ENVIRONMENTAL IMPACT OF SAND MINING: A CASE STUDY IN THE RIVER CATCHMENTS OF VEMBANAD LAKE, SOUTHWEST INDIA

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BY

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Dedicated to my

Beloved Father

Be still like a mountain and flow like a great river.

Lao Tse

DECLARATION

I hereby declare that this thesis entitled **"ENVIRONMENTAL IMPACT OF SAND MINING: A CASE STUDY IN THE RIVER CATCHMENTS OF VEMBANAD LAKE, SOUTHWEST INDIA"** is an authentic record of the research work carried out by me under the guidance of Dr. D Padmalal, Scientist, Environmental Sciences Division, Centre for Earth Science Studies, Thiruvananthapuram, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Environmental Management under the faculty of Environmental Studies of the Cochin University of Science and Technology. No part of it has been previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title or recognition of this or of any other University.

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CERTIFICATE

This is to certify that this thesis entitled **"ENVIRONMENTAL IMPACT OF SAND MINING: A CASE STUDY IN THE RIVER CATCHMENTS OF VEMBANAD LAKE, SOUTHWEST INDIA"** is an authentic record of the research work carried out by **SREEBHA S** under my scientific supervision and guidance, in Environmental Sciences Division, Centre for Earth Science Studies, Thiruvananthapuram, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Environmental Management under the faculty of Environmental Studies of the Cochin University of Science and Technology. No part of it has been previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title or recognition of this or of any other University.

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SREEBHA S

PREFACE

Ever growing population and economic development result in increased per capita consumption of natural resources – both living and non-living. Industrialization, agricultural activities and intense pace of urbanization have not only complicated the natural processes but also accelerated the pace of ecological degradation. Rivers are widely exploited for sand and gravel, besides water. Sand and gravel are non-renewable resources, possibly in the human life scale. The in-channel or near channel mining for sand inevitably alters the sediment budget in addition to changing the channel hydraulics and biological harmony of the system. Further, depending on the geologic setting, sand mining from rivers can cause serious environmental problems, if the river being mined is erosional.

Environmental problems arising from river sand mining is typically severe in Kerala State in the southwest coast of India, as its rivers are small and swift with limited river bed resources. The exponential rise in the developmental activities and socio-economic standards in the State, however, have led to over exploitation of river bed resources, especially sand, since early 1970's for building constructions and other infrastructural developments. Among the 44 rivers in the State, the rivers draining the hinterlands of Vembanad lake are the most affected by indiscriminate sand extraction for meeting the requirements of construction activities in the fast developing urban-*cum*-industrial centre – the Kochi City and its satellite townships. Degradation of the river ecosystems would continue further as the area demands additional infrastructural facilities for the several new mega developmental initiatives being undertaken in the area.

Despite the fact that unabated sand extraction causes severe damage to the structure and functions of river ecosystems, its impacts on various environmental components are not yet fully addressed neither in the public conscience nor in the scientific domain. Lack of adequate baseline environmental data of previous periods is a major lacuna in achieving this, and the impact of river sand mining on the environment, generally comes to light only after a long period. Further, scientific literature on the environmental impact of sand mining in peer reviewed national and international journals is also very limited, and whatever available is often insufficient to meet the scientific requirements fully. This is, perhaps, the major constraint to lay down environment-friendly management strategies to salvage the rivers from indiscriminate sand mining. Even within these constraints and also taking into consideration the degree of degradation of the rivers in Kerala consequent to sand mining, an attempt has been made in this study to address the environmental impact of sand mining from instream and floodplain areas, taking the river catchments of the Vembanad lake as a case study site.

The entire study is addressed in nine chapters. Chapter 1 deals with the general introduction about rivers, problems of river sand mining, objectives, location of the study area and scope of the study. A detailed review on river classification, classic concepts in riverine studies, geological work of rivers and channel processes, importance of river ecosystems and its need for management are dealt in Chapter 2. Chapter 3 gives a comprehensive account of the study area - its location, administrative divisions, physiography, soil, geology, land use and living and non-living resources. The various methods adopted in the study are dealt in Chapter 4. Chapter 5 contains river characteristics like drainage, environmental and geologic setting, channel characteristics, river discharge and water quality of the study area. Chapter 6 gives an account of river sand mining (instream and floodplain mining) from the study area. The various environmental problems of river sand mining on the land adjoining the river banks, river channel, water, biotic and social / human environments of the area and data interpretation are presented in Chapter 7. Chapter 8 deals with the Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP) of sand mining from the river catchments of Vembanad lake. The summary and the recommendations / suggestions drawn from the study are given in Chapter 9. The references cited in the study are placed at the end of the thesis.

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1. **Sreebha S.**, Padmalal D., Maya K. and Vishnu Mohan S. (2008). Environmental impact of sand mining from Pamba River, SW India. Proceedings of National Seminar on Environmental Degradation of Pamba River – Causes, Consequences and Management Strategies, 11-12.
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Chapter 1

INTRODUCTION

1.1 Introduction

Rivers are the most important life-sustaining systems of nature. They play a major role in the transfer of materials from terrestrial environment to ocean realm. Of the total quantity of materials transported by rivers, a substantial part is detained within its channels and adjoining environments as fluvial deposits. Several attempts have been made to compute the quantity of particulate transfer to the world oceans (Meybeck, 1976; Gibbs, 1977; Lal, 1977 and many others). However, the most widely accepted computation was that of Milliman and Meade (1983). They estimated that an amount of $12 - 13 \times 10^9$ tonnes of suspended particulates and $1 - 2 \times 10^9$ tonnes of bed sediments are transported to the world oceans annually through rivers.

Historically, rivers, their floodplains, estuaries, and deltas have been the foci of human development involving agriculture, transport, industry, waste disposal and settlement. The ancient cultures of humans are inseparably centered around rivers. In India, earlier settlements were succeeded by the progressively developing cultures - the one best known is the Indus Valley Civilization which flourished on the valleys of Indus river dating back to 5500-4600 years before present (ybp); (Valdiya, 2002). In fact, the Tigris and Euphrates rivers in Iraq provided the cradle for the dawn of civilization in Mesopotamia (literally means "between two rivers") over 4,000 years ago. The long historical association of society and rivers is also evident in their mystical and religious significance (L'vovich, 1979).

Despite its importance in supporting the life and greenery of tropics and subtropics, rivers have been widely exploited by humans for their natural resources – both living and non-living, without understanding much on how these ecosystems maintain its vitality (Naiman, 1992; Naiman et al., 1995; Naiman and Bilby, 1998). Man has changed the nature of many of the world's rivers by controlling their floods, constructing large impoundments (Ittekkot and Lanne, 1991), overexploiting the resources (Kitetu and Rowan, 1997; Macfarlane and Mitchell, 2003) and using rivers for disposal of wastes (Haslam, 1990). With ever increasing human population and economic developments, these life support systems are under immense pressure owing to various kinds of anthropogenic activities, among which indiscriminate extraction of sand and gravel is most disastrous, as this activity threatens the very existence of the river ecosystems (Kondolf, 1994a; Poulin et al., 1994).

1.2 Sand: Definition, occurrence and importance

Sand is a loose, non-cohesive 'granular' material whose size varies between 0.063 mm and 2 mm (Pettijohn et al., 1972). The term 'sand' is used to cover almost any comminuted rock or mineral, but technically it is restricted to quartz sand with minor impurities of feldspar, mica and iron oxides (Jensen and Bateman, 1979). Sand and gravel occur as sedimentary beds, lenses and pockets lying at or near the surface or inter-bedded with other sedimentary formations. They occur as river channel and floodplain deposits, fluvioglacial deposits, seashore deposits, wind blown deposits along and near water bodies, desert sand dunes and marine and freshwater sedimentary beds.

Sand is an important economic resource and also a source of silica for making sodium silicate, a chemical compound used for manufacture of both common and optical glasses. Sand is an ingredient in plaster and concrete and is added to clays to reduce shrinkage and cracking in the manufacture of bricks. Sand in the river channel and floodplains constitutes an important raw material in the construction industry and has a variety of uses in this sector. River sand is used along with cement, gravel, water and steel for making reinforced concrete. Along with cement and water, it is used as mortar for joint filling and plastering.

The economic aspects of sands are not confined to its value as raw material and its various uses. Sand production, movement and deposition are of great concern to the engineering geologist and to the geomorphologist, especially those concerned with river basin management, shore erosion and harbour development. A better understanding of the sand budget is necessary if the problems of river and coastal environments are to be solved.

Besides its economic importance, sand also constitutes an important abiotic component in aquatic ecosystems like rivers. It provides suitable substrate for many benthic organisms. It is an unavoidable component for psammophilic fishes as it provides breeding, spawning, feeding and hiding grounds. Inter-beds of sand within floodplain deposits act as aquifer systems storing large quantities of ground water. In addition to this, sand acts as an efficient filter for various pollutants and thus maintains the quality of water in rivers and other aquatic ecosystems. In earlier days, mining of sand did not create any problem to river ecosystem as the quantity of mining was well within the replenishment limits. However, increase in population and the rise in economic and industrial developments during the past few decades have aggravated mining of river sand many folds higher than natural replenishments which really made a host of damages to river ecosystems in the world.

1.3 River sand mining: The problem

Throughout the developing world, river sand is widely exploited as fine aggregates for building constructions. The demand for construction grade sand increased in consonance with the expansion of transportation and construction infrastructure in the mid-twentieth century. Sand is extracted directly from the active river channels or from its floodplains and / or overbank areas. It is a non-renewable resource in human life scale. It can be easily extracted from rivers as it requires almost no processing other than size grading. But it is now well understood that continued and indiscriminate sand mining can cause serious environmental impacts, particularly if the river being mined is erosional. The in-channel or near-channel mining of sand inevitably alters the sediment budget and may considerably change the channel hydraulics in addition to negatively affecting productivity in the nearby agricultural lands, river bank stability, engineering structures and river ecology. In short, the degradation of river ecosystem makes it difficult to provide for the basic needs of local communities residing on the banks and valleys (Starnes, 1983; Rivier and Seguier, 1985; Sandecki, 1989; UNEP, 1990; Kitetu and Rowan, 1997; Brown et al., 1998; Kondolf et al., 2002; Padmalal et al., 2008). Studies reveal that creation of deep pits as well as ponding of water within river channels and floodplain areas, migration of pits and subsequent undermining of side protection walls and other engineering structures etc., are frequent in the midland and lowland reaches of the mining-hit areas (Bull and Scott, 1974; Harvey and Smith, 1998; Sreebha and Padmalal, 2006). In addition, there are several reports of aggravated salt-water ingression consequent to channel incision in areas close to river mouth zones.

The scenario is not different in Kerala State, in the southwest coast of India. The rivers in the State have played an important role in the making of its economic, social, religious and cultural heritage. Due to fast pace of industrialization, urbanization and associated developments, the demand for construction grade sand is rising exponentially in the State over the past few decades. All the 44 rivers in the State (Kerala) are small in size (catchment area <6200 km^2) and with limited resource capability. The net sand reserve in these rivers is very small compared to the rivers in neighbouring States like Karnataka and Tamil Nadu. At the same time, indiscriminate mining of sand is booming since early 1970's to meet its ever-increasing demand in the construction sector. The fast pace of economic development, rise in foreign remittances and liberalized housing schemes for building constructions, mainly from banking sector are some of the reasons that promoted unabated sand mining. Sand mining in an unscientific manner leads to severe environmental problems to river ecosystems that obviously need immediate attention and corrective measures. Lack of adequate scientific studies on this environmentally sensitive activity is a major set back in wise decision making and also creating awareness among people at different levels. The present study is an attempt to address the sand mining and related environmental problems of the small catchment rivers in the Vembanad lake basin, often referred in scientific literature as the Greater Kochi Region (GKR); (NEERI, 2003).

1.4 Objectives of the study

In view of the severity of environmental degradation caused by indiscriminate river sand mining and also considering its potential impacts on the developmental initiatives of the State, an attempt has been made to evaluate the sand mining processes and related environmental issues of the rivers draining the hinterlands of the Vembanad lake, the largest backwater system, in the southwest coast of India. The following are the major objectives of the present study.

- To evaluate the general environmental setting and other salient features of the rivers in the study area.
- To record the sand mining activities (instream and floodplain sand mining) and consequent environmental problems of the rivers draining into the Vembanad lake.
- To analyse the effects of sand mining on land adjoining the river banks and river channel, water, biotic and social / human environments of the study area.
- To carry out an Environmental Impact Assessment (EIA) of instream and floodplain sand mining.
- To suggest an Environmental Management Plan (EMP) for the conservation and management of the rivers of Kerala in general and the river catchments of Vembanad lake, in particular.

1.5 Location of the study area

The area selected for the present study is the river catchments of Vembanad lake (Fig. 1.1). The area is located between north latitudes $9^0 0'$ – $10^0 35'$ and east longitudes $76^0 05'$ - $77^0 25'$. The total area of the river catchments and the lake basin is about 15100 km^2; out of this about 96% of the area is drained by seven rivers such as Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy

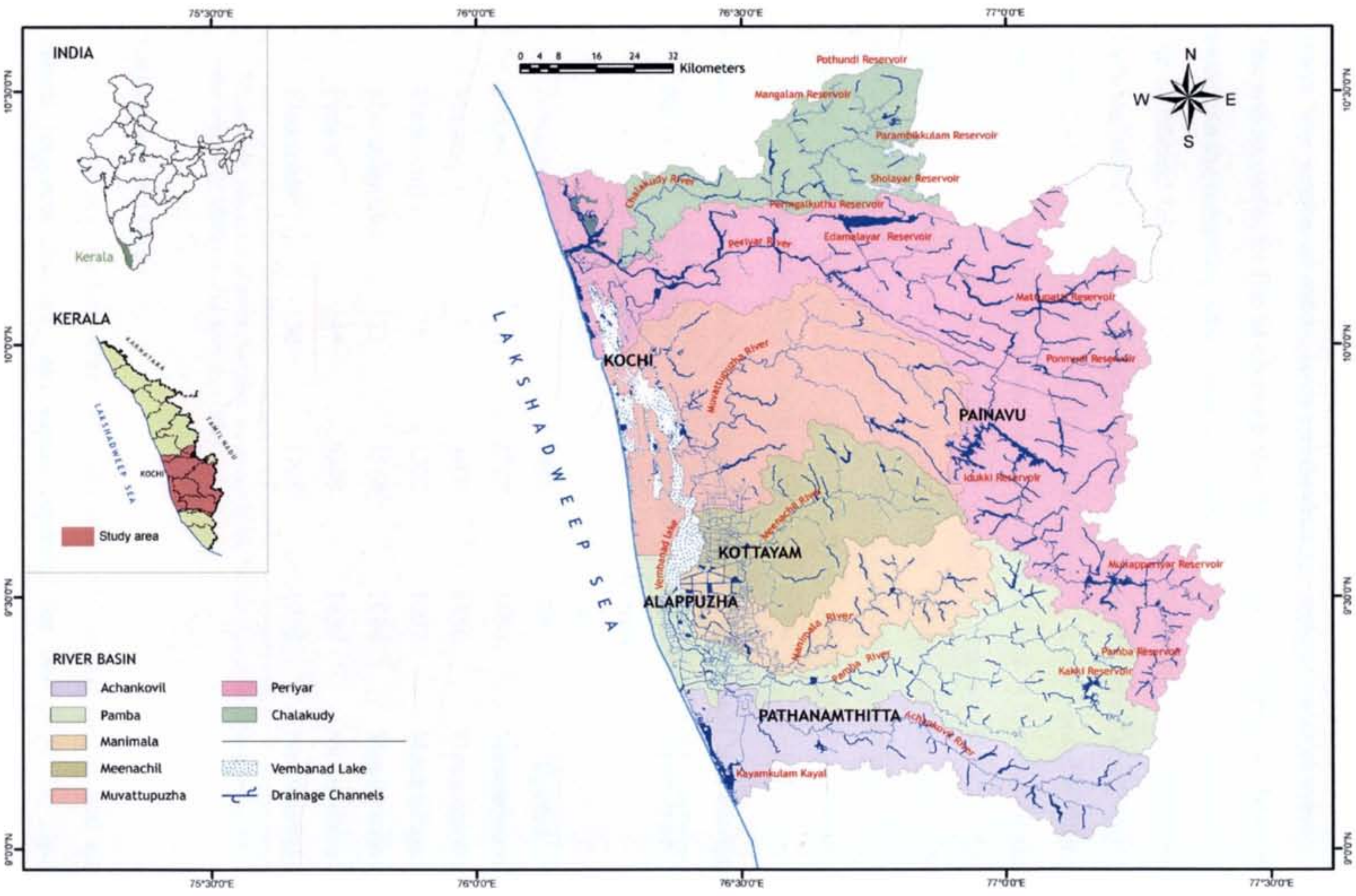


Fig. 1.1 Location map of the study area showing Vembanad lake and the river catchments

rivers. The Vembanad coastal lands and the drainage areas of minor channels (i.e., the first and second order fluvial channels that directly join the Vembanad lake) together constitute the remaining area. Table 1.1 shows salient features of the rivers draining the Vembanad lake catchments. The coastal areas of the Vembanad basin, perhaps, have the highest density of population (eg., population density of Kochi Corporation as per 2001 Census = 6277 inh.km^{-2}), in the country. Another possible stress in the area will be from the emerging mega developmental projects. A few such projects like 'Smart City', Vallarpadam Transhipment Container Terminal (VTCT), Liquified Natural Gas (LNG) terminal, etc., have already initiated in the area. All these developmental projects require sand for building infrastructural facilities. This would naturally aggravate the extraction of sand from the rivers in the Vembanad lake catchments ultimately leading to its degradation.

Table 1.1 Salient features of the rivers draining the Vembanad lake catchments

River	River length (km)	Basin area (km^2)	Headwater elevation$^\#$ (m)	River type*
Achankovil	128	1484	700	Upland
Pamba	176	2235	1650	Mountainous
Manimala	90	847	1156	Mountainous
Meenachil	78	1272	1097	Mountainous
Muvattupuzha	121	1554	1094	Mountainous
Periyar	244	5398	1830	Mountainous
Chalakudy	130	1704	1250	Mountainous

*#Headwater elevation is measured from mean sea level; *River type is identified following the scheme of Milliman and Syvitsky (1992).*

1.6 Scope of the study

Rivers are the last refuge of many plant and animal species and also, the natural resources that they can supply represent the best hope for sustainable development. In a State like Kerala, where highlands and lowlands are close by narrow strips, the rivers are invariably short with limited instream and floodplain sand deposits. The population growth, the fast pace of urbanization and associated developmental activities in the second half of the post independence era led to construction boom in Kerala, which in turn, enhanced the demand for aggregate materials like sand and gravel. As rivers are the first to be adversely affected in any economic developments, their monitoring and management based on scientific studies are very essential for setting developmental activities within sustainable limits.

In Kerala, the maximum impairment of rivers, especially in areas close to urban centres, has occurred as a result of activities such as extraction of river bed materials like sand and gravel, water extraction, disposal of wastes, construction of engineering structures, encroachments, etc. As rivers are the major sources of construction grade fine aggregates, especially sand, its clandestine mining creates extremely serious environmental impacts. All these problems / issues require immediate attention and remedial measures. But, lack of adequate scientific information / data on the negative effects of sand mining is a major constraint in tackling the issues.

Therefore, the present study and its recommendations will be useful for chalking out sustainable management strategies for the conservation of the small rivers of densely populated, tropical regions like the rivers in the Vembanad lake catchments.

Chapter 2

THE RIVER ENVIRONMENT: A GENERAL PROFILE

2.1 Introduction

Rivers are the fundamental components of landscape and lifescape. These complex systems of flowing waters drain through specific land areas and have evolved through multiple and complex interactions of geological, geomorphological, climatic and hydrological processes. River flow determines many of the land-life systems' key features and transports particulate and dissolved materials in the form of sediments from land to ocean. River sediments, especially the fine particulates containing nutrient elements and other geochemical components transported downstream, play an important role in maintaining the productivity of the coastal-nearshore environments (Meybeck, 1982; Webb et al., 2000; Cruzado et al., 2002; Boyer et al., 2006). In addition to this, rivers provide habitat for many biotic communities all along their courses. The longitudinal changes in community structure within a river system reflect differences in the capacity of various species to tolerate the changing physical and chemical conditions, along with differences in food resources, predators and competitors in the system. The importance of physical processes in rivers draws increasing attention, in general, and hydrology and geomorphology, in particular, leads to better insight into the interrelationships between physical and biological factors. Without understanding the fundamentals of ecological and physical processes that provide information onto the functional and structural characteristics in river systems, a better management of the system is not possible. This chapter addresses a few general aspects of the river environment for a logical presentation of central theme of the present study.

2.2 River research – a brief review

The study of rivers has emerged as a major area of interest since 1972 with the publication of the classic treatise 'The Ecology of Running Waters' (Hynes, 1972). This publication, in combination with the previous work of Leopold et al. (1964) on the geomorphology of channels and the later published work on the 'Biogeochemical Process of Rivers and their Watershed Areas' by Bormann and Likens (1979) provided the foundation of the vast area of river research. Since the mid 1970's, many volumes on river ecosystems have been published, the important among them are Richards (1982), Naiman and Decamps (1990) and Gordon et al. (1992). Many of the synthesis produced in the last two decades are edited volumes, a trend that perhaps reflects the highly interdisciplinary nature of river ecology.

The early researchers who recognised the obvious unitary feature of drainage basins, both of geometry and process, were Playfair (1802) and Chorley et al. (1964). A cursory glance of literature reveals that numerous studies are available on ecology and related aspects of rivers (Steinmann, 1907; 1909; Thienemann, 1925; Ward and Tockner, 2001; Weins, 2002; Molle, 2007). Many classic studies exist on fluvial geomorphology as well (Horton, 1945; Schumm, 1956; Melton, 1957; Strahler, 1958; Chorley and Morgan, 1962; Leopold et al., 1964; Gregory and Walling, 1973; Orr and Pawlick, 2000; Jeje and Ikeazota, 2002; Church, 2002 and several others). The overall balance between dissolved and sediment load carried to the oceans was computed by researchers like Holeman (1968), Meybeck (1976), Martin and Meybeck (1979) and Milliman and Meade (1983). Many studies are also available on the characteristics of sediments transported by world rivers (Folk and Ward, 1957; Mason and Folk, 1958; Friedman, 1961; 1967; Griffiths, 1962; Folk, 1966; Goldberg, 1980; Sly et al., 1982; Judith and Michael 1998; Lamy et al., 1998; Yaacob and Hussain, 2005).

Excellent reviews of organism - substrate relationships in rivers are made by Cummins (1962), Hynes (1972) and Minshall (1984). Several researchers have dealt the changes in the trophic system of rivers resulting from anthropogenic disturbances (Naiman and Decamps, 1990; Haslam, 1990). Stanford and Ward (1993) summarized different types of human interventions that disrupt ecological linkages between terrestrial and aquatic ecosystems. Since the mid 1970's, a number of works have been published addressing the different components of stream ecosystem which include riparian forests (Naiman and Decamps, 1990; 1997), aquatic invertebrates (Mellanby, 1986; Ward, 1992), conceptual advances in ecosystem structure and process (Barnes and Minshall, 1983; Webster and Meyer, 1997), dynamics of regulated rivers (Ward and Stanford, 1979; Petts, 1984), methodological approaches (Hauer and Lamberti, 1996) and conservation / management of river ecosystems (Boon et al., 1992).

Chemical analysis of river water and sediments is being carried out for the exploration as well as environmental monitoring and management. Gibbs (1970) in a classic study discussed the mechanisms that control the world river water chemistry. Extensive studies have been done in the world's major rivers by several investigators (Reeder et al., 1972, in Mackenzie river; Trefrey and Presley, 1976, in Missisippi river; Duinker and Notling, 1976, in Rhine river; Gibbs, 1977, in Amazon and Yukon rivers; Meybeck, 1978, in Zaire river; Yeats and Brewens, 1982, in St. Lawrence river; Sarin and Krishnaswamy, 1984, in Ganges – Brahmaputra rivers; Qu and Yan, 1990, in Chang Jiyang and Don Jiang rivers; Galero et al., 1998, in Chicam-Toctino river; Singh et al., 2008 in Damodar river).

Extraction of natural resources from rivers and their consequent environmental problems has received much attention in the past few decades. Researchers like Troitskii et al. (1991), Mossa and Austin (1998), Douglas (2000), Kondolf et al. (2002), Roberge (2002), Alvarado et al. (2003), Farrant et al. (2003), Macfarlane and Mitchell (2003), Weeks et al. (2003) and Mol and Ouboter (2004) have tried to unfold the impact of sand mining on various environmental components of river ecosystems. River restoration has emerged as an increasingly important activity in most of the developed countries like North America and Europe. This is to improve water quality of the river ecosystems in addition to enhancing the aquatic and riparian habitat to facilitate human uses (Petts and Calow, 1996; Bernhardt et al., 2005; Wohl, 2005). A series of legal actions and water rights hearings have established minimum flow requirements, including flushing flows, and initiated a court-mandated programme of restoration projects to enhance aquatic and riparian habitat (Dunning, 1994). Palmer et al. (2005) proposed standards for river restoration with emphasis on an ecological perspective. The effectiveness of braided, gravel-bed river restoration in the Upper Waitaki basin, New Zealand has been performed by Caruso (2006). River restoration in California has been dealt in many studies of Kondolf (Kondolf, 1994b; Kondolf, 1995a; Kondolf, 1995b; Kondolf, 2006; Kondolf et al., 2006; Kondolf et al., 2007). Carline and Walsh (2007) analysed the responses of Spring Creek Watershed to riparian restoration.

In India, there are many reports available on the sediment texture (Borole, et al. 1982; Subramanian, 1987; Badarudeen, 1997; Mohan, 2000a; Srinivas, 2002, Maya, 2005, Arun, 2006), water quality (Ganapathi, 1956; Venkateswarlu and Jayanthi, 1968; Agarwal et al. 1976; Balchand, 1983; Sankaranarayanan et al., 1986; Premchand et al., 1987; Joy, 1992; Krishnakumar, 2002), biota (Joy, 1989; Arun, 1992; Bachan, 2003; Sushama, 2003; Subramanian and Sivaramakrishnan, 2005) and nutrient status (Sankaranarayanan et al., 1984; Saraladevi et al., 1991; Babu and Sreebha, 2004) of river-estuarine-shore regions. All these studies in one way or the other, helped in strengthening our understanding of rivers and its role in sustaining life on the Mother Earth.

2.3 River classification

The classification of streams is complicated by both longitudinal and lateral linkages, by changes that occur in the physical features over time, and by boundaries between apparent patches that are often indistinct. Davis (1899) divided rivers into three classes based on relative stage of adjustment – youthful, mature and old age. River classification systems based on qualitative and descriptive delineations were developed by Melton (1936) and Matthes (1956). Broadly, two types of river classifications exist in literature – 1) physical and 2) biotic. Most classifications are based on characteristics of biota (Huet, 1954; Hawkins, et al., 1993) or valley types (Thornbury, 1969) or fluvial features (Galay et al., 1973; Mollard, 1973), but a few are based on other characteristics like levee formations (Culbertson et al., 1967) and floodplain types (Nanson and Croke, 1992). Table 2.1 shows river types based on discharge characteristics and river basin properties.

Table 2.1 Classification of rivers based on water discharge and river characteristics.

River size	Average discharge (m^3s^{-1})	Drainage area (km^2)	River width (m)	Stream order
Very large rivers	> 10000	> 10^6	> 1500	> 10
Large rivers	1000 - 10000	100000 - 10^6	800 - 1500	7 - 11
Rivers	100 - 1000	10000 - 100000	200 - 800	6 - 9
Small rivers	10 - 100	1000 - 10000	40 - 200	4 - 7
Streams	1 - 10	100 - 1000	8 - 40	3 - 6
Small streams	0.1 – 1.0	10 - 100	1 - 8	2 – 5
Brooks	< 0.1	< 10	< 1	1 - 3

Source: Gray (2005)

Another important classification proposed by Milliman and Syvitski (1992) is based on headwater elevation of rivers. They classified rivers as high mountain (Head water elevation > 3000 m amsl), mountainous (1000 – 3000 m amsl), upland (500 – 1000 m amsl), lowland (100 – 500 m amsl) and coastal plain (< 100 m amsl) rivers. The quality of river water was also considered, in some cases, for classifying rivers (Sioli, 1950; Furch and Junk, 1997). Based on this, the rivers are classified as black water rivers, white water rivers and clear water rivers. A black water river is one with a deep, slow moving channel that flows through forested swamps and wetlands. The black colour of river water is attributed by leaching of tannins from decayed leaves of adjoining vegetated lands. Black water rivers are seen in Amazonia, Orinoco basin, Southern and Northern United States. Negro river is the largest black water river in the world and is one of the largest Amazonian tributaries. The white water rivers are muddy in colour due to their high sediment content, while clear water rivers drain areas where there is little erosion. Based on the flow characteristics / water availability, rivers are classified into three – (1) ephemeral, (2) intermediate and (3) perennial. Ephemeral rivers are those which do not flow continuously throughout the year. Such rivers are common in semi-arid and desert regions. Intermediate rivers are those that carry water almost throughout the year and dry up in extreme droughts. Some rivers flow throughout the year even in extreme droughts and are called perennial rivers. Zonation of fish distributions along river course has been used to provide a simple classification, akin to the youthful, mature and old-age physical zones. The typical pattern in temperate streams is (from headstream to downstream) trout zone, grayling zone, barbel zone and bream zone (Huet, 1954).

2.4 Stream pattern and drainage pattern

A variety of streams may be recognized in a region of sufficiently old age. On the basis of their genesis, the streams in a given terrain / region can be classified into 1) consequent streams – streams that are formed as a consequence of the existing surface relief and follow slope of the initial land surface; 2) subsequent streams – tributary streams which are developed on the sloping sides of the river valleys; 3) obsequent streams – tributary streams flowing in opposite direction to the main consequent stream; 4) superimposed streams – streams originally following surface relief of the overlying younger formation will later be changed by its flow according to the slope / dip of the older formation, after eroding the former (i.e., the younger formation); and 5) antecedent streams – streams that are able to maintain their original course in spite of later crustal deformation resulting in the uplift of the area.

In any region, a number of the above types of streams may be developed and be responsible for draining out water made available to that region by surface flow. The relationship of such streams with one another and with the region as a whole gives rise to drainage pattern. The most important and common types of drainage patterns are 1) Dendritic – the overall appearance of the channel arrangement will be tree like with numerous branches joining in the middle and lower reaches of the river; 2) Trellis – when consequent streams receive a number of subsequent streams from either side at right angles; 3) Rectangular – characteristic drainage pattern of faulted or fractured terrain; 4) Parallel – the stream channels will be arranged mutually parallel to each other; 5) Radial – the drainage channels will be oriented like the radius of a circle and 5) Annular – the channel follows a circular pattern. A compilation of stream patterns and drainage patterns is illustrated with examples in the classic studies of Howard (1967) and Bloom (1979).

2.5 River channels and channel classifications

River channels form the most important component in a river ecosystem. On one side, they are avenues of sediment transport from continents to the oceans. On the other, they are conducive environments for freshwater ecosystems that have economic and social significance. Variability in sediment delivery, hydraulic discharge, and channel slope give rise to spatial and temporal variations in channel morphology and response. Over geologic time, channels respond to tectonic uplift, erosion of the landscape and climate change. But over historical time, channels respond to changes in discharge and sediment supply from both land use and such extreme events as floods and droughts (Montgomery and Buffington, 1998). Human influences on channels and their inputs can affect rapid destabilization of equilibrium conditions, or force rapid change of equilibrium values. The most common and drastic human influences are related to urbanization and industrialization, and include changes to the hydrologic regime and imposing constraints on the channel, such as levees, revetments or culverts.

River channels are classified based on various criteria. According to Kondolf (1995b), no single classification can satisfy all possible purposes or likely encompass all possible channel types. River classification based on geomorphic characteristics came into prominence in the 1940's (Horton, 1945; Strahler, 1957; Leopold and Wolman, 1957). The most widely used channel classification is based on the concept of stream order proposed by Horton (1945), and later modified by Strahler (1957). In this system, the channel segment from the head of the channel network to the first confluence constitutes a first order channel. Two first order channels give rise to a second order channel and so on and so forth. Leopold and Wolman (1957) quantitatively differentiated straight, meandering and braided channel patterns based on the relationships between slope and discharge. Based on grain size and sediment mobility characteristics, Henderson (1963) recognised two types of channels – (1) 'live bed' channels (that are actively mobile at most stages) and (2) 'threshold' channels (that exhibit significant mobility only during high flows). Schumm (1968; 1977) classified alluvial channels based on dominant modes of sediment transport (Table 2.2) and recognised three geomorphic zones within a watershed: 1) degrading headwater channels that are the primary source of sediment and water inputs, 2) stable mid-network channels with roughly balanced inputs and outputs and 3) aggrading channels low in the network characterised by extensive depositional floodplains or deltas.

Table 2.2 Classification of alluvial channels based on nature of sediment load (Schumm, 1977)

Channel type	**M (%)**	**Bedload (% of total load)**	**Channel behaviour**		
			Stable	**Depositing**	**Eroding**
Suspended load	> 20	< 3	$F < 10$ $P > 2$ Gentle slope	Deposition on banks; Narrowing	Erosion of bed; deepening
Mixed load	5 – 20	3 – 11	$10 < F < 40$ $1.1 < P < 2.0$ Moderate slope	Deposition on banks, then bed	Erosion of bed, then banks
Bed load	< 5	> 11	$F > 40$ $P < 1.3$ Steep slope	Deposition on bed, bar formation and shallowing	Erosion of banks, widening

M – Silt and clay in channel perimeter; F width/depth ratio; P = Sinuosity Index

A heirarchial approach to channel classification was proposed by Frissell et al. (1986) that addressed different factors influencing channel properties over a range of spatial and temporal scales. A hierarchy of spatial scales that makes differences in processes and controls in channel morphology include geomorphic province, watershed, valley segment, channel reach and channel unit (Table 2.3).

Table 2.3 Hierarchial levels of channel classification (Frissell et al., 1986)

Classification level	**Spatial scale**
Geomorphic province	**1,000 km^2**
Watershed	**50-500 km^2**
Valley segment	**10^2-10^4 m**
Colluvial valleys	
Bedrock valleys	
Alluvial valleys	
Channel reaches	**10^1-10^3 m**
Colluvial reaches	
Bedrock reaches	
Free-formed alluvial reaches	
Cascade reaches	
Step-pool reaches	
Plane-bed reaches	
Pool-riffle reaches	
Dune-ripple reaches	
Forced alluvial reaches	
Forced step-pool	
Forced pool-riffle	
Channel units	**10^0-10^1 m**
Pools	
Bars	
Shallows	

Various classification schemes for river channel morphology have been suggested by Montgomery and Buffington (1998). Channels containing sediments, that they have previously deposited, are termed alluvial channels. Alluvial channels are certainly competent to modify their form, since they previously moved the sediment that makes up their bed and banks. Montgomery and Buffington (1997) proposed a classification based on a hierarchy of spatial scales that reflect different geomorphic processes and controls on channel morphology. The three basic channel reaches progressing from top to bottom in the stream network are colluvial reaches, bedrock reaches and alluvial reaches. The alluvial reach is categorized into five free-formed alluvial channel reach types such as cascade, step-pool, plane-bed, pool-riffle, and dune-ripple morphologies. These terminologies are followed in the present investigation also.

Colluvial reaches typically occupy headwater portions of a channel network and occur where drainage areas are large enough to sustain a channel for the local ground slope (Montgomery and Dietrich, 1988). Episodic transport by debris flows accounts for most of the sediment transport in steep headwater channels (Swanson et al., 1982). This reach does not govern deposition, sorting or transport of most valley fill because of low shear stresses (Benda, 1990). Bedrock reaches exhibit little, if any, alluvial bed material or valley fill, and are generally confined by valley walls and lack floodplains. They occur on steeper slopes than alluvial reaches with similar drainage areas thereby lacking an alluvial bed due to high transport capacity than sediment supply (Gilbert, 1914; Montgomery et al., 1996).

Cascade reaches occur on steep slopes with high rates of energy dissipation. Cascade reaches are characterized longitudinally and laterally by disorganized bed material, typically consisting of cobbles and boulders confined within valley walls. Flow in cascade reaches follows a tortuous convergent and divergent path over and around individual large clasts; tumbling flow over these grains and turbulence associated with jet-and-wake flow around grains dissipates much of the mechanical energy of the flow (Peterson and Mohanty, 1960; Grant et al., 1990). Large particle size relative to flow depth make the largest bed forming material of cascade reaches mobile only during infrequent events (Grant et al., 1990). In contrast, rapid transport of the smaller bedload material over the more stable bed-forming clasts occurs during flows of moderate recurrence interval.

Step-pool reaches consist of large clasts organized into discrete channel spanning accumulations that form a series of steps separating pools containing finer material. The stepped morphology of the bed results in alternating turbulent flow over steps and tranquil flow in pools. Channel spanning steps provide much of the elevation drop and roughness in step-pool reaches (Whittaker and Jaeggi, 1982). Step-forming clasts may be viewed as a congested zone of large grains that causes increased local flow resistance and further accumulation of large particles (Church and Jones, 1982), or as macroscale antidunes (Whittaker and Jaeggi, 1982). Step-pool morphologies develop during infrequent flood events and are associated with supply-limited conditions, steep gradients, coarse bed materials, and confined channels (Chin, 1989). Like cascade reaches, large bedforming material mobilizes infrequently (Grant et al., 1990) while finer pool-filling material transports annually as bedload (Schmidt and Ergenzinger, 1992). Step-pool reaches often receive episodic slugs of sediment input that move downstream as bed load waves (Whittaker, 1987).

Plane-bed reaches are characterized by relatively featureless gravel / cobble bed that encompasses channel units often termed glides, riffles, and rapids (Bisson et al., 1982). Plane-bed reaches may be either unconfined or confined by valley walls and are distinguished from cascade reaches by the absence of tumbling flow and smaller relative roughness (ratio of the largest grain size to bank full flow depth). Plane-bed reaches lack sufficient lateral flow convergence to develop pool-riffle morphology because of lower width-to-depth ratios and greater relative roughness, which may decompose lateral flow into smaller circulation cells (Ikeda, 1977). Lack of depositional features, such as bar forms, and typically armored bed surfaces demonstrate some supply-limited characteristics of plane-bed reaches (Dietrich et al., 1989). However, studies of armored gravel-bed channels show a general correlation of bed load transport rate and discharge during armor-breaching events (Jackson and Beschta, 1982), indicating that sediment transport is not limited by supply, once the bed is mobilized. Hence, plane-bed reaches represent a transition between supply and transport-limited morphologies.

Pool-riffle reaches are typically unconfined by valley walls and consist of a laterally oscillating sequence of bars, pools, and riffles resulting from oscillating cross-channel flow that causes flow convergence and scour on alternating banks of the channel. Concordant downstream flow divergence on the opposite side of the channel results in local sediment accumulation in discrete bars. Bedforms in many pool-riffle reaches are relatively stable morphologic features, even though the material forming the bed is transported annually. Alluvial bar development requires a large width-to-depth ratio and small grains are easily mobilized and aggraded by the flow (Church and Jones, 1982). Although the presence of depositional bar forms in pool-riffle reaches suggests that they are generally more transport-limited than plane-bed reaches, the transport-limited character of both of these morphologies contrasts with the more supply-limited character of step pool and cascade reaches.

Dune-ripple reaches are unconfined, low-gradient and sand-bedded channels. They exhibit a succession of mobile bedforms with increasing flow depth and velocity that proceeds as lower regime plane bed, ripples, sand waves, dunes, upper regime plane bed, and finally antidunes (Gilbert, 1914). The primary flow resistance is provided by bedforms (Kennedy, 1975), several scales of which may coexist; ripples and small dunes that climb over larger dunes as they all move down the channel. Sediment transport in dune-ripple reaches occurs at most stages, and strongly depends on water discharge.

Rosgen's classification of natural rivers (Rosgen, 1994) is well known and frequently used in river management studies. This classification involves morphologically similar stream reaches that are divided into seven major stream type categories that differ in entrenchment, gradient, width-depth ratio and sinuosity in various landforms which based on variables such as channel patterns and channel slope. Within each major category are six additional types delineated by dominant channel materials from bedrock to silt / clay along a continuum of gradient ranges. However, this is not process-based and this may limit its usefulness when assessing the response of stream channels to disturbances, for instance. A process-based classification of rivers should involve bed material size, channel gradient and channel depth (Whiting and Bradley, 1993). Church (1992) introduced a relatively simple classification of stream channels based on channel size and sediment size. This classification is based on the ratio of flow depth (d) to a characteristic grain size index (D). The ratio d/D is used in numerous process-based equations in fluvial studies. Based on this ratio, three types of alluvial channels are distinguished. They are small, intermediate and large channels. Small channels are those having d/D ratio less than 1, where individual clasts (e.g. cobbles, greater in diameter than 64 mm) may protrude above the water surface and significantly affect local flow processes. Under these conditions, the bed is usually arranged in a sequence of steps and pools or cascades and are usually characterised by high gradients. Intermediate channels can be defined by a d/D greater than 1 and lesser than 10 (the depth being as much as 10 times greater than the bed material size). They are usually associated with channel gradients varying between 0.1 and 1 percent. In the downstream direction, the beds of these rivers are often characterised by a succession of shallow and deep sections, referred to as pool-riffle sequences. The pools are usually associated with meander bends (more specifically with the scour zone often observed along the outer section of a meander bend). The third category, large channels can be defined by a d/D ratio greater than 10. These rivers are either meandering or braiding and the actual pattern depends upon sediment supply as well as stream discharge, channel gradient and the degree of stability of the river banks.

Biotic stream classification is essential for understanding the distribution of ecological patterns within drainage networks and also for developing management strategies that are responsive to the ecological patterns. Shelford (1911) attempted to produce a biological classification scheme for rivers based on his idea of succession. Early classifications generally were based on perceived patterns of biotic zonation using species of fish or invertebrates as indicators of segment types (Ricker, 1934; Huet, 1954). In addition, experts used certain orders of invertebrates (Plecoptera, Ephemeroptera, Trichoptera) for stream classification (Macan, 1961; Illies and Botosaneanu, 1963). Geomorphic classification of rivers became important to fisheries biologists and land managers because geomorphic patterns are strongly linked to species distribution and abundance (Bisson et al., 1988; Morin and Naiman, 1990). Based on the effects on invertebrates and fish populations, a bed material based (inorganic sediment) classification of stream reaches is established by American Society of Civil Engineers (ASCE, 1992) and is given in Table 2.4.

Table 2.4 Bed material-based stream reach classification (ACSE, 1992)

Bed material type	Particle size (mm)	Bed movement	Macro invertebrate		Use of bed sediments to fishes
			Density	Diversity	
Boulder - cobble	≥ 64	Rare	High	High	Cover, spawning, feeding
Gravel – pebble – cobble	2 - 64 64 - 256	Rare to periodic	Moderate	Moderate	Spawning, feeding
Sand	0.062 - 2	Continual	High	Low	Off-channel fine deposit used for feeding
Fine material	< 0.062	Continual or rare	High	Low	Feeding

Channel pattern and style of channel sediment storage are two yet another useful bases for morphological classification of rivers. Since the style of lateral instability may also be important in determining the character of riverine habitat, this provides a third useful dimension for classification. The channel pattern, or planform, of an alluvial river reach reflects the hydrodynamics of flow within the channel and the associated processes of sediment transfer and energy dissipation (Richards, 1982). Channel pattern reflects the configuration of the river. It is affected by the nature of the rocks on which it flows, the resistance to flow, amount and character of the available sediment and the quantity and variability of the discharge (Leopold et al., 1964). Channel patterns can be broadly classified based on the sinuosity index. Sinuous rivers are common type observed in nature because of frequent topographical and sedimentological constraints that disturb the directional uniformity of low power streams. Meandering streams are actively migratory as a result of selective bank erosion and subsequent point bar development. The morphology of alluvial channels responds to varying hydrological conditions, despite the possible existence of equilibrium (Richards and Wood, 1977). Kellerhals et al. (1976)

have classified the river channels according to the channel pattern and the style of sediment storage within the channel environment. They have identified six types of channel plan-form patterns such as straight, sinuous, irregular-wandering, irregular, regular and tortuous meanders. Transitional morphologies also occur, as this classification envisages order on a natural continuum. These channel types are defined by qualitative morphological descriptions and sketches rather than physical measurements. Figs. 2.1 a & b show channel (river) segment classification of Kellerhals and Church (1989).

2.6 The classic concepts in riverine studies

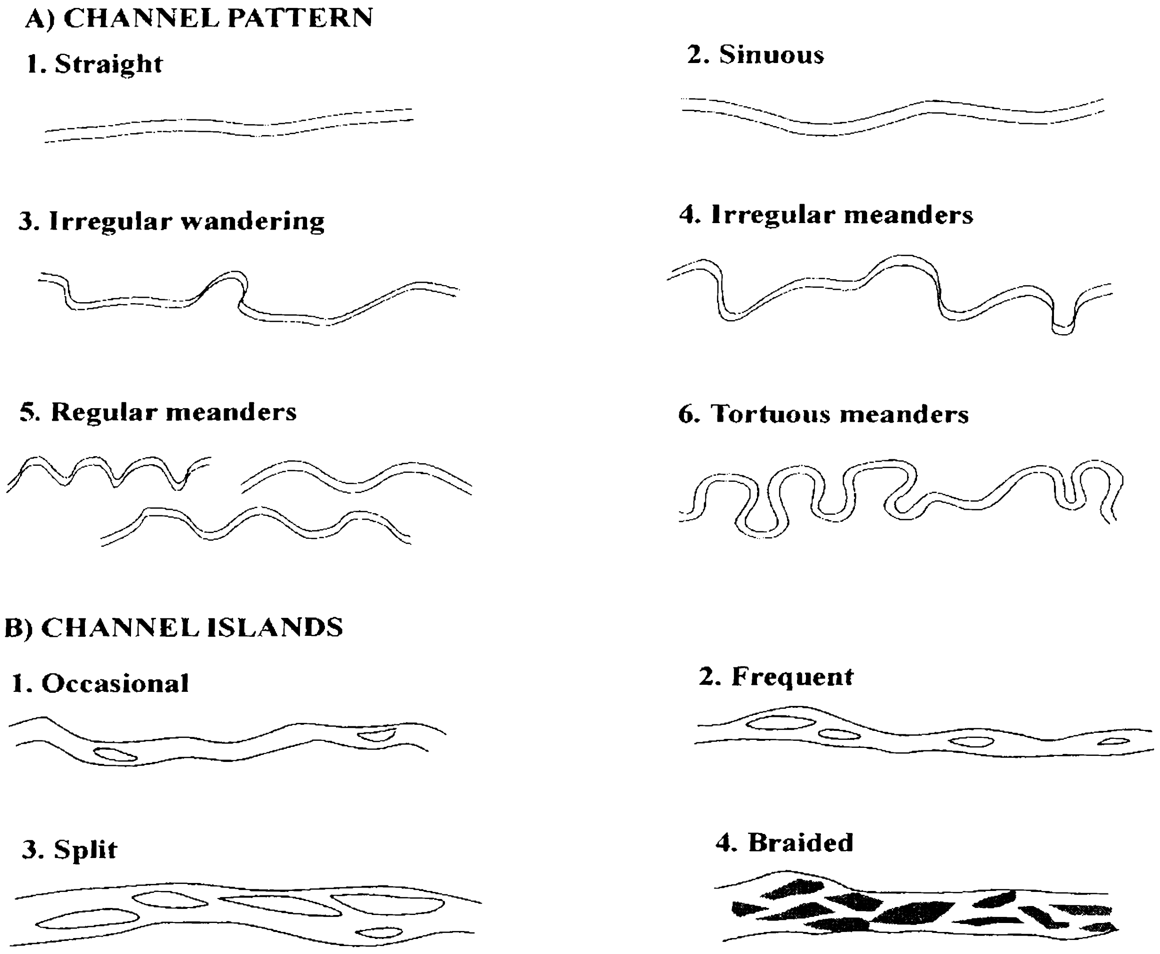
Ecological studies of river systems have made many advances during 1980's and 1990's, and many new paradigms such as the river continuum and nutrient spiralling concepts have emerged during this period. The following sections deal with a brief account of the various classic concepts of riverine studies put forth by world's eminent scientists / research groups.

2.6.1 River Continuum Concept

The river continuum concept was developed by Vannote et al. (1980). The concept was developed from the idea that river systems, from headwaters to the mouth, present a continuous gradient of physical conditions. This gradient provides the physical template upon which the biotic communities and their associated processes developed. As a result, one would expect to observe recognisable patterns in the community structure and input, transport, utilisation, and storage of organic matter. It proposes that energy inputs will change in a longitudinal direction, in relation to channel size, degree of shading, light penetration, and so on. And, the relative importance of functional feeding groups will change in tandem.

