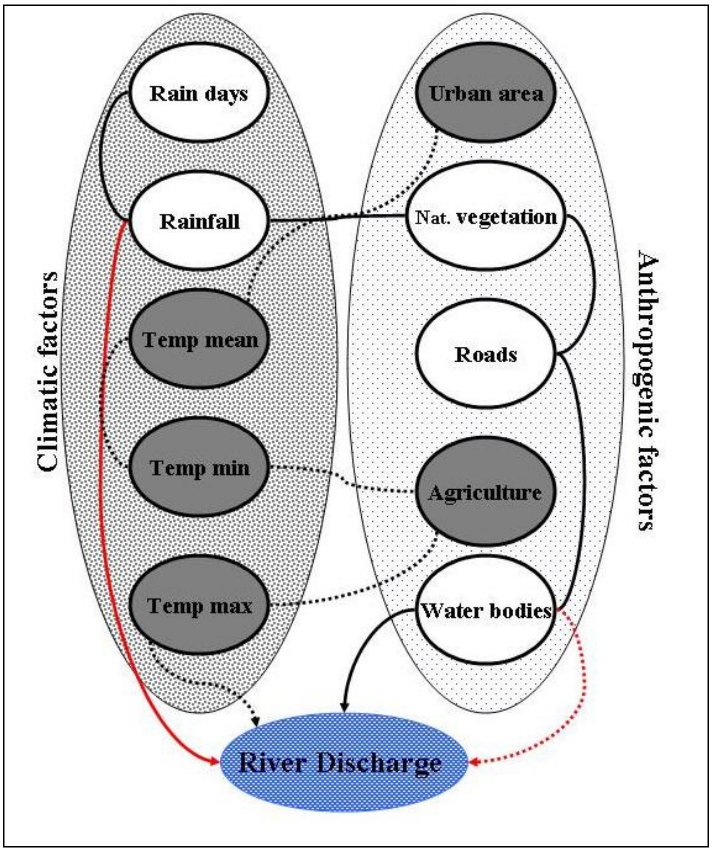


Figure.7.2. Schematic representation of the factors influencing the river discharge in the Bharathapuzha River basin. Black lines represent the hypothetical scenario, while red line marks the results after the analysis. Thick lines denote the positive relationship while the dotted one the inverse relationships among the factors.

Concurrent results on the decreasing trend of rainfall in the basin (See Chapter.5.1.) in this context will have a crucial role in determining the health of the river in the coming years. The presence of dams and the other human made water storage structures have a negative effect on the river discharge. Many of the streams in the river basin, especially Kunthi river at Silent Valley, Thuppanadupuzha river in the Chenat Nair RF have gone through pressures from various corners for harnessing for irrigation as well as power generation, during the last couple of decades that would have seriously affected the discharge in the Bharathapuzha river.

7.4. Summary

The discharge of a river could be a reflection of the health of the river, and can be considered as an integrated effect of climate, land cover, and human activities over a drainage basin. The present study analyzes the trend in annual discharge and the factors affecting the annual discharge in the medium river basin, Bharathapuzha river basin, India, using Man-Kendall rank correlation and multiple regression methods. Our examination of the discharge for more than three decade shows a decreasing trend in annual discharge in the basin. Among the variable rainfall was found to be the factor with highest influence on the annual discharge. Rain days, forest cover, area under agriculture, are other parameters with notable positive consequence on the discharge. While maximum, minimum and mean temperature, area under plantation, urban and road area expansion are negatively influencing the river discharge. The multiple regression model, attempted using all the possible factors reduced the factors functionally influencing the discharge as rainfall and water bodies.

8. Summary

The world's fresh water resources are depleting at a fast pace. It is believed that the current fresh water crisis will escalate in the future to proportions that could trigger another world war. The United Nations has identified 300 potential water conflict zones over the globe in various river basins. Concern regarding the conservation of fresh water resources, especially rivers, started during the second half of 20th century in India. Several authors have studied almost all the large river basins in India covering various aspects. However medium sized rivers and small rivers are yet to be studied, despite many of them being the life line for a large number of people and relatively more vulnerable to damage. The case of almost all the west flowing medium sized rivers in southern India especially in the state of Kerala also conform to this situation. A timely analysis and documentation of the environmental and ecological status of these rivers can help in identifying appropriate measures towards effectively improving the environmental quality of the river basins and their sustainable development.

In this context the present study attempts to analyze the environmental status of the Bharathapuzha river basin, a medium sized river basin and the second longest (209 km) amongst the west flowing perennial rivers in Kerala. It originates from the Western Ghats as brooks and rivulets that later form four major tributaries namely Kalpathipuzha, Gayathripuzha, Thootha, and Chitturpuzha. The main river finally discharges into the Arabian Sea at Ponnani on the west coast. The river has a total basin area of 6,186 km^2 of which 4,400 km^2 falls in the state of Kerala and the rest in Tamil Nadu. The river basin covers a ninth of the total geographical area of Kerala. The flow regime of the river covers highlands (> 76 m), midlands (76-8 m) and the lowlands (< 8 m). The river currently faces tremendous pressure due to encroachments, sand and clay mining, and illegal diversion of water. The river is the life line water resource for a population of 4.6 million residing in four administrative districts of Kerala, namely Malappuram, Thrissur and Palakkad and Coimbatore and the Tiruppur district of Tamil Nadu. There are eleven irrigation projects and several check dams in the river basin catering to 493064 ha of cultivations. However, the basin remains relatively undocumented with respect to important baseline information. Given this background, the present study was undertaken with the following objectives;

- To study the morphometric characteristics of the river basin
- To investigate the land use changes that happened in the basin during the last three decades,
- To evaluate the meteorological status of the river basin,
- To study the quality and quantity of surface water in the river course, and
- To examine major factors influencing the river discharge in the basin.

The morphometric characters of the river basin were analyzed using the Survey of India (SOI) topographic map series (58 A/4, A/8, A/12, A/16, E/4, B/1, B/5,B/9,B/13, B/2, B/6,B/10, B/14,F/2, B/11, B/15, F/3; 49 N/13, N/14) of scale 1:50,000. These topographic maps were used as base maps for delineation of Bharathapuzha River basin and its sub-basins. Land-sat imageries (available at www.landcover.org) were also used for the analysis. The slope and relief of the basin were examined using the digital elevation model data (DEM, available at www.asterdem.com). Stream order, stream length, mean stream length, stream length ratio, bifurcation ratios, mean bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, circulatory ratio and elongation ratio were estimated. Arc GIS 9.3 and ERDAS IMAGINE 8.5 were used for the entire study. The baseline data on the morphometric characteristics of the river basin as well as its sub- basins were generated.

Bharathapuzha River basin is a seventh order river basin with four sub-basins. The drainage pattern of the Bharathapuzha River basin is dentritic. The mean stream length of the river ranged from 0.69 km to 166.17 km among different stream orders. The drainage texture of the basin can be categorized as 'fine'. The elongation and circulatory ratios show the elongate nature of the basin. The peculiar location in the Palakkad Gap of the Western Ghats with unique geological characteristics greatly influences the morphology of the river basin. Other aspects such as slope, relief, and environmental factors such as rainfall also contributed considerably to the basin morphology.

The Land Use and Land Cover changes (LULC) that had happened in the river basin during the last three decades were analyzed using multispectral LANDSAT TM data, with a pixel resolution of 30 m collected for the years 1973, 1990 and 2005, for the entire basin, from the Global Land Cover Facility. After delineating the basin area with SOI topographic maps we used Arc GIS 9.3 and ERDAS IMAGINE 8.5 for the entire analysis. The study could find extensive changes in the LULC in Bharathapuzha river basin; in terms of reduction in the natural vegetation cover, increase in the urban area, decrease in area under wetland agriculture, and increase in road density. The urban spread in the basin has increased by 32%, during the period of the present study. 31% of the natural vegetation covers and 8.69% of wetland agriculture area in the basin have depleted in three decades. The area under road has increased by 6.8% in the basin during the period (1973-2005) while the area under plantation showed a steep increase during the first half (1973-1990) of the study period and started reducing during the second half (1990-2005).

Meteorological data (rainfall and temperature) were procured from various departments and analysed to locate patterns. Rainfall data of 34 years (1968-2002) from 29 rain gauge stations located in the basin were collected and analyzed for various descriptive measures such as mean (Normal), standard deviation (STDEV) and Coefficient of variation (CV). The data is categorized in four rainy seasons; the south west monsoon (June-September), the north east monsoon (October- November) the pre monsoon months (March - May) and the winter months (December- February). Time series of data were examined for different temporal changes with the aid of various statistical analyses. The study revealed significant decrease in annual, pre monsoon and south west monsoon rainfall in the study area. No significant decrease could be seen in the north east monsoon. The daily maximum, minimum and mean temperatures during the period 1969-2005 collected from the IMD, Pune for the entire basin were also examined for its trend. The historical data analysis on temperature revealed that there is a significant rise of 0.27º C in the annual temperature over the basin. The temperature hikes are also obvious for certain seasons.

The hydrology especially the spatio-temporal variation of surface water chemistry and river discharge were analyzed from various data sources (CWC, Government of India) for 10 water years (1993-2003) for the five river gauge stations in the basin. Multivariate statistical techniques like Hierarchical Cluster Analysis (HCA), and Principle Components Analysis (PCA) were used to segregate and examine the water quality data. HCA is used to see the spatial variation in water quality as well as quantity among stations. The average discharge of the river basin was found to be 3.94 km^3 per year at the lower most station Kumbidi. The study identified distinct spatial variation in water chemistry. Spatial variations in the water discharge, water quality and elemental load can be due to changes in land use especially the reduction of forest cover in the catchments and the presence of irrigation projects.

Environmental changes that took place in the river basin were examined for their role in influencing the discharge of the basin. Historical data sets on rainfall and temperature were used along with the land use change data of the basin, which was acquired through the analysis of imageries. Multiple regression analyses and partial regression analyses were carried out to identify the most influential parameter which determined the river discharge and to measure the influence of each parameter towards the river discharge. Results show that the annual river discharge in the basin decreases significantly with time. Among the variables area under water bodies especially dams and manmade water ponds and annual rainfall show high significance with the annual discharge in the basin.

The present study thus accentuates the major environmental changes happening in the river basin. To summarize, the information generated during the study reiterates the necessity of a scientific management plan for conserving the highly vulnerable medium river in rapidly changing global climatic conditions.

9. Appendices

Appendix.1.

Item	Regression equation	R^2
Area under natural vegetation	y = 336.24x2 - 17203x + 271325	1
Agriculture area	y = -105.25x2 + 1882.6x + 161361	1
Area under plantation	y = -143.14x2 + 5035.7x + 38841	1
Area under urban center	y = -148.39x2 + 10662x + 47088	1
Area under water bodies	y = -54.384x2 + 1492.2x + 20952	1
Area under road	y = 81.448x2 - 1278.8x + 45809	1

Appendix.2: List of research articles published during the study period

Raj, N. and Azeez, P.A. 2009. Spatial and temporal variation in surface water chemistry of a tropical river, the river Bharathapuzha, India. Current Science. 96(2): 245-251.

Raj, P.P.N. and Azeez, P.A. 2009. Real estate and agricultural wetlands in Kerala. Economic and Political Weekly. XLIV(5): 63-66.

Raj, N. and Azeez, P.A. 2009. The shrinking rice paddies of Kerala. India Economy Review. VI: 176-183.

Raj, N. and Azeez, P.A. 2009. Development of a city and disappearing urban water bodies: a case from Palakkad city of Kerala, India. 3(1): 20-21.

Raj, P.P.N. and Azeez, P.A. 2009. Climate change congress at Copenhagen. Current Science. 97(3): 299.

Raj, P.P.N. and Azeez, P.A. 2010. Deteriorating health status of Kerala state, India: an environmental and cultural diagnosis. Seronica. 1(1); 23-27.

Raj, P.P.N. and Azeez, P.A. 2010. Changing rainfall in the Palakkad plains of south India. Atmósfera. 23(1): 81-88.

Raj, P.P.N. and Azeez, P.A. 2010. Public on Conserving an urban wetland: a case from Kerala, India. International Journal of Social Ecology and Sustainable Development, 1(1), 14-19.

Raj, N. and Azeez, P.A. 2009. The general rainfall trend using the historical data: a case from the Palakkad plains of Kerala. In: Climate Change, Biodiversity and Food Security in the South Asian Region (Eds: Jerath N; Bhooj R; and Singh G) PSCS&T, Chandigarh and UNESCO, New Delhi.Macmillian Publishers India Ltd, New Delhi

Raj, P.P.N; Ranjini, J; Dhanya R and Azeez, P.A. 2009. Energy scenario and environmental implications: an over view of Kerala, India. Journal of Environment and Energy. 1 (1): 60-76.

Raj, N. and Azeez, P.A. 2009. Historical analysis of the first rain event and the number of rain days in the western part of Palakkad gap, south India. Climate change: global risks, challenges and decisions IOP Conf. Series: Earth and Environmental Science.

10. References

Altaiee, T. and Alhamdani, A. 1990. Morphological variations of a certain Tigris River reach for different periods in Iraq. (www.balwois.com).

Ananthakrishnan, R., Parthasarathy, B. and Pathan, J.M. 1979. Meteorology of Kerala. Contributions to Marine Sciences. 123- 125.

Angillieri, M.Y.E. 2008. Morphometric analysis of Colangu¨ il river basin and flash flood hazard, San Juan, Argentina. Environmental Geology. 55: 107–111.

Arora, M., Singh, P., Goel, N.K. and Singh, R.D. 2006. Spatial Distribution and Seasonal Variability of Rainfall in a Mountainous Basin in the Himalayan Region. Water Resource Management. 20: 489–508.

Arun, P.R. 2000. Seasonality and abundance of insects with special reference to butterflies (Lepidoptera:Rhopalocera) in a moist deciduous forest of Siruvani, Nilgiri Biosphere Reserve, South India. Ph.D. Thesis, Bharathiar University, Coimbatore.

Ashley, W.S., Mote, T.L., Dixon, P.G., Troti'er, S.L., Powell, E.J., Durkee, J.D. and Grundstein, A.J. 2003 Distribution of mesoscale convective complex Rainfall in the United States. Monthly weather review. 131: 3003-3017.