2.6.2 Nutrient Spiraling Concept

Webster (1975) and Webster and Patten (1979) proposed nutrient spiraling as a mechanism to account for the apparent ability of stream ecosystems to withstand and recover from disturbance. The term spiraling refers to the spatially dependent cycling of nutrients and the processing (i.e., oxidation, conditioning) of organic matter in lotic



Description

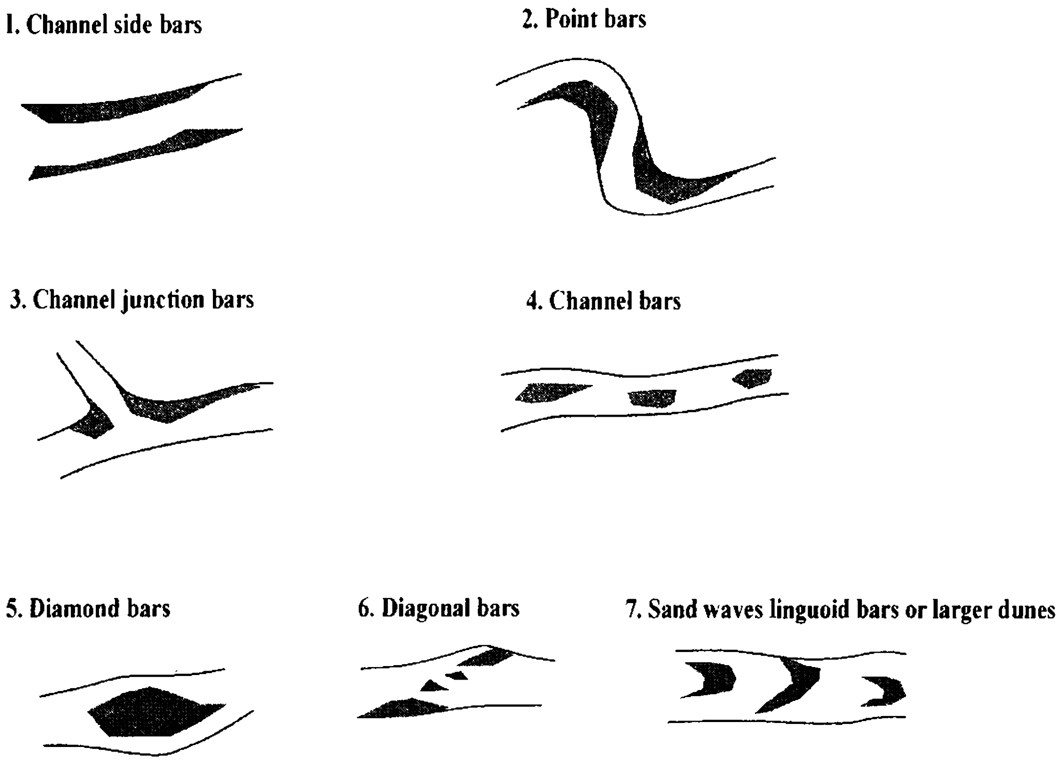
A) CHANNEL PATTERN

1. Very little curvature, occurs mainly in braided channels, delta distributaries and structurally controlled rivers.
2. Slight curvature with a belt width of less than approximately two channel widths.
3. No repeatable pattern. Many braided and split channels fall into this category.
4. A repeated pattern vaguely present in channel plan; free meanders of sand-bed channels with high bed load, and many entrenched meanders are irregular.
5. Characterised by a clearly repeated pattern. The angle between the channel and the valley axis is less than 90^0.
6. A more or less repeated pattern with angles greater than 90^0 between the channel axis and the valley trend.

B) CHANNEL ISLANDS

1. No overlapping of islands, average spacing being ten or more river widths.
2. Infrequent overlapping, with average spacing less than ten river widths.
3. Islands overlap frequently or continuously; the number of flow branches usually is two or three.
4. Continuously overlapped islands, with two or more flow branches.

Fig. 2.1a Classification of river channels based on channel pattern and channel islands
(after Kellerhals and Church, 1989)



1. Channel side bars

2. Point bars

3. Channel junction bars

4. Channel bars

5. Diamond bars

6. Diagonal bars

7. Sand waves linguoid bars or larger dunes

Description

1. In entrenched straight or sinuous channel, side bars may be developed and are associated with slight channel bends and therefore stable.

2. These features form on the inside of well-developed bends.

3. Where a tributary joins a larger river, a bar frequently occurs immediately downstream, or on both sides of the tributary mouth.

4. The bar position remains stable over decades with bed load transport taking place across the bar. Deposition of suspended load in the lee sometimes converts them into islands.

5. Also called 'spool' bars by sedimentologists, they are an extreme development of mid-channel bars characteristic of braided rivers in sand or gravel.

6 This bar type occurs only in gravel bed channels.

7. This type of bar is common in relatively active sand bed channels. The most characteristic property is the dune-like profile.

Fig. 2.1b Classification of river channels based on channel bars
(after Kellerhals and Church, 1989)

ecosystems. In effect, the nutrient spiraling concept provides both a conceptual and quantitative framework for describing the temporal and spatial dynamics of nutrients and organic matter in flowing waters. It also allows the structural and functional aspects of the biotic communities that enhance the retention and utilization of nutrients and organic matter to be interpreted in terms of ecosystem productivity and stability. Later Wallace et al. (1977) applied the idea in describing the role of filter feeders in streams. Newbold and his colleagues developed mathematical models at Oak Ridge National Laboratories to explain this concept (Newbold et al., 1981; 1982a; 1982b; Elwood et al., 1983). These collective studies are termed the nutrient spiraling concept.

2.6.3 Serial Discontinuity Concept

Ward and Stanford (1983) put forth the serial discontinuity concept. A few river systems remain free flowing over their entire course. Rather, regulation by dams typically results in an alternating series of lentic and lotic reaches. The serial discontinuity concept attempts to attain a broad theoretical perspective on regulated rivers, similar to that proposed by the river continuum concept for unregulated rivers.

2.6.4 Hierarchial Controls on System Functions

This idea was proposed by a team of scientists led by Frissell et al. (1986). The relative importance of factors controlling the physical and biological components of stream changes with the spatial and temporal scales are considered here. A hierarchial perspective is necessary because stream processes operate at a wide range of scales (10^{-7} to 10^{8} m spatially and 10^{-8} to 10^{7} year temporally). This approach is an effective management tool because it classifies streams (from microhabitat to watershed scales) using relatively limited variables. This important conceptual advancement addresses channel form or pattern within each hierarchial level, as well as origins and processes of development of channels.

2.6.5 Ecotones

Naiman et al. (1988) proposed the concept of Ecotones in 1988. The compelling reasons for examining the river continuum as a series of discrete patches or communities with reasonably distinct boundaries, rather than a gradual gradient or a continuum. The boundary perspective is complementary to the river continuum concept, but it addresses lateral linkages (eg. channel – riparian forest exchanges) rather than upstream – downstream relations, and provides a better understanding of factors regulating the exchange of energy and materials between identifiable resource patches.

2.6.6 Flood Pulse Concept

This concept was developed by Junk et al. (1989). A principal driving force behind the existence, productivity and interaction of the diverse biota in river – floodplain systems is the flood pulse. A spectrum of geomorphological and hydrological conditions produces flood pulses, which range from unpredictable to predictable and from short to long duration. Short and generally unpredictable flood pulses occur in headwater streams and in streams heavily modified by human activities, whereas long duration and generally predictable floods occur in larger rivers. The net result is that the biota and the associated system level processes reflect the characteristics of the flood regime. Its basis is that the pulsing of river discharge – the flood pulse – is the major force controlling biota in river floodplains, and that lateral exchange between the river channel and its floodplains is more important in determining nutrient and carbon supply in lower reaches than longitudinal connections.

2.6.7 Hyporheic Dynamics

Stanford and Ward (1993) proposed the idea of hyporheic dynamics. Hydrologists have long considered streams and rivers to be dynamic regions linking groundwater with water draining the Earth's surface. Ecologists, in contrast, have typically perceived streams as bounded systems, consisting of the stream bottom and the overlying water. The hyporheic zone (the subsurface region, located beneath and adjacent to streams and rivers, that exchanges water with the surface) is also an integral part of streams that significantly expands the spatial extent of lotic ecosystems. This region is now known to harbour a rich assemblage of organisms, which exert a significant influence on stream metabolism, nutrient cycling and surface – subsurface interactions.

2.7 Geological work of rivers

For millions of years geological agents like rivers, wind, glaciers and gravity have been working unceasingly to reduce the landmasses to the level of seas. Among these geological agents, rivers are the most important agents in tropical and subtropical regions.

Only about one-sixth of the quantity of water falling on land is carried by the rivers into the world oceans; a major part is either evaporated or infiltrated into the ground (Richards, 1982). An idealized river system is composed of three dynamic geomorphic components - the water and sediment source area (drainage basin), the transfer component (main river channel) and the depositional area (alluvial fan, delta, etc.); (Schumm, 1977). It is a true process-response system. The water flowing in a river erodes the land over which it flows, transports the sediments which are formed as a result of weathering and erosion, and finally deposits the transported materials, under favourable conditions into varied landform features. The geological work of rivers is, therefore, of considerable importance and can broadly be divided into several distinct processes like erosion (hydraulic action, abrasion, attrition and solution), transportation (bedload, saltation, suspension and dissolved forms) and deposition (as fluvial landforms). Of these processes, the first process brings about degradation of the terrain while deposition causes aggradation at suitable sites and under favourable conditions. In the upper course of a river, processes are dominated by sediment production and incision of the channel into the landscape. The process of erosion becomes very conspicuous in excavating or downcutting the valley floor. At this stage, therefore, the river passes through narrow but deep valleys which may develop, in the softer rocks, into what is known as a gorge or canyon (Leet et al., 1982).

In the earlier stages of development of a river valley, its transverse profile is more or less "V" shaped. The actual shape of the "V" depends on the relationship between, on the one hand, the speed of downcutting and efficiency of sediment removal by the river, and, on the other hand, the efficiency of slope processes, such as creep and mass movement, and the rate of weathering, which is conditioned by factors such as climate, vegetation cover, and the chemical structure of the underlying rock. The river's erosive capacity is concentrated on downcutting, although it can also contribute to valley widening by undercutting the valley sides, which increases hill-slope erosion and creates landslides that deliver sediments directly into the streams. Channel widening through bank erosion occurs if influx of coarse sediment raises the bed level.

Middle course river processes are dominated by lateral erosion rather than vertical one. The majority of sediment is transported as suspended load, and the sediment becomes finer. Coarser cobbles and pebbles derived from upland erosion are largely deposited, and gravels and sands stored in alluvium and colluvium become the dominant sediment type. The valley is wider than in the upper course, the sides are less steep, and the channel is bordered by a floodplain—an area of low relief that is inundated by water when the river floods, and which is covered in alluvium. The river commonly adopts a sinuous (winding) course, sweeping across its floodplain in a series of long bends called meanders, named after the Menderes, a river in south-western Turkey (Leet et al., 1982). The precise cause of meandering remains uncertain, but it is probably triggered by the sinuous movement that occurs naturally in fluid flows, even in straight channels, and which helps create irregularities in the river's long profile, called pools and riffles. These are regularly spaced, alternating areas of deep and shallow water. Pools comprise hollows scoured in the bed and usually covered in relatively fine gravel and silt; riffles are accumulations of coarser pebbles and cobbles (Clifford and Richards, 1992). Pools and riffles are observed in various environmental conditions. The characteristics of the sediment sorting pattern along pool-riffle sequences may vary significantly as a function of local environmental and sediment supply conditions. Sediment transport processes at the scale of pools and riffles are significant from an ecological and geomorphological perspective. The physical diversity introduced by the presence of pools and riffles is also important in terms of aquatic habitat (Thompson and Hoffman, 2001).

River processes in the lower part (downstream) are dominated by sediment deposition and floodplain building. Sediment is deposited during lateral shifting by the channel (or channels, in the case of braided rivers), and during flood flows. Lowland rivers may be either meandering or braided, depending on levels of energy and sediment load. Lowland meandering rivers are more sinuous than their middle-course and channels may become so tortuous and bends so pronounced that during a flood the river cuts through the narrow neck of land separating the ends of the bend. This is known as a neck cut-off. Because the river has straightened its channel, at least temporarily, the main current returns to the centre of the river and deposition occurs at the sides, eventually cutting off the old curve. Abandoned bends are characteristically horseshoe-shaped and they persist in the riverscape as oxbow lakes.

The conditions that cause a stream to deposit its load are exactly opposite to those that enable it to carry a load. Therefore, a reduction in gradient, volume or velocity will result in deposition. The velocity of stream is checked when they flow from steep to gentle slopes (on the foot of mountains) and the deposits spread out at an alluvial fan. When valley is clogged with debris, the flow of the stream is divided among many channels. Such an interlacing network of ever-changing, braiding and re-uniting channels with islands of shingle and sand in between is called a braided stream. Another depositional feature is the floodplains. Floodplains are low relief features formed by deposition of alluvium on valley flats by meandering streams. They are so called because these wide flats are flooded during high water. The various types of channel deposits (bars) are described in section 2.5. Another important fluvial deposit is delta which is deposited in the river mouth areas. The name derives from the fact that its shape, which is roughly triangular, resembles the Greek letter delta (?). Deltas form because sediment accumulates at the mouth of the river, blocking it and diverting flow to a new location (Coleman, 1969). An essential condition for the growth of a delta is that the rate of deposition of sediment at or just beyond the mouth of a river should exceed the rate of removal by waves and currents (Pichamuthu, 1967). The southwest coast rivers in India do not build deltas as the rate of deposition is lower than that of the quantity of material removed by wave and currents.

2.8 River sediments and channel processes

River sediments comprise a spectrum of particle sizes such as boulder, cobble, pebble, granule, sand, silt and clay. Among this, the largest particles occur in upland channels where the terrain gradient is the highest, while finer entities are enriched progressively downstream due to sediment sorting based on size and specific gravity (Blatt et al., 1972). Lower channel gradients in the lowlands favour deposition of small-sized particles and help floodplain development (Kondolf, 1997). However, in the lower reaches, smaller tributaries can often contribute coarser particles in the receiving mainstream.

The grain size scale introduced by Wentworth is commonly used in fluvial geomorphology to differentiate particle size categories. The Wentworth scale is based on a geometric sequence with ratio 2. The most common size categories in the Wentworth size scale are shown in Table 2.5. Particle sizes can be expressed in different units – in mm, microns (1 μm equal to 0.001 mm), or in 'phi' (ϕ) units.

Table 2.5 Wentworth's particle size classification

Size category	**Particle diameter**	
	mm	**ϕ units**
Boulder	= 256	= -8
Cobble	64-256	-6 to -8
Pebble	4 - 64	-2 to -6
Granule	2-4	-1 to -2
Sand		
Very coarse	1 – 2	0 to -1
Coarse	0.5 – 1	1 to 0
Medium	0.25 – 0.5	2 to 1
Fine	0.125 – 0.25	3 to 2
Very fine	0.0625 – 0.125	4 to 3
Silt	0.0039 – 0.0625	8 to 4
Clay	= 0.0039	= 8

Source: Blatt et al. (1972)

Three sediment delivery processes are recognised (Collins and Dunne, 1989). They are 1) mass wasting on hill slope, 2) hill slope erosion and 3) erosion of channel bed and banks. Mass wasting includes landslides and soil creep, and occurs when gravity moves soil to the river channels. Hill slope erosion occurs when precipitation intensity exceeds the absorption capacity of soil and generates overland flow. Stream channels and floodplains are built up and maintained by erosion and deposition of sediments during high stream flows (Whiting, 1998). In relatively undisturbed river systems at its mature phase, gradual erosion of outside bends of meanders and deposition of eroded materials on inside bends cause an imperceptible shifting of channels within its floodplain. This form of stability is called dynamic equilibrium (Heede, 1986). Although river flows and sediment loads are variable within and among years, sediment balance and channel stability occur over the long term. Instabilities introduced by human activities like deforestation, sand and gravel mining and other activities, and by natural processes like extreme precipitation, forest fires and other events can cause channel bed and banks to become net sources of sediment.

2.9 River as an ecosystem

The flux of energy, expressed as organic matter (or carbon), and other elements and minerals / nutrients are principal components in ecosystem level investigations. River ecology focuses on energy transformation, nutrient turnover and, the storage and processing of organic substrates. Rivers are basically heterotrophic; a substantial proportion of the biotic energy that drives stream communities is organic matter derived from allochthonous sources. Many aquatic plants, invertebrates and fishes have adapted to fill a specific niche. Within most rivers, the pattern of flow variation, and its ramifications in terms of substrate stability and water quality, is the dominant factor controlling species distributions. Elwood et al. (1983) showed that lotic (pertaining to running water) ecosystems are longitudinally interdependent and that energy processing depends on the retention and cycling of nutrients by biological communities in upstream areas.

From a biological point of view, flowing water has a number of advantages over still water. It is constantly mixed up by turbulence providing nutrients, exchange of respiratory gases, and removal of wastes. Lotic water is fundamental for the downstream and lateral movement of plants and animals. However, the character of flow changes from the headwaters to the river mouth and this leads to a characteristic zonation in the biota of rivers. In floodplain rivers, the recession of the annual flood delivers high levels of dissolved organic carbon and detritus (wood, leaves, seeds, etc.) to the main channel. This lateral connectivity is so important for sustaining the integrity of large floodplain rivers.

Autotrophs and heterotrophs are the two main sources of energy to lotic food webs. Autotrophs are organisms that acquire their energy from sunlight and their materials from non-living sources. Heterotrophs obtain energy and materials by consuming living or dead organic matter. Together, the autotrophs and microbial heterotrophs in running waters make energy available to consumer organisms at higher trophic levels. The major autotrophs of running waters include large plants, referred to as macrophytes, and various small autotrophs. The latter are referred to as periphyton when found on substrates, and phytoplankton when occur in suspension within the water column. Heterotrophic production requires a source of non-living organic matter, and the presence of microorganisms (bacteria, fungi) to breakdown the organic matter and release its stored energy. Heterotrophic pathways are of greatest importance where the opportunities for photosynthesis are least (Vannote et al., 1980). This diverse mix of autotrophic and heterotrophic energy inputs provides the support for higher trophic levels.

Nutrients are inorganic materials necessary for the sustenance of life, the supply of which is potentially limiting to biological activity within river ecosystems. Their uptake, transformation and release are influenced by various abiotic and biotic processes. Important metabolic processes likely to affect and be affected by the supply of nutrients include primary production and the microbial decomposition of organic matter. Both phosphorus and nitrogen have been shown to stimulate primary production, and silica likely is important to diatoms because of the high silica content of their cell walls. In addition to these major nutrients, many other chemical constituents of freshwater are potentially important for the sustenance of life in rivers. Nutrient cycling describes the passage of an atom or element from dissolved inorganic nutrient through its incorporation into living tissue to its eventual re-mineralization by excretion or decomposition. In lotic ecosystems, downstream flow cycles into spirals. A number of abiotic and biotic processes influence nutrient spiraling. Although rivers unquestionably transport large quantities of materials downstream, biologically reactive elements cycle repeatedly during their passage, governed by a complex and interdependent set of biological, hydrological and physical-chemical processes.

2.9.1 Influence of channel morphology in river ecology

The morphology of a river channel is resulted from the movement of water and sediment in relation to the material locally available in the bed and the banks (Brookes, 1996). Hydraulic and morphological variability through space and time determine the different habitats found both within a given river channel and also in the adjacent riparian and floodplain zones. Channels change in a variety of ways through the processes of erosion and deposition. Surface runoff and sediment load may be expected to change in response to land use alterations such as deforestation, agriculture, grazing, urbanization and other influences. However, a change in the discharge and sediment load rarely produces an immediate response but instead initiates a change, or sequence of changes, which may extend over a long period of time. Alterations of channel size and shape and substrate characteristics have major impacts on benthic invertebrates (Keefer and Maugham, 1985; Petts and Greenwood, 1985), fish (Milhous, 1982) and aquatic macrophytes (Brookes, 1987). Pools, riffles and bars are composed of different bedload materials which provide environments for a variety of benthic organisms. Substrate size, heterogeneity, frequency of turnover of sediment, and the rates of erosional or depositional processes are all thought to determine invertebrate diversity and abundance

(Petts, 1984). At higher discharges, shelter areas are available as protection for organisms from higher water velocities. Overhanging banks cut on the outside of a bend adjacent to a pool may provide natural cover for fish.

2.9.2 Physical factors essential for instream biota

The physical environment of running waters has been influenced by many features / parameters like current, substrate, temperature, oxygen, etc., that pose special challenges to the organisms that dwell in the environment (Allan, 1995). Recent studies on river ecology provide ample evidence that water current is of direct importance to the biota of these environments. Current affects food resources via the delivery and removal of nutrients and food items. Much attention has also paid on the near-bed flow environment, because many of the animals and plants of lotic waters live in contact with the substrate. Substrate is a complex aspect of the physical environment. Current, together with the available parent material, determines mineral substrate composition. Substrate includes everything on the bottom or sides of streams or projecting out into the stream, not excluding a variety of human artifacts and debris, on which organisms reside (Minshall, 1984). Substrate is highly variable and exhibit small-scale patchiness both vertically and horizontally within the river bed. The great majority of stream dwelling macro-invertebrates live in close association with the substrate. Some stream dwelling organisms are quite restricted in the conditions they occupy and these substrate selective organisms are known by different names such as lithophilous (those found in association with stony substrates), psammophilous (sand substrate), xylophilous (wood dwelling) and phytophilous (aquatic plants as substrate) taxa. Temperature affects the growth and respiration of individual organisms and the productivity of ecosystems through its influences upon metabolic processes. Organisms generally perform best within the subset of possible temperatures that corresponds to where they are found, but some organisms tolerate a wider temperature range than others. Since temperature influences both the availability and the demand for oxygen, it is difficult to say whether temperature directly excludes cold-water species from occupying warmer environments, or if oxygen supply is responsible. Under most conditions in rivers, oxygen is not limiting to biological activity, but under certain conditions, particularly high temperatures and low flows, oxygen can be a critical environmental variable.

Aquatic and riparian vegetation are vital for a healthy and sustainable river ecosystem. However, vegetation is more likely to be of greatest significance for fisheries when a water course has little or no variation in physical structure; it is here that the aquatic vegetation becomes a physical habitat in its own right (FAO, 1998). The importance of aquatic plants to organisms especially fishes, are water purification, nutrient recycling, physical link between water and air for many invertebrates, refugia for zooplankton which graze phytoplankton, cover for huge range of invertebrates, cover for fish, spawning areas and sites of oviposition for many fish species, food source, affects flow patterns, creation of discrete habitat structure, etc. At the same time, riparian vegetation provides shade to cool waters, control excessive weed growth by shading, overhangs provide favoured cover for fishes, underwater fine root systems are important habitat for invertebrates (potential food), fine roots may be used as spawning habitat by species which utilize vegetations, invertebrates and leaves dropping into the water are an important source of fish food, improved landscape setting etc. The riparian vegetation along the river banks is a unique habitat, existing in a mutual balance with the channel (Mason et al., 1984). They are as vulnerable to careless management as the river channel itself. The riparian zone is often a kalcidoscope of reworked river deposits and different successional communities of plants (Kalliola and Puhakka, 1988).

Rivers are characterized by changing flows, variable water quality conditions, unsteady hydraulics and changing channel forms. These dynamic conditions can be detected over periods as short as a minute and as long as 10000 years or more. Water quality and fine sediment dynamics fingerprint headwater catchment characteristics (Foster et al., 1995) and determine the environment within which the biota lives.

However, it is the nature of river channel changes (Brookes, 1996) that determines the availability of suitable habitat for biota.

2.10 Human interventions on river environment and threats

Today, the dynamics of river systems, throughout the world, are affected greatly by human interventions either within the catchment or directly within the river corridor (Petts and Calow, 1996). Disturbances like erosion and abrasion, siltation and burial, dessication and extremes of water quality plays a critical role in organizing communities and ecosystems (Reice et al., 1990). Ecologically and geomorphologically, running waters are ever changing systems. It is often implicitly assumed in fluvial geomorphology that, given sufficient time between disturbances or environmental changes, a fluvial system will reach a state of adjustment with a characteristic form, and that a dynamic steady-state will be maintained. In many cases streams do maintain dynamic steady-state equilibrium, but many do not, either because they are too frequently disturbed, or they are inherently unstable (Renwick, 1992). There is no evidence that stable, steadystate equilbrium stream channels or fluvial systems are notably more common or more "normal" than non-equilibrium states (Tooth and Nanson, 2000; Philips et al., 2005; Philips, 2007).

River regulation by dams, diversions, channelisation and other physical controls, resource extraction including sand and gravel, etc., has significantly altered majority of the world rivers. The physical, chemical and biological characteristics of rivers suffer from these effects. In addition to directly altering river flow, anthropogenic activities transform the landscape through which the river flows. Erosion delivers more sediments to river channel, with detrimental effects on the instream habitat. Removal of riparian vegetation leads rise in temperature of overlying waters, shift from heterotrophy to autotrophy, reduced bank stability, and loss of the natural capacity to prevent sediments and nutrients from reaching river channels. Anthropogenic activities also enhance the quantity of chemical wastes entering rivers, both from agricultural and urban sources.

Human impacts on river ecosystems may vary in character, and the way in which they are mitigated or resolved depends on whether they are 'planned' or 'unplanned'. 'Planned impacts' are usually direct, quickly felt effects, such as land use change or in-channel changes by construction and / or mining activities. Clear-felling of forest cover on slopes close to channel margins may increase the quantity and speed of overland flow. Construction of bridges and check dams modifies local flow behaviour in channels, causing scour of adjacent bed and bank sediments. Construction of large impoundments as well as large-scale river bed mining is the most radical forms of human impacts (Elliott and Parker, 1997; Hadley and Emmett, 1998; Kondolf, 1997). Although this form of intervention can exert long-term effects, most of them are, in principle, reversible, or at least amenable to mitigation. Channel works can be removed or redesigned; land use change can be reversed. 'Unplanned effects' are usually delayed in their onset, are often more difficult to identify, and may be cumulative. Protection and restoration of rivers from anthropogenic disturbances is the need of the hour. Rivers have considerable ability to recover from 'pulse events', such as chemical inputs from an accidental spill or a point source. Unfortunately, the most serious threats like sand and gravel mining, channelisation and other forms of regulation are essentially continuous, or 'press events'. These require much more effort to address, and one hopes that the principles of ecology and geomorphology will have to be considered / viewed seriously while designing conservation and management strategies to these life sustaining systems.

Chapter 3

THE STUDY AREA

3.1 Introduction

The lowlands of Kerala is endowed with a chain of water bodies such as fluvial channels, estuaries, lagoons, swamps and marshes. These aquatic systems play a significant role in the social, economic and environmental scenarios of Kerala State. Among these water bodies, the Vembanad lake (Vembanad lagoon *sensu stricto*), popularly called the Vembanad *kayal*, is the largest one in areal extension. The lake is with a length of 113 km and breadth varies from a few hundreds of metres to about 7 km. The total area of the lake is about 210 km^2 (Kurup et al., 1993). The hinterlands of the lake are drained by Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy rivers. The area drained by these rivers (12647 km^2) together with the Drainage areas of Minor Channels (DMC) joining the lake and the Vembanad Coastal Lands (VCL); (2453 km^2) – the Vembanad lake and its adjoining lowlands other than the areas included under major rivers and the minor channels - together comprises about 15100 km^2 (i.e. 39% area of the Kerala State). The lake bank, near the river confluence of Periyar, hosts the industrial capital of Kerala, the Kochi City. All the 7 rivers in the Vembanad lake catchments are under severe stress due to various types of human interventions, among which indiscriminate mining for sand and gravel is the most disastrous one as it threatens the very existence of these aquatic ecosystems. The mega developmental projects on the anvil would further deteriorate these life sustaining systems, if adequate measures are not taken to conserve these crucial aquatic systems.

3.2 Drainage

The seven rivers (Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy rivers) draining the Vembanad lake catchments originate from the Western Ghat mountains and flow generally westwards before merging with the Vembanad lake. These rivers exhibit dendritic-subdendritic drainage pattern. The longest river in the study area is the Periyar river which has a length of about 244 km and the shortest one is the Meenachil river (78 km). Basin-wise, Periyar river basin is the largest one (5398 km^2) and Manimala river basin, the smallest one (847 km^2). Out of the total river catchments, 68% of the area lies in the highlands, 30% in the midlands and the remaining (2%) in the lowlands. There are four outlets in the coastline of the study area where the backwaters join the sea. They are located at Thottapally, Andakaranazhi, Fort Kochi and Munambam. The former two are temporary outlets closed by sand bars which open only during southwest monsoon. The latter two are permanently opened (NEERI, 2003).

3.3 Administrative divisions

The study area spreads mainly in 5 districts namely, Idukki, Ernakulam, Kottayam, Alappuzha and Pathanamthitta. Small portions of Kollam, Thrissur and Palakkad districts also fall within the area. The study area comprises 9 revenue divisions. They are Fort Kochi, Muvattupuzha, Alappuzha, Chengannur, Thiruvalla, Adoor, Kottayam, Pala and Idukki revenue divisions. The area consists of 27 taluks, 337 grama panchayats, 21 municipalities and the Kochi Corporation (KSLUB, 1995). Table 3.1 shows the area of each river basins in different administrative as well as physiographic boundaries. Fig. 3.1 depicts locations of major developmental centres in the study area.

3.4 Demography

The total population of the study area as per 2001 census is 9,658,886 (DES, 2001). This constitutes about 30% of the total population of the State. The population density of the entire area is 640 $inh.km^{-2}$. There is an exponential increase in population density towards coastal areas. The population density computed for the highlands, midlands and lowlands are 197 $inh.km^{-2}$, 946 $inh.km^{-2}$ and 1889 $inh.km^{-2}$, respectively. Urban centres in the coastal areas have the highest population density. In consonance with the high population density, the construction activities are also high in the lowlands.

Table 3.1 District-wise coverage of the river catchments of Vembanad lake falling within the highland, midland and lowland physiographic zones along with that of Vembanad Coastal Lands (VCL) and Drainage areas of Minor Channels (DMC)

		Area in km^2			
River basin	**District**	**Highland**	**Midland**	**Lowland**	**Total**
Achankovil	Alappuzha	-	102	119	221
	Pathanamthitta	478	210	-	688
	Kollam	196	-	-	196
Pamba	Alappuzha	-	26	24	50
	Pathanamthitta	1330	245	6	1581
	Kottayam	41	-	-	41
	Idukki	93	-	-	93
Manimala	Pathanamthitta	26	178	5	209
	Kottayam	210	254	-	464
	Idukki	109	-	-	109
Meenachil	Kottayam	346	703	11	1061
Muvattupuzha	Kottayam	-	93	44	137
	Ernakulam	-	791	-	791
	Idukki	321	148	-	469
Periyar	Ernakulam	549	697	27	1273
	Idukki	3870	-	-	3870
Chalakudy	Ernakulam	-	101	4	105
	Thrissur	479	234	-	713
	Palakkad	577	-	-	577
VCL + DMC*	Alappuzha	-	-	818	818
	Kottayam	-	225	296	521
	Pathanamthitta	-	36	36	73
	Ernakulam	-	351	460	810
	Thrissur	-	141	89	230
Total area		**8625**	**4534**	**1941**	**15100**

**Drainage area of channels (eg. Vaikom thodu, Edapally thodu, etc.) that are not included under the 7 rivers listed above, are considered under DMC.*

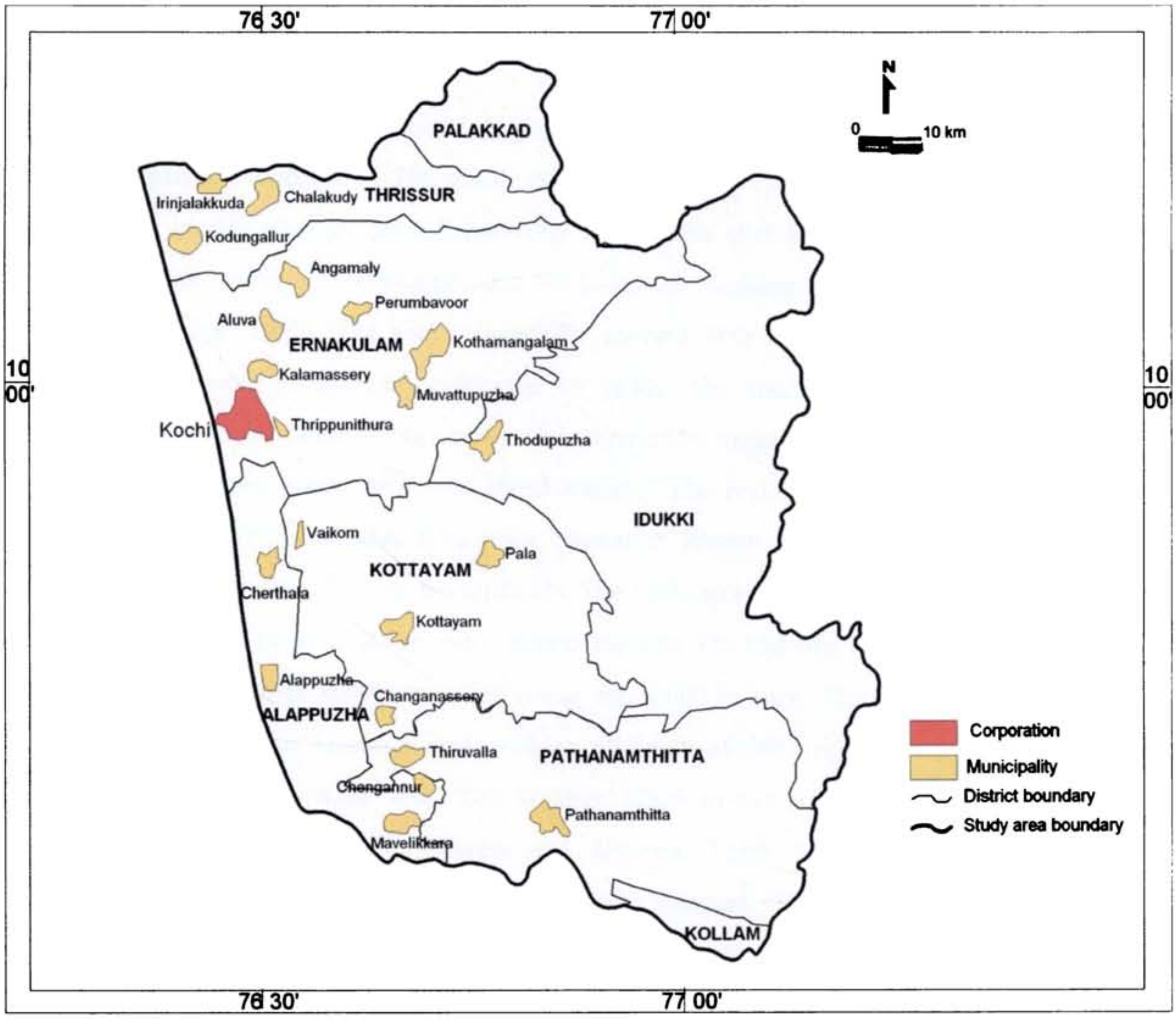


Fig. 3.1 Major urban centres and their locations in the study area

Table 3.2 summarises the population and population density in the study area along with other relevant details.

3.5 Physiography

The study area is divided physiographically into three broad zones – the lowlands (<8m amsl), the midlands (8-75m amsl) and the highlands (>75m amsl); (Fig. 3.2a). The lowlands located close to the Lakshadweep Sea, is with stretches of sand bars, beach ridges, spits, estuaries, backwaters and fluvio-marine landforms (Chattopadhyay and Chattopadhyay, 1995). The area is generally covered with alluvial sediments in the eastern side which is generally cultivated for paddy. The midland is intersected by a number of rivers and streams. The area is characterised by rugged topography comprising small, flat-topped low mounts and broad valleys. The region is marked by gently undulating landforms covered by a thick blanket of laterite at many places. Laterite capped mounds occur all along the midlands. The other prominent feature in the area is the occurrence of incised valleys within laterite mounds. The highland is characterised by high ranges with high mountains often rising upto 2000 m amsl. The highest point in peninsular India, the Anamudi Peak with an elevation of 2695 m, is situated in the highland part of the study area. The Western Ghats in the highlands, is the most important catchment area for Kerala and southern Tamil Nadu. The region is characterised by Idukki, Periyar and Peerumedu plateaus. The highland region is composed of a succession of ridges, midpeaks and presents a general irregular outline (Fig. 3.2b). This region has a precipitous descent towards the west and is connected with a succession of low hills diminishing in altitude towards coast. Out of the total area selected for the present study, highlands constitute a major portion compared to midlands and lowlands. These natural divisions and its diversity are a reflection of the uniqueness of the study area in terms of agro-climatic zones, soil, vegetative cover and productivity of land as well as vulnerability to natural hazards.

Table 3.2 Population and population density (inh.km^{-2}) in the highland, midland and lowland physiographic zones of various river basins / subenvironments of the study area

River basin	Highland		Midland		Lowland	
	Population	Population density	Population	Population density	Population	Population density
Achankovil	107404	158	372404	1192	185193	1557
Pamba	236200	161	295996	1094	43186	1436
Manimala	158176	458	372914	864	7990	1585
Meenachil	158716	458	756134	1075	19995	1811
Muvattupuzha	164646	512	770195	746	54501	1233
Periyar	857266	194	560923	805	63116	2338
Chalakudy	19239	18	324342	968	6751	314
VCL + DMC	-	-	838751	1114	3284848	1909
Total	**1701647**		**4291659**		**3665580**	

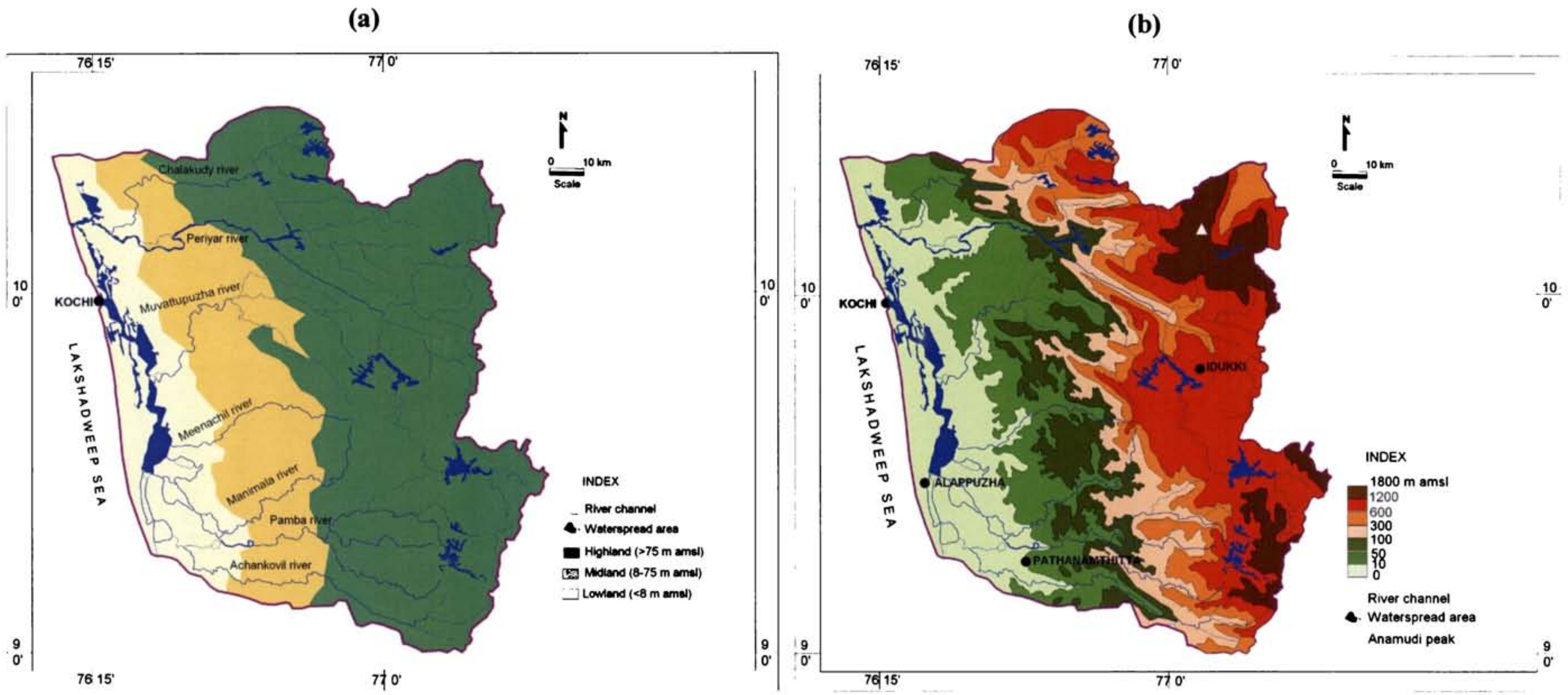


Fig. 3.2 Maps showing a) physiographic and b) altitudinal zones of the study area.
amsl: above mean sea level

3.6 Geology

The major rock types of the study area are presented in Fig. 3.3. The rocks of the study area fall in four major categories - 1) crystalline rocks of Archaean age occurring in the highlands and the midlands, 2) sedimentary rocks of Tertiary age, spread in the lowlands, 3) laterite capping over crystallines and sedimentary rocks spread mainly in the midlands and 4) Recent to Sub-Recent sediments forming the low-lying areas of the coast and river valleys. Among these, the Archaean crystallines cover about 85% of the study area and composed mainly of charnockites, khondalites, garnet-biotite gneisses and hornblende gneisses. The Tertiary sedimentary rocks are represented by rocks of Quilon, Vaikom and Warkalli Formations. The Vaikom and Warkalli Formations are represented by sandstones and claystones. The Warkalli Formation can be differentiated from the Vaikom Formation by the presence of lignite seams. The Quilon Formation is composed of sandstones, claystones and interlayers of fossiliferrous limestones. Recent to Sub-Recent sediments of Late Quaternary age are represented by coastal sands and alluvium (GSI, 1995).

3.7 Soil

Soil, the end product of rock weathering, is a basic natural resource that supports life on earth. The formation of soil is influenced by many factors like climate, geology, relief and biological processes of the area (Ekanade, 1996). Soil types in the study area can be broadly classified into 8 groups. They are: coastal alluvium, riverine alluvium, forest loam, greyish onattukara, acid saline, brown hydromorphic soil, hydromorphic saline soil and lateritic soil (CESS, 1984). Coastal alluvium is seen in the western part of the study area all along the coast and has been formed from recent marine and estuarine processes. Riverine alluvium occurs mainly in the central pediplains along the banks of the rivers and associated channels. The eastern part of the study area is covered by forest loam. The upper layer of the soil is highly enriched with organic matter derived from the decomposed vegetative matter. Due to the presence of excessive organic matter, the soil is dark reddish brown to black in colour. It exhibits loam to silty loam texture. Greyish

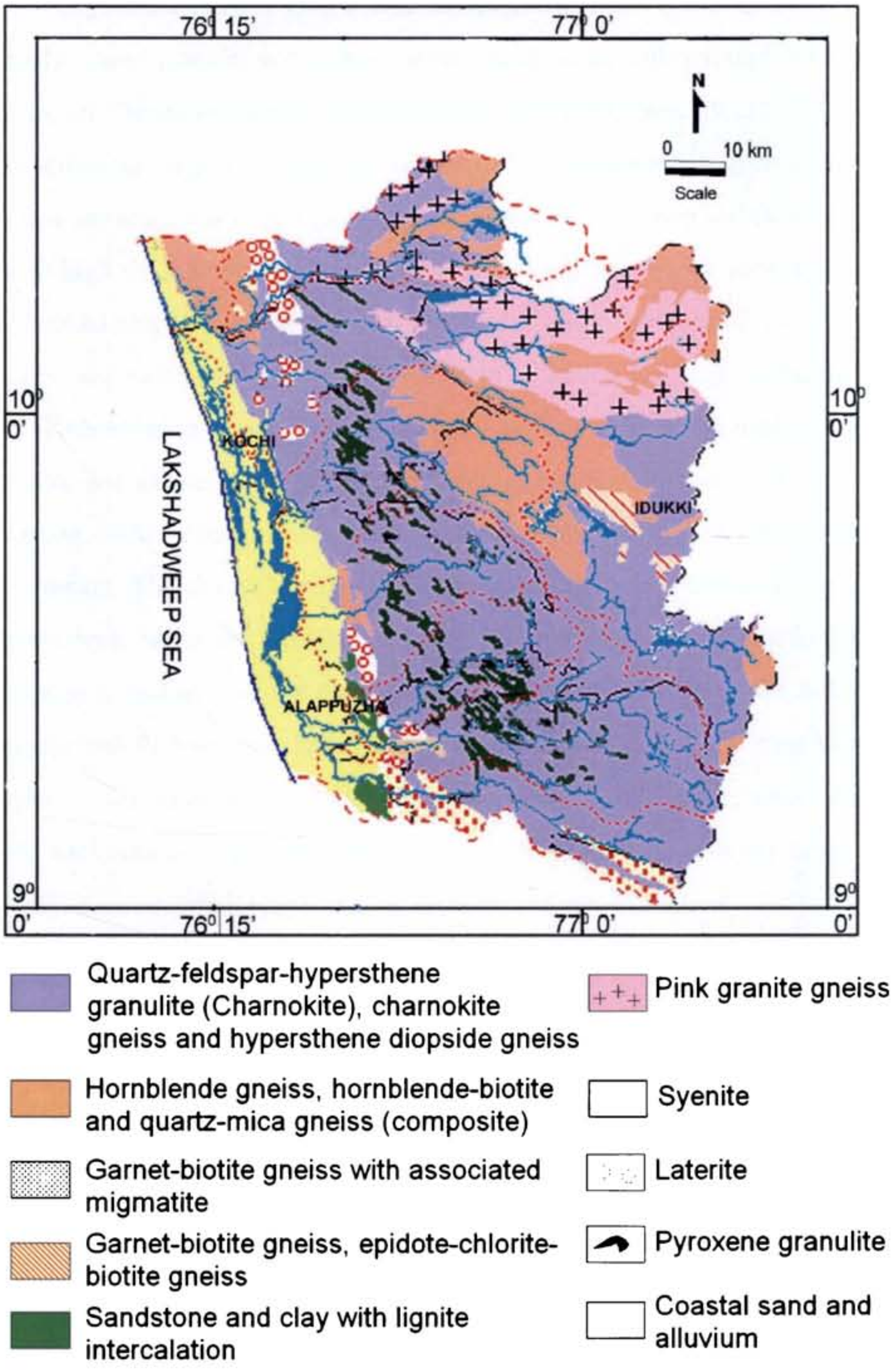


Fig. 3.3 Geology of the study area

onattukara with its characteristic grey colour occurs in southwest corner of the study area. It is generally coarse grained and highly porous. Acid saline soil is found mainly in the Kuttanad region. Developed under hydromorphic conditions, these include the k*ari* soil (black soil with high organic content developed in low lying water logged areas), k*ayal* soil (soil in reclaimed areas with high clay content) and *karappadam* soil (soil along river courses with high silt content). Brown hydromorphic soils are mostly confined to valley bottom of undulating topography in the midlands. They are formed as a result of transportation and sedimentation of materials from adjoining hill slopes. Hydromorphic saline soil is observed as small patches along the coastal strip of the study area where inundation by sea causes salinity. Lateritic soil is the predominant soil type in the midland region. Soils of the study area vary in their depth, texture, internal drainage and degree of erosion. The salient features of the soils occurring in different physiographic regions of the river basins are furnished in Table 3.3. In the lowlands, the soils vary from sandy to clayey in texture, and the erosion status is slight to moderate in the Achankovil, Muvattupuzha and Periyar river basins and moderate in the Chalakudy river basin. The soils present in the midlands are very deep and deep to very deep, well drained to moderately well drained clays with gravel content. In highlands, soils are deep to very deep and well drained with loamy to clayey textures and gravel content.

3.8 Slope

The study area consists of 5 slope units: (1) Steep to very steep hill ranges, (2) Moderately to steeply sloping ridges, (3) Gently to moderately sloping spurs, (4) Nearly level to very gently sloping and (5) Valleys gently sloping to flat bottom (CESS, 1984). Steep to very steep hill ranges correspond to the physiographic zones of the Western Ghats and adjoining midland, having an altitude of more than 300 m. The dissected segments and high level plateaus (>600 m) of Western Ghats exhibit this slope range. Plateau edges are highly indented having 70 - 100% slope. Moderately to steeply sloping ridges correspond to the upland zone having an altitudinal range of 50 - 300 m. The slope ranges from 55 to 60%. The topography is highly dissected due to intensive fluviatile

Table 3.3 Soil characteristics in the river catchments of Vembanad lake

Physiographic region	Soil characteristics	River basins						
		Achankovil	**Pamba**	**Manimala**	**Meenachil**	**Muvattupuzha**	**Periyar**	**Chalakudy**
Highland	Texture	Clayey, clay with coherent material at 100 to 150cm, gravelly loam	Gravelly clay, clayey, loamy and gravelly loam	Clay, gravelly clay, loam, gravelly loam	Clay, gravelly clay, gravelly loam	Loam, gravelly loam, clay, gravelly clay	Loam, gravelly loam, clay, gravelly clay	Loam, gravelly loam, clay, gravelly clay
	Depth	Deep (100-150cm) to very deep (>150cm)	Deep (100-150cm) to very deep (>150cm)	Deep (100-150cm) to very deep (>150cm)	Deep (100-150cm) to very deep (>150cm)	Deep (100-150cm) to very deep (>150cm)	Deep (100-150cm) to very deep (>150cm)	Deep (100-150cm) to very deep (>150cm)
	Drainage	Well drained	Well drained	Well drained	Well drained	Well drained	Well drained	Well drained
	Erosion status	Moderate to severe	Moderate to severe	Moderate to severe	Moderate to severe	Moderate to severe	Moderate to severe	Moderate to severe
Midland	Texture	Clay, gravelly clay, loamy	Gravelly clay	Gravelly clay	Clay, gravelly clay	Clay, gravelly clay	Clay, gravelly clay	Gravelly clay, gravelly loam
	Depth	Deep (100-150cm) to very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Deep (100-150cm) to very deep (>150cm)
	Drainage	Moderately well drained to well drained	Well drained	Well drained	Moderately well drained to well drained	Well drained to moderately well drained	Well drained to moderately well drained	Well drained
	Erosion status	Slight to severe	Moderate	Moderate	Slight to moderate	Slight to moderate	Slight to moderate	Moderate to severe
Lowland	Texture	Sandy, gravelly clay	Loamy, clayey, sandy	Clayey, loamy	Clayey, loamy	Sandy, clayey, gravelly clay	Sandy, clayey, gravelly clay	Gravelly clay
	Depth	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)	Very deep (>150cm)
	Drainage	Moderately well drained to somewhat excessively drained	Moderately well drained to very poorly drained	Very poorly drained to moderately well drained	Moderately well drained to very poorly drained	Very poorly drained to somewhat excessively drained	Very poorly drained to somewhat excessively drained	Well drained
	Erosion status	Slight to moderate	Slight	Slight	Slight	Slight to moderate	Slight to moderate	Moderate

Source: KSLUB (1996)

action. The valleys are deep and narrow. The interfluve area is occupied by ridges. The change in slope from the first type (i.e., steep to very steep hill ranges) to this region (moderately to steeply sloping ridges) is evident from knick points observable in the profiles of rivers. Gently to moderately sloping spurs lies between the uplands and coastal plains. This is presumed to be a transitional zone between degradational and aggradational plains and is characterised by a slope range of 10-20%. The interfluve areas occupied by the spurs usually have lateritic flat surfaces. Nearly level to very gently sloping areas fall between the coastline and the 10 m contour. This is the youngest planation surface, mostly depositional, developed by fluviatile as well as marine action. Features like alluvial plains, lagoons, coastal dunes and mudflats indicate the broad aggradational character of this unit in contrast to the degradational character of the other geomorphic units. Valleys of gently sloping to flat bottom, are identified along the river courses where the bed level is <50 m. Here the valley sections are broad and mostly 'U' shaped with extensive development of river terraces. The valleys have gentle slopes of 3 - 5% and gradually merge with the coastal plain.