Avvannavar, M.S. and Shrihari, S. 2007. Evaluation of water quality index for drinking purposes for river Netravathi, Mangalore, South India. Environmental Monitoring and Assessment. (On line) 2007.

Ayyar, V.T.V. 1939. A revised working plan for the forests of the Walayar, Bolampatty and Thadagam valley. Palghat Forest Division. 1937-1946.

Azeez, P.A., Bhupathy, S., Rajasekharan, A., Arun, P.R., Stephan, D. and Kannan, D. 1999. Comprehensive EIA (Botanical and Zoological aspects) of the proposed Puyankutty Hydroelectric Project, Kerala. Sálim Ali Centre for Ornithology and Natural History (SACON), Coimbatore, Tamil Nadu.

Azeez, P. A., Bhupathy, S., Rajasekaran, A. and Arun, P. R. 2004. Ecodevelopment plan for Mangalavanam Bird Sanctuary, Cochin, Kerala. Sálim Ali Centre for Ornithology and Natural History (SACON), Coimbatore, Tamil Nadu.

Basistha, A., Goel, N.K., Arya, D.S. and Gangawar, S.K. 2007. Spatial pattern of trend in Indian sub-divisional rainfall. Jalavigyan Sameekha. 22: 47-57.

Bates, B.C., Kundzewicz, Z.W., Wu, S. and Palutikof, J.P. 1995. Second assessment synthesis of scientific-technical information relevant to interpreting article 2 of the UN framework convention on climate change.

Bates, B.C., Kundzewicz, Z.W., Wu, S. and Palutikof, J.P. 2008. Climate change and water. Technical paper of the intergovernmental panel on climate change, secretariat, Geneva, pp. 210.

Bhaduri, B., Harbor, J., Engel, B. and Grove, M. 2000. Assessing watershed-scale, long-term hydrologic impacts of land-use change using a GIS-NPS model. Environmental Managemant. 26(6): 643–658.

Bidin, K. and Chappell, N.A. 2006. Characteristics of rain events at an inland locality in northeastern Borneo, Malaysia. Hydrological Processes. 20: 3835–3850.

Buchanan, M.D.F. 1807. A journey from Madras through the countries of Mysore, Canara and Malabar. vol. 2. Published under the authority of and patronage of the honorable directors of East India company, London.

Burguen˜o, A., Serra, C. and Lana, X. 2004. Monthly and annual statistical distributions of daily rainfall at the Fabra Observatory (Barcelona, NE Spain) for the years 1917–1999. Theoretical and Applied Climatology. 77: 57–75.

Burke, M., Jorde, K. and Buffington, J.M. 2009. Application of a hierarchical framework for assessing environmental impacts of dam operation: changes in stream flow, bed mobility and recruitment of riparian trees in a western North American river.

Calder, I. 2000. Land use impacts on water resources. Land-water linkages in rural watersheds. Electronic Workshop, 18 September-27 October 2000, Food and Agriculture Organization of the United Nations, Rome, Italy.

Calder, I.R. 1998. Water-resource and land-use issues. SWIM Paper 3. Colombo, Sri Lanka: International Water Management Institute.

Census of India. 2001a. District Census Hand Book Palakkad.

Census of India. 2001b. District Census Hand Book Thrissur.

Census of India. 2001c. District Census Hand Book Malappuram.

Census of India. 2001d. District Census Hand Book Coimbatore.

Centre for Earth Science Studies (CESS), 2004. Bharathapuzha and its problems with special reference to sand mining from the river stretch between Chamravattom and Thirunavaya.

Centre for Earth Science Studies (CESS), 2004. Bharathapuzha and its problems with special preference to sand mining from the river stretch between Chamravattom and Thirunavaya, Centre for Earth Science Studies, Thiruvanathapuram.

Chandran, M.D.S. 1997. On the ecological history of the Western Ghats. Current Science. 73(2): 146-155.

Chandrashekara, U.M. 2005. Anthropogenic pressure on structure and composition of a shola forest in Kerala. Indian Journal of Mountain Science. 3(1): 58-70.

Changming, L. and Xiaoyan, L. 2009. Healthy river and its indication, criteria and standards. Journal of Geographical Science. 19: 3-11. DOI: 10.1007/s11442-009-0003-6.

Chattopadhyay, S. and Chattopadhyay, M. 1997. Sustainable land management in Kerala, India-A bio-physical approach. Proc. Geo-Information for Sustainable Land Management (SLM), (eds.) K.J. Beek, K.D. Bie & P. Driessen), Enschede, ITC J. 3(4): 165-174.

Chattopadhyay, S. 1985. Deforestation in parts of Western Ghats region (Kerala), India. Journal of Environmental Management. 20: 219-230.

Chow, V.T. 1964 (ed.). Handbook of applied hydrology. McGraw Hill Inc, New York.

Chung, U., Choi, J. and Yun, J.I. 2004. Urbanization effect on the observed change in mean monthly temperatures between 1951–1980 and 1971–2000 in Korea. Climate Change. 66: 127–136.

Convention on Biological Diversity (CBD), 2005. Inland waters biodiversity introduction. Secretariat of the convention on biological diversity, montreal. http://www.biodiv.org/programmes/areas/water/default.asp

Cowell, C.M. and Stoudt, R.T. 2002. Dam-induced modifications to Upper Allegheny river stream flow patterns and their biodiversity implications. Journal of American water Resource Association. 38(1): 187-196.

CWRDM, 2004. Master plan for drought mitigation in Palakkad district. CWRDM/WMD/04/2.

CWRDM. 1991. Water resources development of Bharathapuzha basin, a status report.

D'Cruz, E., Nair, P.K.R. and Prasannakumar, V. 2000. Palghat gap - A Dextral shear zone from the south Indian granulite terrain. Gondwana Research. 3(1): 21-31.

Dade, W.B. 2001. Multiple scales in river basin morphology. American Journal of Science. 301: 60–73.

Dai, Z.J., Du, J., Chu, A., Li, J., Chen, J. and Zhang, X. 2010. Groundwater discharge to the Changjiang River, China, during the drought season of 2006: effects of the extreme drought and the impoundment of the three Gorges Dam. Hydrogeology Journal. 18: 359–369. DOI 10.1007/s10040-009-0538-8.

Dalai, T.K., Rengarajan, R. and Patel, P.P. 2004. Sediment geochemistry of the Yamuna River system in the Himalaya: implications to weathering and transport. Geochemical Journal. 38: 441-453.

Das, K.S.A. 2008. Bird community structure along the altitudinal gradient in Silent Valley National Park, Western Ghats, India. Ph.D. Thesis, Bharathiar University Coimbatore.

Dash, S.K., Jenamani, R.K., Kalsi, S.R. and Panda, S.K. 2007. Some evidence of climate change in twentieth-century India. Climate Change. 85: 299–321.

De, U.S. 2001. Climate change impact: Regional scenario. Mausam, 52: 201–212.

DeWit, M.J.M., Hurk, B.V.D., Warmerdam, P.M.M., Torfs, P.J.J.F., Roulin, E. and Deursen, W.P.A. 2007. Impact of climate change on low-flows in the river Meuse. Climate Change. 82: 351–372. DOI 10.1007/s10584-006-9195-2

Dow, K. and Downing, E.T. 2007. The atlas of climate change: mapping the world's greatest challenge, Earthscan U. K.