3.9 Land use

The study area comprises a spectrum of land use classes which include forests, forest plantations, scrub land, barren rocky land, mixed crops, built-up area and water bodies (Fig. 3.4). Land use types are distinctly governed by physiography and climate of the area. The eastern part of the study area is occupied by forest land which consists of wet evergreen, semi evergreen, moist deciduous, dry deciduous, temperate shola, grasslands and forest plantations. While the high altitude areas in Periyar plateau are used mainly for tea, coffee and cardamom plantations, the western fringe of the forests are used for rubber plantations. The midland regions are intensely cultivated. A major portion of the midland area is under mixed agricultural / horticultural plantations. The lowland is occupied by agricultural land and water bodies. Agricultural lands occupy a major portion (36.9%) of the total area, followed by forest (29.6%), agricultural plantations (24.4%), water bodies (4.6%), grassland (3.6%), built-up area (0.5%) and barren and

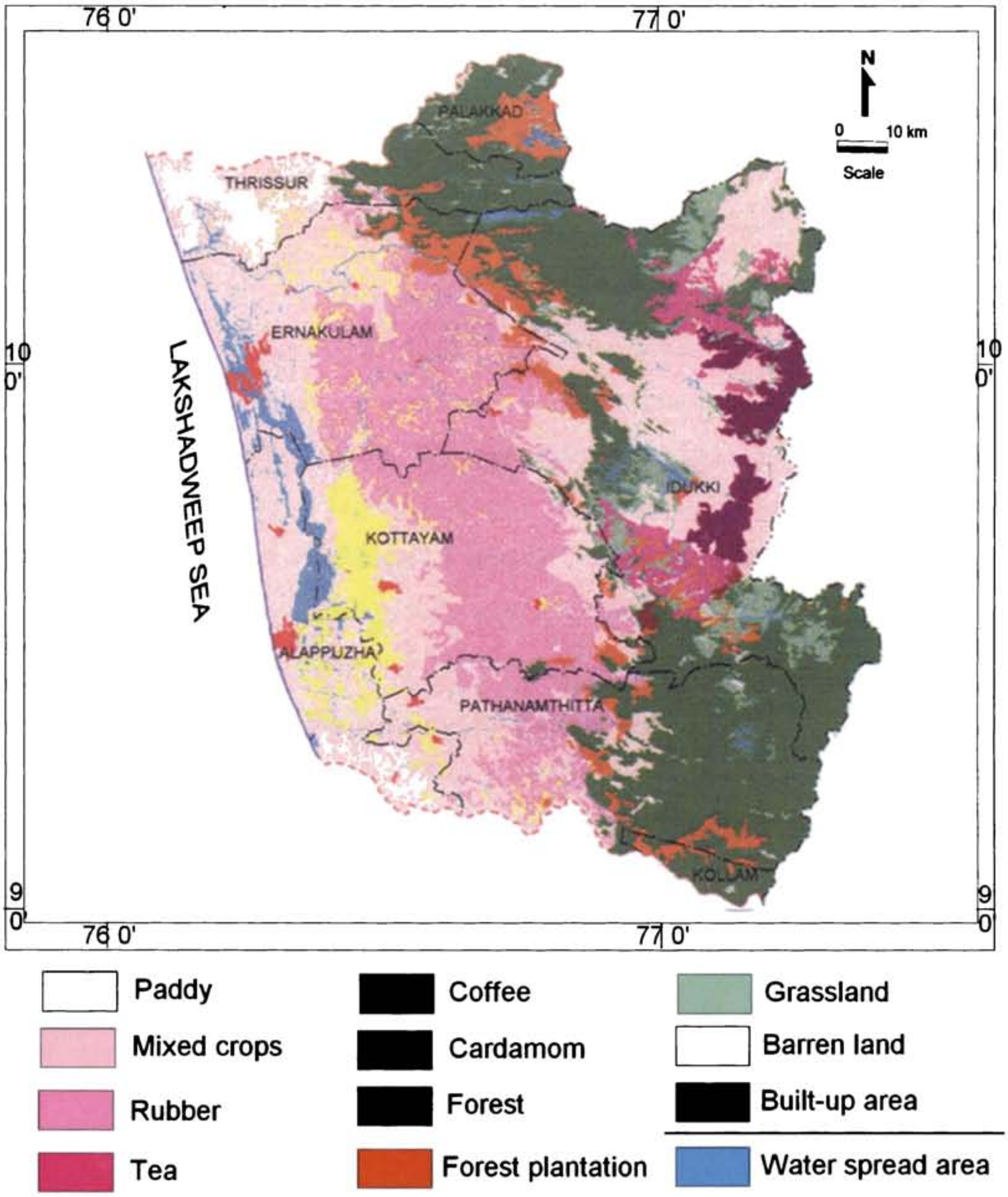


Fig. 3.4 Land use map of the study area

scrub land (0.4%). Agricultural lands are predominant in Idukki district followed by Ernakulam and Kottayam districts. Forest area is found more in Idukki and Pathanamthitta districts. Ernakulam district dominates in built-up lands and water bodies (NEERI, 2003).

3.10 Climate

The study area enjoys a tropical humid climate. The principal rainy seasons are southwest (June-September) and northeast (October-December) monsoons. Orographic influence of rainfall is pronounced in the area. Moisture-laden air condenses in the hills and hence the foothills receive the maximum rainfall. Idukki plateau receives high rainfall, as there is a level of high altitude over the plateau (Nair and Chattopadhyay, 2005). The eastern slopes of the Anamudi around Chinnar and north Marayur, being in the lee-ward side of Western Ghats, receive an annual rainfall of only less than 1000 mm. Vembanad lake and its immediate low lying areas receive an average annual rainfall of 3300 mm. The relative humidity is higher (> 80%) during monsoon months. Though the area experiences almost uniform temperature throughout the year, the maximum temperature is recorded in the month of March and minimum in December. Average evapo-transpiration rate is about 120 mm / month.

3.11 Mineral resources

The study area is endowed with a variety of mineral resources like graphite, silica sand, tile and brick clay and lime shells. The area hosts abundant reserves of hard rocks of diverse petrological characteristics grouped under the category of dimension stones which are distributed mainly in the highlands and midlands. The major rocks or group of rocks that are included under this category are charnockite and khondalite group of rocks (Pathanamthitta, Kottayam and Idukki districts), true intrusive or anatectic granite and associated migmatites (Idukki district) and dolerite-gabbro dykes (Kottayam and Idukki districts). Graphite is observed within khondalitic rocks in various parts of the study area. The flaky type of graphite is extensive in occurrence in Peringala, Nagapuzha, Memadangu and Koothattukulam areas in Ernakulam district and parts of Kottayam district (GSI, 1976). Silica sand mining is prevalent in Alappuzha district, especially in the Thycattussery, Pallippuram and Panavally areas. Tile and brick clays are associated with the Tertiary and Quaternary sediments (Singh, 1996; Thampi, 1997). Indiscriminate mining of tile and brick clays for meeting the raw material requirements of numerous brick kilns and tile factories creates serious socio-economic and environmental problems in the study area. In addition to these, the rivers and their floodplains in the study area provide resources of construction grade sand. But overexploitation of these resources in unscientific manner creates an array of environmental problems in the area. A detailed account of these activities is given in the succeeding chapters of this thesis.

3.12 Flora and fauna

The flora and fauna varies notably depending on the physiographic variation of the study area. The coastal plains are comparatively poor in vegetation. Studies by Kurien et al. (1994) and Forest Survey of India (FSI, 2003) showed that mangrove vegetation that are adapted to flourish in coastal areas is now confined largely to river mouths and tidal creeks because of human interventions. Intense mining operations and the present peculiar geomorphology of the estuarine area of Kerala pose challenging problems to the natural regeneration of mangroves (Sunilkumar, 2002a). Sacred groves, the relicts of ancient forests, are seen in the midland regions and needs special attention for their conservation, as these are medicinally important and are the last asylum for numerous lowland species of animals and resident and migratory birds. The highland vegetation comprises of tropical evergreen, tropical moist deciduous, sub-tropical montane and montane temperate forest types. Riparian vegetation protects river banks against erosion. They are also rich in biodiversity. Bachan (2003) made a detailed study on the various issues leading to the degradation of riparian vegetation along Chalakudy river. The study area is known for its biodiversity due to the rich and diverse ecosystems.

The wetlands of the area support diverse fauna, including a large variety of fish, prawns and clams, reptiles and birds and provide habitat for both anadromous and catadromous fish species. The avifauna of this area requires special mention. During winter months, the Vembanad lake supports the third largest population of more than 20,000 waterfowls in India. In Mangalavanam, primarily a bird refuge, 41 species of birds representing 25 families are identified (Jayson, 2001). The area is also rich in insect biodiversity and 26 species of insects are identified from the area. The highlands serve as hotspots of several rare and endangered species of the Western Ghats. The protected network of area is 1354 km^2 (Table 3.4).

Table 3.4 Wildlife sanctuaries and national parks in the study area

Sl. No.	Name of national parks / sanctuaries	Area (km^2)	Year of formation
1	Periyar tiger reserve	777.54	1950
2	Parambikulam wildlife sanctuary	285.00	1973
3	Idukki wildlife sanctuary	70.00	1976
4	Eravikulam national park	97.00	1978
5	Thattekkad bird sanctuary	25.00	1983
6	Chinnar wildlife sanctuary	90.44	1984
7	Kumarakom bird sanctuary	0.130	1985
8	Anamudi shola national park	7.50	2003
9	Mangalavanam bird sanctuary	0.027	2003
10	Pampadam shola national park	1.32	2003
Total		**1353.96**	

3.13 Environmental significance and developmental initiatives

The river catchments of the Vembanad lake is subjected to considerable level of human interferences such as mining and quarrying, reclamation of water bodies and wetlands, deforestation, urbanisation, etc. This has ultimately led to marked changes in the land and water systems of the region. Wetlands are dynamic ecosystems and form the transitional zone between the aquatic and terrestrial environments sharing the characteristics of both. Heavy loading of pollutants from factory effluents, pesticides, sewage and domestic discharges, etc., has stressed the wetland ecosystem irrecoverably. The backwater ecosystems face degradation due to reduction in surface area, sedimentation and pollution. Incidence of large scale fish mortality due to pollution in the backwaters has become quite common. Serious impact of organic pollution on the hydrography of Vembanad lake has been reported by several researchers.

The Vembanad lake is a receptacle of a large variety of industrial effluents and domestic sewage from Kochi City and a string of satellite towns nearby. Kochi City alone generates an amount of 2550 million litres of waste water per day that directly get discharged into the backwaters untreated (Nair and Chattopadhyay, 2005). The lake also receives pollutants from Kottayam and Alappuzha districts in the southern end in addition to contribution of agricultural pollutants from the Kuttanad region. The water quality is very poor in the Vembanad lake near Alappuzha (KSCSTE, 2007). Urbanisation and land use changes have significant impact on the hydrological conditions including water pollution of the area.

The study area hosts a number of important tourist destinations like Munnar, Thekkady, Kochi and Kumarakom. There are 4 wild life sanctuaries (Periyar, Parambikulam, Chinnar and Idukki wild life sanctuaries), 3 bird sanctuaries (Kumarakom, Mangalavanam and Thattekad) and 3 national parks (Eravikulam, Pampadam shola and Anamudi shola) in the area. The most pronounced waterfalls in the area are Athirapally and Vazhachal (Chalakudy river), Valara (Periyar river), Thommankuthu (Muvattupuzha river), Perunthenaruvi (Pamba river) and Tuval *thodu* (Achankovil river). According to the peculiar physiography of the study area, different types of tourism-related activities have emerged; hill station tourism (Munnar, Devikulam, Peermedu), backwater tourism (Kochi, Kumarakom, Alappuzha) and beach tourism (Kochi, Cherai and Alappuzha). There are many culturally, historically and archaeologically important places including ancient temples and churches situated on the banks and hinterlands of the Vembanad backwaters. Other categories include pilgrimage tourism, health tourism and monsoon tourism.

One of the most actively emerging cities in South Asia, the Kochi City forms the chief development centre in the area. The earliest human intervention in the area was in the form of dredging for a major harbour at Kochi and subsequent reclamation for locating port facilities during 1838-1845 (NEERI, 2003). Recently, a handful of mega developmental projects like Smart City, Vallarpadam International Container Terminal (VICT), Liquified Natural Gas Terminal (LNGT), southward extension of Willington island, foreshore reclamation programme, extensive reclamation of wetlands situated to the east and north of Ernakulam towards Edappally and Thripunithura, Single Buoy Mooring (SBM) project proposed by Kochi Refineries Ltd., new ship building unit in and around the Kochi Shipyard, Kochi Metro Rail Project etc. are likely to transform Kochi into a key centre of economic development in South Asia. The setting up of the first port-based Special Economic Zone (SEZ) will be a major milestone in the development of both Kochi and also the Kerala State. The suburbs of Kochi have become the nerve centre of real estate activities in recent years. Construction activities (residential and commercial) are in full swing to cater to the needs of the emerging city. All these activities could impose added stress to the aquatic systems (rivers and backwaters) in the area.

Chapter 4

MATERIALS AND METHODS

4.1 Introduction

The degradation of river ecosystems is directly linked to development process. Indeed, no one can remain aloof from the issues related to environmental degradation of rivers. Among the various kinds of human interventions, indiscriminate mining for construction grade sand from the active channels and floodplains is the major cause for the degradation of rivers in Kerala. Although the sand extraction is a destructive activity as far as river ecosystem is concerned, a proper assessment of its impact on various environmental components of the system is often difficult as many of the adverse effects are surfaced only after a long period of time. Hence, obtaining a standard set of spatial and temporal data related to the mining activity is a major hindrance in the process of Environmental Impact Assessment (EIA). Therefore, considering all these and also the time bound nature of the present study, a method that involves original investigations to document the existing environmental conditions and selected case analyses of primary and secondary nature are appropriately blended in order to achieve the key objectives of the study. Table 4.1 summarizes some of the important case studies used for illustrating the present work. The locations / river reaches selected for case studies are shown in Fig. 4.1.

4.2 Field work and sample collection

The study includes systematic field surveys in the entire channel networks and the adjoining overbank areas of the river catchments of Vembanad lake for: 1) mapping locations of sand mining, sand storing centres, screening and cleaning areas, reaches of river degradation, locations of engineering structures associated with river environments, and 2) collection of primary and secondary data on mining operations, quantity of sand and gravel extraction from each locations and other relevant information of the respective rivers. The current extraction of sand from the each river basin was estimated from number counts and select weighing of the loaded vehicles moving out of the mining locations with sand, interviews with local people and labourers, secondary information available with the district administration and local

Table 4.1 Details of the study components, area(s) / river(s) selected for the study and nature of the study carried out / adopted in the investigation

Sl. No.	Study component(s)	River(s) selected for the study	Nature of the study / Source
1.	Channel characteristics (sinuosity index, stream tortuosity, channel pattern, channel measurements, etc.)	All the rivers (Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy rivers)	Present study
2.	Sediment characteristics	All the rivers	Present study
3.	River discharge (water and sediment)	All the rivers	Data collected from CWC gauging station are used for the study
4.	Water quality	All the rivers	Present study
5.	Sand mining (Instream and floodplain)	All the rivers and adjoining overbank areas	Present study (Analysis of primary and secondary data)
6.	In-channel survey for bed form changes	Muvattupuzha river reach near Ayavana and Periyar river reach near Sreemoolanagaram	Present study
7.	Channel incision (bed lowering)	All the rivers	Data collected from CWC gauging station and present observations are used for the study
8.	Bed coarsening	Achankovil river reach near Valanchuzhi and Muvattupuzha river	Present study
9.	Impact of sand mining on water		
	(a) Surface water	Manimala river reach between Vellavoor and Thondara	Present study
	(b) Groundwater	Achankovil river reach near Thumpamon	Updated after Prasad and Nair (2004)
10.	Benthic fauna	Achankovil river near Maroor	Sunilkumar (2002) (Sponsored study of CESS)
	Fish fauna	Periyar lake and its feeder channels	Arun (1999)
11.	Social / human environment	All the rivers	Present study
12.	Environmental Impact Assessment (EIA)		
	(a) Instream mining	Pamba river Reach 1: Edakadathi and Mannadishala Reach 2: Kottatur and Kozhenchery Reach 3: Kallissery and Parumala	Present study using questionnaire survey
	(b) Floodplain mining	Muvattupuzha river (downstream reach)	Present study using questionnaire survey

CWC: Central Water Commission

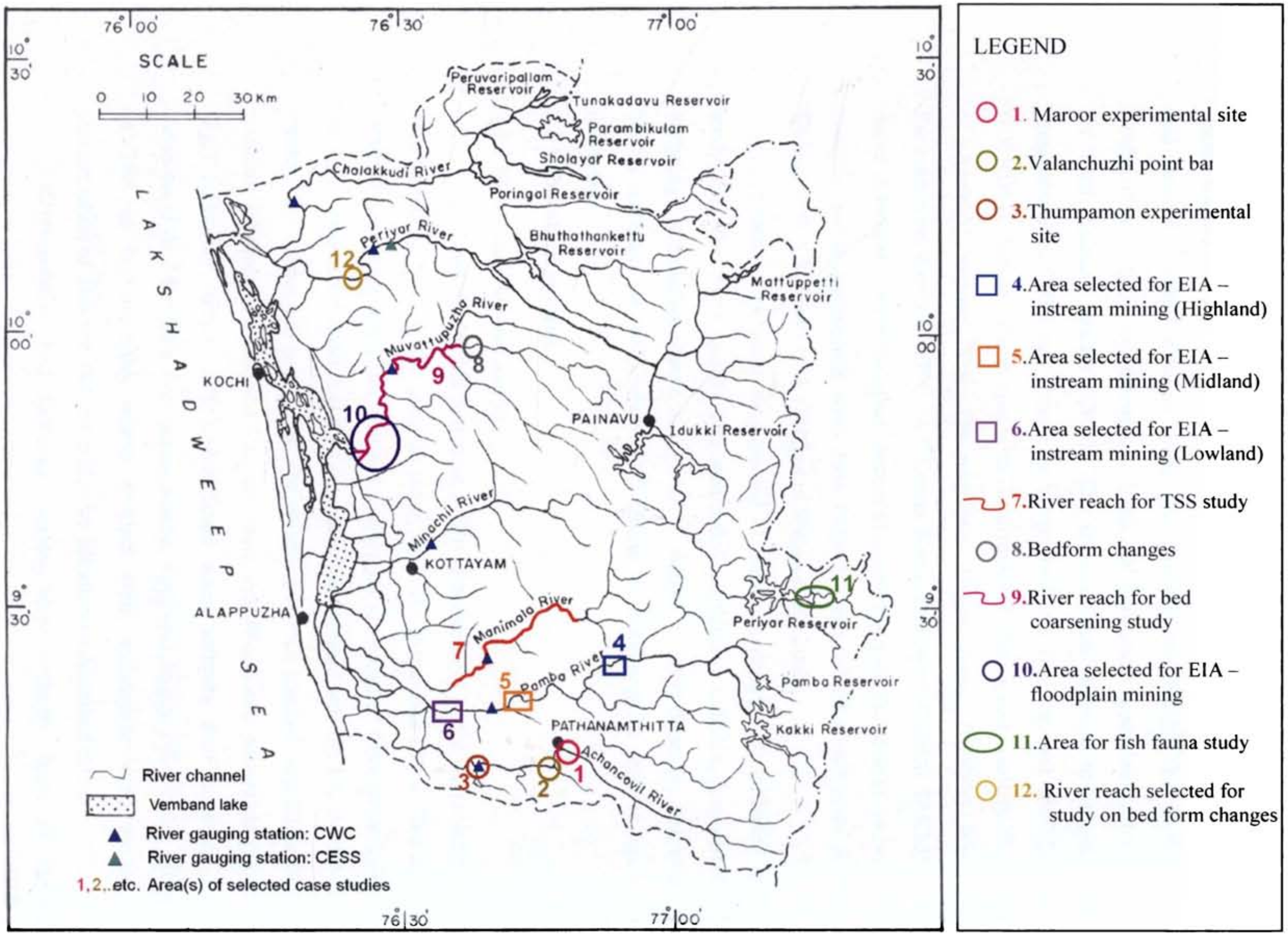


Fig. 4.1 Map of the Vembanad lake and its river catchments showing important locations / areas of selected case studies (Also refer Table 4.1 for details).

bodies following standard formats (Gilpin, 1995). The data on river discharge and river bed lowering were collected from the gauging stations of the Central Water Commission (CWC), Government of India and permanent monitoring sites of Centre for Earth Science Studies (CESS). The data collected through the major research programmes of CESS and Centre for Water Resource Development and Management (CWRDM), data on sand mining with Department of Mining and Geology (Government of Kerala), various Non Governmental Organisations (NGO's) like Pampa Parirakhshana Samithi (PPS), All Kerala River Protection Council (AKRPC), news paper reports etc., were the other sources of information for the present study. The data analysis and interpretations were done following the published works of Kitetu and Rowan (1997), Kondolf et al. (2002) and Weeks et al. (2003).

A total of 34 water samples and 21 sediment samples are collected from the study area for water quality and suspended particulate analysis, respectively. The sampling locations are shown in Fig. 4.2. A sample of wood deposited below the sand bed is collected for radiocarbon (C^{14}) dating for obtaining the relative age of sand deposition.

4.3 Laboratory analysis

4.3.1 Water and sediment analysis

The Total Suspended Sediment (TSS) concentration in the water samples were determined by filtering the samples using 0.45 μm membrane filters. The sediments retained were oven dried and weighed along with pre-weighed filter paper to estimate the TSS. Suspended sediments thus separated were treated with $HClO_4$ and HNO_3 acid mixture and evaporated to dryness. The residue was then leached with dilute HCl. The resultant solution was analysed for particulate iron (Fe_{par}) and particulate phosphorus (P_{par}) following APHA (1985). Additional water samples were collected from 5 locations of the Manimala river during March, April and August 2006 for the estimation of TSS in the overlying waters resulted from clandestine sand mining. The concentration of TSS was then estimated by filtration as described earlier.

Representative bed sediment samples were collected from all the three physiographic zones (highlands, midlands and lowlands) of the rivers in the study area

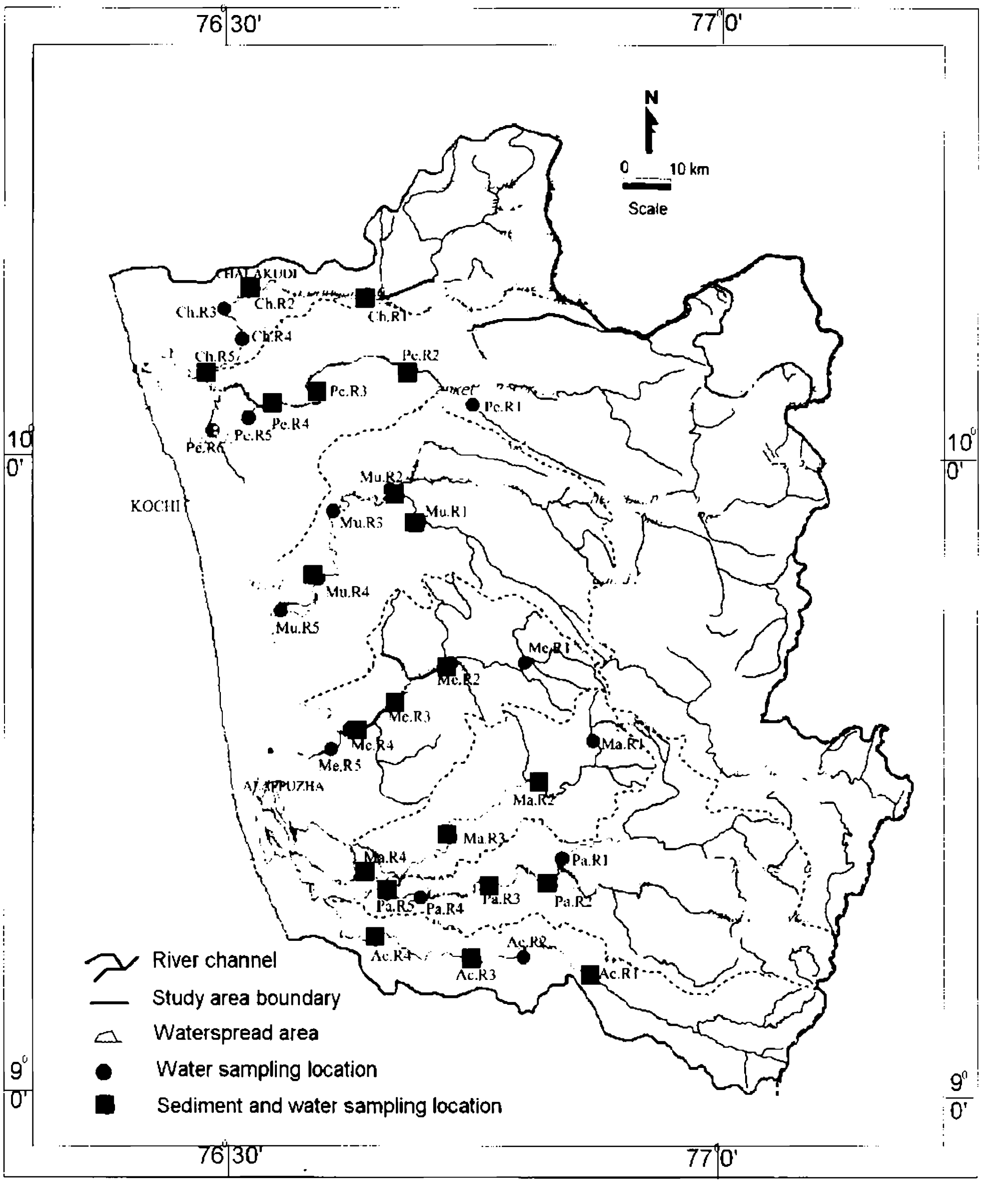


Fig. 4.2 Water and sediment sampling locations in the study area. (Ac.R: Achankovil river; Pa.R: Pamba river; Ma.R: Manimala river; Me.R: Meenachil river; Mu.R: Muvattupuzha river; Pe.R: Periyar river; Ch.R: Chalakudy river)

(Fig.4.2). Detailed sediment sampling was carried out in the Muvattupuzha river as well as the Valanchuzhi point bar of Achankovil river for the study of the effects of sand mining on bed sediment granulometry. One core sample was also retrieved from the Valanchuzhi poit bar to examine variations of sediment size characteristics (Fig. 4.3). All the bed sediment samples were sieved on a Ro-Tap sieve shaker at half phi interval and the percent content of grain size classes in each sample was calculated. The sediment types were identified using the ternary diagram of Folk et al. (1970) for gravel bearing sediments.

4.3.2 Study of river channel characteristics

Survey of India topographic maps (1:50,000 scale) were used as the base maps for computation of sinuosity index and stream tortuosity and also for the identification of types of channel pattern, nature of features like bars, islands etc. Necessary field checks were also done to verify the results. Sinuosity Index (SI) is described as the ratio between the average channel length and the average direct length (Leopold, et al., 1964). It is calculated using the formula:

$$P = X/Y$$

[where P is the sinuosity index, X is the average channel length and Y is the average direct length].

Stream Tortuosity (ST) is also an important parameter generally used in the morphometric studies to distinguish between the various types of land areas and to ascertain the degree of establishment made by a drainage line in its area of influence. It is expressed as:

$$ST = \frac{X - Y}{Y} \times 100$$

Channel pattern indicates the configuration of a river. Channel pattern can be broadly classified based on the SI. An attempt has been made to classify the river channels of the study area based on the study of Kellerhals and Church (1989).

4.3.3 Bed form changes of river channels

Bed form features of river channels respond to all types of human interventions. Here, in the present study, two different approaches are adopted to evaluate the changes

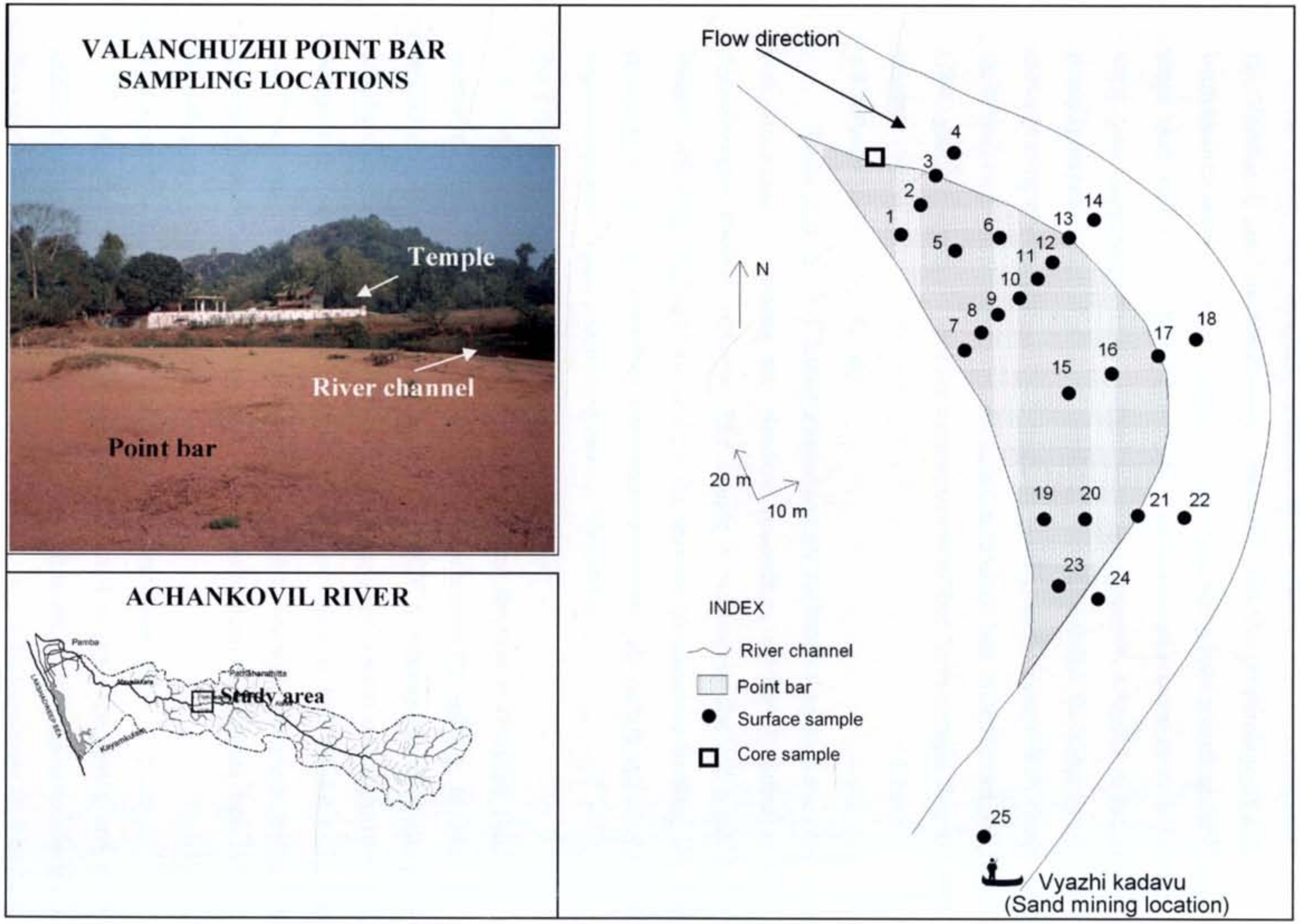


Fig. 4.3 Valanchuzhi point bar and the channel of Achankovil river showing sediment sampling locations. Inset photograph: Valanchuzhi point bar and the Valanchuzhi Devi Temple .

occurred in bed form features of specific alluvial channel reaches of the rivers draining the Vembanad lake catchments. One approach was the preparation of a time series bathymetric contour map of a specific river reach using lead sounding method. These maps were compared with the previously published bathymetric contour maps of the same area using map overlay method. Another approach, adopted in the exposed or partially exposed part of alluvial channels, was to examine the changes of bed form features using photographs of the river reach at different time periods. A combination of these two methods together with the actual records of bed lowering obtained from the CWC gauging stations is used for the assessment of bed form changes due to river sand mining.

4.3.4 Radio carbon (^{14}C) dating

Radio carbon (^{14}C) date of a wood sample collected from the base of sand layer was determined following the standard procedures of Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow. The sample is washed in distilled water and then treated with dilute hydrochloric acid for the removal of carbonate fraction. The carbon in the wood was then converted into benzene and the radiocarbon activity of benzene was measured by liquid scintillating counter 'Quantulus'.

4.3.5 Scanning Electron Microscopic (SEM) studies

A few quartz grains were scanned using electron microscope following the method of Krinsley and Doornkamp (1973). Approximately, 0.25 g of sample was treated with concentrated hydrochloric acid at 90^0C to remove the carbonate particles and washed in distilled water. The samples were then soaked overnight in hydrogen peroxide to remove the organic debris and washed again in distilled water. The grains are then mounted in 13 mm specimen stubs. The mounted grains were sputter coated with gold and then photomicrographs were taken using Stereoscan Jeol JSM 35 C scanning microscope.

4.3.6 Remote sensing and Geographic Information System (GIS)

Remote sensing techniques are widely used to study the spatial and temporal changes in the land use / land cover of an area. Remote sensing is essentially a tool of data acquisition. In the present study, this method was used to prepare land use map of the study area. The random sample locations were field verified for ground truth and the accuracy of the map is set at 90% significance level.

Nowadays, GIS is emerging as an important tool in EIA studies since map overlays can easily and accurately be performed using this technique. With the evolution of automated mapping and the development of GIS, the tedious and practically difficult method of preparation and analysis of various thematic maps has become easy, accurate and fast. The Survey of India topographic maps in 1:50,000 scale formed the base material for the study area. Specific themes are digitized and used for detecting the changes in the study area using MAP/INFO software. The Digital Elevation Model (DEM) of the areas selected for EIA studies in the Pamba river basin was prepared with the help of ARC/INFO. Maps were vectorised in AutoCAD and the digitized data were taken in ARC/INFO through DXF format. The topology creation, labelling, and projection were done. Polyconic projection is used in the DEM, which gives area and shape more accurately at micro-level. For developing a strong database of the study area, the integration of spatial and non-spatial data was done. The values of certain parameters like grain size variations, topographic contours, etc., were incorporated into the GIS. All the information was updated through field surveys and corrections, if any, are incorporated in the maps.

4.3.7 Environmental Impact Assessment (EIA) of sand mining

Two types of sand extractions are performed in the study area – instream and floodplain mining (the details of which are described in Chapter 6) – two typical areas are selected for impact assessment studies. For instream mining, three stretches of Pamba river, representing the highlands, midlands and lowlands were chosen. For floodplain mining, the lowland region of Muvattupuzha river where the activity is taking place at an alarming rate has been selected. The study employed the use of both qualitative and quantitative methods of measurement and evaluation. The baseline information was collected by questionnaire surveying. The design of the questionnaire was driven by the objectives of EIA (Annexure 1). The purpose of the survey was to identify and address the key environmental issues in order to mitigate negative and to enhance positive impacts, if any. The questionnaire covers the details like information on land characteristics, river channel characteristics, water resources, air quality, human interventions, socio-economics of the region, etc. Detailed mapping was done to demarcate the existing land use, instream sand mining locations, areas of bank slumping / sliding, locations of damaged engineering structures, etc., using base maps derived from Survey of India topographic sheets of 1:50,000 scale. Various *modus operandi* were applied during the conduct of the assessment of social impacts which included field visits, interviews with groups of residents and sand mining labourers and discussions with officials. The field survey was useful in measuring the perceptions, attitudes and opinions of a wide section of persons in the study area. The same procedure is applied for the EIA of floodplain sand mining in the lowlands of Muvattupuzha river basin, as well. In brief, EIA study of sand mining was undertaken in three stages:

- Collection of baseline environmental information through secondary sources and literature reviews at the most general level. This is the most important preparatory procedure in the EIA process and helps to clarify the issues relevant to the area including the key social variables (socio-economic, socio-health, socio-cultural and socio-livelihood) to be considered for analyses. The main method used to conduct the general scoping exercise is the review of relevant general secondary sources of information.
- Identification of impacts (environmental and social) through fieldwork in the study area. This involves assessment of the impacts relevant to the specific sites (highlands, midlands and lowlands), including the identification of impacts at all phases of mining, positive as well as negative. The assessment of social impacts involves investigation of the impacts of the river sand mining and its response to the affected stakeholders largely based on the questionnaire.
- Development of Environmental Management Plan (EMP) with recommendations for mitigating negative and enhancing positive environmental and social impacts at the strategic and technical levels. It is important to recommend measures that involve, first, avoiding all adverse impacts, second, minimising any adverse impacts that cannot be avoided, and, third, compensating for unavoidable adverse impacts.

4.4 Data computation and compilation

The voluminous data generated through fieldwork and laboratory analyses were processed using various statistical tools / computational techniques to obtain useful results. Similar studies carried out by various international and national researchers / research groups were used for comparison and drawing better conclusions. The set of primary and secondary information collected from the field were processed carefully to assess the environmental impact of sand mining. Simple matrix method is adopted to assess the positive and negative impacts on the environment (Rau and Wooten, 1980). This is elaborated in Chapter 8 which deals with the Environmental Impact Assessment of sand mining. The database generated in the study could be utilized for chalking out strategies for the conservation and sustainable management of rivers and its resources in the study area.

Chapter 5

RIVER CHARACTERISTICS

5.1 Introduction

The study area is drained by seven important perennial rivers of Kerala – the Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar, and Chalakudy rivers. Out of these, the one draining the southernmost part of the study area, i.e., the Achankovil river, is an upland one, (head water elevation of 700 m amsl) and all others are mountainous with head water elevation between 1000 m and 3000 m amsl. These rivers are the lifelines of the Greater Kochi Region of the Kerala State (NEERI, 2003); (Plate 5.1). It is unfortunate that these rivers are degrading at an alarming rate consequent to industrialisation and urbanisation. The construction of infrastructural facilities for the ongoing mega projects and other developmental initiatives on the anvil, as mentioned in Chapter 3, requires huge volumes of fine aggregates (i.e., sand). Indiscriminate exploitation of construction grade sand imposes severe impairments to the rivers in the study area. The impact of these activities may vary among the rivers depending upon their size, resource capability and discharge characteristics. This chapter summarises the general aspects of the rivers draining the Vembanad lake catchments.

5.2 Achankovil river

5.2.1 Drainage

Achankovil river originates from Pasukida Mettu of the Western Ghat mountain ranges at an elevation of 700 m above msl. The river has a length of about 128 km and a catchment area of 1484 km^2. The drainage characteristics of the Achankovil river along with the other rivers are given in Table 5.1. The highlands of the river basin is characterised by dendritic drainage pattern which turns to be trellis and subtrellis towards lowlands. Kallar is one of the major tributaries of the Achankovil river which joins the mainstream near Kadakkolamala (Fig. 5.1). The other important tributaries of the river

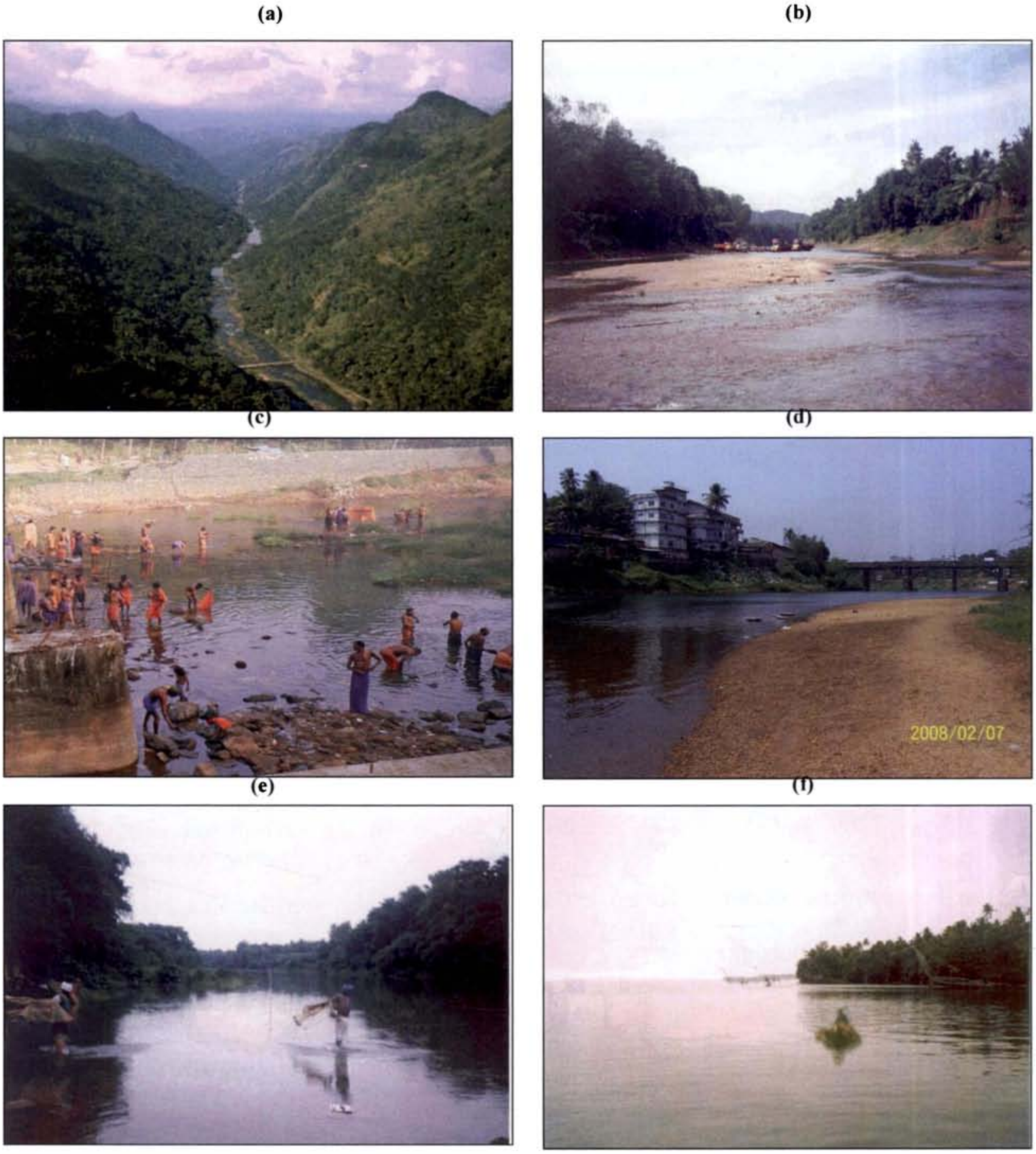


Plate 5.1 Some selected scenes from the study area. (a) Periyar river in the highlands flowing through Kanjikuzhy grama panchayat; (b) Achankovil river near Aruvappulam; (c) Manimala river near Erumeli; (d) Muvattupuzha river near Muvattupuzha town; (e) Meenachil river near Kidangoor; (f) Vembanad lake – the receiving water body of the seven rivers of the study area.

Table 5.1 Drainage characteristics and other salient features of the rivers draining the Vembanad lake catchments

Sl. No.	Drainage characteristics / Salient features	Rivers						
		Ac. R	Pa. R	Ma. R	Me. R	Mu. R	Pe. R	Ch. R
1.	River type[a] / HWE (m)	U/700	M/1650	M/1156	M/1097	M/1094	M/1830	M/1250
2.	Basin area (km^2)	1484	2235	847	1272	1554	5398	1704
3.	Basin population (in number)	665001	575382	539080	934845	989342	1481305	350332
4.	Average rainfall (mmy^{-1})	2600	3600	3300	3000	3100	3200	3600
5.	River length (km)	128	176	90	78	121	244	130
6.	Navigable river length (km)	32.0	73.6	54.4	41.6	25.6	72	16
7.	Stream flow (million m^{3}y^{-1})	1484	3424	1561	1059	3560	4868	1629
8.	Drainage density (km/km^2)	1.94	0.30	0.29	0.32	0.26	0.21	0.19
9.	Stream order	7	6	6	6	6	7	6
10.	Bifurcation ratio	3.61	4.91	3.25	2.75	3.53	3.00	3.93
11.	Elongation ratio	0.46	0.68	0.51	0.81	0.71	0.55	0.64
12.	Alluvial reach of the Main Channel (MC)[b] (km)	95	65	75	50	46	50	70
13.	River channel with exposed sand bars[c] (km)	60	32	40	42	37	48	43
14.	Width of the MC (m)	50-200	50-275	50-125	50-175	100-300	150-700	50-300
15.	Sinuosity index of the MC	1.12-1.74	1.23-1.95	1.38-1.82	1.12-1.44	1.57-1.90	1.15-1.79	1.08-1.59
16.	Stream tortuosity of the MC (%)	12.17-73.72	22.58-95.56	38.07-82.40	12.09-43.66	57.56-90.00	15.31-79.18	7.89-59.34
17.	Major reservoirs (number)	-	2	-	-	1	11	5
18.	Major waterfalls (number)	1	1	2	3	1	2	2

[a]Based on the classification of Milliman and Syvitsky (1992); [b]Main channel of the river excluding tributaries and distributaries; [c]Shown in Survey of India topographic maps published in 1968; HWE: Head Water Elevation; Ac. R: Achankovil river; Pa. R: Pamba river; Ma. R: Manimala river; Me. R: Meenachil river; Mu.R: Muvattupuzha river; Pe. R: Periyar river; Ch. R: Chalakudy river; U: Upland; M: Mountainous

Data sources other than the present study: CWRDM (1995); Manu and Anirudhan (2008); Maya (1999); Menon (1988a; 1988b); Shivane et al. (1988)

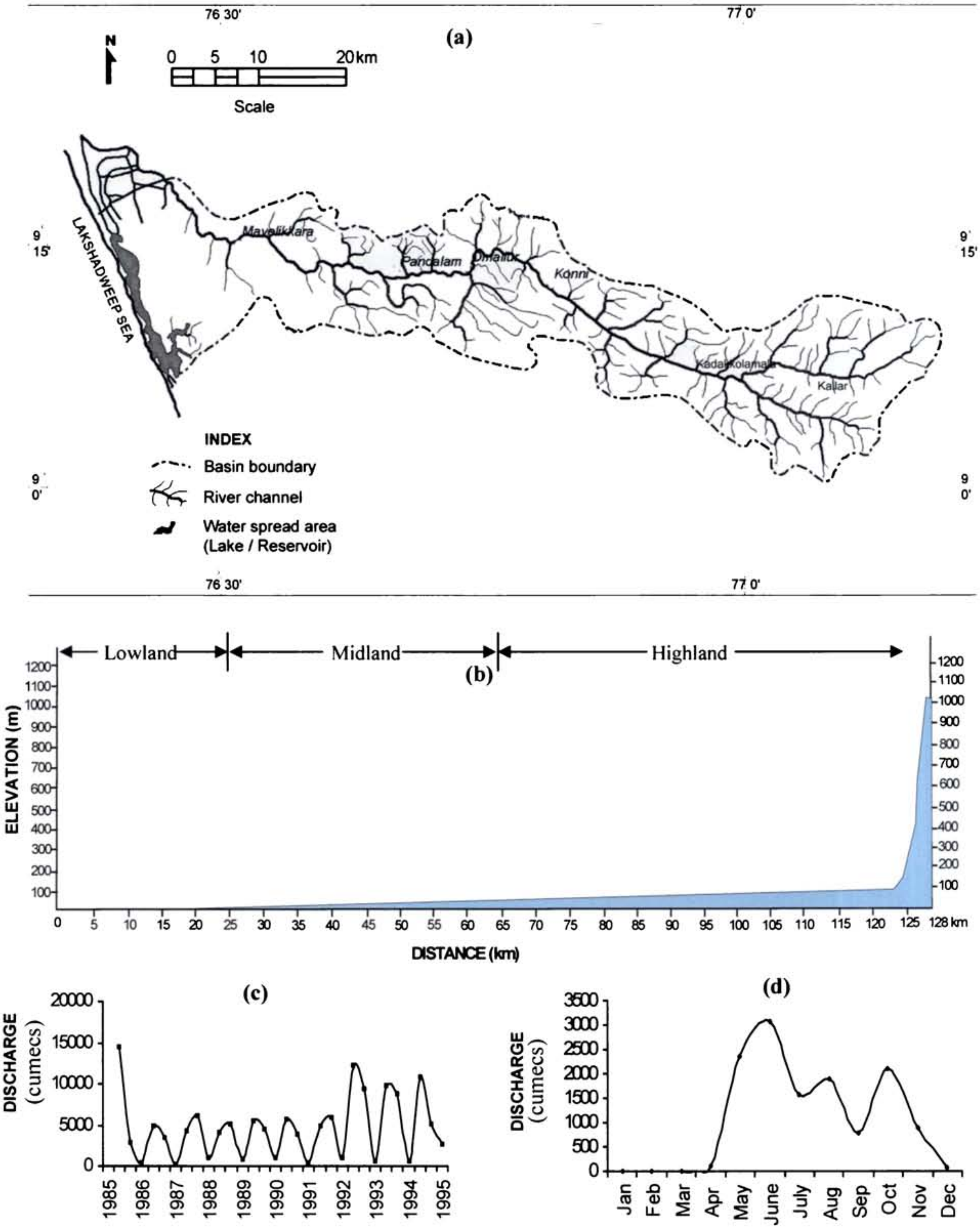


Fig. 5.1 Map showing drainage basin of Achankovil river (a), along with the longitudinal profile (b) and water discharge [c – Annual water discharge for the period 1985-1995 & d – Monthly water discharge for the year 2004; Source: Central Water Commission (CWC), Kochi]

are Chittar *Ar*, Pallikondan *Ar* and Tuval *thodu*. The river, in general, flows westerly and is controlled mainly by the Achankovil Shear Zone (ASZ). About 25 km of the mainstream and 16 km of the Kallar tributary are blanketed by alluvial sediments rich in boulders, cobbles and gravel in the upper part and gravelly sand in the lower part. Two minor tributaries - Nampakkad *thodu* and Kodumon *thodu* join the Achankovil river in the midlands at Azhur and Vazhamuttom, respectively. In the lowlands, the river splits up into several small distributaries and the main branch flows northwesterly and joins Pamba river at Viyapuram. The river hosts a 16 m waterfall in Tuval *thodu* at Palakappara. One of the important distributary namely the Kakkad *Ar* branches out near Gramam and flows northwards to join the river Pamba at Parumala. Another distributary that branches out from Mattam also flows northwards to some distance and joins the Achankovil river through a network of canals. Yet another tributary takes a southerly course and finally merges with the Kayamkulam *kayal*. The majority of the regions on either side of the river channel in the lowlands are flooded during monsoon season. The river channel in the downstream part upto Nangiarkulangara is influenced by tidal activities.