Eapen, M. 1999. Economic diversification in Kerala: a spatial analysis. Centre for Development Studies, Thiruvananthapuram.

Eltahir, A.B.E. 1992. Drought frequency analysis of annual rainfall series in central and western Sudan. Hydrological sciences-Journal. 3: 6.

Fang, Z.F., Xue, X.Z., Lu, Z. and DePeng, Z. 2009. Stream flow response to climate variability and human activities in the upper catchment of the Yellow River Basin. Sci. China Ser. E-Tech Sci. 52:11, 3249-3256. DOI: 10.1007/s11431-009-0354-3

Fasullo, J. and Webster, P.J. 2003. A hydrological definition of Indian monsoon onset and withdrawal. Journal of climate. 16: 3200-3211.

Fischer, G., Tubiello, F.N., Velthuizen, V.H. and Wiberg, D. 2006. Climate change impacts on irrigation water requirements: global and regional effects of mitigation, 1990–2080. Technological Forecasting and Social Change. 74. DOI:10.1016/j.techfore.2006.05.021.

Foley, J.A., Asner, G.P., Costa, M.H., Coe, M.T., DeFries, R., Gibbs, H.K., Howard, E.A., Olson, S., Patz, J., Ramankutty, N. and Snyder, P. 2007. Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. Frontiers in Ecology and Environment. 5:1, 25–32.

Fung, T. and Zhang. Q. 1989. Land use change detection and identification with Landsat digital data in the Kitchener–Waterloo area, In: Remote Sensing and methodologies of land use change analysis, C.R. Bryant and E.F. LeDrew, (eds.), Canada, Department of Geography, University of Waterloo. 135-153.

Gadgil, A. and Dhorde, A. 2005. Temperature trends in twentieth century at Pune, India. Atmospheric Environment. 39: 6550–6556.

Gadgil, S. and Joseph, P.V. 2003. On breaks of the Indian monsoon. Proceedings of the Indian Academy of Sciences. (Earth and Planetary Science). 112: 529-558.

Galster, J.C., Pazzagila, F.J., Hargreaves, B.R., Morris, D.P., Peters, S.C. and Weisman, R.N. 2007. Natural and anthropogenic influences on the scaling of discharge with drainage area for multiple watersheds. Geosphere 3: 260-271.

Garrels, R.M., Mackenzie, F.T. and Hunt, C. 1975. Chemical cycle and the global environment. William Kaufman, New York, pp. 260.

Gaur, V.K., Gupta, S.K., Pandey, S.D., Gopal, K. and Misra, V. 2005. Distribution of heavy metals in sediment and water of river Gomti. Environmental Monitoring and Assessment. 102: 1-3.

George, P.S. and Chattopadhyay, S. 2001. Population and land use in Kerala, Growing populations, changing landscapes: studies from India, China, and the United States. The National Academy of Sciences, The National Academies press.

Ghosh, S. and Mujumdar, P.P. 2006. Future rainfall scenario over Orissa with GCM projections by statistical downscaling. Current Science. 9: 396-404.

Giusti, E.V. and Schneider, W.J. 1965. The distribution of branches in river networks. USGS professional paper, 422 G, US Geological Survey.

Gopikuttan, G. and Kurup, K.N.P. 2004. Paddy land conversion in Kerala An inquiry into Ecological and Economic aspects in a Midland Watershed Region. Centre for Development Studies, Thiruvananthapuram.

Gordon, N.D., McMahon, T.A. and Finlayson, B.L. 1992. Stream Hydrology: An introduction for Ecologists. John Wiley and Sons, New york, pp. 93.

Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S. and Xavier, P.K. 2006. Increasing trend of extreme rain events over India in a warming environment. Science 314: 1442-1445.

Goswami, P. and Gouda, K.C. 2007. Objective Determination of the date of onset of monsoon rainfall over India based on duration of persistence. CSIR Centre for Mathematical Modelling and Computer Simulation, Research Report. RR CM 0711.

Gottaschalk, L.C. 1964. Reservoir sedimentation In: V.T. Chow (ed.) Handbook of Applied Hydrology. McGraw Hill Book Company, New York. Section 7–1.

GSI. 1976. Geology and mineral resources of the states of India-Kerala, Miscellaneous publication, Pt. IX: 30.

Guhathakurta, P. and Rajeevan, M. 2007. Trends in the rainfall pattern over India. Intern. Journal of Climatology. 28:11, 1453–1469.

Guhathakurta, P. 2005. Long-range monsoon rainfall prediction of 2005 for the districts and sub-division Kerala with artificial neural network. Current Science. 90: 773-779.

Guler, M., Yomraloglu, T. and Reis, S. 2007. Using landsat data to determine land use/land cover changes in Samsun, Turkey. Environmental Monitoring and Assessment. 127: 155–167. DOI 10.1007/s10661-006-9270-1.

Gunawardene, N.R., Daniels, A.E.D., Gunatilleke, I.A.U.N., Gunatilleke, C.V.S., Karunakaran, P.V., Nayak, K.G., Prasad, S., Puyravaud, P., Ramesh, B.R., Subramanian, K.A. and Vasanthy, G. 2007. A brief overview of the Western Ghats-Sri Lanka biodiversity hotspot. Current Science. 93: 1567-1572

Gupta, H. and Chakrapani, G.J. 2005. Temporal and spatial variations in water flow and sediment load in Narmada River basin, India: natural and man-made factors. Environmental Geology. 48: 579–589

Hamilton, L.S. 1987. What are the impacts of deforestation in the Himalayas on the Ganges-Brahmaputra lowlands and delta: relations between assumptions and facts. Mountain Research and Development. 7: 256-263.

Haylock, M.R., Peterson, T.C., Alves, L.M., Ambrizzi, T., Anunciação, Y.M.T., Baez, J., Barros, V.R., Berlato, M.A., Bidegain, M., Coronel, G., Corradi, V., Garcia, V.J., Grimm, A.M., Karoly, D., Marengo, J.A., Marino, M.B., Moncunill, D., Nechet, D., Quintana, J., Rebello, E., Rusticucci, M., Santos, J.L., Trebejo, I. and Vincent, L.A. 2006. Trends in total and extreme south American rainfall in 1960–2000 and links with sea surface temperature. Journal of climate. 19: 1490-1512.

Henry, A.N. 1963. Taxonomic studies on the flora of Madras state – Siruvani – Boluvampatti forests in Coimbatore District. M.Sc. Dissertation, The University of Bombay.

Horowitz, A.J. 1995. The use of suspended sediment and associated trace elements in water quality studies, IAHS special publication No. 4, IAHS press, Wallingford, UK, pp. 58.

Horowitz, A.J. 1997. Some thoughts on problems associated with various sampling media used for environmental monitoring. Analyst. 122: 1193–1200.

Horton, R.E. 1945. Erosional development of streams and their drainage basins; Hydrophysical approach to quantitative morphology. Geological Society of America Bulletin. 56: 275– 370

Horton, R.E. 1932. Drainage basin characteristics. Trans American Geophysics. Union 13: 350–361.

Hudson, J.A., Crane, S.B. and Robinson, M. 1997. The impact of the growth of new plantation forestry on evaporation and stream flow in the Llanbrynmair catchments. Hydrology and Earth System Sciences. 1:3, 463-475.