5.2.2 Environmental and geologic setting

The highlands of Achankovil river basin cover an area of about 676 km^2 which constitute about 61% of the total basin area. The Ariyankavu, Pramadom and Aruvappulam panchayats completely and Mailapra, Malayalappuzha, Konni and Thannithode panchayats partially fall within the highlands. The total population and population density of the highlands, as per 2001 census, are 107404 and 159 inh.km^{-2}, respectively. Midlands constitute only 28% area (312 km^2) of the entire Achankovil river basin. The population and population density of the midlands are 372404 and 1193 inh.km^{-2}, respectively. The upper part of the midlands falls within the Pathanamthitta district (18.98%) and the lower part (9.23%) in the Alappuzha district. The lowlands constitute only 11% (area: 119 km^2) of the total basin area. The total population in the lowlands is 185193. This part of the Achankovil river is densely populated (1557 inh.km^{-2}) compared to the highlands and midlands.

The river basin exhibits a diverse land use pattern. The highland part of the Achankovil river basin occupies forest and agricultural lands. Forest land includes forest plantations, evergreen / semi-evergreen forests, deciduous forests and degraded forests. Nearly 60% of the basin area is covered by forest plantations and 5% by degraded forests. About 10% of the area is under agricultural land that includes mixed agricultural / horticultural plantations. The midland region of the basin is characterized by mixed crops with settlements interspersed with narrow valleys where paddy is grown. Nearly 40% of the area is under double crop paddy cultivation. The lowland area covers agricultural lands and water bodies. About 80% of the agricultural land is under mixed crops with settlements and about 10% under double cropped paddy lands. The remaining area is covered by water bodies (KSLUB, 1996).

Geologically, the highlands of the Achankovil river basin is dominated by Precambrian crystallines namely charnockite, charnockitic gneiss and hypersthene-diopside gneiss. A few patches of garnet-biotite gneisses with migmatites are also reported from the basin. These crystallines are intruded at many places by granite and pyroxene granulites. The upstream part of the midlands is dominated by Archaean crystallines whereas the downstream part by the Tertiaries and the Quaternaries. The western part of the lowland area shows ridge-runnel topography with unconsolidated coastal sands. The Tertiaries and Quaternaries form the major aquifer systems in the lowlands.

5.2.3 Channel characteristics

The degree of meandering of a river is usually expressed by its sinuosity. Studies of Langbein and Leopold (1966) show that a sine generated curve describes symmetrical meander paths. From this observation they predicted the radius of curvature of meander bends from meander wavelength and channel sinuosity. Table 5.2 and Fig. 5.2 a and Fig. 5.2 b shows the Sinuosity Index (SI) of the rivers draining the Vembanad lake catchments.

The sand dominant reaches in the highlands between Perunthomoozhi and Pramadom exhibits high degree of sinuosity index (1.5). The Stream Tortuosity (ST) in

Table 5.2 Sinuosity Index (SI) and Stream Tortuosity (ST) along with Channel Length (CL) and Channel Width (CW) of the river channels in the study area (See Annexure II for locations)

Sl. No.	River / River reach	CL (km)	CW (m)	ST (%)	SI
I	**Achankovil river**				
1	Kadakkolamala to Karuppanthodu	12.10	25-50	26.70	1.27
2	Karuppanthodu to Forest range office	12.75	50	21.43	1.21
3	Forest Range Office to Vettur	10.60	50	12.17	1.12
4	Vettur to Pramadom	9.60	75-175	50.00	1.50
5	Pramadom to Thumpamon	13.55	75-125	73.72	1.74
6	Thumpamon to Venmoni	13.45	100-125	46.20	1.46
7	Venmoni to Kunnam	10.75	75-175	55.80	1.56
8	Kunnam to Kottaikkakom	15.10	75-275	59.79	1.60
9	Kottaikkakom to Viyapuram	9.65	50-200	35.92	1.36
II	**Pamba river**				
10	Pamba dam to Ponnambalamedu	9.7	50	26.80	1.37
11	Ponnambalamedu to Guest House	7.9	50-75	20.25	1.16
12	Guest House to Moolakkayam	11.15	50-100	28.25	1.39
13	Moolakkayam to Edakadathi	10.25	75-100	24.24	1.24
14	Edakadathi to Naranamoozhi	13.95	125	34.78	1.35
15	Naranamoozhi to Edakkulam	8.80	90-150	95.56	1.95
16	Edakkulam to Puthiyakavu temple	11.55	100-200	63.83	1.64
17	Puthiyakavu temple to Malakkara	12.80	175-225	34.03	1.34
18	Malakkara to Pandanad	13.30	125-175	22.58	1.23
19	Pandanad to Viyapuram	12.05	75-175	14.76	1.15
20	Viyapuram to Nadubhagom	16.85	115-175	41.60	1.42
21	Nadubhagom to Pallathuruthy	10.40	100-150	6.12	1.06

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Sl. No.	River / River reach	CL (km)	CW (m)	ST (%)	SI
III	**Manimala river**				
22	Puvathilappu to Uzhakkanad	15.10	50-125	73.56	1.74
23	Uzhakkanad to Chenappadi	11.40	75-140	82.40	1.82
24	Chenappadi to Kottangal	12.15	95-125	38.07	1.38
25	Kottangal to Madathumbhagom	19.50	55-100	77.27	1.77
26	Madathumbhagom to Kallungal	17.75	60-100	46.69	1.47
IV	**Meenachil river**				
27	Erattupetta to Kondur	5.10	25-100	12.09	1.12
28	Kondur to Pala	10.20	75-150	43.66	1.44
29	Pala to Punnathara	15.20	100	30.47	1.30
30	Punnathara to Govindapuram	15.15	100-150	38.99	1.39
31	Govindapuram to Vembanad lake	11.05	50-75	19.46	1.19
V	**Muvattupuzha river**				
32	Muttam to Thodupuzha	8.05	50-75	13.42	1.04
33	Thodupuzha to Kizhmadangu	13.75	55-150	25.57	1.26
34	Kizhmadangu to Muvattupuzha	11.10	75-145	66.92	1.67
35	Muvattupuzha to Urayam	12.15	135-175	66.44	1.66
36	Urayam to Pazhur	19.00	125-300	90.00	1.90
37	Pazhur to Vettikkattumukku	14.25	130-150	57.56	1.57
38	Vettikattumukku to Vaikom (Ittupuzha distributary)	12.70	75-125	41.11	1.41

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Sl. No.	River / River reach	CL (km)	CW (m)	ST (%)	SI
VI	**Periyar river**				
39	Periyar lake downstream to Mlamala	22.2	50-100	49.49	1.49
40	Mlamala to Idukki dam	21.4	50-175	49.65	1.50
41	Idukki dam to Pannamkutti	15.35	25-200	28.99	1.29
42	Pannamkutti to Thattakanni	12.50	50-175	2.04	1.02
43	Thattakanni to Inchathotti	17.55	50-275	4.78	1.05
44	Inchathotti to Bhagavathikulam	15.70	100-400	8.28	1.08
45	Bhagavathikulam to Kalady	25.60	200-350	15.31	1.15
46	Kalady to Aduvathuruthu	28.40	175-595	79.18	1.79
47	Aduvathuruthu to Ayiroor Vayal	11.30	175-450	1.80	1.02
48	Ayiroor Vayal to Vembanad lake	8.90	175-700	1.14	1.01
VII	**Chalakudy river**				
49	Peringalkuthu dam to Kannankuzhi	12.10	50-300	27.37	1.27
50	Kannankuzhi to Kanjirapalli	17.10	100-200	7.89	1.08
51	Kanjirapalli to West Chalakudy	14.50	125-190	59.34	1.59
52	West Chalakudy to Puvathissery	12.30	105-150	46.43	1.46
53	Puvathissery to Elanthikkara	12.15	100-140	37.29	1.37

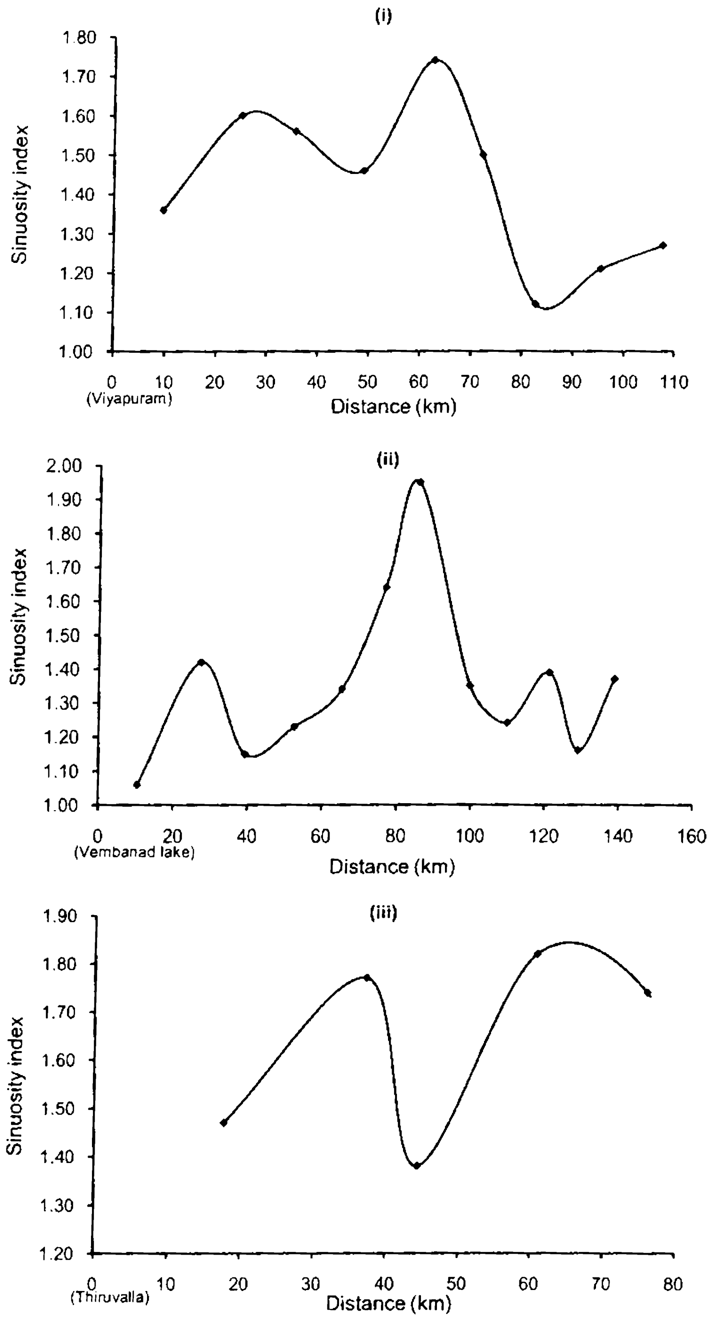

Fig. 5.2a Variation of sinuosity index along the main channel of (i) Achankovil, (ii) Pamba and (iii) Manimala rivers draining the Vembanad lake catchments

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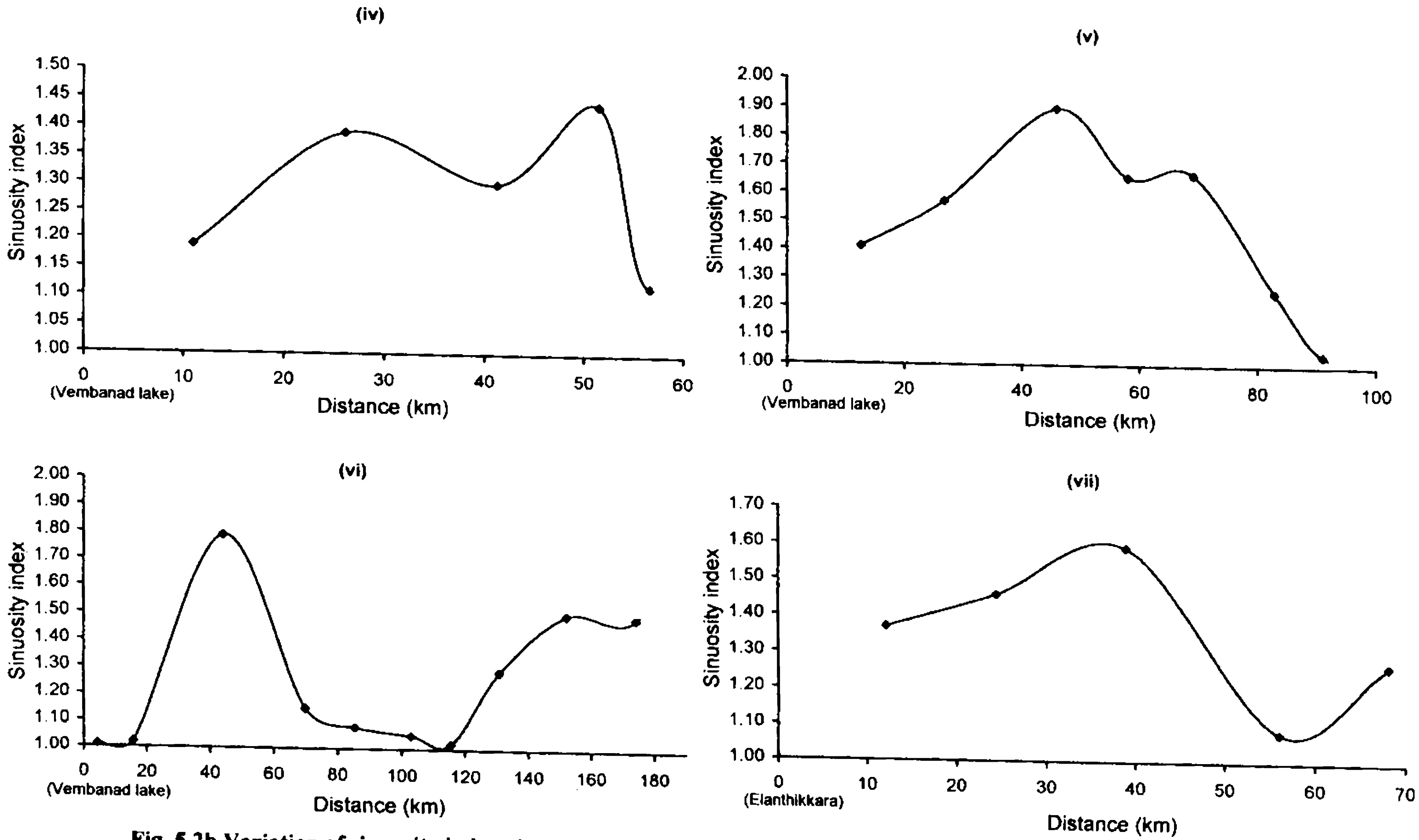


Fig. 5.2b Variation of sinuosity index along the main channel of (iv) Meenachil, (v) Muvattupuzha, (vi) Periyar and (vii) Chalakudy rivers draining the Vembanad lake catchments

this part is about 50% (Table 5.2). The river channel in the downstream part is sand dominant with a width range of 50 - 175 m. A comparative evaluation of the sinuosity index among various physiographic units reveals that the midlands are more sinuous than the other two zones (Fig. 5.2 a). Within the midlands, the maximum sinuosity index and stream tortuosity values are observed in the river reach between Pramadom and Thumpamon (SI 1.74; ST 73.72%). The channel width ranges from 75 m to 125 m. In the lowlands, the river channel widens to ~ 275 m near Cheriyanad. The sinuosity index of upstream end (Kunnam to Kottaikkakom) is markedly higher (1.6) than the downstream end (Kottaikkakom to Viyapuram; SI: 1.36).

Three types of channel pattern are observed in the river such as sinuous, irregular wandering and irregular (See Fig. 2.1 a in Chapter 2). Of the three types, irregular pattern is frequent in midland and lowland areas, whereas irregular wandering and sinuous patterns are seen in the highlands. The alluvial reaches of the main channel of Achankovil river exhibit three distinct morphological classes towards downstream. They are plane bed reach, pool riffle reach and dune ripple reach (See Chapter 2 for the details). The length of the alluvial reach of the main channel is about 95 km.

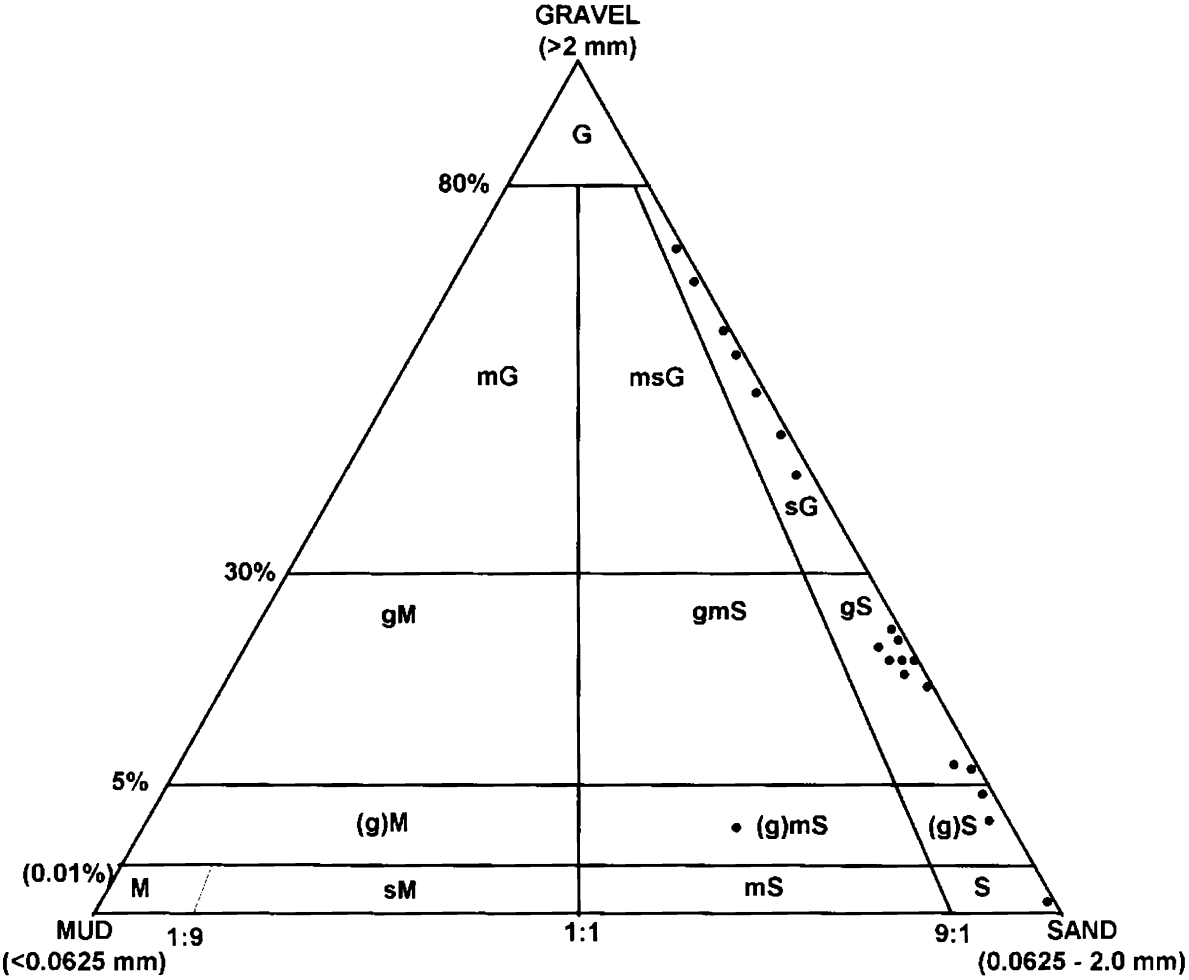
The percent contents of various grain size classes in the bed sediments of the Achankovil river are given in Table 5.3. Fig. 5.3 depicts the nature of sediments in the entire river basins in the Vembanad lake catchments with that of the Achankovil river. The riverbed of Achankovil river in the highlands is generally rocky with sporadic patches of coarser sediments. Sands are of coarser grade with small amounts of gravel in the midlands. Medium to fine grained sand is the major textural type in the lowlands. The sediment type in the highlands and midlands, according to Folk et al. (1970), is gravelly sand (gS) and lowlands, slightly gravelly sand [(g)S]. The content of sand is substantially high in the lowlands (95.38%).

5.2.4 River discharge and water quality

Analysis of water and sediment discharge data during the period 1985/86 – 1994/95 shows that on an average, about 14779 cumecs of water and 85813 tonnes of sediment (11484 tonnes of sand; 74328 tonnes of mud) are discharged through Achankovil river annually. The year-wise discharges of water and sediments during

Table 5.3 Particle size characteristics and types of bed sediments in the rivers of the study area

Sample No.	Pebble (a)	Granule (b)	Very coarse sand (c)	Coarse sand (d)	Medium sand (e)	Fine sand (f)	Very fine sand (g)	Gravel (a+b)	Sand (c+d+e+f+g)	Mud	Sediment type (Folk et. al, 1970)
I) Achankovil river											
1.00	2.23	8.74	26.59	29.37	23.70	9.29	0.07	10.98	89.02	0.00	Gravelly sand
2.00	5.29	13.12	37.15	22.11	13.02	7.21	1.60	18.41	81.09	0.49	Gravelly sand
3.00	0.00	3.91	5.38	50.49	35.60	3.77	0.14	3.91	95.38	0.71	Slightly gravelly sand
II) Pamba river											
4.00	21.21	24.27	35.91	11.53	4.64	1.82	0.51	45.49	54.41	0.10	Sandy gravel
5.00	3.02	12.61	35.39	28.16	20.62	0.11	0.04	15.63	84.33	0.04	Gravelly sand
6.00	0.00	5.65	15.71	32.77	34.18	10.42	0.71	5.65	93.79	0.55	Gravelly sand
III) Manimala river											
7.00	37.25	12.88	27.05	15.61	6.28	0.75	0.14	50.13	49.83	0.04	Sandy gravel
8.00	48.31	7.28	10.54	9.48	19.74	4.03	0.51	55.59	44.31	0.10	Sandy gravel
9.00	0.00	0.00	14.45	41.29	37.13	6.01	0.80	0.00	99.67	0.33	Sand
IV) Meenachil river											
10.00	33.39	26.17	29.32	9.13	1.58	0.27	0.11	59.55	40.40	0.04	Sandy gravel
11.00	4.56	14.24	27.10	22.51	21.16	7.64	2.55	18.79	80.97	0.24	Gravelly sand
12.00	0.00	1.95	6.18	18.48	34.54	8.76	0.61	1.95	68.58	29.47	Slightly gravelly muddy sand
V) Muvattupuzha river											
13.00	55.91	11.05	2.35	2.92	17.17	8.06	0.92	66.96	31.42	0.00	Sandy gravel
14.00	54.93	15.51	9.65	8.51	8.82	2.39	0.07	70.44	29.45	0.10	Sandy gravel
15.00	4.54	8.31	18.12	28.98	27.74	9.78	0.88	12.86	85.49	1.65	Gravelly sand
VI) Periyar river											
16.00	7.09	5.97	22.95	44.05	13.71	2.68	0.23	13.06	83.62	3.32	Gravelly sand
17.00	1.36	2.41	22.31	23.12	37.46	8.89	2.84	3.77	94.62	1.47	Slightly gravelly sand
18.00	0.22	6.13	10.84	20.70	40.74	18.61	1.44	6.35	92.33	1.25	Gravelly sand
VII) Chalakudy river											
19.00	24.75	15.65	27.96	17.11	10.88	2.55	0.21	40.40	58.71	0.90	Sandy gravel
20.00	13.38	4.46	15.23	21.34	28.01	13.31	2.30	17.84	80.19	2.92	Gravelly sand
21.00	3.66	9.45	40.92	32.56	10.69	1.55	0.22	13.11	85.94	0.90	Gravelly sand



G – gravel; mG – muddy gravel; msG – muddy sandy gravel; sG – sandy gravel; gM – gravelly mud; gmS – gravelly muddy sand; gS – gravelly sand; (g)M – slightly gravelly mud; (g)sM – slightly gravelly sandy mud; (g)mS – slightly gravelly muddy sand; (g)S – slightly gravelly sand; M – mud; sM – sandy mud; mS – muddy sand; S – sand.

Fig. 5.3 Ternary diagram showing the nature of sediments in the rivers of the study area (after Folk et al., 1970)

1985/86 – 1994/95 are given in Table 5.4. Fig. 5.1 c depicts the seasonal variations in the discharge of water through the Achankovil river during the period 1985 to 1995. About 55% of water discharge occurs during monsoon period (June – September). The water discharge in Northeast monsoon (October – December) is only 39%. Fig. 5.1 d shows the monthly discharge of water through Achankovil river during 2004.

Table 5.4 Annual discharge of water and sediments through Achankovil river

Sl. No.	Year	Water discharge (cumecs)	Sediment discharge (Tonnes)		
			Sand	**Mud**	**Total**
1	1985-86	17736	8837	35275	44112
2	1986-87	8647	6172	33125	39297
3	1987-88	11271	6411	75992	82403
4	1988-89	10837	4587	45426	50013
5	1989-90	16663	11308	92858	104166
6	1990-91	9959	5744	31137	36881
7	1991-92	17017	20532	79387	99919
8	1992-93	22124	22745	159277	182022
9	1993-94	14863	12253	76708	88961
10	1994-95	18680	16260	114103	130363
Average		**14779**	**11484**	**74328**	**85813**

Source: Central Water Commission (CWC), Kochi; Gauging station: Thumpamon

The average concentrations of various physico-chemical parameters analysed for the water samples of the Achankovil river along with other rivers in the study area are given in Table 5.5. The pH exhibited slightly higher values during summer season (6.4) whereas conductivity was high during monsoon season (59.7 µS/cm). During monsoon, nutrients in the river, especially Total Nitrogen (N_{tot}) and Total Phosphorus (P_{tot}) show high concentrations (N_{tot}: 1004 µg/l; P_{tot}: 473 µg/l) compared to summer season (N_{tot}: 465 µg/l; P_{tot}: 116 µg/l). The river also exhibits high concentration of Total iron (Fe_{tot}) during monsoon season (1100 µg/l) compared to non-monsoon counterpart (488 µg/l). Total Suspended Solids (TSS) show higher concentration during monsoon (15.03 mg/l) than non-monsoon period (5.88 mg/l). The average Dissolved Oxygen (DO) in the river during monsoon and non-monsoon periods was estimated to be 6.38 mg/l and 8.13 mg/l, respectively.

Table 5.5 Average concentrations of various physico-chemical parameters in the river waters of the study area

Sl. No	Parameters	Achankovil river		Pamba river		Manimala river		Meenachil river		Muvattupuzha river		Periyar river		Chalakudy river	
		M	NM	M	NM	M	NM	M	NM	M	NM	M	NM	M	NM
1	pH	6.13	6.40	5.97	6.92	5.98	6.65	5.52	6.35	5.87	6.76	5.45	6.53	5.67	7.24
2	Conductivity (µS/cm)	59.70	48.00	30.48	33.27	33.50	56.58	63.60	958	42.99	62.4	77.90	1033	34.96	3491
3	DO (mg/l)	6.38	8.13	6.37	6.92	5.85	6.65	6.08	6.40	5.71	5.72	5.74	6.41	5.92	6.48
4	Alkalinity (mg/l)	21.00	20.00	11.83	15.67	10.75	19.00	13.60	15.20	12.00	18.75	13.63	21.50	10.80	24.20
5	BOD (mg/l)	2.05	2.95	2.07	2.05	2.21	2.78	2.20	3.34	2.11	2.61	1.98	2.64	1.86	2.46
6	Chloride (mg/l)	11.35	9.46	7.47	7.10	8.84	12.80	16.35	370	10.89	11.84	22.20	1352	9.80	1665
7	Sulphate (mg/l)	6.08	1.02	2.05	0.29	1.34	0.80	3.88	42.20	3.83	24.28	3.98	148	2.17	209
8	Hardness (mg/l)	21.00	13.25	9.00	11.17	9.75	14.00	17.40	156	14	86.88	17.38	494	10.20	611
9	NO_2 N (µg/l)	1.69	43.00	5.70	15.02	9.63	25.33	26.21	28.35	5.23	4.11	5.14	0.30	4.12	3.67
10	NO_3 – N (µg/l)	691	180	743	192	957	157	1037	219	841	450	808	247	519	167
11	NH_3 – N (µg/l)	0.28	5.95	0.09	0.27	0.31	6.14	-	1.96	0.05	-	9.50	43.88	0.42	3.80
12	N_{tot} (µg/l)	1004	465	1155	427	1272	359	1487	592	1071	649	1042	694	862	353
13	Reactive P (µg/l)	65.20	30.40	46.13	25.97	41.65	27.05	44.58	34.78	56.58	23.76	39.71	25.90	47.28	38.56
14	P_{tot} (µg/l)	473	116	446	96.67	283	123	196	181	108	93.25	164	113	112	61.00
15	SiO_2 – Si (µg/l)	5.70	9.83	5.32	5.92	6.17	4.98	6.12	7.12	6.16	8.56	5.42	7.86	4.53	8.91
16	Ca (mg/l)	5.51	3.13	1.94	2.39	2.30	2.91	4.08	11.63	2.25	5.79	3.46	25.91	2.16	37.68
17	Mg (mg/l)	1.77	1.32	1.01	1.27	0.97	1.64	1.75	30.74	2.04	17.65	1.34	104	0.88	125
18	D-Fe (µg/l)	85.25	13.90	141	30.30	131	60	87.80	30.32	83.25	26.73	33.38	77.00	18.92	74.80
19	Fe_{tot} (µg/l)	1100	488	2150	458	3379	443	1630	547	1918	481	1766	633	695	287
20	TDS (mg/l)	38.65	27.98	20.30	19.22	22.85	34.45	40.96	525	29.09	36.37	46.40	379	24.42	2083
21	TSS (mg/l)	15.03	5.88	41.1	3.00	21.17	4.45	135	5.3	34.5	4.44	60.80	4.61	29.56	5.80

M: Monsoon; NM: Non-monsoon

5.3 Pamba river

5.3.1 Drainage

Pamba river originates from Pulachimala in the Western Ghats at an altitude of about 1650 m above msl. The river has a length of 176 km and a catchment area of about 2235 km^2. The drainage pattern and longitudinal profile of the Pamba river basin are presented in Fig. 5.4 a and b. The Pamba river generally displays dendritic to subdendritic drainage pattern. The two major reservoirs in the basin are Kakki and Pamba. The river hosts many waterfalls in the uplands, the important one is the Perunthenaruvi falls. The major hydro-electric project in the basin is located at Sabarigiri. Additionally, two minor hydro-electric projects are also in operation – one at Kakkad and the other at Azhutha – in the Pamba river basin. The reservoirs constructed in the uplands trap a substantial quantity of sediments, which are otherwise being transported downstream through the fluvial channels. Pamba river is considered as a sacred river in South India because of the famous 'Lord Ayyappa' temple at Sabarimala, in the basin. The river takes a different flow direction from its source and drains through highland, midland and lowland areas. Of the six major tributaries, the Kakki *Ar* and Kakkad *Ar* are the most important ones in contributing water and sediments to the Pamba river. The other tributaries are Azhutha *Ar*, Kallar and Pambiar. While Azhutha *Ar* joins the river in northern side at Kanamala, the Kakki *Ar* merges the river in southern side at Pamba Thriveni. Next important tributary, the Kakkad *Ar* joins the river Pamba at Perinad. The lower most tributary namely the Kallar, joins the Pamba river at Vadasserikkara after draining through the dense forests in the uplands. In the lowland area, near Pandanad, the river bifurcates and one branch flows to Neerettupuram in a southwesterly direction, while the other takes a westerly course and again bifurcates near Parumala. In the downstream near Chengannur, a distributary of Pamba river namely Varattar originates and flows encircling Idanad. A branch of Achankovil river merges the Pamba river at this portion. The river channel experiences tidal influence upto Pandanad. Thereafter, the river flows northwards and finally merges with the Vembanad lake.

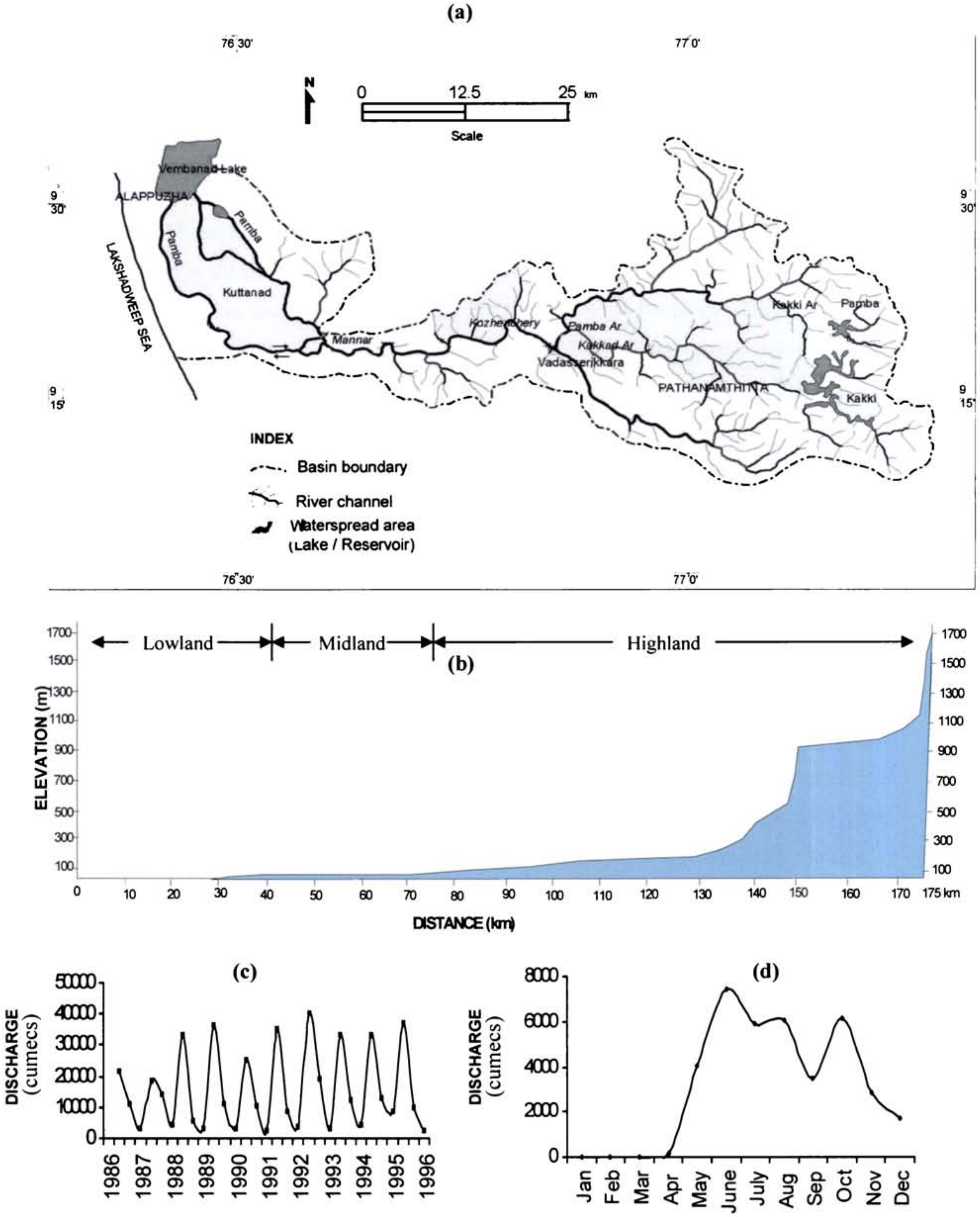


Fig. 5.4 Map showing drainage basin of Pamba river (a), along with the longitudinal profile (b) and water discharge [c – Annual water discharge for the period 1986-1996 & d – Monthly water discharge for the year 2004; Source: Central Water Commission (CWC), Kochi]

5.3.2Environmental and geologic setting

The total population and population density of the Pamba river basin, as per 2001 census, are 575382 and 326 inh.km^{-2}, respectively. The highlands of the Pamba river basin cover an area of about 1466 km^2 and constitute over 83% of the total basin area. About 91% of the highlands fall within the jurisdiction of Pathanamthitta district. The remaining is shared by Idukki (6%) and Kottayam (3%) districts. Midlands occupy 15% of the total basin area and the remaining 2% spreads in the lowlands. The midlands and lowlands fall within the jurisdiction of Pathanamthitta and Alappuzha districts. About 91% of the midlands and 20% of the lowlands fall within the Pathanamthitta district. A major portion (80%; area: 24 km^2) of the lowlands falls within Alappuzha district.

Approximately 80% of the highlands is under forest cover and include forest plantations, degraded forests, evergreen and deciduous type. Evergreen forests are the predominant type in the basin. The southern part of the river channel is under Konni and Gudarakkal reserved forests. The Kakki and Pamba reservoirs occupy nearly 10% of the highlands. This area is characterized by rocky slopes and escarpments. Towards the lower part, teak and rubber plantations are seen. A few pockets of settlements are noticed in the upstream. The major settlements are concentrated in the downstream part of the highlands around Vadasserikkara, Ranni Perinad, Ranni and Vechoochira grama panchayats. The midland region of the basin occupies forest land and agricultural land. The forest land consists of forest plantations and deciduous forests. About 85% of the area is characterized by mixed crops with settlements. The lowlands consist of agricultural lands, wastelands and water bodies. Paddy cultivation is the main agricultural activity in the lowlands. Mixed crops with settlements form the next predominant land use category. The wastelands consist of sandy area as well as water-logged lands. Water bodies occupy nearly 2% in the lowlands.

Geologically, the highland part of the Pamba river basin is composed of Precambrian crystallines, represented by charnockites, charnockite gneisses and hypersthene-diopside gneisses. Like the lowlands of Achankovil river basin, the area is covered mainly by unconsolidated sediments of Quaternary age, which is underlain by semi-consolidated Tertiary sediments which form the major aquifer systems in the lowlands.

5.3.3 Channel characteristics

The river channel in the highlands is rich in boulders, cobbles and gravel. Gravelly sand segregates in the downstream part of the river channel where the river meanders to higher degrees (SI: 1.95); (Table 5.2). The channel width of the river varies from 50 to 200 m in the highlands. The river channel in the midland is comparatively less sinuous than that in the highland (Fig. 5.2 a). Of the two segments analysed in the midlands, the segment upstream of Puthiyakavu temple upto Malakkara is more sinuous with an index of 1.34 than the downstream segment (Malakkara to Pandanad; SI: 1.23). The river is more wide (125 – 225m) in the midlands than in the highlands. Compared to highlands and midlands, the sinuosity index is generally low in the lowlands of the Pamba river basin except for the segment between Viyapuram and Nadubhagom, where maximum sinuosity index of 1.42 is observed. The width of the river channel varies from 75 to 175 m.

Like Achankovil river, three types of channel patterns are observed in Pamba river also. They are sinuous, irregular wandering and irregular. In the highlands and lowlands, all the three channel patterns are observed. Irregular and irregular wandering types of the channel pattern occur in the midland area. Three distinct classes of alluvial reaches are identified in the main channel of Pamba river – plane bed reach, pool riffle reach and dune ripple reach. The total length of the alluvial reach in the main channel is 65 km.

The percent content of various grain size classes in the sediments of Pamba river is given in Table 5.3. The gravel content (45.49%) decreases downstream, whereas the content of sand exhibits an opposite trend. Highland reaches of the river are characterised by sandy gravel (sG). Gravelly sand (gS) predominates in the midlands and lowlands. In general, sand is coarse to medium grained all along the river stretch in the midlands and medium to fine grained in the lowlands.

5.3.4 River discharge and water quality

The water and sediment discharge data of Pamba river for the period 1987/88 – 1996/97 reveals that on an average, 47417 cumecs of water and 168218 tonnes of sediment (42012 tonnes of sand; 126205 tonnes of mud) are being discharged annually through the Pamba river. Table 5.6 shows the year-wise discharge of water and sediments during the period 1987/88 – 1996/97. Fig. 5.4 c depicts the seasonal discharge of water through this river during the period 1986 to 1996. About 67% of water discharge occurs during monsoon period. Northeast monsoon records only 25% of water discharge. The monthly discharge of Pamba river during the year 2004 is given in Fig. 5.4 d.

Table 5.6 Annual discharge of water and sediments through Pamba river

Sl. No.	Year	Water discharge (cumecs)	Sediment discharge (Tonnes)		
			Sand	Mud	Total
1	1987-88	36608	37528	105588	143116
2	1988-89	42203	27351	117472	144823
3	1989-90	50400	24246	148981	173227
4	1990-91	38087	15766	50004	65770
5	1991-92	47039	25438	79330	104768
6	1992-93	62461	122232	379330	501562
7	1993-94	49765	42452	75005	117457
8	1994-95	54644	72809	128707	201516
9	1995-96	49158	31310	100070	131380
10	1996-97	43813	20991	77571	98562
Average		**47417**	**42012**	**126205**	**168218**

Source: Central Water Commission (CWC), Kochi; Gauging station: Malakkara

The quality of water also shows marked seasonal variations. The pH and conductivity exhibit slightly higher values during non-monsoon season (pH: 6.92; conductivity: 33.27 µS/cm). The nutrients in the river, especially N_{tot} and P_{tot} show high concentrations (N_{tot}: 1155 µg/l; P_{tot}: 446 µg/l) during monsoon season than non-monsoon season (N_{tot}: 427 µg/l; P_{tot}: 96.67 µg/l). The river also displays high amounts of Fe_{tot} during monsoon (2150 µg/l) than non-monsoon (458 µg/l). The monsoon values of TSS are several fold higher than non-monsoon values (Monsoon: 41.10 mg/l; Non-monsoon:

3.00 mg/l). The average DO contents in the river during monsoon and non-monsoon periods are 6.37 mg/l and 6.92 mg/l, respectively.

5.4 Manimala river

5.4.1 Drainage

Like the Achankovil river, the river Manimala is also devoid of any major reservoirs. The river has a length of about 90 km. It originates from the Thattamala hills at an elevation of 1156 m above msl. The drainage characteristics and longitudinal profile of the river are shown in Fig. 5.5 a and b, respectively. The Manimala river exhibits a dendritic drainage pattern. The major tributaries of the Manimala river are Kokkayar, Para *thodu*, Kanjirapally *thodu*, Pullaga *Ar*, Chemban *thodu*, Elakkal *thodu*, Papan *thodu*, Atta *thodu*, Gopara *thodu*, Erumeli *thodu*, Karinbum *thodu*, Para *thodu* and Kuvani *thodu*. The upstream part of the channel from Olayanad to Koottickal is known as Pullaga *Ar* which flows southerly upto Naduvilakoratti. Then the river takes a westward deviation and form the proper Manimala river. Another tributary called the Atta *thodu* merges with Pullaga *Ar* near Koottickal check dam. The tributary namely Gopara *thodu* originating from Gopara *Mala*, after draining through teak plantations, joins the main channel near Kanamala. Then the river takes a southerly course upto Mundakkayam and then deviates westerly upto Manimala. Thereafter, the river takes a meandering course till Neerettupuram. From Neerettupuram one branch of the river flows towards west and joins the river Pamba at Edathua. The other branch flows northwards and at Kidangara the river bifurcates into distributaries. One of its channel again joins the Pamba river and the other (i.e., Chela *Ar*) after flowing through the Kuttanad wetlands merges with the Vembanad lake. Lowland region is usually flooded during monsoon season.

5.4.2 Environmental and geologic setting

Of the total river basin area (781 km^2), about 345 km^2 spreads in the highlands and 432 km^2 in the midlands. Only a small portion (4 km^2) of the total basin area falls under the lowlands. The entire area of the basin lies within the jurisdiction of Pathanamthitta, Kottayam and Idukki districts. The total population and population

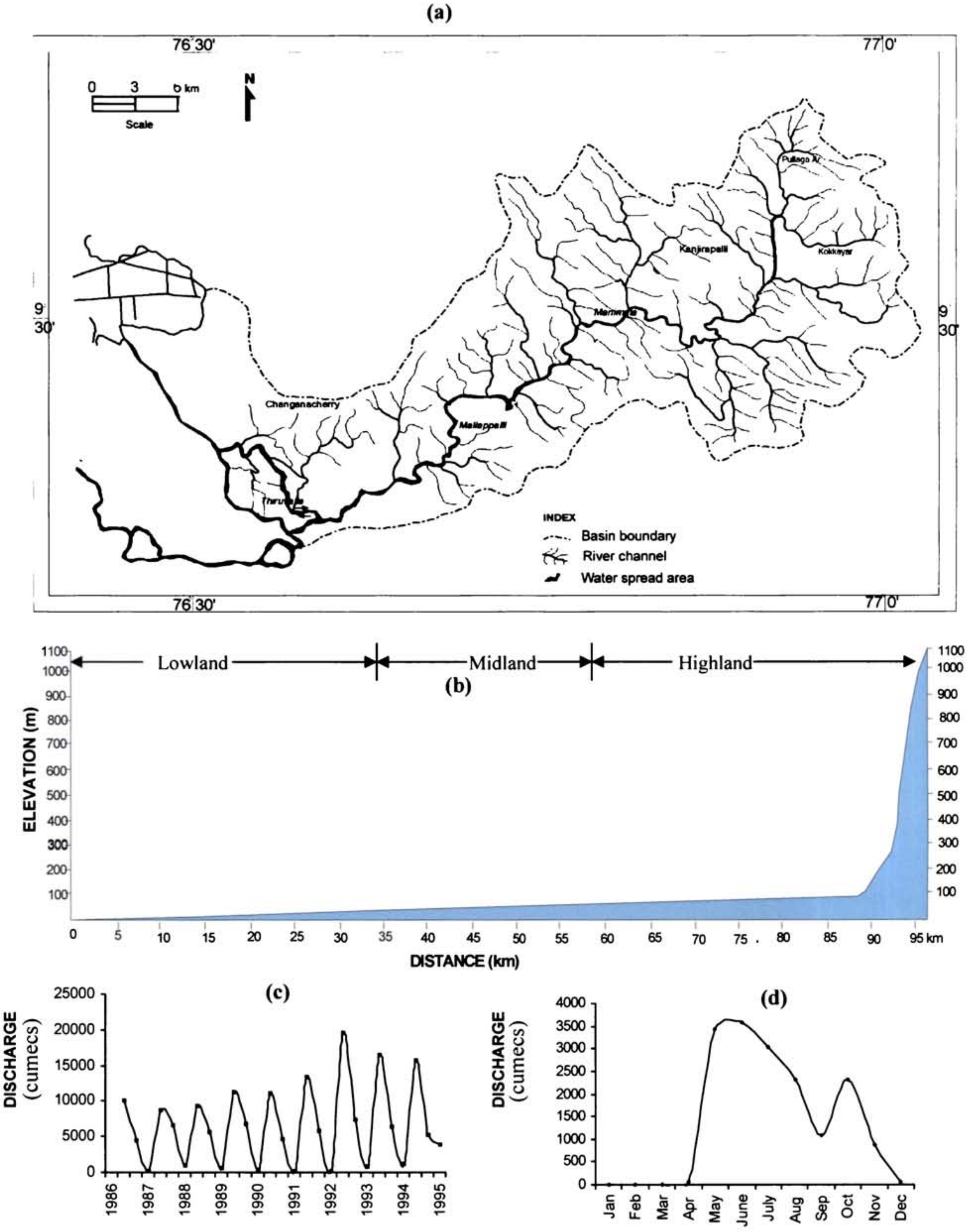


Fig. 5.5 Map showing drainage basin of Manimala river (a), along with the longitudinal profile (b) and water discharge [c – Annual water discharge for the period 1986-1995 & d – Monthly water discharge for the year 2004; Source: Central Water Commission (CWC), Kochi]

density of the basin are 539080 and 690 inh.km^{-2}, respectively. The lowlands have the highest population density (1585 inh.km^{-2}) compared to the highlands (458 inh.km^{-2}) and midlands (864 inh.km^{-2}).

The highlands consist of agricultural land, forest land and wasteland. The forest land (which is nearly 15%) consists of forest plantations as well as deciduous forests. The wasteland occupying the basin area (nearly 2%) is composed of barren rock. Majority of the area is under plantation crops. Rubber plantations are more common in the area. Pockets of tea plantations are also seen in some parts of the uplands. Unlike Achankovil and Pamba rivers, dense settlements are seen in Manimala basin in the highlands. In certain parts of the area, open scrub lands are also seen. Nearly 10% of the midlands consist of deciduous forests as well as forest plantations. Rubber plantations are dominant in the upper part of the midlands. Mixed crops with settlements form the other important land use category in the area. The lowlands are occupied predominantly by agricultural land. Nearly 50% of the agricultural land is used for double cropped paddy cultivation. Reclaimed areas at some places downstream of Chennankari are also used for paddy cultivation. About 2% of the basin area is occupied by water bodies.

In Manimala river basin, the Precambrian crystallines (the major rock formation) are intruded at many places by acidic (granite, quartz veins) and basic (dolerite) rocks. In the downstream, the river flows over laterites as well as coastal sands and alluvium. Sub-surface occurrence of sandstones and clays of Warkalli Formation is also reported from the downstream part of the Manimala basin.

5.4.3 Channel characteristics

The channel width of the Manimala river in the highlands vary between 50 and 140 m. The width of the upper part of the channel is only about 50 m and in the lowlands, channel width increases and often reaches upto 140 m. High sinuosity index is observed in the river stretch from Uzhakkanad to Chenappadi (SI: 1.82), followed by Puvathilappu to Uzhakkanad (SI: 1.74). The channel width in the midland area ranges between 55 and

125 m. The river channel exhibits comparatively high sinuosity index (SI: 1.77) in the midlands between Kottangal and Madathumbhagom (Table 5.2); (Fig. 5.2 a).

Three types of channel patterns are observed in Manimala river. They are (1) irregular (2) tortuous and (3) sinuous patterns. The river stretch in the highlands from Olayanad to Uzhakkanad is characterised by irregular meander followed by tortuous pattern from Uzhakkanad to Chenappadi. The river channel shows irregular meander in the midlands. Lowlands are characterised by irregular (Kallungal to Muttar) and sinuous (Muttar to Kavalam) meander patterns. The main channel of the Manimala river is categorised into three distinct morphological classes towards downstream – plane bed reach, pool riffle reach and dune ripple reach. The length of the alluvial reach is about 75 km.

In general, the Manimala river channel in the highlands is rocky in nature and sand deposits are found as sporadic patches within the channel. The results of the grain size analysis are given in Table 5.3. The highlands and midlands are characterised by sandy gravel (sG) sediments. Gravel is totally absent in the lowlands of the Manimala river. The higher content of sand (99.67%) in the lowlands might be resulted from the improved sediment sorting as the river enters the low gradient downstream reaches.

5.4.4 River discharge and water quality

Analysis of water and sediment discharge data (1986/87 – 1994/95) reveals that on an average, 19641 cumecs of water and 79545 tonnes of sediment (15137 tonnes of sand and 64408 tonnes of mud) are discharged through Manimala river annually. The year-wise discharge of water and sediments during the period (1986/87 – 1994/95) is summarised in Table 5.7. Fig. 5.5 c depicts the seasonal discharge of water through the Manimala river during the period 1986 to 1995. About 65% of water discharge occurs during monsoon period. The river discharges only about 30% of water into the receiving backwater system (i.e., the Vembanad lake) in northeast monsoon. Fig. 5.5 d shows the monthly water discharge of Manimala river during the year 2004. The highest water discharge is recorded during the months of May and June.

Table 5.7 Annual discharge of water and sediments through Manimala river

Sl. No.	Year	Water discharge (cumecs)	Sediment discharge (Tonnes)		
			Sand	**Mud**	**Total**
1	1986-87	14834	6330	28112	34442
2	1987-88	16365	10411	61757	72168
3	1988-89	15702	10002	51521	61523
4	1989-90	18663	10951	80249	91200
5	1990-91	15954	5451	37962	43413
6	1991-92	19471	17816	81907	99723
7	1992-93	27758	18516	84915	103431
8	1993-94	23174	25236	76728	101964
9	1994-95	24846	31519	76522	108041
Average		**19641**	**15137**	**64408**	**79545**

Source: Central Water Commission (CWC), Kochi; Gauging station: Kallooppara

The water quality analysis reveals that the river water shows wide seasonal variations. The pH and conductivity exhibit higher values during non-monsoon season (pH: 6.65; conductivity: 56.58 µS/cm) compared to monsoon season (pH: 5.98; conductivity: 33.5 µS/cm). The nutrients like N_{tot} and P_{tot} show higher concentrations during monsoon season (N_{tot}: 1272 µg/l; P_{tot}: 283 µg/l) than the non-monsoon season (N_{tot}: 359 µg/l; P_{tot}: 123 µg/l). The river exhibits high amounts of Fe_{tot} during monsoon period (3379 µg/l). The TSS content was found to be five times higher during monsoon season than non-monsoon season (monsoon: 21.17 mg/l; non-monsoon: 4.45 mg/l). This might be due to the higher turbulence and suspended loads in the river water during monsoon season. The average DO concentration in monsoon season (5.85 mg/l) was slightly lower than that of non-monsoon season (6.65 mg/l).

5.5 Meenachil river

5.5.1 Drainage

The Meenachil river is the lifeline of Kottayam district. The river is undammed at present, and originates from the Arikunnumudi mountains of the Western Ghats at an elevation of 1097 m above msl. The river has a length of 78 km and a catchment area of

1272 km^2 (Table 5.1). The river exhibits a dendritic drainage pattern (Fig. 5.6 a). The longitudinal profile of the Meenachil river basin is depicted in Fig. 5.6 b. The major tributaries are Vazhikadavu *Ar*, Kala *Ar*, Tikovil *Ar* and Chittar. The former three tributaries originate from the eastern side and the latter one from the southern side. Another small tributary namely Kalattukadavu *Ar* joins the Tikovil *Ar* at Karilakkanam and flows southwards before merging with the Meenachil river (proper) at Erattupetta. The Chittar merges with the main river channel at Kondur. Unlike other tributaries of Meenachil river, the river channel of Chittar is wider and enfolds instream sand deposits. Though the midlands of the river basin is drained by various tributaries feeding the main channel, the important ones draining the northern flanks are the following: (1) Parayi *thodu*, (2) Payappara *thodu*, and (3) Kottachira *thodu*. The important tributaries that drain the river from the southern side are Mannani *thodu*, Pannagan *thodu* and Minadam *Ar*. The river splits into a number of distributaries in the lowlands and finally merges with the Vembanad lake. The Kaippuzha *Ar*, Pennar *thodu*, Kavan *Ar*, Chengalam *Ar* and Puttan *thodu* are the major distributaries that receive water and sediments discharged from the Meenachil river.

5.5.2 Environmental and geologic setting

The river basin falls mainly within the jurisdiction of Kottayam district. The midlands of Meenachil river basin cover an area of about 703 km^2 and constitute about 66% of the total basin area. Highlands constitute 33% (area: 346 km^2) of the basin area whereas lowlands spread only 1.04% (area: 11.04 km^2). The total population and population density as per 2001 census are 934845 and 881 inh.km^{-2}, respectively.

The highlands of the Meenachil river basin consist of agricultural land and wasteland. About 85% of the highland is under mixed agricultural plantations with settlements. Rubber and tea plantations spread at certain pockets in the Meenachil river basin. Small proportions of wastelands with barren rocks, grasslands etc., are also noticed in the highlands. The midland region consists mainly of agricultural lands. Rubber plantations are dominant in the upper part of the midlands. Mixed crops with settlements

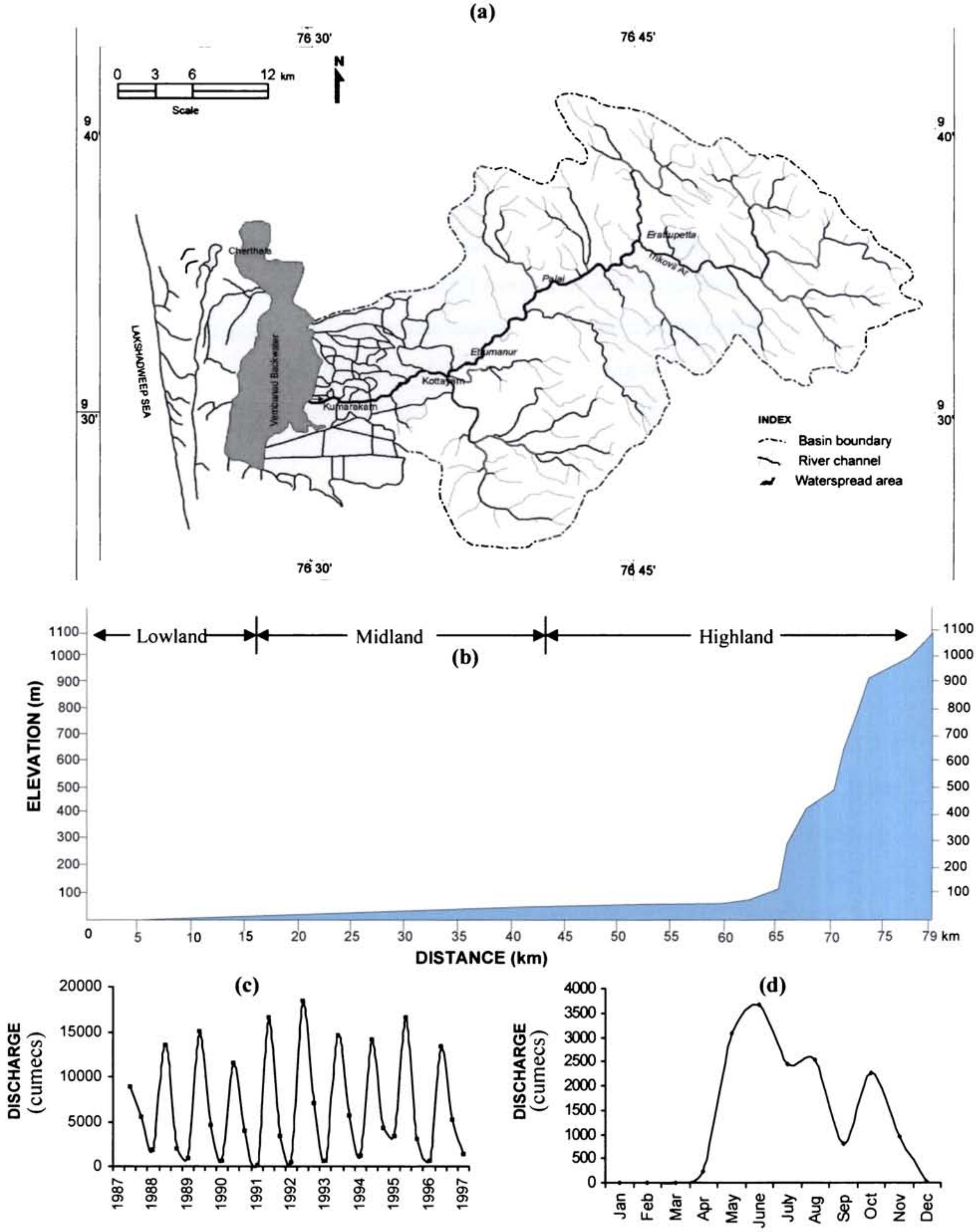


Fig. 5.6 Map showing drainage basin of Meenachil river (a), along with the longitudinal profile (b) and water discharge [c – Annual water discharge for the period 1987-1997 & d – Monthly water discharge for the year 2004; Source: Central Water Commission (CWC), Kochi]

(85%) form the other important category of land use in the area. About 15% of the area is under double cropped paddy lands. The lowlands comprise agricultural land, wasteland and water bodies. The upper part of the lowlands is occupied by mixed crops with settlements. The lower part is covered by paddy land and water-logged areas.

The major rock types in Meenachil river basin are quartzite, charnockite, biotite gneiss and pink granite. A considerable area in the highlands is covered by charnockites and charnockite gneisses. Numerous dolerite dykes trending NW – SE are also reported in the Meenachil river basin. Recent sediments of coastal sands and alluvium occupy the areas close to the river mouth zones.

5.5.3 Channel characteristics

The width of the river channel in the upstream of Meenachil basin is usually less than 25 m. At Erattupetta, the river channel widens and attains an average width of 100 m near Kondur. The sinuosity index of the river reach between Erattupetta and Kondur in the highlands is 1.12. In the midlands, the width of the main river channel ranges between 75 and 150 m. The upper segment of the river channel in the midlands from Kondur to Pala exhibits high sinuosity index (1.44) than that of the other segments (Fig. 5.2 b). The sinuosity index decreases in the downstream reaches (SI: 1.19) of Govindapuram. Here, the channel width ranges from 50 to 75 m. The sinuosity index computed for the Meenachil river are given in Table 5.2 along with other relevant features.

The river channels of the Meenachil river exhibit three distinct channel patterns - regular, irregular and sinuous patterns (See Fig. 2.1 a for details). Regular and irregular meanders are noticed both in the highlands and the midlands; whereas sinuous and irregular meanders are seen in the lowlands. Like the other rivers in the study area, plane bed, pool riffle and dune ripple reaches are encountered in the channel bed of Meenachil river as well. The total length of the alluvial reach of the main channel is about 50 km.

In the highlands, the river bed of Meenachil river is generally rocky with isolated pockets of sand and gravel deposits. Patches of pebble and cobble beds are also seen at certain reaches of the river channel. The sediment type in the highlands is sandy gravel with 59.55% of gravel, 40.40% of sand and 0.04% of mud. The middle stretch is with gravelly sand sediment type. In the lowlands, the sediments are slightly gravelly muddy sand [(g)mS]; (Table 5.3).

5.5.4 River discharge and water quality

On an average, the Meenachil river transports about 19897 cumecs of water and 39530 tonnes of sediment (7608 tonnes of sand and 31922 tonnes of mud) annually. Table 5.8 gives the water and sediment discharge during the period 1987/88 – 1996/97. The water discharge of the river recorded at the Kidangoor gauging station during the period 1987 – 1997 is presented in Fig. 5.6 c. About 72% of water discharge occurs during southwest monsoon. The water discharge in the northeast monsoon is only 22%. Fig. 5.6 d shows the monthly discharge of water through Meenachil river during 2004. The highest water discharge in the Meenachil river is recorded in May-June months.

Table 5.8 Annual discharge of water and sediments through Meenachil river

Sl. No.	Year	Water discharge (cumecs)	Sediment discharge (Tonnes)		
			Sand	**Mud**	**Total**
1	1987-88	16316	2923	21401	24324
2	1988-89	16371	2884	24278	27162
3	1989-90	20262	13764	31112	44876
4	1990-91	15750	4332	9709	14041
5	1991-92	20385	10015	48109	58124
6	1992-93	26063	8689	38697	47386
7	1993-94	21687	14740	47016	61756
8	1994-95	21908	8111	38720	46831
9	1995-96	20290	5456	30112	35568
10	1996-97	19941	5166	30074	35240
Average		**19897**	**7608**	**31922**	**39530**

Source: Central Water Commission (CWC), Kochi; Gauging station: Kidangoor

The water quality parameters analysed for the Meenachil river is given in Table 5.5. The pH and conductivity exhibit slightly higher values during non-monsoon season (pH: 6.35; conductivity: 958 µS/cm) than monsoon season (pH: 5.52; conductivity: 63.60 µS/cm). On the other hand, nutrients like N_{tot} show high concentrations during monsoon season (1487 µg/l) than that of non-monsoon season (592 µg/l). But the concentration of

P_{tot} exhibited only a marginal hike in monsoon season (196 µg/l) compared to non-monsoon season (181 µg/l). The Fe_{tot} values were also high during monsoon season (1630 µg/l) than the non-monsoon season (547 µg/l). The average concentrations of DO in the river during monsoon and non-monsoon periods were 6.08 mg/l and 6.40 mg/l, respectively. The TSS content was many folds higher in monsoon season (135 mg/l) than non-monsoon season (5.3 mg/l).

5.6 Muvattupuzha river

5.6.1 Drainage

Muvattupuzha river draining through the outskirts of Kochi City has a length of 121 km with a total basin area of 1554 km^2. The drainage map and longitudinal profile of the river are given in Fig. 5.7 a and b respectively. The river originates from Taragamkanam hills at an elevation of 1094 m above msl. The highest elevation of the Muvattupuzha basin is recorded at Palkolamedu, which is about 1194 m above msl. Drainage pattern of the river is dendritic. Thodupuzha *Ar*, Kaliyar and Kothamangalam *Ar* are the major tributaries of the river. The southernmost tributary, Thodupuzha *Ar*, is formed by the confluence of two streams, Valiya *thodu* and Nach *Ar* at Munnuvayal. The tail race water from Moolamattom power station is directed into the Thodupuzha tributary of Muvattupuzha river since 1976, after the commissioning of Idukki hydro-electric project across the adjoining Periyar river (Balchand, 1983). This has led to considerable changes in the river morphology, sediment dynamics and ecological characteristics of the Muvattupuzha river. The Kaliyar tributary is formed by joining two streams namely Velur *Puzha* and Kannadi *Ar*. The northernmost tributary, the Kothamangalam *Ar* takes a westerly course and flows through the Thodupuzha reserved forests. The Kothamangalam *Ar* merges with Kaliyar at Perumattam and then flows westwards for a short distance upto Muvattupuzha town where the Thodupuzha *Ar* also joins with the river to form the Muvattupuzha river (proper). In the midlands also, several minor tributaries join with the main channel of Muvattupuzha river and the important ones are Kuriya *thodu* and Kurapalli *thodu*. The main channel takes a southerly course downstream after Kadamattom. In the lowlands at Vettikattumukku, the Muvattupuzha river bifurcates into distributaries namely Murinjapuzha and Ittupuzha. The former

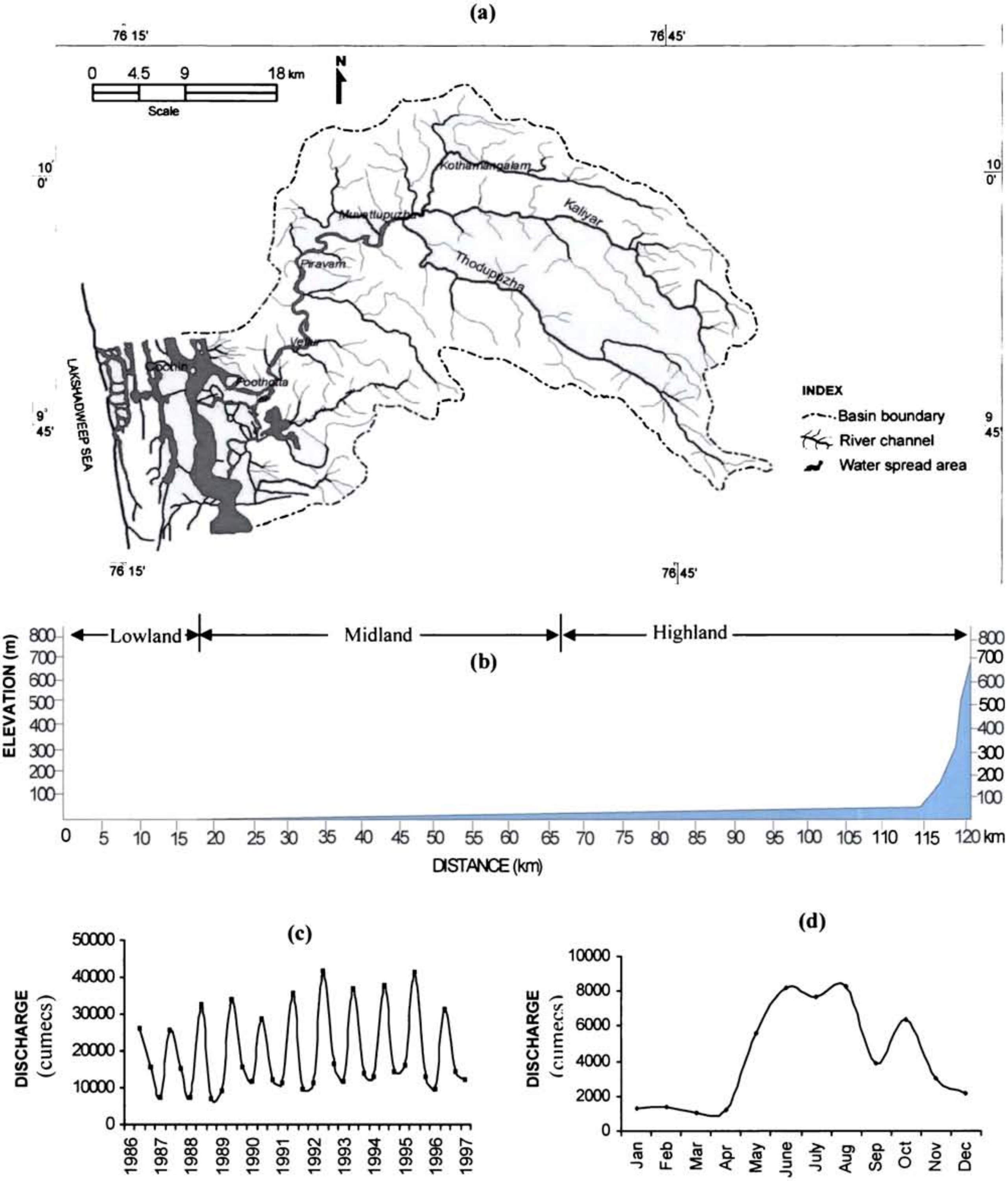


Fig. 5.7 Map showing drainage basin of Muvattupuzha river (a), along with the longitudinal profile (b) and water discharge [c – Annual water discharge for the period 1986-1997 & d – Monthly water discharge for the year 2004; Source: Central Water Commission (CWC), Kochi]

merges with the Vembanad lake at Chempu and the latter at Vadakkemuri. Another distributary originating from the Ittupuzha, known as Kari *Ar*, takes a southerly course before joining with the Vembanad lake near Thirumanivenkitapuram. The distributaries are interconnected by a number of small perennial channels, thus forming a channel network in the lowland area.

5.6.2 Environmental and geologic setting

The highlands of the Muvattupuzha river basin spread an area of about 321 km^2 and constitute 23% of the total basin area. The entire area in the highlands falls within the jurisdiction of Idukki district and lowlands within Kottayam district. Midlands constitutes about 74% of the entire river basin and fall mainly within Ernakulam district. The lowlands of the basin constitute only 3% of the total basin area. The total population and population density of the highlands are 164646 and 512 $inh.km^{-2}$, respectively. The population density is maximum in the lowlands (1233 $inh.km^{-2}$) followed by midlands (746 $inh.km^{-2}$). The population of the midlands and lowlands are 770195 and 54501, respectively.

The highlands consist of agricultural land, wasteland and forest land. The forest area occupies nearly 50% of the highlands and consists of deciduous forests, evergreen forests and degraded forests. The eastern side of the highlands is covered by the Thodupuzha reserved forest. Teak plantations are identified in the forest fringes. Arakulam reserved forest is in the uplands of Thodupuzha *Ar*. Small patches of grasslands are seen in this area. Tenkondam reserved forest constitutes a small portion in the uplands of Kaliyar tributary. Patches of dense mixed jungle is seen in the lower part of the area. Rocky cliffs and escarpments are other features in the highlands. Nearly 40% of the area is classified as mixed crops with settlements. Rest of the area is land with or without scrub. The midlands consist of agricultural land and wasteland. The upper part of the midlands is dominated by rubber plantations, which in turn, intermingled with mixed crops and settlements. Reserved forests like Nedumala, Ezhallur and Maniyandram are seen as small pockets in areas between Thodupuzha *Ar* and Kaliyar. Open scrub are also seen as patches in the upper region. The wasteland, which occupies only 2% of the total area, is land with or without scrub. The downstream areas are characterized by valleys and floodplains and are usually flooded during monsoon season. The lowlands consist of agricultural land, wasteland, built up land and water bodies. Nearly 35% of the region is under mixed agricultural / horticultural plantations and about 15% under double cropped paddy cultivation. Built up land occupies nearly 5% in the region. Fallow land covers nearly 8% and sandy area about 2%. The rest of the area is water bodies.

Geologically, the Muvattupuzha river basin is occupied by highly varied formations of Precambrian crystallines, laterites and Cenozoic sediments. Charnockites, hornblende-biotite gneisses and other unclassified gneisses form a major portion in the highlands. They are often intruded by acid (granite, pegmatite and quartz vein) and basic (gabbro and dolerite) rocks. The laterites and Warkalli beds, found near the mouth of the river, together constitute approximately 15% of the total drainage basin (Padmalal, 1992).

5.6.3 Channel characteristics

The width of the Thodupuzha *Ar* in the highlands ranges between 50 and 75 m. The sinuosity index calculated for the Muvattupuzha river is given in Table 5.2. The sinuosity index of Thodupuzha *Ar* in the midland region is high in the downstream reach between Kizhmadangu and Muvattupuzha (1.67) than the upstream between Thodupuzha to Kizhmadangu (1.26). The width of the main river channel in the midlands ranges between 125 and 300 m. Muvattupuzha river exhibits high sinuosity index in the midlands than the other two physiographic zones. The segment of the river channel in the midland from Urayam to Pazhur exhibits the highest sinuosity index (1.9). The bend is more pronounced in this area with large deposits of sand and gravel (Fig. 5.2 b).

Four types of channel patterns are observed in the Muvattupuzha river - regular, irregular, irregular wandering and tortuous meanders (Refer Chapter 2; Fig. 2.1 a). The former is seen in the highlands and the remaining three types are noticed in the midlands and lowlands. The river stretch from Urayam to Pazhur exhibits a tortuous channel pattern. Irregular wandering channel pattern is frequent in the midland area. The two distributaries of Muvattupuzha river such as Ittupuzha and Murinjapuzha, exhibit irregular channel pattern. In the lowland area, frequent type of channel islands is seen. The total length of the alluvial reach of the main channel is 46 km.

In highlands, the river bed is composed mainly of rocky substratum and, sand and gravel deposits occur as isolated pockets all along the tributary channels. Patches of pebble and cobble beds also occur as sporadic patches within the tributaries. The amount of gravel is high in the midland area (70.44%) compared to highland area (66.96%). The sand dominant stretch of the lowlands at Vettikattumukku (85.5%) indicates a low energy regime, which manifests the difference in the transportational pattern of bed load (Table 5.3).

5.6.4 River discharge and water quality

The water and sediment discharge data (1986/87 – 1996/97) reveals that on an average, 58192 cumecs of water and 165881 tonnes of sediments (24706 tonnes of sand and 141175 tonnes of mud) are being discharged through the Muvattupuzha river annually. The year-wise discharge of water and sediments during the period 1986/87 – 1996/97, gauged at Ramamangalam CWC station, are summarised in Table 5.9. Fig. 5.7 c depicts the seasonal discharge of water through this river during the period 1986 to 1997. About 58% of water discharge occurs during southwest monsoon. The water discharge during northeast monsoon is only 23% of the total discharge. The monthly discharge of Muvattupuzha river given in Fig. 5.7 d, shows that the peak flows are in the months of June and August.

Table 5.9 Annual discharge of water and sediments through Muvattupuzha river

Sl. No.	Year	Water discharge (cumecs)	Sediment discharge (Tonnes)		
			Sand	**Mud**	**Total**
1	1986-87	49152	31602	120272	151874
2	1987-88	48275	15468	131063	146531
3	1988-89	48419	20817	124489	145306
4	1989-90	61226	24409	193440	217849
5	1990-91	52355	12928	89593	102521
6	1991-92	56433	21230	128611	149841
7	1992-93	70584	29547	200510	230057
8	1993-94	63714	35448	179159	214607
9	1994-95	68302	32692	127480	160172
10	1995-96	63761	25758	140076	165834
11	1996-97	57887	21867	118228	140095
Average		**58192**	**24706**	**141175**	**165881**

Source: Central Water Commission (CWC), Kochi; Gauging station: Ramamangalam

The results of the water quality analysis of Muvattupuzha river is given in Table 5.5. The pH and conductivity exhibits slightly higher values during non-monsoon season (pH: 6.76; conductivity: 62.4 µS/cm) compared to monsoon season (pH: 5.87; conductivity: 42.99 µS/cm). During monsoon, N_{tot} exhibited markedly high concentration (1071 µg/l) than the non-monsoon season (649 µg/l). The P_{tot} also exhibited slightly higher values during monsoon season (108 µg/l) than non-monsoon season (93 µg/l). The river exhibited high amounts of Fe_{tot} during monsoon season (1918 µg/l) than that of the non-monsoon season (481 µg/l). The TSS displayed higher concentration in monsoon season (34.50 mg/l) than non-monsoon season (4.44 mg/l).

5.7 Periyar river

5.7.1 Drainage

The Periyar river, also known as *Poorna nadi* is the longest river in Kerala with a length of 244 km and catchment area of 5398 km^2 (5284 km^2 lies in Kerala and 114 km^2 in Tamil Nadu). The river generally exhibits dendritic drainage pattern (Fig. 5.8 a). Periyar is a holy river in Kerala, the vast sandy plains of the river at many places are used for holding annual religious congregation in connection with the '*Sivarathri*' festival. The river originates from Sivagiri hills at an elevation of 1830 m above msl. The longitudinal profile of Periyar river is given in Fig. 5.8 b. Erattayar, Panni *Ar*, Karintiri *Ar*, Pooyamkutty *Ar*, Muthirapuzha *Ar*, Idamala *Ar*, Perinjankutty *Ar* and Mangalapuzha *Ar* are the important tributaries of Periyar river in the upstream areas. After ~ 45 km from its origin, the main channel receives the perennial Mullayar tributary before debouching into the Periyar lake near Mullakkudi. Erattayar originating from Ambalamedu joins with the Kallar near Tekkumkanam. Yet another tributary, Muthirapuzha *Ar* that originates from Kannimala takes a southerly course to join with Panni *Ar* at Panniyarkutti. From thereon, it flows southwesterly to join the main channel at Panamkutti. The main river channel flows in a northwesterly direction from Panamkutti to Kuttikkal. A major tributary namely, Karintiri *Ar* flows westwards receiving a number of streams upto Pooyamkutty. From thereon, it is known as Pooyamkutty *Ar* and joins with the northernmost tributary Idamala *Ar* near Kuttampuzha. Periyar river flows north-south initially upto Kuttikkal near Thattekkad and then takes westward flow. The basin hosts several reservoirs

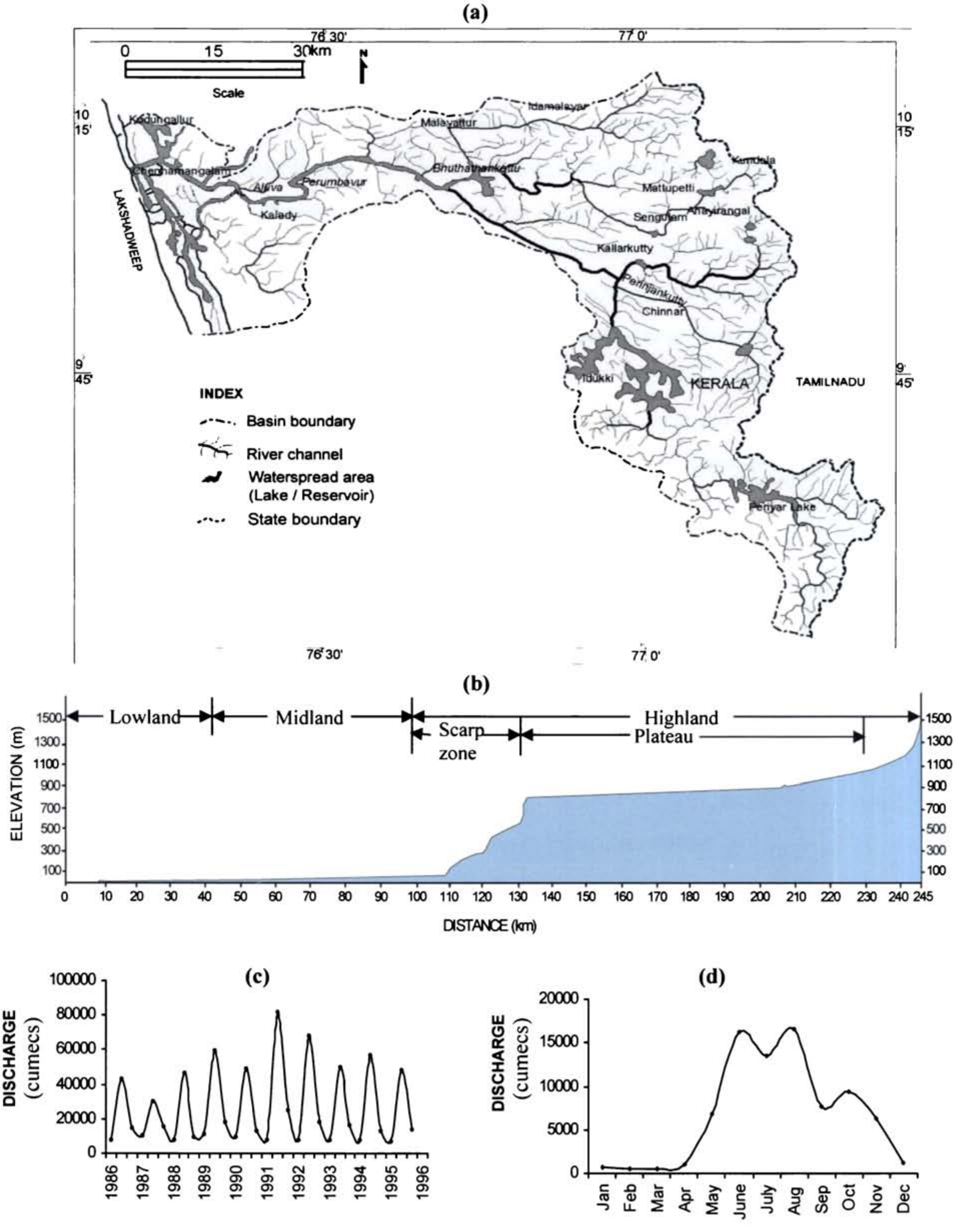


Fig. 5.8 Map showing drainage basin of Periyar river (a), along with the longitudinal profile (b) and water discharge [c – Annual water discharge for the period 1986-1996 & d – Monthly water discharge for the year 2004; Source: Central Water Commission (CWC), Kochi]

constructed for hydroelectric projects in its uplands. The important projects in the basin are Sengulam, Neriyamangalam, Panniyar, Idukki, Perinjankutty, Pallivasal, Lower Periyar, Edamalayar, Pooyamkutty, Erattayar and Kallar. In the midlands, a perennial stream known as Kotayi *thodu* joins the river near Kottamom. In the lowland, the river bifurcates into two - the southwesterly branch is known as Marthanda Varma distributary and the northwesterly branch is the Mangalapuzha distributary. The Mangalapuzha distributary merges with the Lakshadweep Sea at Munambam. The Marthanda Varma distributary flows through the Eloor – Kalamassery industrial belt and then develop a network of channels before joining the Varapuzha backwaters (part of Vembanad lake).

5.7.2 Environmental and geologic setting

The highlands of Periyar river basin cover an area of about 4419 km^2 and constitute over 86% of the total basin area. About 89% of the highlands fall within the jurisdiction of Idukki district and the remaining (11%) in the Ernakulam district. The total population and population density of the highlands are 857266 and 194 inh.km^{-2}, respectively. Midlands constitute (area: 697 km^2) 13.5% and lowlands 0.5% (27 km^2) of the Periyar river basin. The population and population density of the midlands and lowlands are 560923 and 805 inh.km^{-2} and 63116 and 2338 inh.km^{-2}, respectively. The midlands and lowlands fall within the jurisdiction of Ernakulam district.

About 35% area of Periyar river basin is under forest cover. But, a part of these areas has already been cleared for various developmental activities (Joseph, 2004). The highlands of the basin are comprised of Periyar lake reserved forest, Cardamom Hills reserved forest, Nagarampara reserved forest, Rattendon valley annexe and Mount Plateau annexe reserved forests, Anamudi reserved forest, Malayattoor reserved forest, etc. The forests in the basin are mainly classified as wet-evergreen, semi-evergreen, moist deciduous, dry deciduous and pure reed areas (CWRDM, 1993). The highest mountain peak in Kerala is the Anamudi (2690 m), which is situated in the uplands of this basin. In the upper part of Periyar lake, patches of eucalyptus plantations are seen. In the lower part, tea plantations are found which is interspersed at many places with eucalyptus, coffee, cardamom and teak plantations. Open scrubs are also seen at certain places in this area. In the highlands, the major human activities are connected with plantations and hydroelectric projects. The land use pattern observed in the southeastern part of the river channel in the midlands is rubber plantations. The rest of the area comprises mixed crops with settlements. Paddy fields and water logged areas intermingled with mixed crops and settlement areas forms the main land use in the lowlands. The major industries and settlements spread in the lower reaches, especially in the Aluva - Ernakulam belt. There are also a number of islands in the lower reaches of the basin.

Geologically, the highlands of Periyar river basin are occupied by Precambrian crystallines, which include quartz-feldspar-hypersthene granulites (charnockites), charnockite gneiss, hypersthene-diopside gneiss, hornblende gneiss, hornblende-biotite gneiss, quartz-mica gneiss and pink granite. A large part of these crystalline rocks have undergone polymetamorphic and polydeformational activities. At many places, acidic and basic rocks intrude the Precambrian crystallines (Maya, 2005). Geologically, Recent to Sub-Recent sediments of Quaternary age overlie the Tertiaries in the lowland, especially near the coastal areas.

5.7.3 Channel characteristics

The width of the Periyar river in the uplands is about 50 m which increases to about 175 m near the Idukki reservoir area. A maximum channel width of 275 m is observed at Chempankuzhi. The sinuosity index computed for the Periyar river is given in Table 5.2. The river segment from Mlamala to Idukki dam is highly meandered with the sinuosity index of 1.5. The sinuosity index is reduced significantly in the channel downstream indicating its structural bearing (Fig. 5.2 b). The width of the main river in the midland area varies between 175 and 700 m. The Periyar river exhibits highly meandered course near Kalady, Perumbavoor and Aluva. The river segment in the midlands from Kalady to Aduvathuruthu exhibits high degree of sinuosity (SI: 1.79) compared to the adjoining reaches. In lowlands, width of the Mangalapuzha distributary of Periyar river ranges from 200 - 650 m. The two segments in the lower reaches – (a)

Aduvathuruthu to Ayiroor vayal and (b) Ayiroor vayal to Vembanad lake - in the Mangalapuzha distributary, however, possess low sinuosity index (SI: 1.02 for the former and 1.01 for the latter).

Four types of channel patterns are identified for the Periyar river. They are irregular, straight, sinuous and irregular wandering. All the four types of channel patterns are seen in the highlands. Straight channel pattern of the river is observed in the Munnar-Peerumedu plateaus. Irregular wandering and irregular types of meanders are seen in the midlands; whereas irregular and straight patterns are observed in the lowlands. Occassional and frequent types of channel islands are seen in the lowlands (See Fig. 2.1 a in Chapter 2 for details). The length of the alluvial reach of the main channel is about 50 km.

The channel bed of the Periyar river in the highlands is composed mainly of rocky substratum and sand and gravel deposits are found as isolated pockets all along the river channel. Particles of coarser entities such as boulders and cobbles are confined to the upstream areas. The granulometric characteristics of the river bed materials of Periyar river are shown in Table 5.3. The grain size categories of the river follow the physiographic attributes of the terrain (Maya, 2005). The main channel of the Periyar river in the midlands consists of slightly gravelly sand [(g)S]. Pebble and granule contents decrease in the river channel towards downstream. The change in physiographic condition from highland to midland is evident in the granulometric characteristics. In the lowlands, sand is usually medium to fine grained and often with minor amounts of clay lumps. Sediments in the Mangalapuzha distributary near Kodungallur possess considerable proportion of lime shells along with sand and clay in the channel. The coarser particles register comparatively low values in the lowlands than the midland and highland reaches. This may be due to the entrainment and removal of finer sediments from the high gradient zones of the upstream reaches. In addition to the physiographic control, rock exposures within the river channel, meanders, man-made structures like bridges and check dams also have a profound effect on the overall dispersal pattern of sediments.

5.7.4 River discharge and water quality

Analysis of water and sediment discharge data (1986/87 – 1996/97) reveals that on an average, about 79967 cumecs of water and 366752 tonnes of sediment (82228 tonnes of sand and 284523 tonnes of mud) are discharged through Periyar river every year. The year-wise discharge of water and sediments during the period 1986/87 – 1996/97 are summarised in Table 5.10. Fig. 5.8 c depicts the seasonal discharge of water through this river during the period 1986 to 1996. About 69% of water discharge occurs during southwest monsoon and 20% during northeast monsoon. The monthly water discharge through Periyar river during the year 2004 is given in Fig. 5.8 d. The peak discharges are noticed during the months of June and August.

Table 5.10 Annual discharge of water and sediments through Periyar river

Sl. No.	**Year**	**Water discharge (cumecs)**	**Sediment discharge (Tonnes)**		
			Sand	**Mud**	**Total**
1	1986-87	65162	122823	198129	320952
2	1987-88	56334	23919	99406	123325
3	1988-89	64357	66700	189886	256586
4	1989-90	88289	166809	479893	646702
5	1990-91	71470	39268	161494	200762
6	1991-92	115370	106619	404084	510703
7	1992-93	94235	137175	332255	469430
8	1993-94	73556	41534	150874	192408
9	1994-95	103140	99921	339119	439040
10	1995-96	77720	58769	478341	537110
11	1996-97	70006	40974	296275	337249
Average		**79967**	**82228**	**284523**	**366752**

Source: Central Water Commission (CWC), Kochi; Gauging station: Neeleeswaram

The average concentrations of various water quality parameters of the Periyar river is given in Table 5.5. Like other rivers in the study area, the analysis of water samples of the Periyar river also reveal wide seasonal fluctuations. The pH exhibits slightly higher values during non-monsoon season (6.53). Conductivity shows very high concentration during non-monsoon season (1033 µS/cm) than monsoon season (77.90 µS/cm). During monsoon, nutrients like N_{tot} and P_{tot} showed high concentrations (N_{tot}:

1042 μg/l; P_{tot}: 164 μg/l) compared to non-monsoon (N_{tot}: 694 μg/l; P_{tot}: 113 μg/l). The river exhibits high concentrations of Fe_{tot} during monsoon season (1766 μg/l) than non-monsoon season (633 μg/l). The TSS displayed three times higher concentration during monsoon period (60.80 mg/l) than non-monsoon period (4.61 mg/l). The average DO concentrations in the river during monsoon and non-monsoon periods are 5.74 mg/l and 6.41 mg/l, respectively.

5.8 Chalakudy river

5.8.1 Drainage

The Chalakudy river originates from the Anamala hills of the Western Ghats and drains through all the three major physiographic provinces of Kerala (Kerala State Gazetteer, 1986). Chalakudy river has a length of about 130 km and a basin area of about 1704 km^2. Out of the total catchments, about 300 km^2 lies in Tamil Nadu State and the remaining in Kerala (Fig. 5.9 a). The river, in general, exhibits a dendritic drainage pattern. Fig. 5.9 b shows the longitudinal profile of the Chalakudy river. About one-third length of the river drains through forest lands. The river is formed by the confluence of 5 major tributaries – Parambikulam *Ar*, Sholayar, Kuriarkutty *Ar*, Karappara *Ar* and Anakkayam *Ar*. Out of these, the first two tributaries originate from Tamil Nadu and remaining from Kerala. The Kuriarkutti *Ar* is formed by the confluence of Tunakkadavu *Ar* flowing downstream of Tunakkadavu reservoir with Tekkadi *Ar*. Parambikulam *Ar* from the east drains through Nelliampathy reserve forests and Parambikulam wildlife sanctuary and merges with Kuriarkutti *Ar* at Kuriarkutti. The Parambikulam reservoir is situated upstream of Parambikulam *Ar* at Pulikalmudi. Another tributary, Sholayar, originates from Sholayarmala in Coimbatore district of Tamil Nadu State. The tributary is dammed at two locations – one in Tamil Nadu and the other in Kerala. This tributary is ephemeral, downstream of Sholayar reservoir (i.e., from Sholayar to Orukumban). Then it becomes perennial and flows northwesterly to join the Parambikulam *Ar* at Orukumbankutti. Yet another tributary, the Karappara *Ar* that originates from the southwestern slopes of Nelliampathy reserved forests joins the Chalakudy river

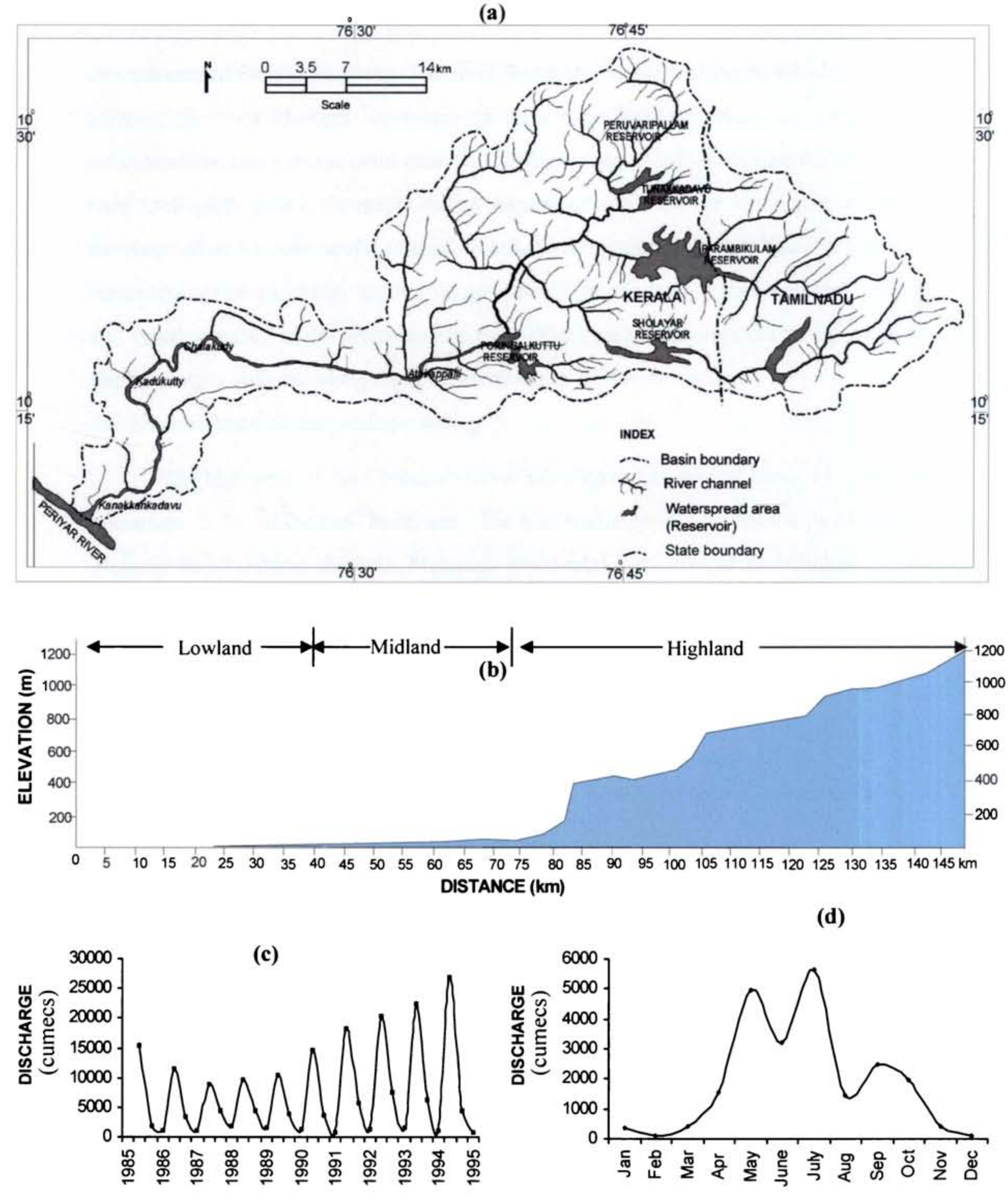


Fig. 5.9 **Map showing drainage basin of Chalakudy river (a), along with the longitudinal profile (b) and water discharge [c – Annual water discharge for the period 1985-1995 & d – Monthly water discharge for the year 2004; Source: Central Water Commission (CWC), Kochi]**

downstream of Orukumbankutti. The river flows southwards till Peringalkuthu and from thereon, the river changes westwards to form the Chalakudy river (proper). Several ephemeral streams join the main channel at different places, of which Kannankuzhi *thodu* near Athirapally falls is the major one. A number of waterfalls are seen in the uplands of the river, of which Athirapally falls of 45 m high is a major attraction. The five important reservoirs within the basin are Perivarippallam, Thunakadavu, Parambikulam, Sholayar and Peringalkuthu. In the lowlands, the river drains mainly through the paddy lands and finally merges with the Mangalapuzha distributary of Periyar river.

5.8.2 Environmental and geologic setting

The highlands of the Chalakudy river basin spread an area of about 4419 km^2 and constitute 75.7% of the total basin area. The highland area falls within the jurisdiction of Thrissur and Palakkad districts. Midlands constitutes 24% area of the Chalakudy river basin. The lowlands cover only a negligible portion (0.30%) of the total basin area. The population of the midland area is 324342. The midlands are densely populated (968 $inh.km^{-2}$) than the highlands (population: 19239 / population density: 18 $inh.km^{-2}$) and lowlands (population: 6751 / population density: 314 $inh.km^{-2}$).