IMD, 2010. www.imd.gov.in/doc/warm2009.pdf.

Jacob, K. and Narayanaswamy, S. 1954. The structural and drainage pattern of the Western Ghats in the vicinity of Palghat gap. Proceedings of National Institute of Science, India. 20: 101-118.

Jain, C.K. and Sharma, M.K. 2002. Heavy metal transport in the Hindon river basin, India. Water, Air, and Soil Pollution 137: 1–19.

Jain, S.K., Agarwal, P.K. and Singh, V.P. 2007. River basins of India. Water Science and Technology Library. Hydrology and water resources of India. DOI: 10.1007/1-4020-5180-8-7.

Jaisawal, R.K., Saxena, R. and Mukherjee, S. 1999. Applications of Remote sensing technology for Landuse/Landcover change analysis. Journal of Indian Society of Remote Sensing. 27:2, 123–128.

James, E.J., Sreedharan, K.E., Ranganna, G., Nayak, I.V. and Prasad, T.S. 1986. Design of rain gauge network using spatial correlation for the Bharathapuzha basin on the Malabar coast of India. Integrated design on hydrological network. Proceedings of Budapest Symposium. 1986, IAHS publ. No. 158.

Jeevanandam, M., Kannan, R., Srinivasalu, S. and Rammohan, V. 2007. Hydrogeochemistry and groundwater quality assessment of lower part of the Ponnaiyar river basin, Cuddalore District, South India. Environmental Monitoring and Assessment. 132: 263–274.

Jha, C.S., Dutt, C.B.S. and Bawa, K.S. 2000. Deforestation and land use changes in Western Ghats, India. Current Science. 79:2, 231-238.

Jianhua, X., Yaning, C., Weihong, L., Minhe, J., Shan, D. and Yulian, H. 2009. Wavelet analysis and nonparametric test for climate change in Tarim river basin of Xinjiang during 1959–2006. Chineese Geographical Science. 19: 4, 306–313. DOI: 10.1007/s11769-009-0306-7.

Jingan, S.O., Jiupai, N., Chaofu, W. and Deti, X. 2005. Land use change and its corresponding ecological responses: a review. Journal of Geographical Sciences. 15:3, 305-328.

John, B. and Rajendran, C.P. 2008. Geomorphic indicators of Neotectonism from the Precambrian terrain of peninsular India: a study from the Bharathapuzha Basin, Kerala. Journal of the Geological Society of India 71: 827-840.

Joseph, P.V. and Xavier, P.K. 1999. Monsoon rainfall and frequencies of monsoon depressions and tropical cyclones of recent 100 years and an out look for the first decades of 21st Century, Meteorology beyond 2000. In: Proceedings of Indian Meteorological Society. TROPMET-99. 364–371.

Joseph, P.V., Simon, A., Nair, V.G. and Thomas, A. 2004. Intra-Seasonal Oscillation (ISO) of south Kerala rainfall during the summer monsoons of 1901-1995. Proceedings of the Indian Academy of Sciences. (Earth and Planetary Science). 113 (2): 139-150.

Joshi, H. 2006. Identifying asset price bubbles in the housing market in India- preliminary evidence. Reserve Bank of India occasional papers. 27 (1 & 2).

Joshi, P.K. and Gairola, S. 2004. Land Cover dynamics in Garhwal Himalayas- A case Study of Balkhila Sub-Watershed. Journal of Indian Society of Remote Sensing. 32(2): 199-208

Kannel, P.R., Lee, S., Kanel, S.R., Khan, S.P. and Lee, Y. 2007. Spatial-temporal variation and comparative assessment of water qualities of urban river system: a case study of the river Bagmati (Nepal). Environmental Monitoring and Assessment. 129: 433–459.

Kothawale, D.R. and Kumar, R.K. 2005. On the recent changes in surface temperature trends over India. Geophysical Research Letters. 32: L18714.

Krishnakumar, K.N., Rao, G.S.L.H.V.P. and Gopakumar, C.S. 2009. Rainfall trends in twentieth century over Kerala, India. Atmospheric Environment. 43: 1940–1944.

Kumar, R.K., Pant, G.B., Parthasarathy, B. and Sontakke, N.A. 1992. Spatial and subseasonal patterns of the long term trends of Indian summer monsoon rainfall. International Journal of Climatology. 12: 257–268.

Kumar, B.A. 2001. Biodiversity of Bharathapuzha (Nila River), Kerala. Report submitted to UGC, Southern regional office, Bangalore.

Kumar, B.M. 2005. Land use in Kerala: changing scenarios and shifting paradigms. Journal of Tropical Agriculture. 42(1-2): 1-12.

Kumar, R.M.R., Shenoi, S.S.S. and Shankar, D. 2004. Monsoon onset over Kerala and Pre-monsoon rainfall peak.
http://drs.nio.org/drs/bitstream/2264/1183/2/Proc_METOC_2004_305.

Kurup, D.N. 1991. Migrant shore birds in estuarine habitats with special reference to Kadalundi and Bharathapuzha estuaries. Proc. 3rd Kerala Sci. Cong. February-March 1991, Kozhikode.

Kutty, S.G. 2008. Fold the umbrella climate change, Kerala Calling. p. 28-29.

Lee, J.H. and Shon, K.T. 2007. Prediction of monthly mean surface air temperature in a region of China. Advances in Atmospheric Science. 24(3): 503–508

Lele, N. and Joshi, P.K. 2008. Analyzing deforestation rates, spatial forest cover changes and identifying critical areas of forest cover changes in North-East India during 1972 -1999. Environmental Monitoring and Assessment. 156: 159–170.

deLinhares, C.A., Soares, J.V., Alves, D.S., Roberts, D.A. and Rennó, C.D. 2007. Deforestation and hydrology dynamic in Ji-Paraná river basin, Brazil. Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, 21-26 abril, INPE, 6799-6806.

Liu,Y.B., De Smedt, F., Hoffmann, L. and Pfister, L. 2004. Assessing land use impacts on flood processes in complex terrain by using GIS and modeling approach. Environmental Modeling and Assesment. 9: 227–235.

Long, H., Heiligb, G.K., Lic, X. and Zhang, M. 2007. Socio-economic development and land-use change: Analysis of rural housing land transition in the transect of the Yangtse River, China. Land Use Policy 24: 141–153.

Mahesh, R. 2000. Farm size-productivity relation ship: some evidence from Kerala; KIED working paper, Kerala Institute for Environment and Development, Thiruvananthapuram.

Mahurkar, P.G. and Senthil, 2004. Final paper on real estate fund management Indian perspective. Asian Real estate Society, AsRES conference.

Manilal, K.S. 1988. Flora of Silent valley tropical rain forests of India. The Department of Science and Technology, Govt. India, Calicut.

Meher-Homji, V.M. 1991. Probable impact of deforestation on hydrological processes. Climate Change. 19:163-73.

Menon, A.S. 2008. Kerala history and its makers, DC books, Kottayam. pp. 236.

Mesa, L.M. 2006. Morphometric analysis of a subtropical Andean basin (Tucuma´ n, Argentina) Environmental Geology. 50: 1235–1242.

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: wetlands and water synthesis.

Miller, V.C. 1953. A quantitative geomorphic study of drainage basin characteristics in Clinch Mountain Area, Virginia and Tennessee. Technical report, 3, Office of the Naval Research. Dept. of Geology, Columbia Univ., New York.