The Chalakudy river basin contains a major portion of the vegetation cover of the Southern Western Ghats. The upper part of the basin consists of agricultural land, forest land and water bodies. The agricultural land (10%) is occupied with mixed agricultural / horticultural plantations. The forest land consists of forest plantation, deciduous forests, evergreen / semi-evergreen forests and degraded forests. Nearly half of the upper part of the basin is occupied by forest plantations and about 5% of the land each by degraded forests and evergreen / semi-evergreen forests. The upstream of the river basin is covered by Nelliampathy, Anamala, Tekkadi, Tunakkadavu and Kodassery reserved forests. Forest type in this part is dense mixed jungle, mainly with bamboo and rose wood. Forest plantations, mainly teak plantations, blanket the Parambikulam Wildlife Sanctuary and adjoining areas of Parambikulam reservoir. There are a few characteristic freshwater marshes in the forest area, particularly around Parambikulam. Coffee, tea and eucalyptus plantations are concentrated in the Sholayar area. Eucalyptus and soft wood plantations are common in areas downstream of Peringalkuthu reservoir. Rubber plantations are seen as patches in the lower part of the highlands. The Peechi - Vazhani Wildlife Sanctuary in the north and the Indira Gandhi Wildlife Sanctuary of Tamil Nadu in the east are connected with the forests in the Chalakudy river basin. The Parambikulam Wildlife Sanctuary, which lies within the basin, is the proposed second "Tiger Reserve" in the State. The Sholayar ranges still contain some of the remaining evergreen forests of Kerala. The northern region of the basin is occupied by Nelliampathy hills. This continuity of the forests is maintained towards westward by the Vazhachal and Chalakudy forests. This tract has a fairly good amount of riparian forests and is ecologically very important (Bachan, 2003). In the midlands, the riparian land use consists mainly of agricultural practices. Coconut, arecanut, nutmeg and paddy are the main crops cultivated in the area. A large part of the midland area is also occupied by banana plantations. Nearly 80% of the area is with mixed crops and settlements and forms the important land use in the midland area. Paddy cultivation is the main agricultural activity in the lowlands. Mixed crops with settlements form the next important land use category.

Like the other rivers in the study area, the highlands of the Chalakudy river basin are also dominated mainly by Precambrian crystallines. The crystallines include quartz-feldspar-hypersthene granulite (charnockite), charnockite gneiss, hypersthene-diopside gneiss, hornblende gneiss, hornblende-biotite gneiss, quartz-mica gneiss and pink granite gneiss. These rocks are intruded at many places by rocks like pyroxene granulite, gabbro, pegmatite, quartz veins etc. The lowlands of Chalakudy river basin is covered mainly by unconsolidated sediments of Quaternary age that is underlained by semi-consolidated Tertiary sediments which forms the major aquifer systems in the lowlands.

5.8.3 Channel characteristics

The channel width of Chalakudy river in the highlands is usually between 50 and 300 m. The width of the upper part of the channel is usually 50 – 100 m and after

Peringalkuthu dam, width increases to 300 m especially near Pukayilapara. The river stretch is less sinuous in the highlands and the sinuosity index varies between 1.27 and 1.08. The upstream reach between Peringalkuthu dam to Kannankuzhi is moderately meandered compared to the downstream segment (Table 5.2). The river channel in the midlands exhibits high degree of sinuosity than the highlands (Fig. 5.2 b). The river segment from Kanjirapalli to West Chalakudy exhibits sinuosity index of 1.59 and the segment from West Chalakudy to Puvathissery exhibits sinuosity index of 1.46. In the lowlands, channel width varies from 100 to 140 m. The sinuosity index is moderate in the Puvathissery – Elanthikkara segment (SI: 1.37) in the lowland area of the Chalakudy river.

Irregular types of meanders are observed in Chalakudy river. In the lowlands, channel islands are seen occasionally. The total length of the alluvial reach of the main channel is 70 km. The alluvial reaches of Chalakudy river can be differentiated into three distinct morphological classes towards downstream - plane bed reach, pool riffle reach and dune ripple reach.

The results of the textural analysis of the river bed materials collected from the Chalakudy river is given in Table 5.3. Pebble and granule content is high in the upstream sample (24.75% and 15.65% respectively) compared with the other samples. This region is with higher channel gradients and hard rock exposures within the river channel. The sediment type in the highlands is sandy gravel with 40.40% of gravel, 58.71% of sand and 0.90% of mud. The sediment type is gravelly sand in the midland and lowland areas with high content of sand fractions (80.19% and 85.94% respectively) due to the comparatively low energy regime in this region. This may be presumably due to the effects of natural and man-made obstacles in the river course.

5.8.4 River discharge and water quality

Analysis of water and sediment discharge data (1985/86 – 1994/95) reveals that on an average, 21054 cumecs of water and 53514 tonnes of sediment (12004 tonnes of sand and 41510 tonnes of mud) are being discharged through Chalakudy river annually. The year-wise discharge of water and sediments during the period 1985/86 – 1994/95 gauged at Arangali CWC station are summarised in Table 5.11. Fig. 5.9 c depicts the seasonal discharge of water through this river during the period 1985 to 1995. About 73% of water discharge occurs during southwest monsoon. The water discharge during northeast monsoon is 21%. Fig. 5.9 d shows the monthly water discharge of Chalakudy river during the year 2004. The months of May and July shows peak discharges in Chalakudy river.

Table 5.11 Annual discharge of water and sediments through Chalakudy river

Sl. No.	Year	Water discharge (cumecs)	Sediment discharge (Tonnes)		
			Sand	Mud	Total
1	1985-86	18235	6428	19183	25611
2	1986-87	16124	9136	21063	30199
3	1987-88	15012	4604	20788	25392
4	1988-89	21232	10784	31306	42090
5	1989-90	20122	15344	44722	60066
6	1990-91	19272	7504	22682	30186
7	1991-92	22701	16935	53718	70653
8	1992-93	27339	24289	59271	83560
9	1993-94	18501	6049	31216	37265
10	1994-95	32002	18969	111151	130120
Average		**21054**	**12004**	**41510**	**53514**

Source: Central Water Commission (CWC), Kochi; Gauging station: Arangali

The average concentrations of various water quality parameters of the Chalakudy river is given in Table 5.5. The analysis of water samples reveals wide seasonal fluctuations in Chalakudy river. Like the other rivers, the pH and conductivity exhibited high concentrations during non-monsoon season (pH: 7.24; conductivity: 3491 µS/cm) than monsoon season (pH: 5.67; conductivity: 34.96 µS/cm). During monsoon season, nutrients in the river, N_{tot} and P_{tot} showed high concentrations (N_{tot}: 862 µg/l; P_{tot}: 112 µg/l) compared to non-monsoon season (N_{tot}: 353 µg/l; P_{tot}: 61 µg/l). The river exhibits high concentrations of Fe_{tot} during monsoon season (695 µg/l) compared to non-monsoon season (287 µg/l). The TSS showed five times higher concentration during monsoon period (29.56 mg/l) than non-monsoon period (5.80 mg/l). The average DO concentrations in the river during monsoon and non-monsoon periods are 5.92 mg/l and 6.48 mg/l, respectively.

5.9 Discussion

The rivers in the study area reveal marked variations in their length, basin area and other river characteristics. The land use and settlement pattern also varies considerably within the study area. The average sinuosity indices worked out for the alluvial reaches of the main channel are 1.5 for Achankovil river, 1.54 for Pamba river, 1.61 for Manimala river, 1.31 for Meenachil river, 1.71 for Muvattupuzha river, 1.47 for Periyar river and 1.35 for Chalakudy river. Pamba, Manimala and Periyar rivers exhibit high values of sinuosity index in the highlands and midlands, whereas Achankovil, Meenachil, Muvattupuzha and Chalakudy rivers register high values in the midlands. The high sinuosity index observed in the highlands of Pamba, Manimala and Periyar rivers may be indications of the higher degree of tectonism to which the river basins have been subjected during their evolutionary phases (Valdiya and Narayana, 2007). The sinuous river channel can reduce the stream velocity causing the sediments to deposit within its channel as channel bars or point bars (Leopold et al., 1964); (Also see Fig. 2.1 b).

Of the different types of channel patterns, the majority of the river channels in the study area falls under the category of irregular meanders followed by irregular wandering ones. Tortuous meanders are confined to the highlands of Manimala and midlands of Muvattupuzha rivers with very high sinuosity indices of 1.82 (for Manimala) and 1.90 (for Muvattupuzha), respectively. Straight channel pattern is observed only in Periyar river which drains through Munnar-Peerumedu plateaus in the highland region. The alluvial reaches exhibit a variety of roughness configurations that vary with slope and position within the channel network. The content of gravel and sand exhibits marked changes over these morphological classes – the former (i.e. gravel) decreases in percent contents, while the latter exhibits a marked increase downstream.

Granulometric analysis of the sediments reveals that in general, there is a progressive decrease in grain size downstream. Coarser grains like pebbles and granules register comparatively high values in river reaches with higher channel gradients and / or local turbulence due to natural and man-made causes. The physiographic control on the granulometric dependence of the rivers is given in Fig. 5.10. Pebbles were totally absent

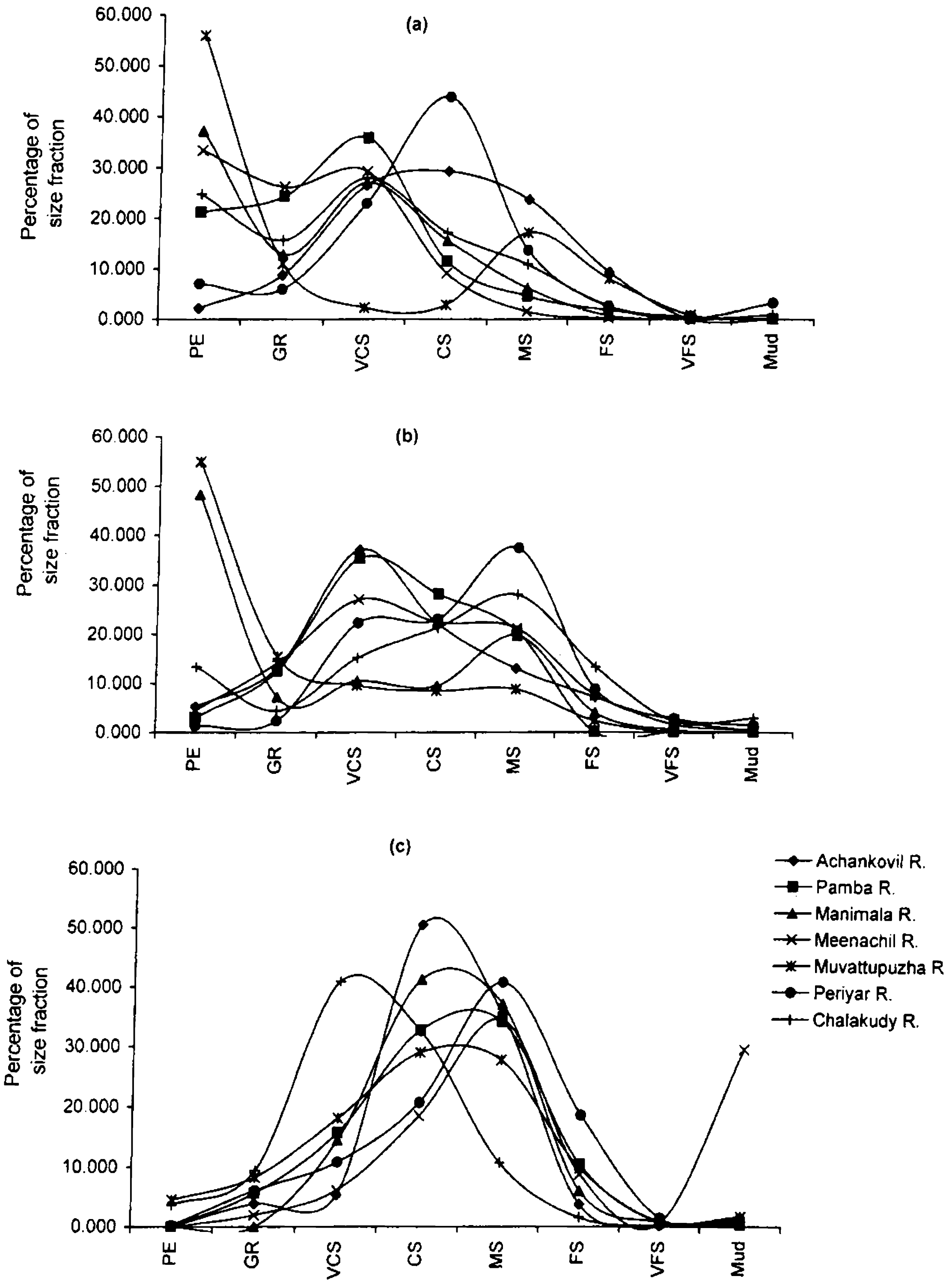


Fig. 5.10 Percentage of various grain size fractions in the sediments of the rivers draining the Vembanad lake catchments; (a) highlands, (b) midlands and (c) lowlands. PE Pebble; GR Granule; VCS Very Coarse Sand; CS Coarse Sand; MS Medium Sand; FS Fine Sand; VFS Very Fine Sand

in the lowlands of southern rivers (Achankovil, Pamba, Manimala and Meenachil rivers) but recorded in small proportions in the northern rivers (Muvattupuzha, Periyar and Chalakudy rivers). The content of gravel is low in the lowlands except in the rivers Periyar and Chalakudy, where the midlands register low gravel contents. The amount of sand and mud was low in the highlands of most of rivers in the study area. Of the seven rivers, the content of gravel was found to be high (70.44%) in the midlands of the Muvattupuzha river and was totally absent in the lowlands of the Manimala river. In general, sandy gravel dominates in the highlands and gravelly sand and sand in the midlands and lowlands with only very little exceptions. Slightly gravelly muddy sand is encountered only in the lowlands of the Meenachil river. Slightly gravelly sand is observed in the lowlands of the Achankovil river as well as midlands of the Periyar river.

The granular materials that make up the river bed and banks customarily vary downstream according to the ease with which they can be transported by the river (Petts and Calow, 1996). The gradual decrease in grain size in the direction of transportation in a river channel is resulted from two important processes namely differential transport (Allen, 1964; Shideler, 1975; Seralathan, 1979) and abrasion (Thiel, 1940). Grains very much larger than sand (pebbles and cobbles) are too large to be moved under normal flow regime, even on a smooth sand bed, by currents just competent to move the sand. Consequently, instead of bypassing the sand, such large grains accumulate in separate lag gravel deposits from which most of the sand has been removed (Blatt et al., 1972; Reinick and Singh, 1973). An overall analysis of the river bed characteristics of the study area reveals that there are combined effects of many aspects like channel morphology, source materials, weathering and sorting processes, climate and rainfall, natural and manmade obstacles in channels and anthropogenic interventions.

Estimates show that during the period 1987/88 to 1994/95, 266944 cumecs of water is discharged annually into the Vembanad lake (i.e., the receiving water body) by all the 7 rivers in the study area. Statistical evaluation of the discharge data of the Central Water Commission (CWC) for the rivers reveals that, about 989763 tonnes per year of sediments inclusive of 205248 tonnes per year sand are being transported down through the respective river gauging stations. A comparative analysis of sand and total sediment transportation during the period 1987/88 to 1994/95 shows that the total discharge of sand and sediments is more in the Periyar river (sand: 681945 tonnes; sediment: 2838956 tonnes) followed by Pamba (sand: 367822 tonnes; sediment: 1452239 tonnes) and Muvattupuzha (sand: 192539 tonnes; sediment: 1366884 tonnes) rivers. These rivers, having greater basin areas (Periyar river: 5398 km^2, Pamba river: 2235 km^2 and Muvattupuzha river: 1554 km^2) compared to other rivers (Achankovil river: 1484 km^2, Manimala river: 847 km^2, Meenachil river: 1272 km^2 and Chalakudy river: 1704 km^2) can naturally contribute a greater amount of sediments to the Vembanad lake as the terrain characteristics are almost the same.

The dissolved nutrient species of the rivers in the Vembanad lake catchments show wide seasonal differences. Except NO_2-N, all other nutrients such as NO_3-N, NH_3-N, N_{tot}, reactive phosphorus and P_{tot} show higher values during monsoon than non-monsoon seasons. Also, the fluvial flux rate of nutrients in all the rivers exhibit wide spatial variations. The four rivers in the southern region exhibit high content of NO_2-N as compared to northern rivers. The reduced water flow in the four rivers from the south during summer and the additional input of wastewaters from many major urban outlets (eg. towns like Erattupetta, Pala etc.), further enhance the incomplete oxidation of nitrites. The rate of flux of nitrate through all the rivers show markedly high values during monsoon season compared to non-monsoon season. During monsoon, the Meenachil river records the highest flux rate while during non-monsoon period, Muvattupuzha river shows the maximum value. The average value of NO_3-N during monsoon was 2 - 6 times the higher than the corresponding non-monsoon values. Generally rivers from the southern region reveal high seasonal difference in NO_3-N flux rate compared to the northern counterparts. Water from highly polluted regions such as Erattupetta and Eloor accounts for nutrient concentration > 1000 µg/l while several other locations that are close to industrial / urban areas exhibit NO_3 values very close to the above upper limit, suggesting the fact that this nutrient has a strong influence on anthropogenic pollution rather than of natural origin.

Chapter 6

RIVER SAND MINING: A DETAILED PRESENTATION

6.1 Introduction

River channels and their floodplains are important sources of construction grade aggregate materials like sand and gravel. The durability of river-borne coarser clastics (eg. sand and gravel) and their sorting by fluvial action make them best suitable raw materials / ingredients for building constructions (Kondolf et al., 2002). Most of the rivers in the world are overexploited for living and non-living resources and today the challenge posed to the society is to restore its natural ecology. As transportation and construction infrastructure expanded since the mid-twentieth century, the demand for construction grade sand also increased exponentially. The market demand of river sand is high throughout the world and Kerala is not an exception. The sand mining, which was only in limited levels before early 1970's, spreads out in a large scale due to State's economic development consequent to rise in foreign remittance attributed by the Gulf Boom.

In Kerala State, sand mining is practiced in all rivers having varied channel morphology, elevation, vegetation patterns, aquatic habitats and aggregate deposits. The form and dimension of river channel is largely a function of its discharge and sediment load contributed from the river basin (Leopold et al., 1964). By directly altering the channel geometry and elevation, sand mining induces marked channel adjustments. Further, continued sand mining disrupts the sediment mass balance in the river environment. Information on the quantity of mining, frequency of occurrence of sand mining locations (locally known as *kadavus*) along the river channel, local bodies involved in mining, labour force, etc., is a pre-requisite for identifying the effects of sand mining on the river environment. The present chapter deals with the extent of sand mining activities in the rivers draining the hinterlands of Vembanad lake.

6.2 Review of literature

Extraction of sand and gravel is the largest mining sector in most part of the world. In recent years, as the environmental impacts of river sand extraction become increasingly well understood, the practice has received increased scrutiny. It is now well established that the rivers that are repeatedly harvested at rates in excess of natural replenishments undergo channel degradation, possibly causing incision of the entire river system including its tributaries. Striking cases of excessive sand and / or sediment removal are summarized by many eminent researchers like Harvey and Schumm (1987), Sandecki (1989), Kondolf and Swanson (1993), Sandecki and Avila (1997), Florsheim et al. (1998) and Meador and Layher (1998). Environmental effects / impacts of sand extraction from rivers and floodplains have been summarized in reviews made by Simons et al. (1985a; 1985b; 1987), Woodward-Clyde Consultants (1980), Collins and Dunne (1987), Norman et al. (1998), Bayley et al. (2001), Padmalal et al. (2003), Padmalal et al. (2004a), Padmalal et al. (2005) and Sreebha and Padmalal (2006). The most widespread effects of sand mining on aquatic habitats have been addressed in detail by Kanehl and Lyons (1992), Hartfield (1993), Waters (1995), Brown et al. (1998) and Sheeba and Arun (2003). River bed degradation caused by pit excavation and bar skimming (the two general forms of instream mining) along with other environmental impacts of river sand mining has been well investigated and documented in a series of papers by Kondolf (1993; 1994a; 1994b; 1997; 1998a; 1998b). Impact of sand mining on river bed morphology and tidal dynamics in lower reaches and delta of the Dong jiang river was studied by Jia and Luo (2007).

Downstream and coastal effects of sediment starvation due to excessive sand and gravel mining have been studied in many parts of the world: California (Brownlie and Taylor, 1981; Inman, 1985), Australia (Erskine, 1988) and Tuscany (Gaillot and Piegay, 1999). Mining-induced incision of instream sand mining has been reviewed by researchers like Scott (1973), Dietrich et al. (1989), Sandecki (1989), Stevens et al. (1990), Kondolf (1997) and Padmalal et al. (2008). Researchers like Lagasse et al. (1980), Collins and Dunne (1989), Petit et al. (1996), Li et al. (1989) and Todd (1989) examined incision and channel instability caused by sand mining. Direct effects of incision such as undermining of bridge piers and side protection walls were studied by researchers like Bull and Scott (1974), Kondolf and Swanson (1993) and Mossa and Autin (1998). Exposure of buried pipeline crossings and water supply facilities are discussed in detail by Marcus (1992) and Lehre et al. (1993). Harvey and Smith (1998) have documented channel incision and widening along the San Benito river, California, and assessed the costs of infrastructural damage directly attributable to sand mining from 1952 to 1995. Collins (1991) documented undermining of a bridge and exposure of a water supply pipeline due to instream mining in the Pilchuck river. Table 6.1 summarises the mining-induced incision caused by sand and gravel extraction in different parts of the world.

Kitetu and Rowan (1997) have made an integrated assessment of the environmental impacts of river sand mining in Kenya. Biological impact of instream sand mining was attempted by many researchers. The high concentration of suspended sediments arising from subaqueous sand extraction could directly affect respiratory system of fishes and other invertebrate communities (Forshage and Carter, 1973; Carling and Reader, 1982; Rivier and Seguier, 1985; Lisle and Hilton, 1991). Roell (1999) summarized the effects of instream and floodplain sand extraction on aquatic resources to aid in decision making on appropriate protection measures for Missouri river.

In United States, preparation of guidelines for the management of sand and gravel extraction is vested upon agencies like Woodward-Clyde Consultants (1976), Boyle Engineering Corporation Water Resources Division (1980), U.S. Army Corps of Engineers (1987) and Arizona Department of Environmental Quality (1994). Instream sand mining regulations are implemented by California State Mining and Geology Board (1977), California Regional Water Quality Control Board (1984), County of Orange (2000) and Flood Control Department of Maricopa County (2001). The economic impacts of sand and gravel mining have been the theme of research by Newport and Moyer (1974) and Langer and Glanzman (1993). In addition, there exist many reviews on offshore sand mining and their effects as well. Byrnes et al. (2004) addressed the environmental concerns associated with potential sand mining operations in the offshore New Jersey for beach replenishment. Maa et al. (2004) made an effort to assess the

Table 6.1 Channel incision due to sand and gravel extraction reported from some of the world rivers (Source: Kondolf et al., 2002)

River	Description	Reference
Tujunga wash	4.3 m average incision over a 814 m reach upstream of gravel pit.	Scott (1973)
Mississippi River, Mississippi	Selective mining for aggregates caused percentage of gravel in bed to decrease from 26% to 4% between 1968 and 1972, with presumed effects on river morphology.	Lagasse and Simons (1979)
Sacramento River, California	Loss of spawning gravels for Chinook salmon between 1942 and 1980 as a result of gravel extraction for construction of Shasta Dam (5.5 x 10^6 m^3) and subsequent urban demand, along with trapping of bedload by the dam.	Parfitt and Buer (1980)
Hunter River, Australia	Annual extraction of 0.2 x 10^6 tonnes sand and gravel down the Glenbawn Dam was predicted to cause channel incision.	Erskine et al. (1985)
Manawatu River, New Zealand	1m average at stream gauge near Palmerston North from 1952-1976.	Page and Heerdegen (1985)
Otaki River, New Zealand	Riverbed lowered exposing base of river control works.	Anon (1985)
Wynoochee, Satsop and Humptulips rivers	0.5 m average incision between 1950 and 1980 on each of 3 rivers studied caused by annual extractions of 'several tens of thousands' of m^3 in excess of supply.	Collins and Dunne (1986)
White River, Washington	0.6 m average over 11 km reach, from 1974-1984.	Prych (1988)
Mamquam River, British Columbia	Upto 2 m over a 1 km reach from 1981-1983 resulting from annual extraction of about 0.14 x 10^6 m^3.	Sutek Services, Ltd. (1989)
South Platte River, Colorado	1.2 m between 1983 and 1986 induced by an in -channel pit and a captured off-channel pit downstream.	Stevens et al. (1990)
McKenzie River, Oregon	2 m over 26 years resulting from gravel mining and the decay of a wooden irrigation sill.	Williams et al. (1995)
Pilchuck river, Washington	0.5 m average and 2.1 m maximum over 12 km reach from 1972-1991	Collins (1991)
San Luis River, California	2.4 - 3.7 m near Hwy 395 bridge, incision (unknown amount) over a 22 km reach.	Sandecki and Avila (1997)

possible changes to physical oceanographic processes that might result from alteration as a result of dredging or sand mining in the offshore of Maryland and Delaware.

In United Kingdom, under the project 'Effective Development of River Mining', a lot of efforts have been made to control sand and gravel mining operations in order to protect local communities, reduce environmental degradation and facilitate long-term rational and sustainable use of the natural resource base. The multidisciplinary studies carried out as part of this project brought out a wealth of information on the impact of river sand mining. For example, in a study, Alvarado et al. (2003) addressed the impacts of the alluvial mining in Costa Rica. In another study, Farrant et al. (2003) made an attempt to describe the river mining, taking sand and gravel resources of the lower Rio-Minho and Yallahs fan delta, Jamaica, as an example. Fidgett (2003) proposed a set of planning guidelines for the management of river mining in developing countries taking the case of a few Jamaican rivers. The other studies carried out under the umbrella of this mega project were (1) viability of alternative sources of aggregates (Harrison and Steadman, 2003); (2) assessment of the environmental and social impacts of river mining (Macfarlane and Mitchell, 2003); (3) aggregate production and supply in developing countries (Scott et al., 2003) and (4) assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers (Weeks et al., 2003).

In India, although huge volumes of river sand and gravel are being mined for meeting its ever increasing demand in the construction sector, no serious attempts have been made to address the impact of sand mining. As urbanization and settlements grow, the demand for fine aggregates (sand) increases in an unprecedented manner. However, only a few documentations exist in literature dealing with the problem of river sand mining. One such study was made by Mohan (2000b) in Kulsi river, Assam. He found that one of the causative factors for the decline of river dolphin population was indiscriminate sand extraction and related disturbances in the river. In another study, Sridhar (2004) reported that sand mining in Coleroon river (tributary of Cauvery river), Tamil Nadu causes serious environmental problems in its lowland areas. Ronnie (2006) reported that illegal sand mining taking place on the banks of Shimsha river near Kokkare Bellur in Bangalore, Karnataka is affecting the life of avian fauna of that region.

Recently, Hanamgond (2007) made an attempt to document river sand mining from different parts of the country - Chapora creek (Goa), Kali estuary (Karwar, Karnataka) and Karli estuary (Konkan coast, Maharashtra). Plate 6.1 shows some of the selected scenes showing indiscriminate sand mining from some of the major rivers of India.

In Kerala, different organizations like Centre for Earth Science Studies (CESS), Centre for Water Resources Development and Management (CWRDM), State Mining and Geology Department, Geological Survey of India (GSI) etc., are involved in sand mining and related studies. Although many of these organizations are involved in resource estimation, only a few studies are available especially dealing with the environmental effects of river sand mining. A pioneer attempt was that of Thrivikramaji (1986). He highlighted the environmental consequences of sand borrowing from the Neyyar river flowing through the Thiruvananthapuram district. Later, Padmalal (1995) carried out a preliminary study on sand mining in Pamba river between Cherukolpuzha and Kizhavara *kadavu*. The environmental impacts of sand and clay mining in the Vamanapuram river basin, Thiruvananthapuram district was attempted by Saritha et al. (1996). A study on the sand budget of Periyar river with special reference to river sand mining was made by Padmalal and Arun (1998). CESS (1998) conducted a study on sand mining in Manimala river falling within the jurisdiction of Mallapally grama panchayat, Pathanamthitta district and pointed out that the river has undergone severe environmental deterioration due to indiscriminate scooping of sands from its active channels. In another study, Padmalal et al. (1999) highlighted the environmental effects of river sand mining from the Pamba river and stressed the need for regulating the mining activity on an environment-friendly basis. Soman and Baji (1999) studied the environmental conditions of sand mining sites of the Kallada river flowing through Kollam district. Sajikumar (2000) also made an attempt to study sand mining and related environmental problems while addressing the land and water issues of the Vamanapuram river basin. Sunilkumar (2002b) made an attempt to study the impact of sand and gravel mining on the benthic fauna of the Achankovil river flowing through the Pathanamthitta district. The sand mining activities in the Manimala river and its adjoining floodplains was documented by Arun et al. (2003). In a study of the Ithikkara river (Kollam district), Sheeba and Arun

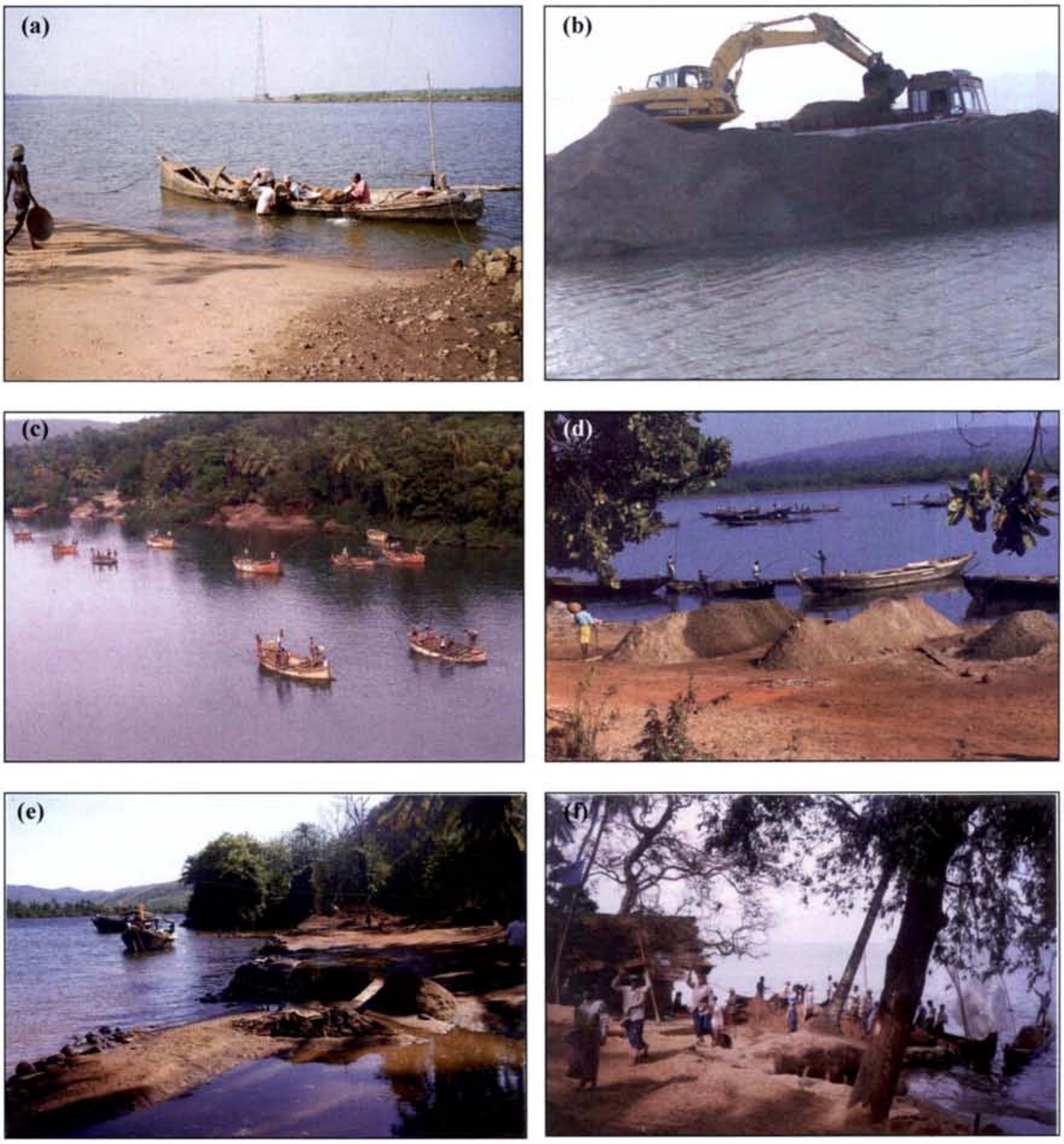


Plate 6.1 River sand mining – the Indian scenario. Indiscriminate extraction of river sand is one of the major causative factors of degradation of many of the Indian rivers. Some selected scenes showing sand mining by manual and mechanical methods. (a) Vyanatheyam, distributary of Godavari river at Pasarapudi, Kakkinada, Andhra Pradesh; (b) Cauvery river, Karur, Tamil Nadu; (c) Karli river estuary, Konkan coast, Maharashtra; (d) Chapora creek, Goa; (e) Kali river estuary, Karwar, Karnataka; and (f) Bharathapuzha river, Ponnani, Kerala.

(2003) opined that, out of the 25 freshwater fishes recorded in the river, a total of 16 fish species are under threat, mainly, due to habitat loss resulted from sand mining. Chandramoni and Anirudhan (2004) attempted the problems of land sand mining in the downstream part of Muvattupuzha river. Studies on the environmental problems of the Bharathapuzha river with special reference to sand mining in the river stretch between Chamravattom and Thirunavaya was made by Padmalal et al. (2004b). The impact of sand mining on the physical and biological environments of river systems of Kerala was dealt by Arun et al. (2006). Sreebha and Padmalal (2006) made an attempt to assess the environmental impact of river sand mining in the lowlands of Pamba river draining into the Vembanad lake. Recently, Padmalal et al. (2008) carried out an analysis on the environmental effects of river sand mining from the hinterland drainages of Vembanad lake.

6.3 River sand mining in the study area

The hinterlands of the Vembanad lake, drained by the Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy rivers, is affected severely by excessive mining of construction grade sand and gravel. The pace of this activity gained momentum since early 1970's consequent to the boom in construction sector in the State. However, the activity became real threat to riverine ecosystems of the State only in the second half of 1990's due to the ripple effects of globalization, boom in IT sector and numerous other factors pertinent to infrastructural developments of the region. The situation is rather alarming in the rivers of the Vembanad lake catchments as it hosts the Kochi City, one of the fast developing coastal townships in South India.

River sand and gravel are mined generally from alluvial deposits – both from active channels and floodplains / overbank areas. Mining of sand and gravel from active channels is referred to as instream mining and mining from overbank areas in the lowlands as floodplain mining. The term terrace mining (or land sand mining) is often used synonymously with floodplain mining. Mining of sand is also reported from abandoned river channels (palaeochannels) of the rivers as well. But in the present study, only two terminologies are used to refer the types of river sand mining – (1) instream mining (sand mining from the active channels) and (2) floodplain mining – sand mining in the lowlands other than instream mining. This is for the sake of better understanding of the mining activities and also overcoming the difficulties in the discrimination of abandoned river channels and true floodplains in the lowlands, as the rivers in the study area are small owing to the unique physiographic setting of Kerala State. Fig. 6.1 shows a schematic model of instream and floodplain mining.

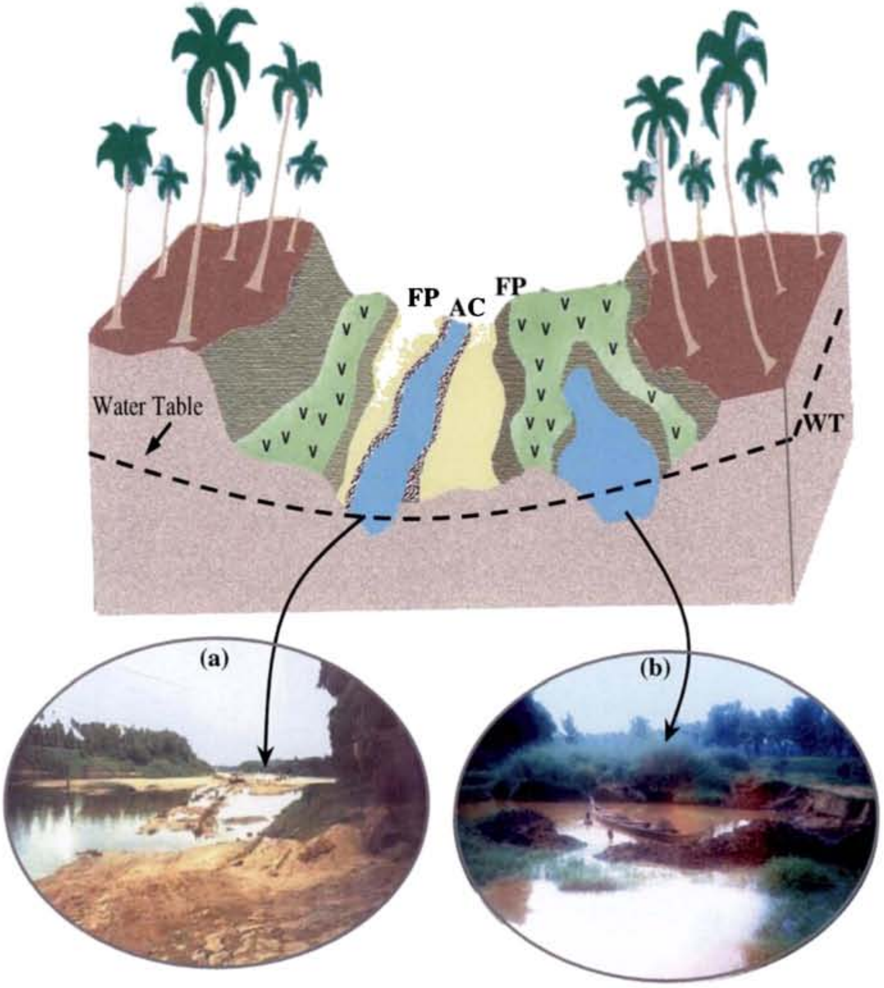


Fig. 6.1 A representative model showing instream (a) and floodplain (b) mining for sand and gravel from a river basin segment in the storage zone of the rivers in the study area. WT - Water Table; FP - Floodplain; AC - Active channel. The case of instream mining is from Periyar river near Kalady and floodplain mining (wet pit mining) from Achankovil river near Puliyoor (Modified after Kondolf 1994b)

(1) Instream mining

Instream sand deposits are easily accessible, well-sorted, and generally free from fine particulates such as silt and clay. Hence, it is extensively used in construction industry for concrete preparation and plastering. Different methods are adopted to extract sand from the active channels of river systems. The commonly adopted practices, as per Kondolf (1997), are pit excavation and bar skimming (also known as bar scalping). Pit excavation can be classified further into dry pit and wet pit mining. Dry pit mining refers to mining of sand from dry ephemeral stream beds by mechanical (using conventional bulldozers, scrapers and loaders etc.); (Plate 6.2) or manual methods. Wet pit mining requires the use of a dragline or hydraulic excavator to extract sand and gravel below the water table level or within a perennial stream itself. If the water is shallow, mining will be carried out manually. In some cases, high power jet pumps are used for the extraction of sand from wet pits and river channel (Plate 6.2). Bar skimming involves scraping off the top layer (of variable thickness) from a gravel bar without excavating below the summer water level (Kondolf, 1994b). Bars are temporary storage features in which sand and gravel pass through. Controlled bar skimming is a recommended sand extraction method in most of the developing countries as a means for achieving stream resource conservation while sustaining the extraction industry.

Of the two types of instream mining, pit excavation is widespread in the river catchments of Vembanad lake. Bar skimming is somewhat a controlled type of sand extraction (Plate 6.2). Usually, bar skimming would be done above the water table and within a minimum width buffer that separates the excavation site from the low flow channel and the adjacent active channel bank. Areas suitable for bar skimming are seen only in a few places in Pamba, Periyar and Chalakudy rivers. As a result of indiscriminate and unscientific sand mining, the river stretches at many places are devoid of sand in its active channels (Plate 6.2). Uncontrolled digging of the river channel for sand extraction especially in the midlands and lowlands has adversely affected the structure and functions of the river ecosystems in the area. Fig.6.2 shows the deep pits formed as a result of pit excavation in the channel segment of Muvattupuzha river in Ayavana grama panchayat.

Plate 6.2 Mechanical and manual river sand mining and sand deficient river reach; (a) Dry pit mining of sand using mechanical method; (b) Extraction of sand using high power jet pumps; (c) Bar skimming from the sand bed; (d) A sand deficient reach in Manimala river.

(2) Floodplain mining

Floodplains and terraces (former floodplains) are the sites of sediment storage in river systems and can contain large quantities of sand and gravel. Floodplain mining pits often extend below the water table, which can provide a convenient water source for separating desired particle sizes from the excavated materials. The deep pits left after floodplain mining often coalesce due to collapse of the separating boundary walls of the pits. Under high flow regimes of monsoon, some of the pits can even be captured by the river ultimately leading to valley widening and disfiguration of the natural channels. All these processes not only change the aesthetics of study area, but also impose tremendous pressure in the geo-environmental and socio-economic settings of the region.

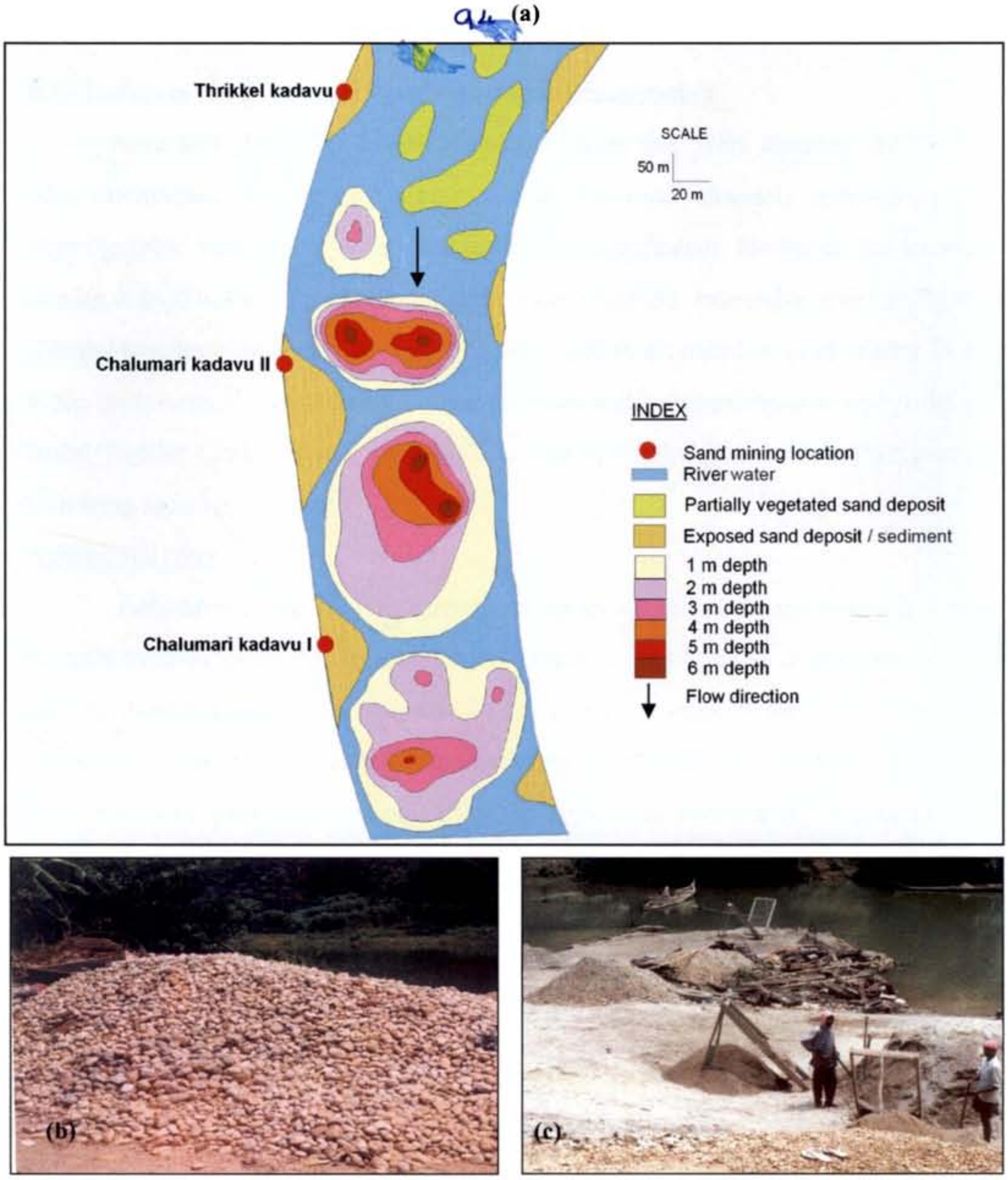


Fig. 6.2 River channel near Chalumari *kadavu* in the Ayavana grama panchayat (Muvattupuzha river) showing deep pits developed consequent to pit excavation for sand, gravel and subfossil wood. (a) Bathymetric contours and other morphological features in the river channel with sand mining locations; (b) Pebbles separated by size grading of sand; (c) Photograph showing the mining and screening activities.

6.3a Instream sand mining: River basin-wise presentation

Sand and gravel are mined extensively from the rivers draining the Vembanad lake catchments. Mining is taking place in the river channels irrespective of the physiographic zones, river orders and ecological significance. However, the intensity of mining is high in the alluvial reaches of the main channels, especially in the midlands and channel reaches close to the lowlands. Fig. 6.3 depicts the instream sand mining locations in the study area. For convenience of presentation and better evaluation, a physiography - based (highland, midland and lowland) description of individual rivers is attempted in the following sections.

Achankovil river

Achankovil river flowing through the southern part of the study area is subjected to indiscriminate extraction for construction grade sand and gravel. In addition to catering sand to developmental requirements of various local bodies of the Pathanamthitta and Alappuzha districts, a substantial quantity of sand is exported to areas in the neighbouring river basins as well. It is computed that an amount of 0.966 x 10^6 tonnes of sand is extracted from the Achankovil river, annually. A total of 11 local bodies of Pathanamthitta district including the Pathanamthitta municipality and 6 local bodies of Alappuzha districts, located on either sides of the Achankovil river, are engaged in sand mining from the river (Fig. 6.4). Total number of labour force engaged in instream sand mining activities is 2031 (Pathanamthitta: 1021; Alappuzha: 1010). Table 6.2 summarises the local body-wise details of the sand mining activity from the Achankovil river.

A greater part of the highlands of the Achankovil river in the upper part falls within dense forests. However, river sand mining is taking place at alarming scale in the lower part of the highlands falling within the jurisdiction of Aruvappulam, Konni, Malayalappuzha and Pramadom grama panchayats (Fig. 6.4). From Table 6.2, it is revealed that an amount of 0.27 x 10^6 ty^{-1} of sand is being removed from the highlands of the Achankovil river; out of which 0.08 x 10^6 tonnes is from the Aruvappulam grama panchayat, 0.083 x 10^6 tonnes from the Konni grama panchayat, 0.027 x 10^6 tonnes from the Malayalappuzha grama panchayat and 0.08 x 10^6 tonnes is from the Pramadom grama

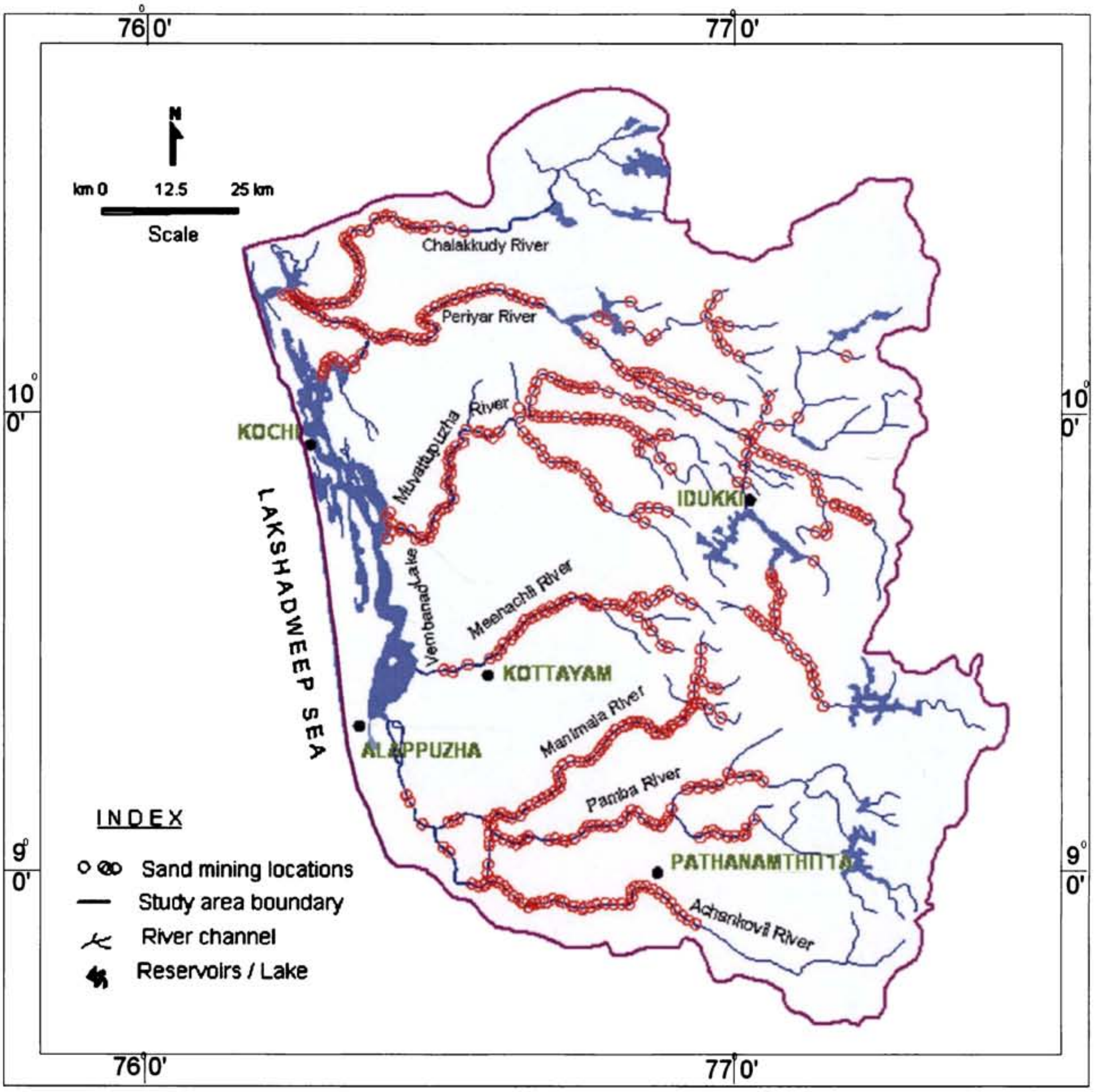


Fig. 6.3 Sand mining locations in the river channels of the study area

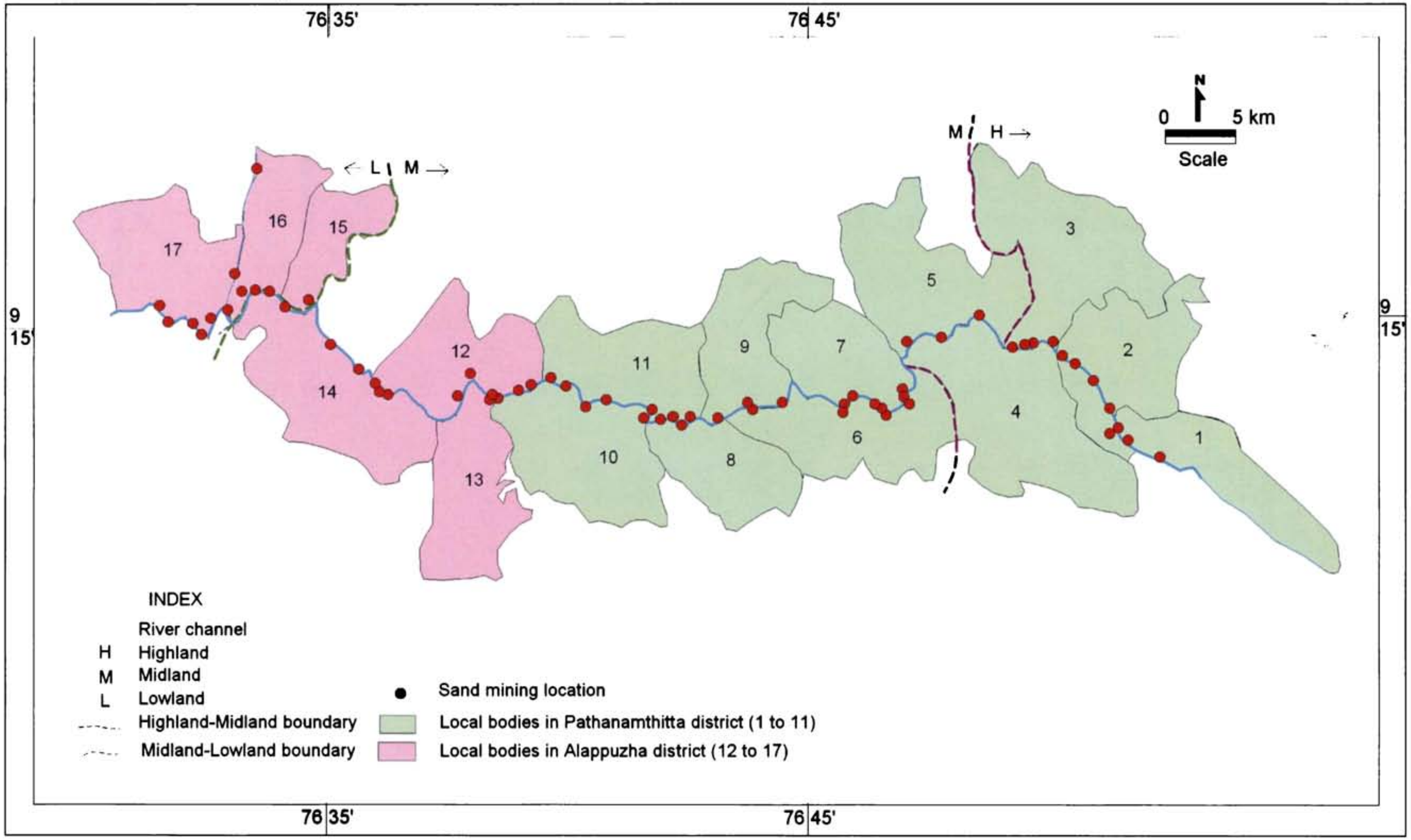


Fig. 6.4 Local bodies in the Pathanamthitta and Alappuzha districts (Refer Table 6.2 for details) engaged in sand mining from the Achankovil river

Table 6.2 Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) along with Population Density (PD) and other relevant details of various local bodies engaged in sand extraction from the Achankovil river

Sl. No.	Local body / District	Physio-graphy	Area (km^2)	PD ($inh.km^{-2}$)	QSM ($x 10^6 ty^{-1}$)	LF (no.)	SMS (no.)
	PATHANAMTHITTA DISTRICT						
1	Aruvappulam	HL	277.7	78.19	0.080	232	3
2	Konni	HL	31.1	670.42	0.083	135	5
3	Malayalappuzha	HL	20.6	652.52	0.027	42	2
4	Pramadom	HL	37.1	808.09	0.080	73	3
5	Pathanamthitta (M)	ML	23.50	1527	0.032	36	3
6	Vallicode	ML	18.66	1059	0.051	141	8
7	Omallur	ML	14.54	1132	0.032	50	5
8	Thumpamon	ML	7.84	975	0.096	96	4
9	Chenneerkara	ML	19.50	992	0.032	43	2
10	Pandalam	ML	28.42	1328	0.090	88	5
11	Kulanada	ML	21.57	1070	0.080	85	3
	ALAPPUZHA DISTRICT						
12	Venmoney	ML	18.01	1129	0.048	50	3
13	Nooranad	ML	21.29	1149	0.064	200	3
14	Thazhakkara	ML	25.26	1391	0.051	250	7
15	Puliyoor	LL	5.96	1343	0.024	110	2
16	Budhanoor	LL	6.46	1352	0.032	100	4
17	Chennithala-Thripperumthura	LL	22.26	1238	0.064	300	5

ty^{-1} = tonnes per year; $inh.km^{-2}$ = inhabitants per square km; HL = Highland; ML = Midland; LL = Lowland; M = Municipality

panchayat. About 482 labourers are engaged in about 13 sand mining locations (*kadavus*) spread on either side of the river channel in the highlands.

The Achankovil river from Pramadom to Kunnam (channel length: 38 km) falls within the midland. A total of 10 local bodies are engaged in sand mining activities in this area; out of which 7 local bodies falls within the jurisdiction of Pathanamthitta district and the remaining (3) in Alappuzha district (Fig. 6.4). An amount of 0.576 x 10^6 tonnes of sand is extracted annually from the midland part of the Achankovil river. Among local bodies involved in sand mining from the midlands, the highest quantity of sand extraction is noticed in Thumpamon grama panchayat (0.096 x 10^6 ty^{-1}), followed by Pandalam (0.09 x 10^6 ty^{-1}) and Kulanada (0.08 x 10^6 ty^{-1}) grama panchayats. A total of 0.064 x 10^6 ty^{-1} of sand is mined from Nooranad and 0.051 x 10^6 ty^{-1} of sand each from the Vallicode and Thazhakkara panchayats. Venmoney panchayat ranks next to these panchayats (0.048 x 10^6 ty^{-1}). Comparatively, a low amount of sand (0.032 x 10^6 ty^{-1}) is being mined from Pathanamthitta municipality, Omallur and Chenneerkara grama panchayats. Thousands of labourers are engaged in the mining sector of the midlands of Achankovil river (Table 6.2). There are 43 sand mining locations identified in this part of the river.

The Achankovil river branches out into distributaries that are generally running parallel to the coast. River sand mining is predominant in the main channel as well as distributaries of the Achankovil river. Only three local bodies falling within the jurisdiction of Alappuzha district are engaged in sand mining from the lowlands of the Achankovil river. Sand extracted from this area amounts to 0.015 x 10^6 ty^{-1}. The details of mining activities in this zone are given in Table 6.2. Of the total quantity of sand extracted (0.032 x 10^6 ty^{-1}) from the Budhanoor grama panchayat, nearly 50% of the sand is mined from the Kakkad distributary (0.016 x 10^6 ty^{-1}) of Achankovil river.

Pamba river

Pamba river is widely exploited for construction grade sand for the past 2 – 3 decades. The Thiruvalla municipality forms the core development centre using a greater quantity of sand extracted from the Pamba river. The Pathanamthitta and Chengannur municipalities are also benefited from sand mined from this river. In addition to local consumption, a substantial portion of sand from the Pamba river basin is being transported to other nearby development centers like the Kollam corporation, Kottayam municipality etc. A total of 0.857 x 10^6 tonnes of sand is being extracted from the Pamba river and its tributaries a year. Seventeen local bodies of Pathanamthitta district, 3 local bodies of Alappuzha district and 2 local bodies of Kottayam district share the sand resource of the Pamba river (Fig. 6.5). A total of 1991 labourers are engaged in sand mining from the Pamba river basin (Table 6.3).

Unlike the Achankovil river, widespread sand mining is noticed in the highlands of the river Pamba (Fig. 6.5). Of the total 11 local bodies engaged in sand mining from the highlands - 7 are mining sand from the main channel and the remaining (4) from the tributaries. Among the various local bodies involved in sand extraction from the main channel, the Vadasserikkara grama panchayat records the highest quantity (0.056 x 10^6 ty^{-1}) and the Erumeli grama panchayat the lowest quantity (0.014 x 10^6 ty^{-1}). The extraction rates of the other grama panchayats were 0.48 x 10^6 ty^{-1} each for Ranni Perinad, Ranni and Ranni Angadi and 0.032 x 10^6 ty^{-1} for Naranamoozhi, Vechoochira and Ranni Pazhavangadi grama panchayats. A total of 780 labourers are working in the sand mining sector in about 26 *kadavus* (sand mining locations) distributed all along the river channel in the highlands. Estimates show that an amount of 0.064 x 10^6 ty^{-1} of sand is being removed exclusively from the tributaries of Pamba river (Table 6.3).

Of the 8 local bodies engaged in sand mining from the midlands, 7 local bodies fall within the jurisdiction of Pathanamthitta district and one (Chengannur municipality) in the Alappuzha district. An amount of 0.368 x 10^6 ty^{-1} of sand is being mined from the midlands of Pamba river, of which one third is from Thottapuzhassery grama panchayat alone (0.12 x 10^6 ty^{-1}). The quantity of sand mining registers the lowest in the Cherukole and Aranmula grama panchayats (0.024 x 10^6 ty^{-1}). This is because the sand bed falling within this panchayat is used traditionally for holding religious and cultural ceremonies / gatherings like Cherukolpuzha Hindu Convention. Annually, 0.04 x 10^6 ty^{-1} of sand are mined from Koipuram grama panchayat. About 776 labourers are engaged in the mining

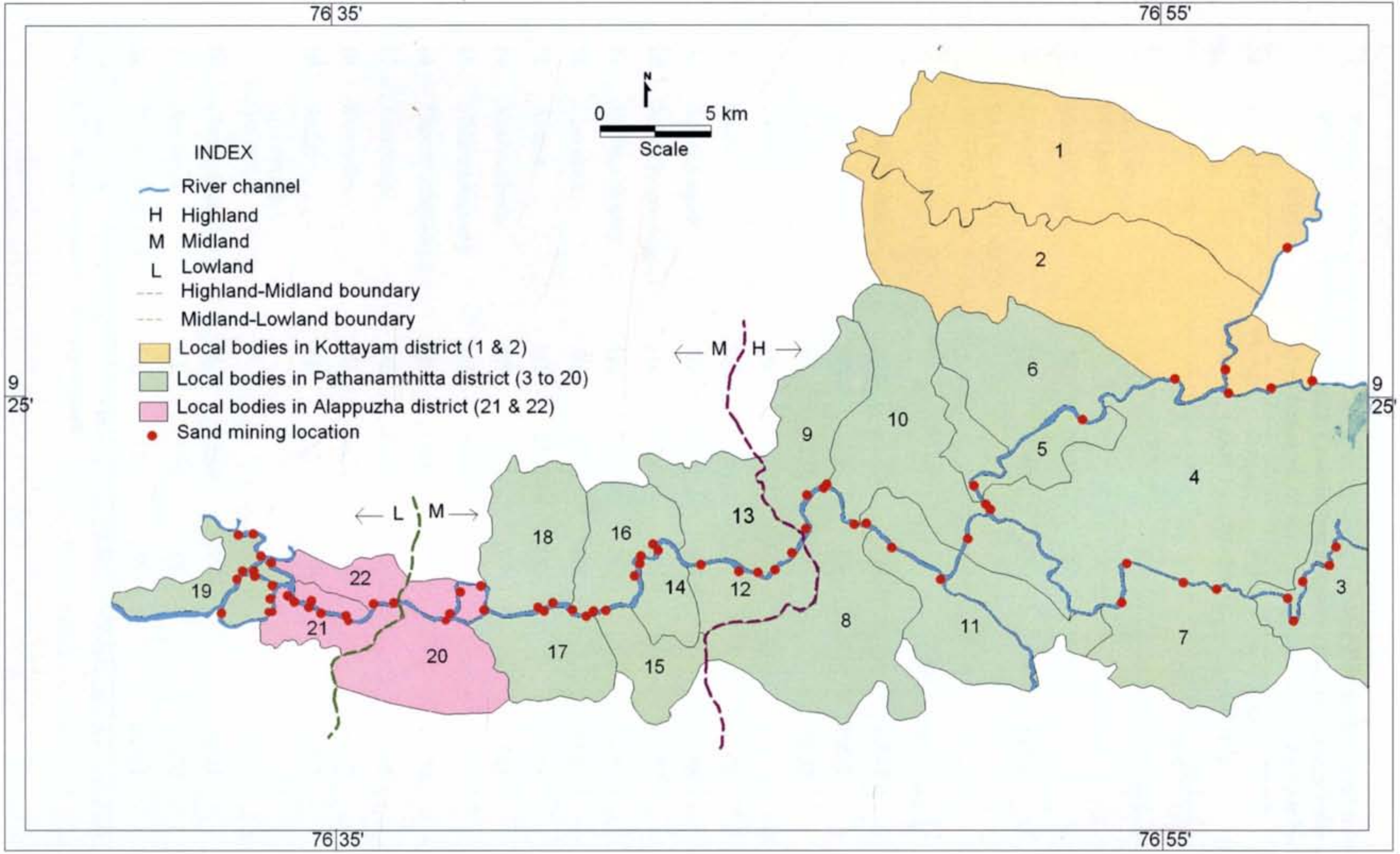


Fig. 6.5 Local bodies in the Kottayam, Pathanamthitta and Alappuzha districts (Refer Table 6.3 for details) engaged in sand mining from the Pamba river

Table 6.3 Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) along with Population Density (PD) and other relevant details of various local bodies engaged in sand extraction from the Pamba river

Sl. No.	Local body / District	Physiography	Area (km^2)	PD ($inh.km^{-2}$)	QSM ($x\ 10^6\ ty^{-1}$)		LF (no.)		SMS (no.)	
					T	MC	T	MC	T	MC
	KOTTAYAM DISTRICT									
1	Mundakkayam	HL	20.67	580	0.003	-	9	-	1	-
2	Erumeli	HL	20.59	472	0.005	0.014	12	188	1	3
	PATHANAMTHITTA DISTRICT									
3	Seethathode	HL	651.94	28	0.032	-	175	-	5	-
4	Ranni Perinad	HL	82.05	270	-	0.048	-	70	-	2
5	Naranamoozhi	HL	33.61	476	-	0.032	-	45	-	1
6	Vechoochira	HL	25.90	431	-	0.032	-	35	-	1
7	Chittar	HL	25.90	672	0.024	-	60	-	4	-
8	Ranni	HL	15.64	907	-	0.048	-	40	-	2
9	Ranni Angadi	HL	30.72	504	-	0.048	-	44	-	2
10	Ranni Pazhavangadi	HL	53.38	456	-	0.032	-	24	-	1
11	Vadasserikkara	HL	59.57	367	-	0.056	-	78	-	3
12	Cherukole	ML	15.61	845	-	0.024	-	80	-	3
13	Ayroor	ML	25.76	882	-	0.048	-	104	-	2
14	Kozhencherry	ML	8.61	1475	-	0.048	-	80	-	2
15	Mallapuzhassery	ML	12.45	934	-	0.032	-	60	-	1
16	Thottapuzhassery	ML	14.46	1080	-	0.120	-	200	-	5
17	Aranmula	ML	24.04	1193	-	0.024	-	90	-	1
18	Koipuram	ML	16.70	1146	-	0.040	-	92	-	2
19	Kadapra	LL	7.37	1479	-	0.032	-	100	-	7
	ALAPPUZHA DISTRICT									
20	Chengannur (M)	ML	13.00	1990	-	0.032	-	70	-	5
21	Pandanad	LL	7.79	1159	-	0.070	-	315	-	8
22	Thiruvanvandoor	LL	5.03	1557	-	0.013	-	20	-	3

T = Tributary; MC = Main channel ty^{-1} = tonnes per year; $inh.km^{-2}$ = inhabitants per square km; HL = Highland; ML = Midland; LL = Lowland; M = Municipality sector in the midlands of Pamba river (Table 6.3). There are only 21 sand mining locations identified in the area. The sandy plains near Maramon are also used for holding religious congregations every year.

Out of the 3 local bodies engaged in sand mining in the lowlands, 2 panchayats namely Pandanad and Thiruvanvandoor fall within the jurisdiction of Alappuzha district and one, the Kadapra grama panchayat, in the Pathanamthitta district. A total of 0.115 x 10^6 tonnes of sand are being extracted from the lowlands annually. The details of sand mining activities in this area are given in Table 6.3. Of the total quantity of the extracted sand, the Pandanad grama panchayat contributes about two-third (0.070 x 10^6 ty^{-1}). An amount of 0.032 x 10^6 ty^{-1} of sand is removed from Kadapra grama panchayat followed by 0.013 x 10^6 ty^{-1} from the Thiruvanvandoor grama panchayat. A total of 435 labourers are engaged in the river sand mining sector in the lowlands.

Manimala river

It is estimated that an amount of 1.1 x 10^6 ty^{-1} of sand is extracted from the main channel and tributaries of the Manimala river. Eight local bodies of Kottayam and 10 local bodies of Pathanamthitta districts located on the banks of the Manimala river are engaged in sand mining (Fig.6.6). In addition, the Kokkayar grama panchayat of Idukki district and Veliyanad grama panchayat of Alappuzha district are also engaged in mining of sand from the river. The total number of labour force in sand mining sector of the Manimala river is estimated to 2358 (70 in Idukki district, 936 in Kottayam district, 1302 in Pathanamthitta district and 50 in Alappuzha district). Table 6.4 summarises local body-wise details of the river sand mining taking place in the Manimala river basin.

In the highlands, sand mining is practiced from the main channel as well as tributaries. Five panchayats are engaged here in river sand mining and they together extract about 0.082 x 10^6 ty^{-1} of sand (Table 6.4). Koottickal, Parathode, Mundakkayam and Erumeli grama panchayats fall under the jurisdiction of Kottayam district, while Kokkayar grama panchayat falls in the Idukki district (Fig. 6.6). More than 50% of the total sand is extracted from the main channel than the tributaries. The Kokkayar (Idukki district) and Koottickal (Kottayam district) grama panchayats together extract about

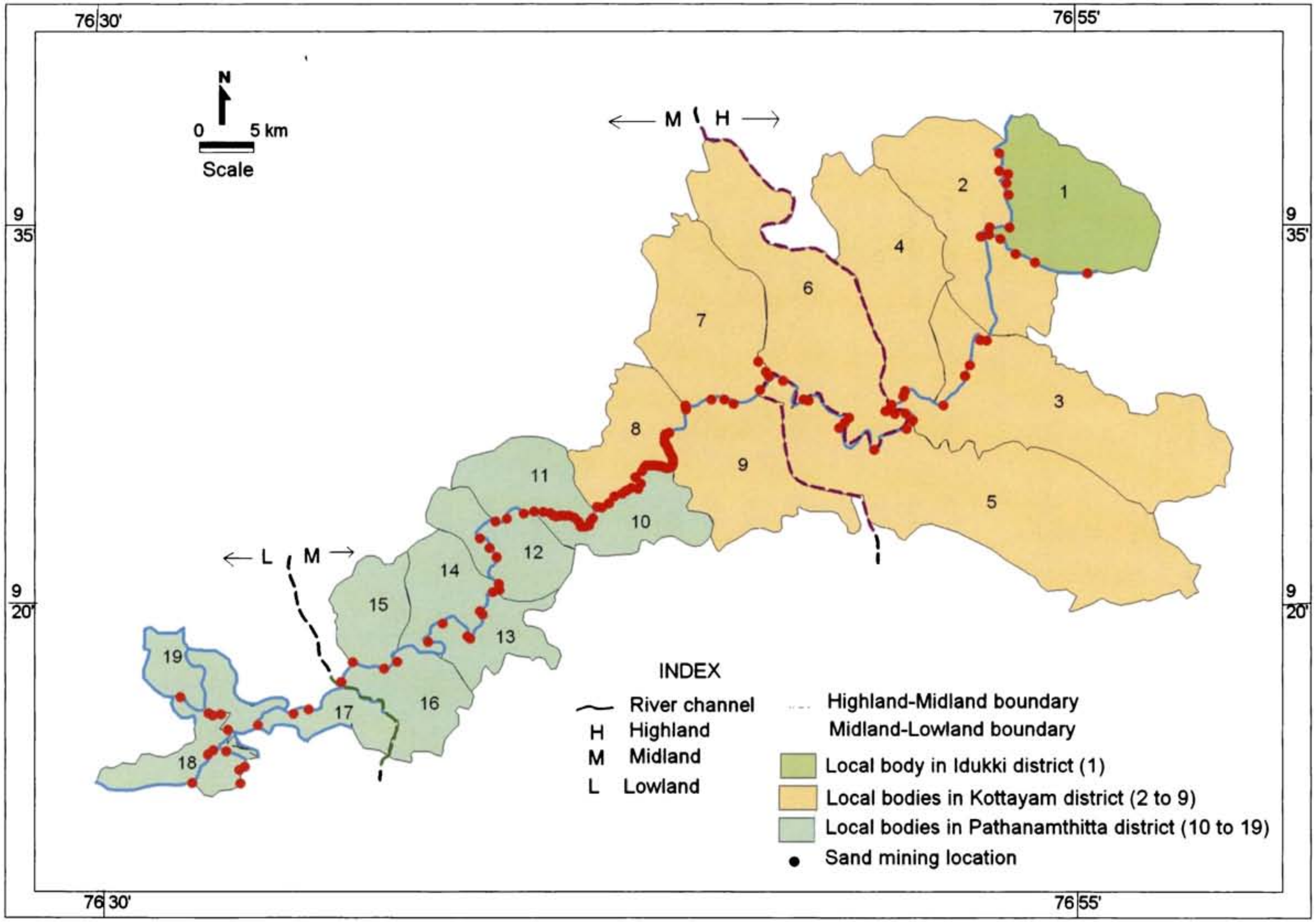


Fig. 6.6 Local bodies in the Idukki, Kottayam and Pathanamthitta districts (Refer Table 6.4 for details) engaged in sand mining from the Manimala river

Table 6.4 Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) along with Population Density (PD) and other relevant details of various local bodies engaged in sand extraction from the Manimala river

Sl. No.	Local body / District	Physiography	Area (km^2)	PD ($inh.km^{-2}$)	QSM ($x\ 10^6\ ty^{-1}$)		LF (no.)		SMS (no.)	
					T / D	MC	T	MC	T	MC
	IDUKKI DISTRICT									
1	Kokkayar	HL	53.11	226	0.019	-	70	-	13	-
	KOTTAYAM DISTRICT									
2	Koottickal	HL	32.13	412	0.016	-	70	-	8	-
3	Mundakkayam	HL	62.00	580	-	0.013	-	29	-	3
4	Parathode	HL	53.49	520	-	0.013	-	20	-	2
5	Erumeli	HL	61.76	472	0.004	0.017	37	148	1	5
6	Kanjirappally	ML	52.47	705	0.003	0.045	10	100	1	10
7	Chirakkadavu	ML	38.81	820	-	0.008	-	20	-	3
8	Vellavoor	ML	23.46	674	-	0.264	-	452	-	29
9	Manimala	ML	37.53	525	-	0.019	-	50	-	9
	PATHANAMTHITTA DISTRICT									
10	Kottangal	ML	23.08	735	-	0.162	-	194	-	16
11	Anicadu	ML	19.04	743	-	0.142	-	253	-	20
12	Mallappally	ML	20.01	876	-	0.102	-	120	-	22
13	Puramattom	ML	14.66	976	-	0.038	-	130	-	6
14	Kallooppara	ML	16.86	1045	-	0.040	-	100	-	5
15	Kaviyur	ML	12.67	1287	-	0.040	-	100	-	3
16	Eraviperoor	ML	9.32	1317	-	0.048	-	123	-	3
17	Kuttur	LL	5.04	1463	-	0.043	-	167	-	6
18	Kadapra	LL	6.08	1793	-	0.016	-	50	-	4
19	Nedumbram	LL	8.49	1515	-	0.024	-	65	-	1
	ALAPPUZHA DISTRICT									
20	Veliyanad*	LL	19.41	697	0.024	-	50	-	3	-

*T – Tributary; D – Distributary; MC = Main channel; ty^{-1} = tonnes per year; $inh.km^{-2}$ = inhabitants per square km; HL = Highland; ML = Midland; LL = Lowland; (*Location of the Veliyanad panchayat is not shown in Fig. 6.5 from where the sand is extracted from the distributary channels)*

0.035 x 10^6 tonnes of sand in alternate years. An amount of 0.013 x 10^6 ty^{-1} of sand each is extracted from the main channel of Manimala river by the Mundakkayam and Parathode grama panchayats. In Erumeli grama panchayat, though the sand mining is widespread in both the tributaries and the main channel, a major share of the extracted sand is from the main channel (0.017 x 10^6 ty^{-1}) and tributary contribute 0.004 x 10^6 ty^{-1} of sand. Out of the 32 sand mining locations in the highlands, 22 are in the tributaries and the remaining in the main channel. It is estimated that about 197 labourers are engaged in sand mining from the main channel and 177 labourers in tributaries of the Manimala river.

A total of 0.912 x 10^6 ty^{-1} of sand is mined from the main channel and tributaries in the midlands of Manimala river (Table 6.4). Except the one sand mining location in the tributary draining the Kanjirapally grama panchayat (Quantity of sand mining: 0.003 x 10^6 ty^{-1}), all the others are in the main channel. Nearly 30% of the total sand extracted is from the 29 mining locations identified in the Vellavoor grama panchayat. An amount of only 0.008 x 10^6 ty^{-1} of sand is being removed from Chirakkadavu grama panchayat located in the upper part of the midlands. An amount of 0.04 x 10^6 ty^{-1} of sand is mined from Kallooppara and Kaviyur grama panchayats. A total of 1652 labourers are working in about 127 sand mining locations in the midlands.

Only 4 local bodies are engaged in sand mining from the lowlands of the Manimala river. They are Kuttur, Kadapra, Nedumbram and Veliyanad grama panchayats. In Veliyanad grama panchayat, sand is mined from the Chela *Ar* distributary of Manimala river. An amount of 0.107 x 10^6 tonnes of sand is extracted from the lowlands a year, out of which 0.043 x 10^6 tonnes are from the Kuttur grama panchayat, 0.024 x 10^6 tonnes each from the Nedumbram and the Veliyanad grama panchayats and 0.016 x 10^6 tonnes from the Kadapra grama panchayat. The relevant statistics of sand mining from the lowlands of Manimala river is given in Table 6.4. A total of 332 labourers are working in the 14 sand mining locations identified in the main river channel and distributaries in the lowland part of the Manimala river.

Meenachil river

The Meenachil river flows almost completely through the Kottayam district. In Meenachil river, sand mining is practiced mainly from the master channel. Small quantities of sand are also extracted from its tributary and distributary channels. Sand extracted from the midlands is mainly utilized for the construction activities of fast developing local bodies like Pala Municipality and Ayarkunnam, Vijayapuram and Ettumanoor grama panchayats. About 0.24 x 10^6 ty^{-1} of sand is being extracted from the main river channel as well as its tributary- distributary systems. The labour force engaged in sand mining sector of the Meenachil basin is estimated to about 991(Table 6.5).

As per available records, only 3 local bodies namely Teekoy, Poonjar and Erattupetta grama panchayats are engaged in sand mining from the highlands of the Meenachil river basin (Fig. 6.7). Together they scoop out 0.04 x 10^6 ty^{-1} of sand from the river channels of the area. The quantity of sand quarried from the tributaries and main channel of the river are 0.023 x 10^6 ty^{-1} and 0.017 x 10^6 ty^{-1}, respectively. It is estimated that an amount of 0.016 x 10^6 ty^{-1} of sand is mined from the Tikovil *Ar* by the Teekoy grama panchayat. The Poonjar and Erattupetta grama panchayats also extract sand from both the main channel (Poonjar: 0.012 x 10^6 ty^{-1}; Erattupetta: 0.005 x 10^6 ty^{-1}) and tributaries (Poonjar: 0.002 x 10^6 ty^{-1}; Erattupetta: 0.005 x 10^6 ty^{-1}). About 120 labourers are working in 10 approved sand mining locations in the main channel and 12 in the tributaries draining the highlands of Meenachil river basin.

In the midlands, except Thalapalam and Vijayapuram grama panchayats, which are mining sand from both the main channel and tributaries, all the other local bodies extract sand from the main channel only. A total of 0.168 x 10^6 ty^{-1} of sand is being mined from the midlands of the Meenachil river. Thalapalam grama panchayat extracts an amount of 0.003 x 10^6 ty^{-1} of sand from the Tikovil *Ar*. The Vijayapuram grama panchayat quarries about 0.004 x 10^6 ty^{-1} of sand from the two sand mining locations in the Minadom *Ar*. The river stretch from Kummannur to Parampuzha, falling in Kidangoor, Ayarkunnam and Ettumanoor grama panchayats together contribute about 0.072 x 10^6 ty^{-1} of sand to the construction sector. Of the various local bodies in the

Table 6.5 Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) along with Population Density (PD) and other relevant details of various local bodies engaged in sand extraction from the Meenachil river

Sl. No.	Local body / District	Physio-graphy	Area (km^2)	PD ($inh.km^{-2}$)	QSM ($x\ 10^6\ ty^{-1}$)		LF (no.)		SMS (no.)	
					T/D	MC	T/D	MC	T/D	MC
	KOTTAYAM DISTRICT									
1	Teekoy	HL	27.19	378	0.016	-	40	-	8	-
2	Poonjar	HL	23.68	462	0.002	0.012	6	44	1	7
3	Erattupetta	HL	14.24	1491	0.005	0.005	15	15	3	3
4	Thalapalam	ML	22.73	535	0.003	0.013	10	40	1	4
5	Bharananganam	ML	27.04	592	-	0.016	-	19	-	3
6	Meenachil	ML	30.14	533	-	0.016	-	40	-	3
7	Pala (M)	ML	15.93	1374	-	0.016	-	100	-	2
8	Mutholy	ML	18.12	843	-	0.016	-	90	-	1
9	Kidangoor	ML	25.12	791	-	0.022	-	150	-	4
10	Ayarkunnam	ML	30.70	1036	-	0.026	-	80	-	10
11	Vijayapuram	ML	29.70	1698	0.004	0.012	25	75	2	3
12	Ettumanoor	ML	27.81	1482	-	0.024	-	170	-	7
13	Nattakom*	LL	25.79	1517	0.032	-	80	-	6	-

**Sand is mined from the distributary channels*

M = Municipality; T Tributary; MC = Main Channel; ty^{-1} = tonnes per year; $inh.km^{-2}$ = inhabitants per square km; HL = Highland; ML = Midland; LL = Lowland

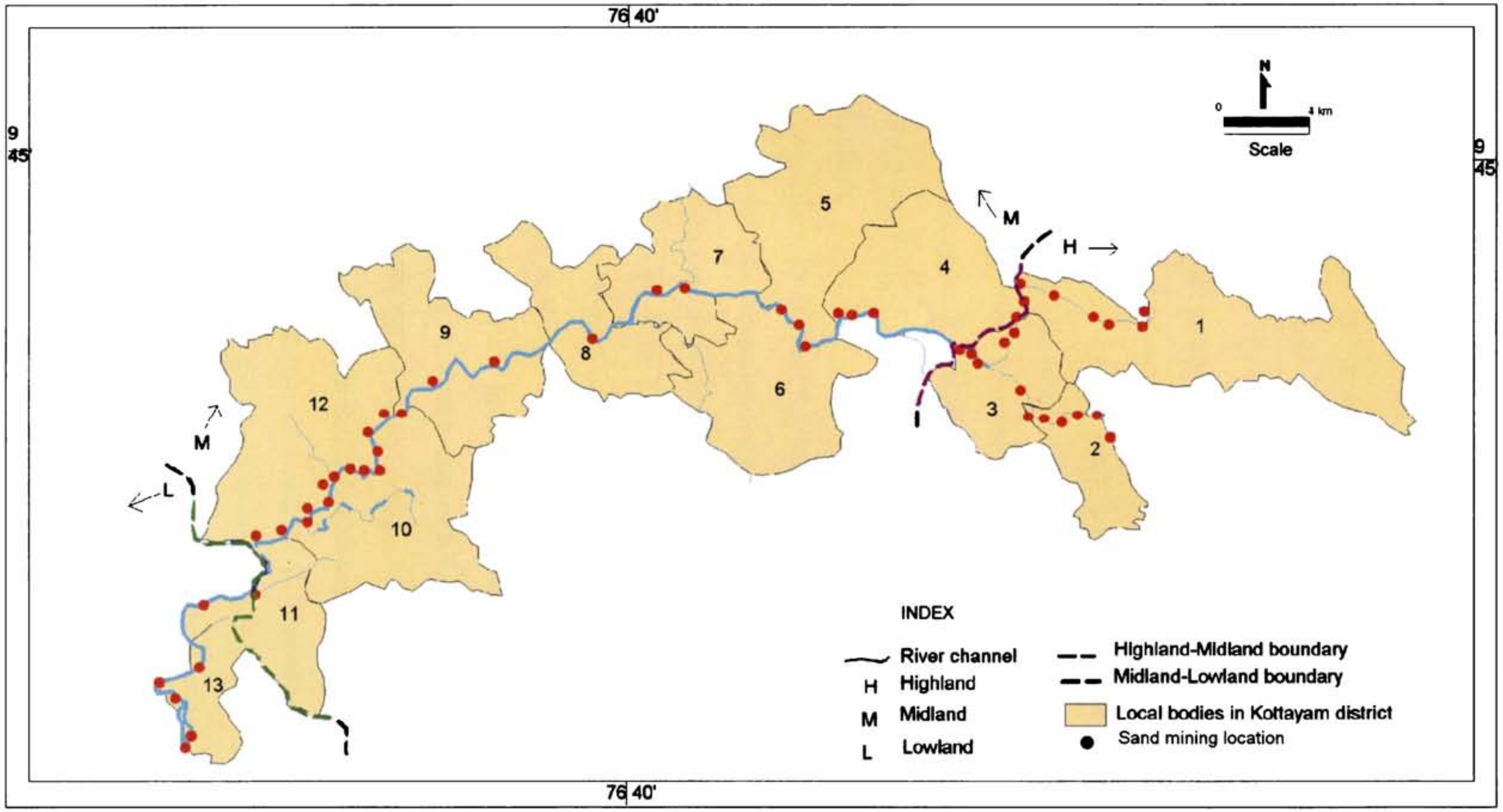


Fig. 6.7 Local bodies in the Kottayam district (Refer Table 6.5 for details) engaged in sand mining from the Meenachil river

midlands, the Ayarkunnam grama panchayat contributes the maximum quantity of sand extracted (0.026 x 10^6 ty^{-1}) in the basin. It is followed by Ettumanoor (0.024 x 10^6 ty^{-1}) and Kidangoor (0.022 x 10^6 ty^{-1}) panchayats. The Vijayapuram grama panchayat in the downstream side of the midlands quarry an amount of 0.012 x 10^6 ty^{-1} from the main channel. Out of the total 799 labourers in sand mining sector of the midlands, only 35 labourers are working in the 3 sand mining locations in the tributaries and all others are working in the 37 sand mining locations spread on either sides of the main channel.

As per the estimate, only one local body, the Nattakom grama panchayat, is involved in sand mining from the lowlands of Meenachil river basin. An amount of 0.032 x 10^6 ty^{-1} of sand is being mined from the distributary channel of Meenachil river by the Nattakom grama panchayat. A total of 80 labourers are working in the 6 sand mining locations in the panchayat.

Muvattupuzha river

Muvattupuzha river draining through Idukki, Ernakulam and Kottayam districts is subjected to indiscriminate extraction for construction grade sand and decorative grade pebbles. In addition to this, huge quantities of subfossil wood interlayered within sand and gravel are also mined from the river channel at certain places (Fig. 6.2). The proximity to the fast developing Kochi City sets the demand of river bed materials on the highest side. It is estimated that an amount of 2.031 x 10^6 ty^{-1} of sand is being extracted from the drainage channels of the Muvattupuzha river. Ten local bodies of Idukki, 20 local bodies of Ernakulam and 6 local bodies of Kottayam districts are engaged in sand mining (Fig. 6.8). The labour force (4885) engaged in sand mining is also on the higher side (682 in Idukki district, 2460 in Ernakulam district and 1743 in Kottayam district) compared to the other 4 southern rivers draining the Vembanad lake catchments. A major chunk of the sand extracted from the Muvattupuzha river is transported to the Kochi City and its satellite townships. The major townships in the Muvattupuzha river basin like the Kothamangalam and Muvattupuzha municipalities and other local bodies in adjacent areas also make use of the sand extracted from this river. Table 6.6 summarises the local body-wise account of the sand mining from the Muvattupuzha river.

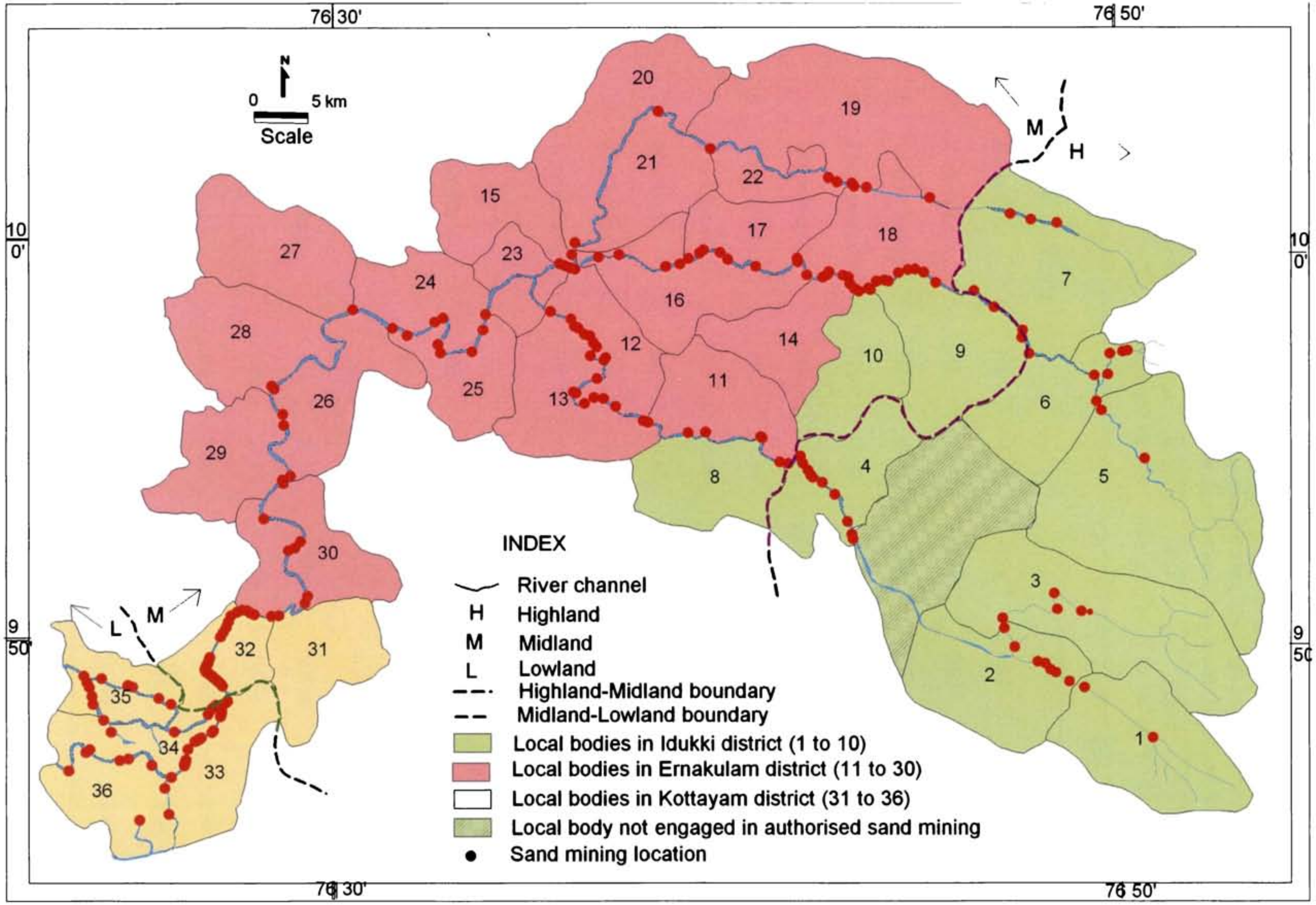


Fig. 6.8 Local bodies in the Idukki, Ernakulam and Kottayam districts (Refer Table 6.6 for details) engaged in sand mining from the Muvattupuzha river

Table 6.6 Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) along with Population Density (PD) and other relevant details of various local bodies engaged in sand extraction from the Muvattupuzha river

Sl. No.	Local body / District	Physio-graphy	Area (km^2)	PD (inh.km^{-2})	QSM (x 10^6 ty^{-1})		LF (no.)		SMS (no.)	
					T/D	MC	T/D	MC	T/D	MC
	IDUKKI DISTRICT									
1	Arakulam	HL	96.32	124	0.013	-	25	-	2	-
2	Kudayathoor	HL	27.64	395	0.024	-	60	-	7	-
3	Velliyamattom	HL	30.56	643	0.016	-	50	-	5	-
4	Thodupuzha (M)	HL	35.43	1148	0.032	-	100	-	10	-
5	Udumbannur	HL	23.21	721	0.019	-	70	-	5	-
6	Karimannur	HL	31.66	564	0.024	-	70	-	5	-
7	Vannappuram	HL	20.96	1040	0.040	-	130	-	6	-
8	Manakad	ML	19.85	678	0.008	-	17	-	1	-
9	Kodikulam	ML	18.92	681	0.051	-	120	-	5	-
10	Kumaramangalam	ML	19.35	662	0.010	-	40	-	3	-
	ERNAKULAM DISTRICT									
11	Manjalloor	ML	23.02	599	0.016	-	60	-	6	-
12	Avoli	ML	18.60	847	0.064	-	200	-	9	-
13	Arakuzha	ML	29.31	510	0.032	-	65	-	9	-
14	Kalloorkad	ML	23.95	529	0.024	-	90	-	4	-
15	Paipra	ML	32.18	1019	0.032	-	100	-	5	-
16	Ayavana	ML	29.47	606	0.048	-	150	-	9	-
17	Pothanicad	ML	17.14	552	0.040	-	120	-	4	-
18	Paingottur	ML	23.50	623	0.040	-	150	-	13	-

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Sl. No.	**Local body / District**	**Physio-graphy**	**Area (km^2)**	**PD ($inh.km^{-2}$)**	**QSM (x 10^6 ty^{-1})**		**LF (no.)**		**SMS (no.)**	
					T/D	**MC**	**T/D**	**MC**	**T/D**	**MC**
19	Kavalangad	ML	53.92	458	0.040	-	60	-	6	-
20	Kothamangalam (M)	ML	40.04	887	0.013	-	30	-	2	-
21	Varapetty	ML	21.50	711	0.011	-	25	-	4	-
22	Pallarimangalam	ML	15.82	728	0.024	-	65	-	6	-
23	Muvattupuzha (M)	ML	13.18	2094	-	0.032	-	50	-	1
24	Valakom	ML	23.72	678	-	0.080	-	150	-	3
25	Marady	ML	21.37	635	-	0.139	-	250	-	7
26	Ramamangalam	ML	23.40	613	-	0.112	-	130	-	3
27	Aikkaranad	ML	25.65	723	-	0.024	-	20	-	2
28	Poothrikka	ML	12.77	718	-	0.040	-	45	-	1
29	Maneed	ML	26.20	592	-	0.088	-	200	-	3
30	Piravom	ML	29.36	858	-	0.216	-	500	-	8
	KOTTAYAM DISTRICT									
31	Mulakkulam	ML	19.61	905	-	0.040	-	140	-	2
32	Vellur	ML	19.29	1119	-	0.202	-	420	-	42
33	Thalayolaparambu	LL	20.63	1011	0.125	0.078	312	192	26	16
34	Maravanthuruthu	LL	15.79	1300	0.056	-	250	-	6	-
35	Chempu	LL	18.42	1022	0.136	-	393	-	12	-
36	Udayanapuram	LL	10.08	1192	0.043	-	176	-	9	-

M = Municipality; T = Tributary; D = Distributary; MC = Main channel
ty^{-1} *= tonnes per year;* $inh.km^{-2}$ *= inhabitants per square km; HL = Highland; ML = Midland; LL = Lowland*

Out of the total quantity of sand extraction, only 8% (0.168×10^6 ty^{-1}) of sand is mined from the highland part of the Muvattupuzha river. Four local bodies namely Arakulam, Kudayathoor, Velliamattom grama panchayats and Thodupuzha municipality are engaged in sand mining from the Thodupuzha tributary (Fig. 6.8). Together, they extract about 0.085×10^6 ty^{-1} of sand from the tributary of Muvattupuzha river. The three local bodies engaged in sand mining from the Kaliyar tributary are Udumbannur, Karimannur and Vannappuram grama panchayats. The total quantity of sand extraction by these local bodies amounts to 0.063×10^6 ty^{-1}. In addition to this, the Vannappuram grama panchayat extracts an amount of 0.02×10^6 ty^{-1} of sand from the Kothamangalam tributary of the Muvattupuzha river, as well.

The midlands of Muvattupuzha river basin are also subjected to indiscriminate sand mining, which in turn, lead to serious problems in its environmental setting. The 3 local bodies of Idukki district namely, Manakad, Kodikulam and Kumaramangalam grama panchayats and 12 local bodies of Ernakulam district (see Table 6.6 for details) are engaged in sand mining from the tributaries. The rest of the panchayats extract sand from the main river channel. Of the total 1.426×10^6 ty^{-1} of sand mined from the midlands, 0.973×10^6 ty^{-1} (68%) are from the main channel and 0.453×10^6 ty^{-1} (32%) from the tributaries. The quantity of sand extracted from the tributaries is 0.246×10^6 ty^{-1} from Kaliyar tributary, 0.112×10^6 ty^{-1} from Thodupuzha tributary and 0.094×10^6 ty^{-1} from Kothamangalam tributary. The Avoli grama panchayat extracts an amount of 0.056×10^6 ty^{-1} of sand from the Thodupuzha tributary and 0.008×10^6 ty^{-1} from the Kaliyar tributary. The Paingottur grama panchayat depends on the Kaliyar and Kothamangalam tributaries for construction grade sand (Kaliyar tributary: 0.034×10^6 ty^{-1}; Kothamangalam tributary: 0.006×10^6 ty^{-1}). The Poothrikka and Mulakkulam grama panchayats together extract an amount of 0.04×10^6 ty^{-1} of sand each from the Muvattupuzha river, followed by the Muvattupuzha municipality (0.032×10^6 ty^{-1}) and Aikkaranad grama panchayat (0.024×10^6 ty^{-1}). Out of the total 3197 labourers working in the midlands of the Muvattupuzha river, 1292 are engaged in sand mining in the tributaries and the remaining in the main channel. About 86 sand mining locations are identified in the tributaries and 72 in the main channel of the midland part of the Muvattupuzha river.

In lowlands, people depend on the main channel as well as distributary channels for construction grade sand. The estimated quantity of sand extracted from the lowlands accounts for 0.437 x 10^6 ty^{-1}. The Thalayolaparambu grama panchayat extracts sand from the main channel (0.078 x 10^6 ty^{-1}) as well as the Ittupuzha distributary (0.125 x 10^6 ty^{-1}). Out of the 42 sand mining locations in the panchayat, 26 locations are in the distributary channel and the remaining 16 are in the main channel. A total of 1323 labourers are working in the 69 sand mining locations spread all along the main channel and the distributary channels of the Muvattupuzha river.

Periyar river

The Periyar river flows through highly varied geomorphic features of Central Kerala and debouch into the Vembanad lake. The river basin falls within the jurisdiction of Idukki, Ernakulam and Thrissur districts. River sand mining is widespread because of its proximity to many developmental centers including the Kochi City. Sand mining is practiced in the main channel as well as tributary / distributary systems. It is estimated that an amount of 6.636 x 10^6 ty^{-1} of sand is being extracted from the Periyar river, out of which 5.657 x 10^6 ty^{-1} is from the main channel and 0.979 x 10^6 ty^{-1} is from tributary / distributary systems. A total of 17 local bodies of Idukki district, 21 local bodies of Ernakulam district and 2 local bodies of Thrissur district are engaged in the sand mining from the Periyar river (Fig. 6.9). The labour force engaged in sand mining in the entire basin is estimated to 8975. The midlands of the Periyar river rank top in the quantity of sand extraction from the basin. This is to meet the rise in demand in the fast developing local bodies like Perumbavoor and Aluva municipalities and other local bodies in adjoining areas as well as the Kochi City. The statistics of sand mining and other relevant information are given in Table 6.7.