Mohapatra, M. and Mohanty, U.C. 2007. Inter-annual variability of summer monsoon rainfall over Orissa (India) in relation to cyclonic disturbances. Natural Hazards. 42: 301–315.

Mohsin, T. and Gough, W.A. 2009. Trend analysis of long-term temperature time series in the Greater Toronto area (GTA). Theoretical and applied Climatology. DOI: 10.1007/s00704-009-0214-x.

Mukherjee, D., Chattopadhaya, M. and Lahiri, S.C. 1993. Water quality of the River Ganga (The Ganges) and some of its physico-chemicai properties. Environmentalist. 13: 199-210.

Murugesan, M. 2003. Flora of river Palar and its envorons, in Pollachi and Udumelpet Taluks, Tamil Nadu. M.Phil. Dissertation, Bharathiar University, Coimbatore.

Nag, S.K. and Chakraborty, S. 2003. Influences of rock types and structures in the development of drainage network in hard rock area. Journal of Indian Society of Remote Sensing. 31(1): 25–35.

Naiman, R.J., Bunn, S.E., Nilsson, C., Petts, G.E., Pinay, G., and Thompson, L.C. 2002. Legitimizing fluvial ecosystems as users of water: an overview.

Environmental Management. 30(4): 455–467. DOI: 10.1007/s00267-002-2734-3.

Nair, P.R. 2008. Literacy on water. Kerala Calling, February 26-27.

Nair, S.C. 1991. The southern Western Ghats: a biodiversity conservation plan. INTACH, New Delhi.

Nair, S.C. 1999. Silent valley – Reflections after two decades. In: Silent Valley – Whispers of Reason (eds. Manoharan, et al.,), Kerala Forest Department pp. 70.

Nathan, K.K. 2000. Characteristics of drought in Kerala, India. Drought Network News (1994-2001). http://digitalcommons.unl.edu/droughtnetnews/61.

Nawaz, N.R. and Adeloye, A.J. 1999. Evaluation of monthly runoff estimated by a rainfall-runoff regression model for reservoir yield assessment. Hydrological Science. 44(1): 113-134.

Negi, A.K., Bhatt, B.P. and Todaria, N.P. 1999. Local population impacts on the forests of Garhwal Himalaya, India. Environmentalist. 19: 293-303.

Neilson, C., Reidy, C.A., Dynesius, M. and Revenga, M.C. 2005. Fragmentation and flow regulation of the world's large river systems. Science. 276: 788-800.

Nicolay, S., Mabille, G., Fettweis, X.and Erpicum, M. 2008. 30 and 43 months period cycles found in air temperature time series using the morlet wavelet method. Clym. Dyn. doi:10.1007/s00382-008-0484-5.

Nilsson, C., Pizzuto, J.E., Moglen, G.E., Palmer, M.A., Stanley, E.H., Bockstael, N.E. and Thompson, L.C. 2003. Ecological forecasting and the urbanization of stream ecosystems: challenges for economists, hydrologists, geomorphologists and ecologists. Ecosystems. 6: 659-674.

Nossiter, T.J. 1982. Communism in Kerala: A study in political adaptation. Royal Institute of International Affairs. Published by Hurst & Co. Publishers.

Odekunle, T.O., Balogun, E.E. and Ogunkoya, O.O. 2005. On the prediction of rainfall onset and retreat dates in Nigeria. Theoretical and applied Climatology. 81: 101–112. DOI: 10.1007/s00704-004-0108-x.

Pai, D.S. and Rajeevan, M. 2006. Empirical prediction of Indian summer monsoon rainfall with different lead periods based on global SST anomalies. Meteorology and Atmospheric Physics. 92: 33–43.

Pandurangan, A.G. and Nair V.J. 1996. Changing pattern of floristic composition in the Idukki Hydro-electric project area, Kerala. Journal of Economic and Taxonomic. Botany. 21: 15-26.

Panigrahy, B.K. and Raymahashay, B.C. 2005. River water quality in weathered limestone: a case study in upper Mahanadi basin, India. Journal of Earth System Science. 114: 533–543.

Parameswaran, K. 2001. Influence of micrometeorological features on coastal boundary layer aerosol characteristics at the tropical station, Trivandrum. Proceedings of the Indian Academy of Sciences. (Earth and Planetary Science). 110: 247-265.

Peel, M.C., Finlayson, B.L. and McMahon, T.A. 2007. Updated world map of the Koppen-Geiger climate classification. Hydrology and Earth System Science. 11: 1633–1644.

Pfister, L., Humbert, J. and Hoffmann, L. 2000. Recent trends in rainfall-runoff characteristics in the Alzette river basin, Luxembourg. Climate Change 45: 323–337.

Pilon, P.G., Howarth, P.J. and Bullock, R.A.Q. 1988. An enhanced classification approach to change detection in semi-arid environments. Photogram. Engineering and Remote Sensing. 54: 1709–1716.

Purushothaman, P. and Chakrapani. G.J. 2007. Heavy metals fractionation in Ganga river sediments, India. Environmental Monitoring and Assessment. 132: 475–489.

Quadir, A., Malik, R.N. and Husain, S.Z. 2007. Spatio-temporal variations in water quality of Nullah Aik-tributary of the river Chenab, Pakistan. Environmental Monitoring and Assessment. 140: 1-3.

Raj, P.P.N. and Azeez, P.A. 2007. Weeds of the Bharathapuzha river basin Kerala with special reference to the influencing factors promoting weed growth. National Conference on Environmental Challenges and Management. (ECM-2007), 8th-9th March 2007, Bharathiar University, Coimbatore.

Raj, N. and Azeez, P.A. 2009a. Spatial and temporal variation in surface water chemistry of a tropical river, the river Bharathapuzha, India. Current Science. 96(2): 245-251.

Raj, P.P.N. and Azeez, P.A. 2009b. Real estate and agricultural wetlands in Kerala. Economic and Political Weekly. XLIV(5): 63-66.

Raj, N. and Azeez, P.A. 2009c. The shrinking rice paddies of Kerala. India Economy Review. VI: 176-183.

Raj, N. and Azeez, P.A. 2009d. Historical analysis of the first rain event and the number of rain days in the western part of Palakkad gap, south India. Climate change: global risks, challenges and decisions IOP Conf. Series: Earth and Environmental Science.

Raj, P.P.N. and Azeez, P.A. 2009e. Climate change congress at Copenhagen. Current Science. 97(3): 299.

Raj, P.P.N. and Azeez, P.A. 2010a. Deteriorating health status of Kerala state, India: an environmental and cultural diagnosis. Seronica. 1(1); 23-27.

Raj, P.P.N. and Azeez, P.A. 2010b. Changing rainfall in the Palakkad plains of south India. Atmósfera. 23(1): 81-88.

Raj, R.M. 2003. Patterns of social change among the migrant farmers of Kannur district- a case study. Project report submitted to Kerala Research Programme on Local Development, Centre for Developmental Studies, Thiruvanandapuram.

Rajeevan, M. 2001. Prediction of Indian summer monsoon: status, problems and prospects. Current Science. 81: 11.

Rajeevan, M., Bhate, J., Kale, J.D. and Lal, B. 2006. High resolution daily gridded rainfall data for the Indian region: analysis of break and active monsoon spells. Current Science. 91:3.

Raju, P.V., Raju, S., Mohanty, U.C. and Bhatla, R. 2007. Interannual variability of onset of the summer monsoon over India and its prediction. Natural Hazards. 42: 287–300.

Ramankutty, N. and Foley, J.A. 1999. Estimating historical changes in global land cover: croplands from 1700 to1992. Global Biogeochemical Cycle. 13: 997-1028.

Ramesh, K.V. and Goswami, P. 2007. The Shrinking Indian summer monsoon. CSIR Centre for Mathematical Modelling and Computer Simulation. Research Report RR CM 0709.

Rao, P.G.S., Jaswal, A.K. and Kumar, M.S. 2004. Effects of urbanization on meteorological parameters. Mausam. 5: 429–440.

Rao, P.J., Harikrishna, P. and Rao, B.S.P. 2006. Studies on silt deposition in Gambhiram reservoir – a remote sensing approach. Journal of Indian Geophysical Union. 10(4): 285-292.

Ratnam, J.V., Sikka, D.R., Kaginalkar, A., Amitkesarkar, Jyothi, N. and Banerjee, S. 2007. Experimental seasonal forecast of monsoon 2005 Using T170L42 AGCM on PARAM Padma. Pure and Applied Geophysics. 164:1641–1665.

Ravi, S.P., Madhusoodhanan, C.G., Latha, A., Unnikrishnan, S. and Bachan, K.H.A. 2004. Tragedy of commons: the Kerala experience in river linking. River Research Centre, Thrissur.

Riedel, G.F., Tvvilliams, S.A., Riedel, G.S., Oilmour, C.C. and Sanders, J.G. 2000. Temporal and spatial patterns of trace elements in the Patuxent River: a whole watershed approach. Estuaries. 23: 521-535.

Rode, M. and Suhr, U. 2007. Uncertainties in selected river water quality data. Hydrology and Earth System Science. 11: 863–874.

Rudraiah, M., Govindaiah, S. and Vittala, S.S. 2008. Morphometry using remote sensing and gis techniques in the sub- basins of Kagna River basin, Gulburga District, Karnataka, India. Journal of Indian Society of Remote Sensing. 36: 351–360

Sadasivan, S.N. 2003. River disputes in India: Kerala rivers under siege. Mittal Publication, New Delhi.

Sala, J.Q., Olcina, A.G., Cuevas, A.P., Cantos, J.O., Amoros, A.R. and Chiva, E.M. 2000. Climatic warming in the Spanish Mediterranean: natural trend or urban effect. Climate Change. 46: 473-483.

Sarkar, S. and Gundekar, H.G. 2007. Geomorphological parameters: are they indicators for installation of a hydropower site? International Conference on Small Hydropower - Hydro Sri Lanka, 22-24 October.

Sarunjith, K.J. and Sanjeevi, S. 2007. Reconnaissance-level mapping of vulnerable areas in a tsunami-prone coast using shuttle radar-derived Digital Elevation Model. Current Science. 92(7): 999-1003.

Saxena, D.P., Joos, P., Grieken, V. and Subramanian, V. 2001. Sedimentation rate of the floodplain sediments of the Yamuna river basin (tributary of the river Ganges, India) by using 210Pb and 137Cs techniques. Journal of Radioanalytical and Nuclear Chemistry. 251: 399–408.

Schaefer, S.C. and Alber, M. 2007. Temporal and spatial trends in nitrogen and phosphorus inputs to the watershed of the Altamaha River, Georgia, USA. Biogeochemistry. 86: 231–249.

Schrier, G.V. and Jones, P.D. 2008. Daily temperature and pressure series for Salem Massachusetts (1786-1829). Climate Change. 87: 499–515.

Schumm, S.A. 1956. Evolution of drainage systems and slopes in Badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin. 67: 597–646.

Schumm, S.A. 1963. Sinuosity of alluvial rivers on the great plains. Geological Society of America Bulletin. 74: 1089–1100.

Schuyt, K. 2005. Freshwater and poverty reduction: serving people, saving nature: an economic analysis of the livelihood impacts of freshwater conservation initiatives. WWF International: Gland, Switzerland.

Sharma, K.P., Moore, B. and Vorosmarty, C.J. 2000 Anthropogenic, climatic, and hydrologic trends in the Kosi basin, Himalaya. Climate Change. 47: 141–165.

Shen, C., Wang, W.C., Hao, Z. and Gong, W. 2007. Characteristics of anomalous precipitation events over eastern China during the past five centuries Climate Dynamics. DOI: 10.1007/s00382-007-0323.

Sileika, A., Lnacke, P., Kutra, S., Gaigals, K. and Berankiene, L. 2006. Temporal and spatial variation of nutrient levels in the Nemunas River (Lithuania and Belarus). Environmental Monitoring and Assessment. 122: 335–354.

Simon, A. and Mohankumar, 2004. Spatial variability and rainfall characteristics of Kerala. Proceedings of the Indian Academy of Sciences. (Earth and Planetary Science). 113: 211-221.

Singh, A.K. and Hasnain, S.I. 1998. Environmental geochemistry of Damodar River basin, east coast of India. Environmental Geology. 37: 1–2.

Singh, A.P., Ghosh, S.K. and Sharma, P. 2007. Water quality management of a stretch of river Yamuna: an interactive fuzzy multi-objective approach. Water Resource Management. 21: 515–532.

Singh, C.V. 1998. Relationships between rainy days, mean daily intensity and seasonal rainfall in normal, flood and drought years over India. Advances in Atmospheric. Science. 15: 424-432.

Singh, K.P., Malik, A., Sinha, S., Singh, V.K. and Murthy, R.C. 2005. Estimation of source of heavy metal contamination in sediments of Gomti river (India) using principal component analysis. Water, Air, and Soil Pollution. 166: 321–341.

Singh, M. and Singh, A.K. 2007. Bibliography of environmental studies in natural characteristics and anthropogenic influences on the Ganga River. Environmental Monitoring and Assessment. 129: 421–432.

Singh, M., Muller, G. and Singh, I.B. 2002. Heavy metals in freshly deposited stream sediments of rivers associated with urbanization of the Ganga plain, India. Water, Air, and Soil Pollution. 141: 35–54.

Singh, N. and Sontakke, N.A. 1999. On the variability and prediction of rainfall in the post-monsoon season over India. International Journal of Climatology. 19: 309–339.

Singh, R.K., Saha, S.K. and Kumar, S. 2005. Soil conservation prioritization of watershed based on erosional soil loss and morphometric analysis using satellite remote sensing & GIS – a case study, Map India.

Smadi, M.M. 2006. Observed abrupt changes in minimum and maximum temperatures in Jordan in the 20th century. American Journal of Environmental Sciences. 2: 114-120.

Smith, I. 2004. An assessment of recent trends in Australian rain. Australian Meteorological Magazine. 53:163-173.

Smith, KG. 1950. Standards for grading textures of erosional topography. American Journal of Science. 248: 655–668.

Soman, M.K., Kumar, K.K. and Singh, N. 1998. Decreasing trend in the rainfall of Kerala. Current Science. 57: 7-12.

Sonechkin, D.M. and Datsenko, N.M. 2000. Wavelet analysis of nonstationary and chaotic time series with an application to the climate change problem. Pure and Applied Geophysics. 157: 653-677.

Sreedevi, P.D., Subrahmanyam, K. and Ahmed, S. 2005. The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environmental Geology. 47: 412– 420.

Strahler, A.N. 1957. Quantitative analysis of watershed Geomorphology. Trans American Geophysical Union. 38: 913–920.

Strahler, A.N. 1964. Quantitative geomorphology of drainage basin and channel networks. In: V.T. Chow (ed.), Handbook of applied hydrology, McGraw Hill book company, New York.

Strayer, D.L., Beighley, R.E., Thompson, L.C., Brooks, S., Nilsson, C., Pinay, G. and Naiman, R.J. 2003. Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. Ecosystems. 6: 407–423. DOI: 10.1007/s10021-002-0170-0.

Subramanian, K.S. and Muraleedharan, M.P. 1985. Origin of the Palghat gap in South India- a synthesis. Journal of Geological Society of India 26: 28-37.

Subramanian, V. 1983. Factors controlling the chemical composition of river waters of India. Proceedings of Hamburg Symposium. (August 1983).

Subramaniyan, K.N. 1966. Further contribution to the flora of Boluvampatti valley forests, Coimbatore District, Madras state. The Indian Forester. 92: 39-50.

Subramanyam, K. 1959. Observations on the flora of Boluvampatti forest, Coimbatore Taluk. Ibid. 1:127-137.

Sundaray, S.K., Panda, U.C., Nayak, B.B. and Bhatta, D. 2006. Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of the Mahanadi river–estuarine system (India) - a case study. Environmental Geochemistry and Health. 28: 317–330.

Sunil, P.T. 2007. Dimensions of Agrarian Distress: the case of Wayanad District, Kerala. Financing Agriculture – National Journal of Agriculture and Rural Development. 7-12.

Sushama, P.N. 1996. Transition from high to replacement-level fertility in a Kerala village, Health Transition Review 6: 115–136. Office of population health and nutrition, New Delhi.

Sushama, S. 2003. Ecology and biodiversity of Nila River. Ph.D. thesis, University of Kerala.

Tendulkar, S.D. 2009. Report of the expert group to review the methodology for estimation of poverty. Government of India Planning Commission. pp. 39.

Thomas, J., Joseph, S. and Thrivikramaji, K.P. 2010. Morphometric aspects of a small tropical mountain river system, the southern Western Ghats, India. International Journal of Digital Earth. DOI: 10.1080/17538940903464370.

Tijiu. C. and Xiaojing, T. 2007. Impact of forest harvesting on river runoff in the Xiaoxing'an mountains of China. Frontiers of Forestry in China. 2: 143–147.

Tiwari, R.C. 2006. Analytical study on variation of climatic parameters at Aizawl, Mizoram (India). Bulletin of Arunachal Forest Research. 22: 33-39.

Tonkaz, T. and Cetin, M. 2005. Effects of urbanization and land-use type on monthly extreme temperatures in a developing semi-arid region, Turkey. Journal of Arid Environment. 68: 143-158.

Tukur, A.L. and Mubi, A.M. 2002. Impact of Kiri dam on the lower reaches of river Gongola, Nigeria. GeoJournal. 56: 93–96.

Turner, M.G., Romme, W.H., Gardner, R.H., O'Neill, R.V. and Kratz, T.K. 1993. A revised concept of landscape equilibrium: disturbance and stability on scaled landscapes. Landscape Ecology. 8: 213–227.

Turner, R.K.1991. Economics and Wetland Management. Ambio. 20.

Vaidyanadhan, R. 1971. Evolution of the drainage of Cauvery in south India. Journal of.Geological Society of India. 12: 14-23.

Vajravelu, E. 1990. Flora of Palghat District including Silent Valley National Park, Kerala, Botanical Survey of India. Calcutta.

Varghese, S. 2009. Integrated Solutions to the Water, Agriculture and Climate Crises, IATP, North America.

Venketesan, C., Raskar, S.D., Tambe, S.S., Kulkarni, B.D. and Keshavamurty, R.N. 1997. Prediction of all india summer monsoon rainfall using error- back-propagation neural networks. Meteorological and Atmospheric Physics. 62: 225-240.

Venugopal, D. 2004. Development-Conservation dilemma in the Nilgiri mountains of South India. Journal of Mountain Science. 1(1): 74-80.

Ward, P.J., Renssen, H., Aerts, J.C.J.H., van Balen, R.T. and Vandenberghe, J. 2007. Strong increases in flood frequency and discharge of the river Meuse over the late Holocene: impacts of long-term anthropogenic land use change and climate variability. Hydrology and Earth System Sciences Discussion. 4: 2521–2560.

Wilk, J. and Hughes, D.A. 2002. Simulating the impacts of land-use and climate change on water resource availability for a large south Indian catchment. Hydrological Science. 47(1): 19-30.

Willis, K.G. 2002. Benefits and costs of forest to water supply and water quality report to Forestry Commission, Edinburgh.

Xiaoming, Z., Xinxiao, Y., Sihong, W., Manliang, Z. and Jianlao, L . 2007. Response of land use/coverage change to hydrological dynamics at watershed scale in the Loess Plateau of China. Acta Ecology Sinica. 27(2): 414–423.

Xu, H., Ye, M., Song, Y. and Chen, Y. 2007. The natural vegetation responses to the groundwater change resulting from ecological water conveyances to the lower Tarim River. Environmental Monitoring and Assessment. 131: 37–48, DOI:10.1007/s10661-006-9455-7.

Yang, Z., Luohui, L., Yansui, L. and Yimei, H. 2004. Land use change during 1960 ~ 2000 period and its eco-environmental effects in the middle and upper reaches of the Yangtze river: a case study in Yiliang county, Yunnan, China. Journal of Mountain Science. 1(3): 250-263. ID: 1672-6316 (2004) 03-0250-14.

Yilmaz, S., Toy, S., Yildiz, N.D. and Yilmaz, H. 2009. Human population growth and temperature increase along with the increase in urbanization, motor vehicle number and green area amount in sample of Erzurum city, Turkey. Environmental Monitoring and Assessment. 148: 205-213.

Yin, Y., Cohen, S. and Huang, G.H. 2000. Global climate change and regional sustainable development: the case of Mackenzie basin in Canada. Integrated Assessment. 1: 21–36.

Zade, M., Ray, S.S., Dutta, S. and Panigrahy, S. 2005. Analysis of runoff pattern for all major basins of India derived using remote sensing data. Current Science. 88(8): 1301-1305.

Zar, J.H. 1999. Biostatistical analysis. 4th edition. Prentice-Hall, New Jersey.

Zhao, S., Peng, C., Jiang, H., Tian, D., Lei, X. and Zhou, X. 2006. Land use change in Asia and the ecological consequences. Ecological Research. 21: 890–896.

Zhaomei, Z., Zhongwei, Y. and Duzheng, Y. 2001. The regions with the most significant temperature trends during the last century. Advances in Atmospheric Science. 18: 481-496.

Zhu, W., Graney, J. and Salvage, K. 2008. Land use impact on water pollution: elevated pollutant input and reduced pollutant retention. Journal of Contemporary Water Research and Education. 139: 15-21.