About 0.707 x 10^6 ty^{-1} of sand is being mined from the main river channel and various tributaries in the highlands of Periyar river. Of the 19 grama panchayats involved in mining, 12 panchayats extract sand from the alluvial deposits of Munnar-Peermedu

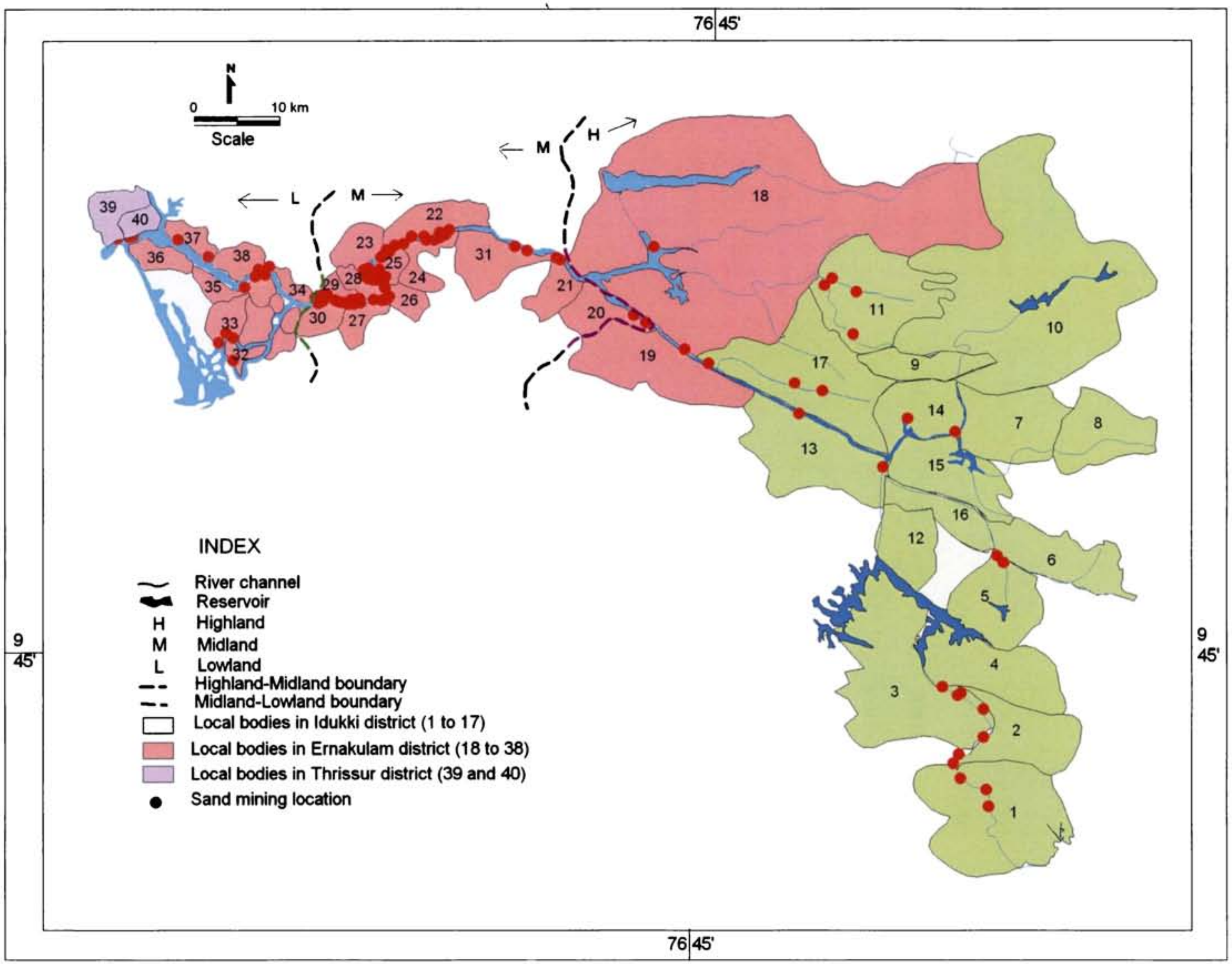

Fig. 6.9 Local bodies in the Idukki, Ernakulam and Thrissur districts (Refer Table 6.7 for details) engaged in sand mining from the Periyar river

Table 6.7 Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) along with Population Density (PD) and other relevant details of various local bodies engaged in sand extraction from the Periyar river

Sl. No.	Local body / District	Physio-graphy	Area (km^2)	PD (inh.km^{-2})	QSM (x 10^6 ty^{-1})		LF (no.)		SMS (no.)	
					T	MC	T	MC	T	MC
	IDUKKI DISTRICT									
1	Vandiperiyar	HL	107.83	423	-	0.040	-	190	-	12
2	Ayyappankovil	HL	42.68	320	-	0.048	-	200	-	12
3	Upputhara	HL	71.62	336	0.010	0.038	40	80	4	9
4	Kanchiyar	HL	64.65	325	0.012	0.008	24	16	3	2
5	Erattayar	HL	32.37	575	0.013	-	50	-	7	-
6	Nedumkandam	HL	71.95	514	0.048	-	100	-	24	-
7	Bison Valley	HL	44.03	301	0.024	-	100	-	11	-
8	Rajakumari	HL	38.15	347	0.013	-	40	-	4	-
9	Pallivasal	HL	67.47	246	0.016	-	30	-	5	-
10	Munnar	HL	556.87	141	0.019	-	50	-	9	-
11	Mankulam	HL	123.00	61	0.024	-	30	-	11	-
12	Mariyapuram	HL	32.18	393	-	0.016	-	40	-	2
13	Idukki – Kanjikkuzhy	HL	204.76	123	-	0.040	-	190	-	5
14	Vellathooval	HL	43.06	591	0.019	-	60	-	6	-
15	Konnathady	HL	93.08	322	0.032	-	98	-	19	-
16	Vathikudy	HL	80.90	316	0.045	0.003	157	13	13	1
17	Adimali	HL	271.53	111	0.012	0.012	15	15	6	6
	ERNAKULAM DISTRICT									
18	Kuttampuzha	HL	543.07	42.4	0.039	0.017	105	45	7	3
19	Kavalangad	HL	5.99	458	-	0.120	-	117	-	11

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Sl. No.	Local body / District	Physio-graphy	Area (km^2)	PD ($inh.km^{-2}$)	QSM ($x 10^6 ty^{-1}$)		LF (no.)		SMS (no.)	
					D	MC	D	MC	D	MC
20	Keerampara	ML	14.37	449	-	0.048	-	165	-	4
21	Pindimana	ML	6.44	580	-	0.019	-	100	-	4
22	Malayattoor-Neeleeswaram	ML	34.22	680	-	0.544	-	500	-	7
23	Kalady	ML	16.44	1503	-	0.960	-	400	-	17
24	Koovapady	ML	43.98	1147	-	0.480	-	700	-	5
25	Okkal	ML	12.8	1605	-	0.480	-	900	-	12
26	Perumbavoor (M)	ML	13.59	1815	-	0.160	-	185	-	1
27	Vazhakkulam	ML	9.82	1456	-	0.784	-	700	-	15
28	Kanjoor	ML	14.32	1377	-	0.800	-	700	-	9
29	Sreemoolanagaram	ML	14.41	1554	-	0.320	-	335	-	8
30	Keezhmad	ML	17.79	1564	-	0.688	-	750	-	11
31	Vengoor	ML	198.41	83	-	0.032	-	65	-	7
32	Eloor	LL	14.21	2424	0.080	-	150	-	8	-
33	Alangad	LL	18.35	1737	0.040	-	60	-	3	-
34	Chengamanad	LL	15.58	1620	0.048	-	200	-	10	-
35	Karumalloor	LL	21.05	1398	0.160	-	750	-	16	-
36	Chendamangalam	LL	10.83	2477	0.056	-	250	-	10	-
37	Puthenvelikkara	LL	16.83	1522	0.037	-	150	-	4	-
38	Kunnukara	LL	21.25	929	0.112	-	150	-	4	-
	THRISSUR DISTRICT									
39	Eriyad	LL	16.75	2508	0.024	-	50	-	1	-
40	Methala	LL	11.66	2889	0.096	-	300	-	9	-

T = Tributary; MC = Main channel; D = Distributary; M = Municipality
ty^{-1} – tonnes per year; $inh.km^{-2}$ = inhabitants per square km; HL = Highland; ML = Midland; LL = Lowland;
Local bodies 1 to 12 are in plateau region and 13 to 16 are in the scarp zone.

plateau. They together extract 0.177 x 10^6 ty^{-1} of sand from the tributaries and 0.15 x 10^6 ty^{-1} from the main river channel. Local bodies in the highlands other than plateau region extract 0.147 x 10^6 ty^{-1} of sand from the tributaries and 0.192 x 10^6 ty^{-1} from the main channel. Among the 12 local bodies engaged in sand mining from the plateau region, 7 extract sand from the tributaries (0.157 x 10^6 ty^{-1}) and 3 from the main channel (0.104 x 10^6 ty^{-1}). Two local bodies namely, Upputhara and Kanchiyar extract sand from both the main channel (0.047 x 10^6 ty^{-1}) and tributaries (0.021 x 10^6 ty^{-1}). The main river channel draining through Idukki-Kanjikkuzhy, Vellathooval, Konnathady and Vathikudy grama panchayats falls partly in the scarp slope. A total of 0.043 x 10^6 ty^{-1} of sand are being mined from the main river channel of Konnathady and Vathikudy grama panchayats. Estimates show that 1805 labourers are working in the 204 sand mining locations in the highlands of the Periyar river.

A total of 12 local bodies are engaged in sand mining from midlands of Periyar river. They together extract 5.315 x 10^6 ty^{-1} of sand. Maximum quantity of sand extraction is noticed in the Kalady grama panchayat (0.96 x 10^6 ty^{-1}) followed by Kanjoor (0.8 x 10^6 ty^{-1}), Vazhakkulam (0.784 x 10^6 ty^{-1}), Keezhmad (0.688 x 10^6 ty^{-1}) and Malayattoor-Neeleeswaram (0.544 x 10^6 ty^{-1}) panchayats. Annually, 0.48 x 10^6 ty^{-1} of sand each is being mined by Koovapady and Okkal grama panchayats. A minimum quantity of sand extraction is noticed in the Pindimana grama panchayat (0.019 x 10^6 ty^{-1}). A total of 5500 labourers are working in the 100 sand mining locations identified in the main channel.

In the lowlands, a total of 9 local bodies are engaged in sand mining from the Periyar river. They together extract 0.653 x 10^6 ty^{-1} of sand from the two distributary channels namely, Mangalapuzha and Marthanda Varma distributaries. Of the total sand extracted from the area (0.653 x 10^6 ty^{-1}), the 7 local bodies in the Mangalapuzha distributary extract together about 0.533 x 10^6 ty^{-1} and the remaining two local bodies extract 0.12 x 10^6 ty^{-1} from Marthanda Varma distributary. Karumalloor grama panchayat extract an amount of 0.16 x 10^6 ty^{-1} of sand from Mangalapuzha distributary. Sand extraction recorded only at minimum level in the Eriyad grama panchayat (0.024 x 10^6 ty^{-1}) that lies near the mouth of the river. A total of 2060 labourers are working in about 65 sand mining locations in the lowlands of the Periyar river.

Chalakudy river

It is estimated that a total of 0.939 x 10^6 ty^{-1} of sand is extracted from the Chalakudy river; of which 0.734 x 10^6 ty^{-1} of sand are extracted from the channel draining through the Thrissur district and 0.203 x 10^6 ty^{-1} from the Ernakulam district. A total of 7 local bodies of Thrissur district and 3 local bodies of Ernakulam districts are engaged in the sand mining from Chalakudy river (Fig. 6.10). The labour force engaged in sand mining from the river is estimated about 1563. Based on the available information, river sand mining is negligible in the highlands as the area is mainly under forest cover. No information is available on the sand mining activities of the highlands, which are mainly under forest cover. However, there are reports regarding illegal mining of sand from the two local bodies in the highlands namely, Athirapally (Thrissur district) and Nelliampathy (Palakkad district) grama panchayats. It is reported that about 0.006 x 10^6 ty^{-1} of sand is illegally mined from these two panchayats. Developmental centers like Chalakudy municipality and Thrissur corporation etc., are the major users of the sand extracted from the highlands and midlands. The details of sand mining and related information are given in Table 6.8.

A total of 0.786 x 10^6 ty^{-1} of sand is mined from the main channel in the midlands of Chalakudy river. The quantity of sand extraction by the Chalakudy municipality amounts to 0.101 x 10^6 ty^{-1}. Maximum quantity of sand extraction is noticed in the Melur grama panchayat (0.176 x 10^6 ty^{-1}) and minimum in the Kodassery grama panchayat (0.010 x 10^6 ty^{-1}). The quantity of sand mining from the Parakkadavu and Kuzhur grama panchayats are 0.056 x 10^6 ty^{-1} and 0.048 x 10^6 ty^{-1}, respectively. A total of 1263 labourers are working in the 40 mining locations in the area. Only 2 local bodies are engaged in sand mining in the lowlands of Chalakudy river basin. They are the Kunnukara and

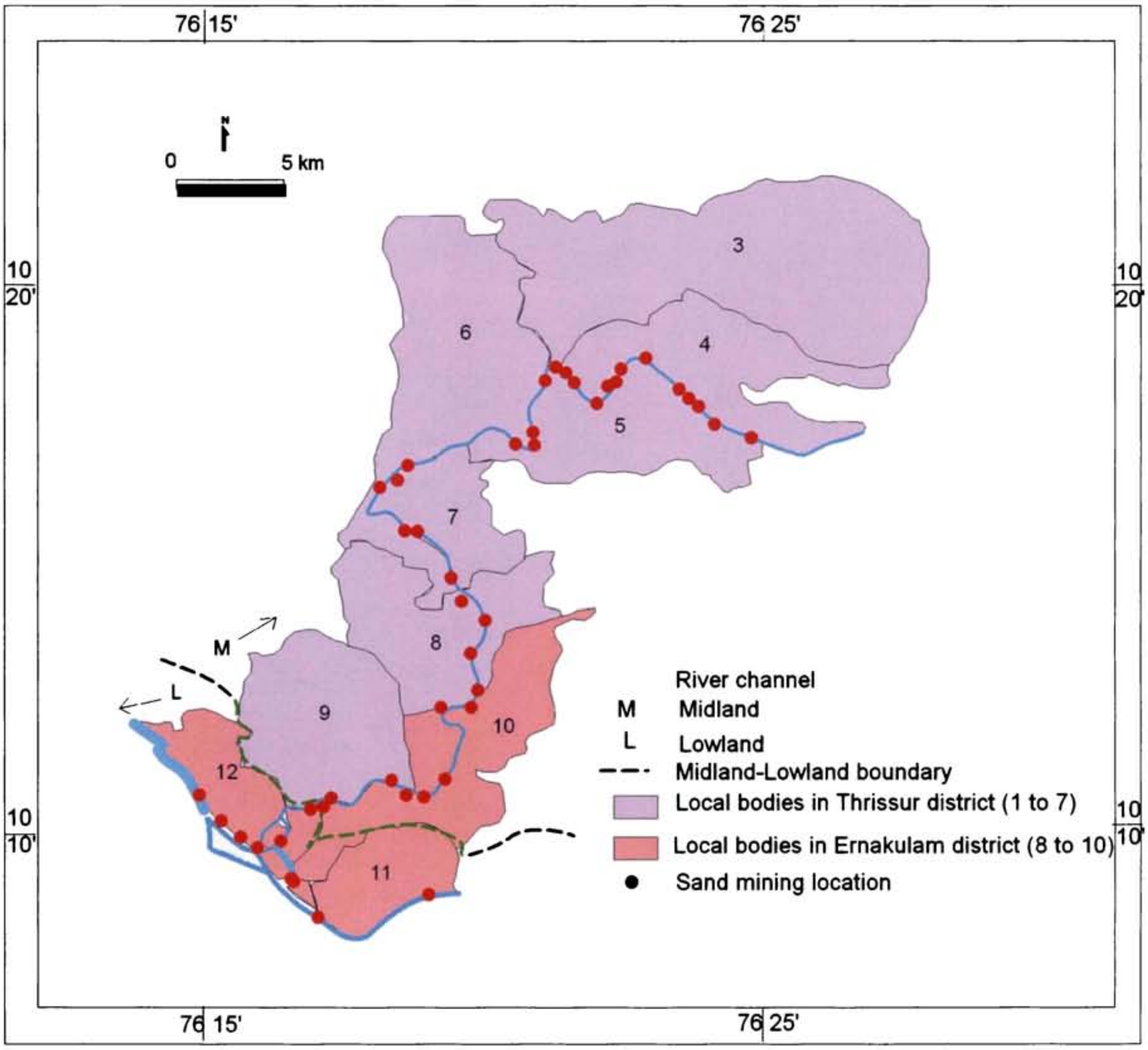


Fig. 6.10 Local bodies in the Thrissur and Ernakulam districts (Refer Table 6.8 for details) engaged in sand mining from the Chalakudy river

Table 6.8 Quantity of Sand Mining (QSM), Labour Force (LF) and number of Sand Mining Sites (SMS) along with Population Density (PD) and other relevant details of various local bodies engaged in sand extraction from the Chalakudy river

Sl. No.	Local body / District	Physiography	Area (km^2)	PD ($inh.km^{-2}$)	QSM ($x\ 10^6\ ty^{-1}$)	LF (no.)	SMS (no.)
	PALAKKAD DISTRICT						
1	Nelliampathy*	HL	576.54	24	0.002	8	1
	THRISSUR DISTRICT						
2	Athirapally*	HL	479.22	20	0.004	10	1
3	Kodassery	ML	23.48	318	0.010	15	1
4	Pariyaram	ML	27.19	770	0.160	300	11
5	Melur	ML	23.06	1012	0.176	100	8
6	Chalakudy (M)	ML	25.23	1786	0.101	112	2
7	Kadukutty	ML	17.63	1259	0.083	425	7
8	Annamanada	ML	25.08	1054	0.152	170	5
9	Kuzhur	ML	19.11	972	0.048	46	3
	ERNAKULAM DISTRICT						
10	Parakkadavu	ML	24.66	1123	0.056	95	3
11	Kunnukara	LL	5.31	930	0.112	150	4
12	Puthenvelikkara	LL	4.21	1521	0.035	150	3

*M – Municipality; ty^{-1} = tonnes per year; $inh.km^{-2}$ = inhabitants per square km; HL = Highland; ML = Midland; LL – Lowland; *Reports of illicit sand mining*

Puthenvelikkara grama panchayats of Ernakulam district. A total of 0.147 x 10^6 ty^{-1} of sand is being extracted from this area. A total of 300 labourers are working in the 7 sand mining locations identified in the river channel.

6.3b Floodplain mining

In addition to mining of sand and gravel from the active channels (instream mining), a significant quantity of sand is being extracted from the floodplains / overbank areas as well. Floodplains and terraces (former floodplains) are the sites of sediment storage and contain large quantities of sand and gravel within it. The sand deposits in the floodplains are also extracted and used extensively for building constructions. The floodplain sand is extracted usually by pit excavation method. Pits in the floodplains often deepen below the water table as these pits provide a convenient water source for the separation of desired size grades. The river basin-wise details and locations of floodplain mining are given in Table 6.9 and Fig 6.11, respectively. A survey conducted by Padmalal et al. (2003) in the midland-lowland stretches of the study area during the period 2002-03 revealed that there were 137 active floodplain mining locations in the area. The sand extraction by this means was to the tune of 0.126 x 10^6 tonnes during the period 2002-03. Surprisingly, the survey carried out as a part of the present study revealed that the floodplain sand extraction attained a figure which is more than double the quantity reported earlier by Padmalal et al. (2003). The total number of labour force also increased from 600 to 3617. Eventhough the number of sand mining sites was reduced to 117 compared to earlier reports (137), the quantity of sand extraction was much higher because of the wide use of mechanical methods using diesel powered engines for sand extraction.

Table 6.9 Details of floodplain mining (land sand mining) in the study area

Location no.	River basin(s)	No. of mining sites		Quantity of mining ($x10^6$ ty^{-1})		Labour force	
		2002-03[(a)]	2006-07[(b)]	2002-03[(a)]	2006-07[(b)]	2002-03[(a)]	2006-07[(b)]
I	Achankovil, Pamba and Manimala	9	11	0.048	0.058	40	105
II & III	Meenachil	7	10	0.024	0.032	30	70
IV	Muvattupuzha	116	76	0.032	2.689	500	3322
V	Periyar	2	14	0.006	0.042	12	84
VI	Chalakudy	3	6	0.016	0.032	18	36
	Total	**137**	**117**	**0.126**	**2.853**	**600**	**3617**

(a)Padmalal et al. (2003); (b)Present study

The floodplains in the lowlands of Achankovil river basin contain rich deposits of sand and clay, which are extensively mined for construction purposes. In Achankovil river basin, floodplain mining is common in Puliyoor and Budhanoor grama panchayats. The Pamba river basin is also not free from floodplain mining. In Pamba river basin, in addition to instream mining, floodplain mining is also practiced in the local bodies like Pandanad and Thiruvanvandoor grama panchayats. Mining of sand from paddy lands are noticed in some lowlying areas of Chengannur municipality. In the lowlands of the Manimala river basin, with the exception of Kadapra grama panchayat, all the local bodies engaged in instream sand mining do practice floodplain mining, as well. It is estimated that an amount of 0.058 x 10^6 ty^{-1} of floodplain sand is extracted together from the lowlands of these three basins (Achankovil, Pamba and Manimala river basins) which are situated in the southern end of the Vembanad lake. In Meenachil river basin, floodplain mining is practiced in five local bodies namely, Mutholy, Kidangoor, Ayarkunnam, Vijayapuram and Ettumanoor grama panchayats in the midlands. Nattakom grama panchayat is the only local body in the lowlands engaged in floodplain mining in the Meenachil river basin. In areas around Nattassery near Kottayam town, floodplain

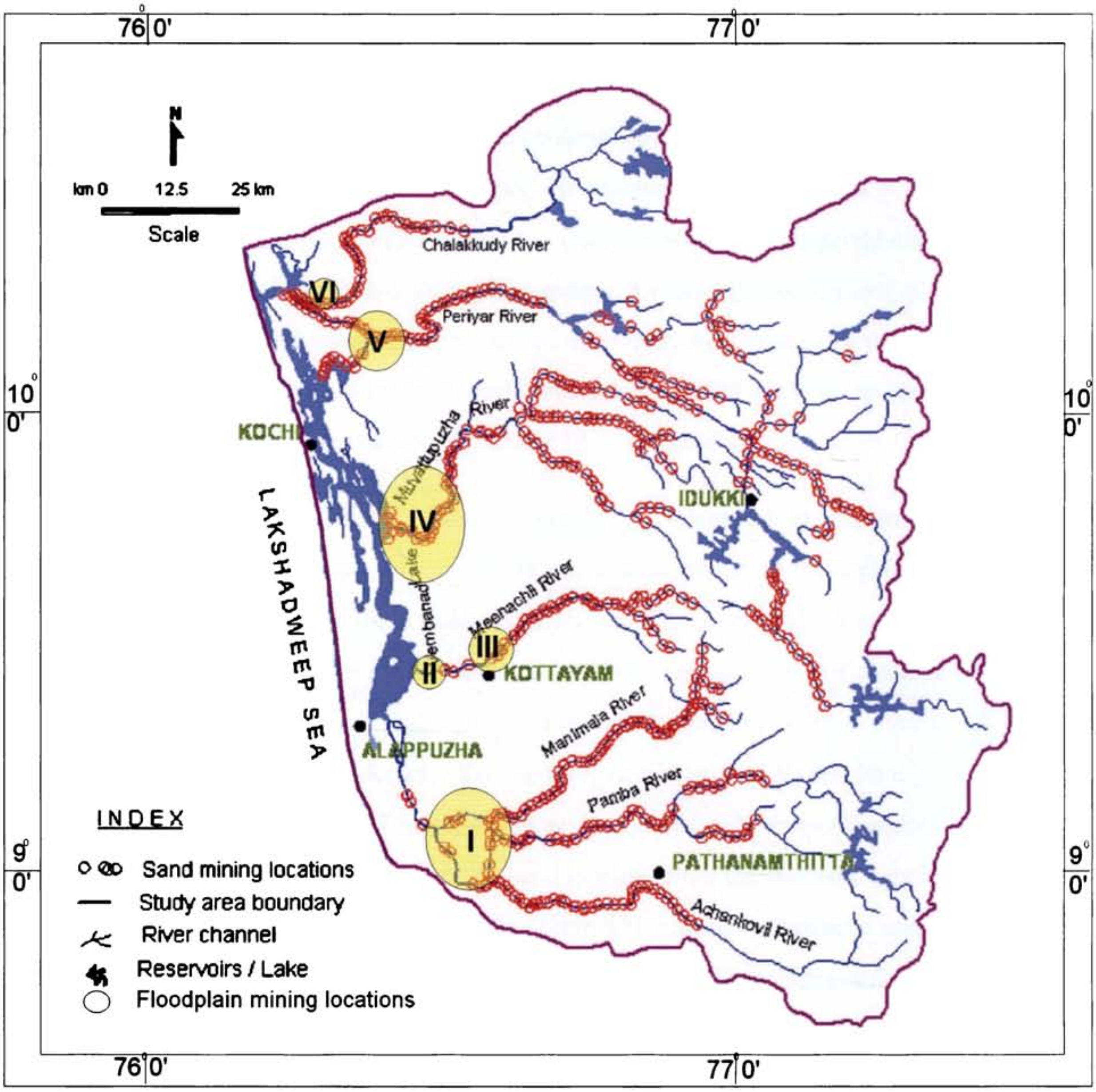


Fig. 6.11 Floodplain sand mining locations along with instream sand mining locations in the study area (Refer Table 6.9 for details of I – VI)

mining has reached at an alarming level. The total quantity of floodplain mining in the Meenachil river basin amounts to $0.032 \times 10^6 ty^{-1}$. In Muvattupuzha river basin, floodplain mining is at critical level. Apart from sand extraction from the distributaries, huge volumes of floodplain sands are extracted using diesel powered sand suction systems for meeting the demands of construction sector. At present, four local bodies – Vellur, Udayanapuram, Chempu, and Maravanthuruthu grama panchayats are actively engaged in floodplain mining, in addition to instream mining. Eventhough the number of sand mining locations is on the decrease in recent years, the quantity of sand extraction shoots up several folds. The total quantity of sand extraction was $2.689 \times 10^6 ty^{-1}$ in the year 2006-07 against the extracted quantity of $0.032 \times 10^6 ty^{-1}$ in 2002-03.

In Periyar river basin, floodplain mining is widespread in the lowlands. Additionally, land sand mining is noticed in the plateau region of the highlands. In highlands, land sand mining (from paddy fields) is prevalent in areas like Anakkara and Chettukuzhy in Vandanmedu grama panchayat and from certain areas in Karunapuram grama panchayat. The six local bodies involved in land sand mining in the midlands are Sreemoolanagaram, Kanjoor, Kalady, Koovappady, Keezhmad and Vazhakulam grama panchayats. In the lowlands, floodplain mining is reported only from Chengamanad grama panchayat. About $0.042 \times 10^6 ty^{-1}$ of sand is mined from the overbank area in the midlands and lowlands of Periyar river basin (Table 6.9). Extensive floodplain mining is carried out in Chalakudy river basin. A total of 5 local bodies are engaged in floodplain mining in the midland area. They are Parakkadavu, Kuzhur, Annamanada, Kadukutty grama panchayats and Chalakudy municipality. In addition, Puthenvelikkara grama panchayat in the lowland area is also engaged in mining from paddy fields and wetlands. Together, they extract about $0.032 \times 10^6 ty^{-1}$ of floodplain sand / land sand from the basin.

6.4 Sand reserve

Estimation of sand deposit in the active channels and floodplain / overbank areas of river basins is an expensive and tedious process. Hence, such an investigation is beyond the scope of this study. However, the secondary information on the sand (instream only) reserve estimated by CESS (1999) is highlighted here for the better understanding of the mining processes and its responses to the river systems subjected to the present study. The Rapid Reserve Estimation (RRE) survey conducted by CESS during the period 1998-99 revealed that the storage zones of the river channels in the study area contain an amount of 112.6 x 10^6 tonnes of sand to a level of 4 - 5 m from the bed surface. Out of the seven rivers, the Periyar river accounted for the maximum sand reserve (53.4 x 10^6 tonnes) and the Achankovil river the minimum (4.2 x 10^6 tonnes). The sand resource of the other rivers were (in the decreasing order) Pamba (19.94 x 10^6 tonnes) > Muvattupuzha (15.12 x 10^6 tonnes) > Chalakudy (9.2 x 10^6 tonnes) > Manimala (5.82 x 10^6 tonnes) > Meenachil (4.92 x 10^6 tonnes) rivers. But the present observations revealed that a major portion of this deposit has been already exploited legally and illegally. And, as a result of this, the storage zones of the rivers have been lowered to significant levels. Now the instream sand deposit has become a scarce commodity in many parts of the river channels in the study area.

6.5 Origin of river sand

It is a fact that the sand in the channel beds of Kerala rivers has been derived through a process that took thousands of years. Radiocarbon ages of wood / peat / sediments just below the sand deposit yielded middle to late Holocene age for the sand (Table 6.10). The highlands and midlands are occupied mainly by primary sand – i.e., the first cycle sand derived from weathering of the crystalline rocks in the uplands. But generation of sand by this means is a very slow process. In addition to this, a substantial part of the sand originated by crustal weathering will be detained within the reservoirs in the uplands constructed mainly for the purpose of irrigation and hydropower generation.

Table 6.10 C^{14} ages of datable materials (wood, sediment and peat) underlying sand deposits

Sl. No.	River basin	Site	Location	Sample type / Material	Depth (mbgl)	C^{14} date (ybp)	Source
1	Achankovil	Thumpamon (upstream side)	9^{0}13'18"N – 76^{0}41'40"E	Instream / Wood	6	5560 ± 90	Present study
2	Karamana	Thrikkannapuram	8^{0}31'30"N – 77^{0}0'20"E	Instream / Wood	12	6140 ± 80	Dr.K.P.N.Kumaran (Personal communication)
3	Vamanapuram	Perunthra *kadavu*	8^{0}43'60"N – 76^{0}53'40"E	Instream / Wood	7	10540 ± 110	Dr.K.P.N.Kumaran (Personal communication)
4	Kallada	Pangod	9^{0}03'00"N – 76^{0}42'00"E	Instream / Wood	5	7490 ± 90	Nair and Kumaran (2006)
5	Meenachil	Thiruvarpu	9^{0}34'35"N – 76^{0}28'13"E	Instream / Sediment	3.5	5339 (calibrated age)	Dr.K.M.Nair (Personal communication)
6	Periyar	Puthenvelikkara	10^{0}11'45"N – 76^{0}14'37"E	Floodplain / Sediment	4.7	7050 ± 140	Santhosh (2006)
7	Chalakudy	Annallur	10^{0}18'08"N – 76^{0}14'44"E	Floodplain / Peat	4	6630 ± 120	Padmalal et al. (2004c)

Another source of channel sand in the storage zones is the reworking of secondary sand from the Cenozoic deposits – the Tertiaries and the Quaternaries - in the coastal lands. The rivers in the study area are flowing through these Cenozoic formations, especially in the coastal lands. Slumping of river banks containing these formations contribute secondary sands in the storage zones of these river channels (Nair and Padmalal, 2006). A part of the sand which forms the bed load of the earlier wide channels is still preserved within the terraces adjoining the present channels. Since extraction of floodplain sand is widespread, contribution of sands from these secondary sources will also become meagre in future. The sands that are found in the river channels were deposited during spells of excessive rainfall in the early to middle Holocene. Plate 6.3 shows SEM photographs of quartz grains of primary and secondary sources showing varied surface relief features substantiating the foresaid view.

6.6 Sand mining *vs* replenishment

'Replenishment rate' is the rate at which sand / gravel is transported into the river channel / reach, which is under examination or subjected to sand extraction. This volume is often considered as sustainable yield of that river (Kondolf, 1994b). Estimation of sand discharge through stream bed and its residence period (temporary deposition) is one of the most difficult tasks in sediment budgeting as it requires sophisticated instruments and establishment of many gauging stations. Therefore, secondary information on sediment discharge obtained from the gauging stations of Central Water Commission (CWC) has been used for substantiating the views evolved from field observations. The available river discharge data of CWC stations in the Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy river basins have been analyzed for getting an account of the natural replenishment of these rivers. From the secondary information, it is estimated that about 0.18 x 10^6 ty^{-1} of sand is being transported down the respective gauging stations as suspension (Table 6.11), the bulk of which is contributed during the high flow regime of the monsoon period.

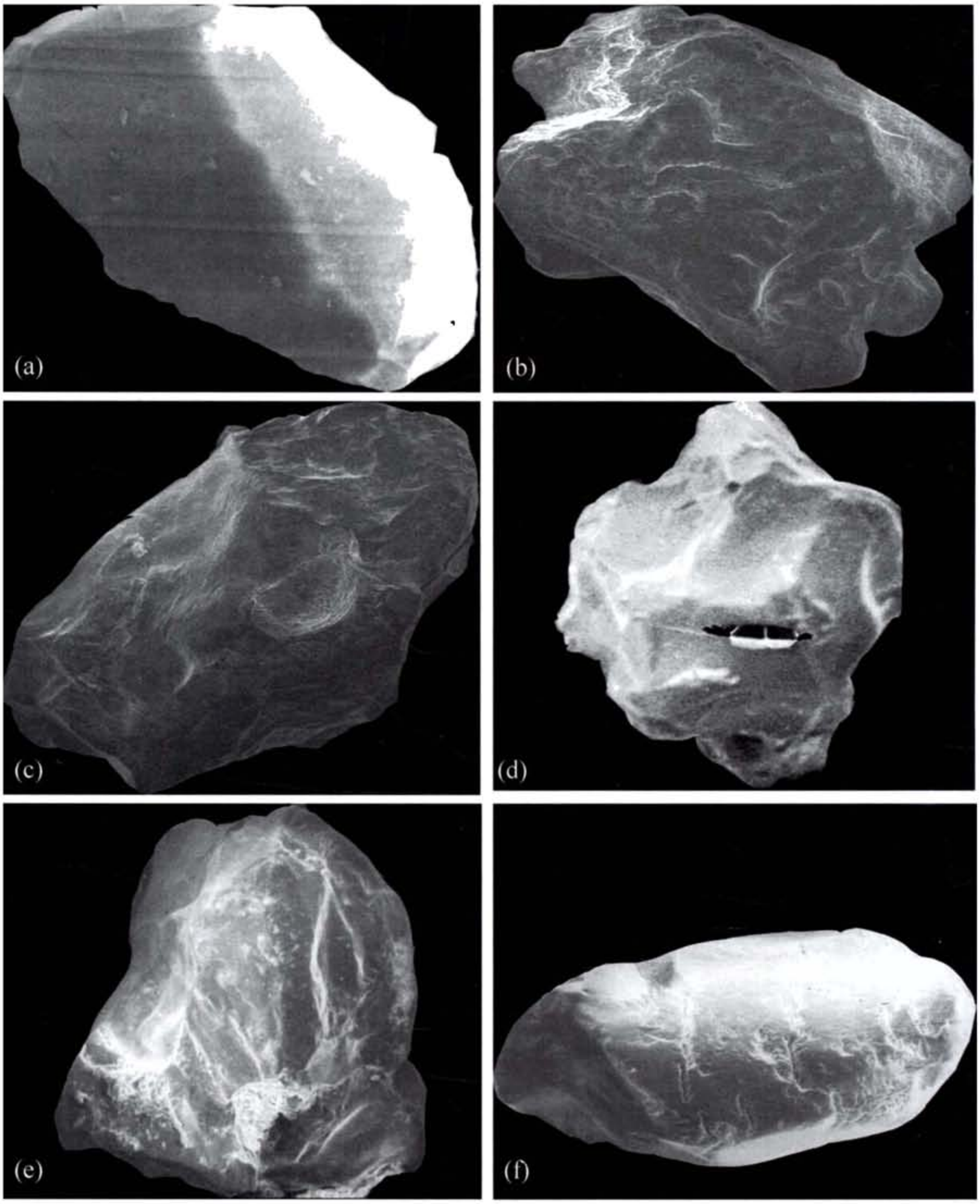


Plate 6.3 Scanning electron micrographs (SEM) of primary and secondary sands showing grain characteristics / micro relief features. (a) Sand grain from the highlands of Muvattupuzha river showing sharp edges and planar surfaces; (b) Sand grain from midlands showing partially rounded edges; (c) and (d) Sand grains from the lowlands showing a spectrum of surface textures of physical and chemical origin; (e) and (f) Grains from the river mouth zones showing sub-rounded to well rounded nature. Scale: 1 cm = 135 μm

Table 6.11 Quantity of river sand mining in relation to the sand discharge estimated in the gauging station of the respective rivers

River	Location of Gauging Station (GS)	River length down the GS (km)	Total sediment discharge ($x10^6ty^{-1}$)	Total sand discharge ($x10^6ty^{-1}$)	Sand mining below the GS ($x10^6ty^{-1}$)
Achankovil	Thumpamon	38	0.09	0.01	0.52
Pamba	Malakkara	27	0.10	0.03	0.21
Manimala	Kallooppara	20	0.09	0.02	0.25
Meenachil	Kidangoor	24	0.03	0.01	0.11
Muvattupuzha	Ramamangalam	35	0.17	0.02	1.09
Periyar	Neeleeswaram	50	0.37	0.08	4.73
Chalakudy	Arangali	27	0.05	0.01	0.58
Total			**0.90**	**0.18**	**7.49**

It is axiomatic that during high flow period, sand which is otherwise moved by saltation (i.e., partially suspension and partially bed load) will completely be in suspension in the overlying waters. Further, studies carried out elsewhere revealed that, in many of the occasions, the quantity of bedload transport was less than 10% of the total sediment discharge (NEDECO 1959, Qian and Dai 1980, Emmet 1984 and Meade, 1995). According to Blatt et al. (1972), the best way for sediment discharge computation is to collect and analyze water samples from a river reach where the entire particles come into suspension. The locations of the CWC gauging stations in the study area fit well within the stipulations of Blatt et al. (1972). The error, if any, in the replenishment computation would become insignificant when one considers the quantity of sand being extracted from the river stretch downstream of the gauging stations. It can be assumed that the sand and other coarser sediments in suspension would be deposited mainly in the river segment between river mouth zone and gauging station(s). The average annual sand discharges of the individual rivers are: 0.01 x 10^6 tonnes for the Achankovil river, 0.04 x 10^6 tonnes for the Pamba river, 0.02 x 10^6 tonnes for the Manimala river, 0.01 x 10^6 tonnes for the Meenachil river, 0.02 x 10^6 tonnes for the Muvattupuzha river, 0.08 x 10^6 tonnes for the Periyar river and 0.01 x 10^6 tonnes for the Chalakudy river.

An apparent assessment of the quantity of sand extraction with respect to the available sand input data reveals that sand mining in the river reaches down the gauging stations amounts to 0.52 x 10^6 ty^{-1} for the Achankovil river, 0.21 x 10^6 ty^{-1} for the Pamba river, 0.25 x 10^6 ty^{-1} for the Manimala river, 0.11 x 10^6 ty^{-1} for the Meenachil river, 1.09 x 10^6 ty^{-1} for the Muvattupuzha river, 4.73 x 10^6 ty^{-1} for the Periyar river and 0.58 x 10^6 ty^{-1} for the Chalakudy river. The total quantity of sand extraction from the storage zones of the entire rivers amounts to 6.57 x 10^6 ty^{-1} (Fig 6.12). That is to say that the current rate of sand mining is of the order of 40 times the higher than the sand input recorded at the gauging stations in the respective rivers.

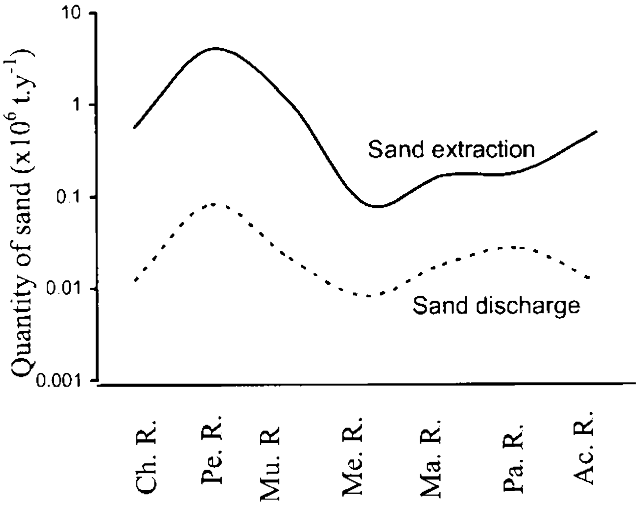


Fig. 6.12 Extraction of sand down to the respective gauging stations of Chalakudy (Ch. R.), Periyar (Pe. R.), Muvattupuzha (Mu. R.), Meenachil (Me. R.), Manimala (Ma. R.), Pamba (Pa. R.) and Achankovil (Ac. R.) rivers (solid line) in relation to sand replenishments (dotted line).

6.7 Discussion

The nature and magnitude of sand mining varies considerably depending on the physiography, geology and degree of construction activity of the area. Mining activities are severe in the river reaches close to development centres. Rivers in the study area differ significantly in their channel properties and river bed resources. Table 6.12 shows the details of sand mining from the rivers in the hinterlands of the Vembanad lake. Fig. 6.13 shows the estimated quantity of instream sand extraction from the river reaches falling within the three physiographic zones. An amount of 12.769 x 10^6 ty^{-1} of sand is extracted from the active channels of the rivers for various purposes. Out of the total quantity of sand extracted from the active channels, about 52% (i.e. 6.635 x 10^6 ty^{-1}) is from the Periyar river alone. Although small in river length and catchment area compared to the river Periyar (244 km / 5398 km^2), the river Muvattupuzha (121 km / 1554 km^2) is also subjected to indiscriminate sand extraction (2.030 x 10^6 ty^{-1}), owing to its proximity to Kochi City and its satellite townships. The quantity of sand extraction in the rest of the rivers are of the decreasing order Manimala > Achankovil > Chalakudy > Pamba > Meenachil. Despite the other rivers in the study area, sand mining in the Pamba river is marginally high in the highlands compared to midlands and lowlands. An overall analysis shows that among the three physiographic zones, the midlands contribute the bulk of sand (75%) to the construction sector. Although, the highlands and lowlands account for almost equal amount of sand extraction (Fig. 6.14), the former covers a greater portion of the study area (57%) than the latter (13%). The sand harvesting (mining) centres are also higher in numbers in midlands (529) than highlands (337) and lowlands (190). A total of 23522 registered labourers (4256 in highlands; 14226 in midlands and 5040 in lowlands) are employed in instream mining sector and the number of indirect workers depending on the extracted sand in the construction sector would be over a lakh.

Fig. 6.15 shows an interbasinal comparison of the quantity of sand mining among highland, midland and lowland physiographic zones of the study area. Among the highland part of various rivers, the maximum quantity of sand is extracted from the Periyar river (41.49%) followed by Pamba (23.28%) and Achankovil (16.82%) rivers. About 0.667 x 10^6 ty^{-1} of sand is extracted from the 192 sand mining locations in the highlands of Periyar river. Though the number of sand mining locations in the Pamba river is less (26) compared to Muvattupuzha (40) and Manimala (32) rivers, the total quantity of sand extracted from the former (i.e, Pamba river) is 2 - 4 times the higher compared to the other two rivers. The main channel and the tributaries of the entire rivers

Table 6.12 Details of sand mining from the main channel, tributaries and distributaries in the study area.

Physiographic province	Rivers	Quantity of sand mining (x 10^6 ty^{-1})		Labour force		No. of sand mining locations		No. of local bodies	
		MC	T / D	MC	T / D	MC	T / D	MC	T / D
Highlands	Achankovil	0.270	-	482	-	13	-	4	-
	Pamba	0.310	0.064	524	256	15	11	8	4
	Manimala	0.042	0.039	197	177	10	22	3	3
	Meenachil	0.017	0.023	59	61	10	12	2	3
	Muvattupuzha	-	0.168	-	505	-	40	-	7
	Periyar	0.342	0.325	1096	899	75	129	10	14
	Chalakudy	0.006	-	-	-	-	-	2	-
	Total	**0.988**	**0.620**	**2358**	**1898**	**123**	**214**	**29**	**31**
Midlands	Achankovil	0.576	-	1039	-	43	-	10	-
	Pamba	0.368	-	776	-	21	-	8	-
	Manimala	0.909	0.003	1642	10	126	1	11	1
	Meenachil	0.161	0.007	764	35	37	3	9	2
	Muvattupuzha	0.973	0.453	1905	1292	72	86	10	15
	Periyar	5.315	-	5500	-	100	-	12	-
	Chalakudy	0.786	-	1263	-	40	-	8	-
	Total	**9.087**	**0.463**	**12889**	**1337**	**439**	**90**	**68**	**18**
Lowlands	Achankovil	0.120	-	510	-	11	-	3	-
	Pamba	0.115	-	435	-	18	-	3	-
	Manimala	0.107	-	332	-	14	-	4	-
	Meenachil	-	0.032*	-	80	-	6	-	1
	Muvattupuzha	0.077	0.360*	192	1131	16	53	1	4
	Periyar	0.000	0.653*	-	2060	-	65	-	9
	Chalakudy	0.147	-	300	-	7	-	2	-
	Total	**0.566**	**1.045**	**1769**	**3271**	**66**	**124**	**13**	**14**
	Grand total	**10.641**	**2.128**	**17016**	**6506**	**628**	**428**	**110**	**63**

**Sand is mined from the distributary channels*

MC = Main Channel; T = Tributary; D = Distributary; ty^{-1} *= tonnes per year*

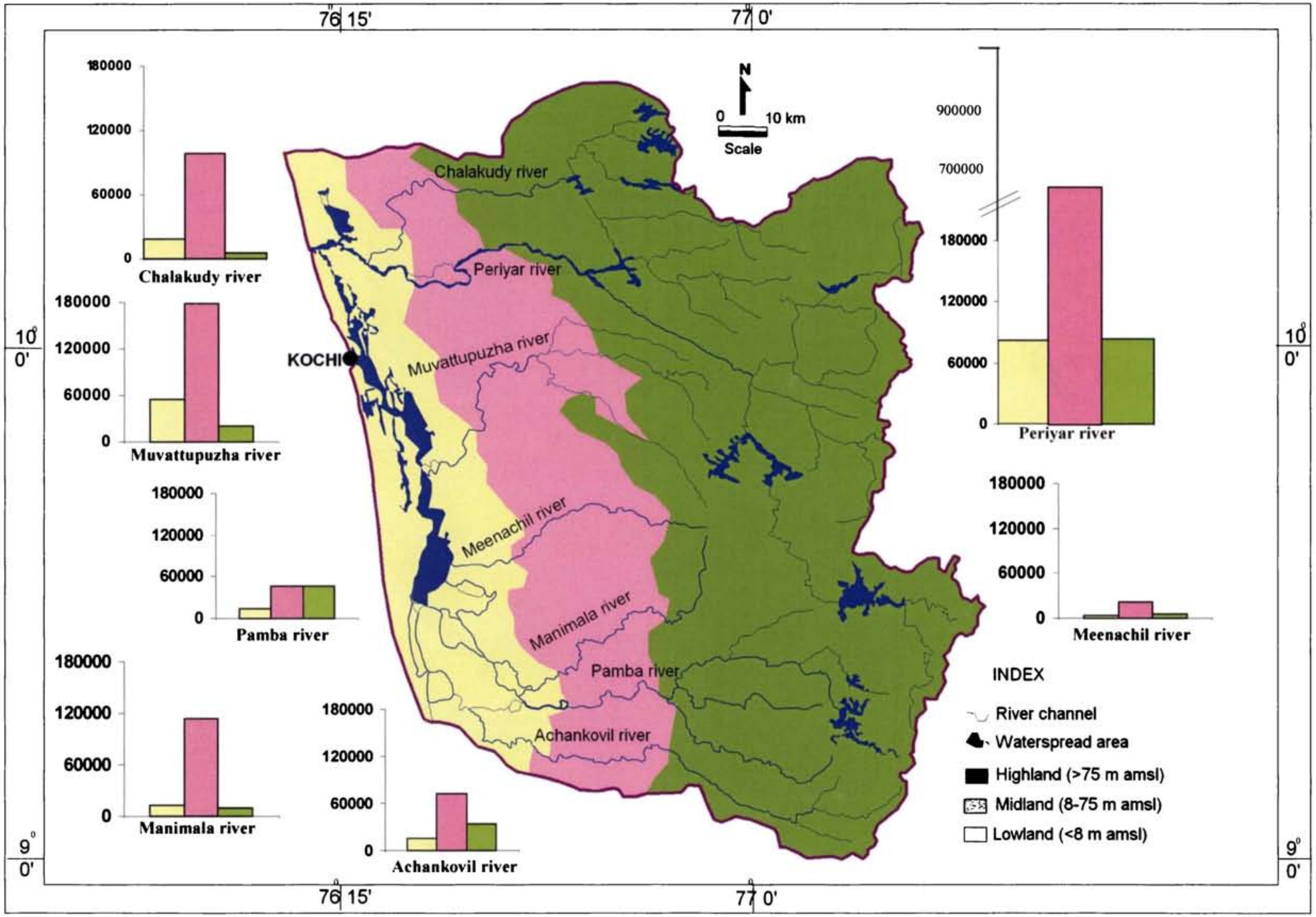


Fig. 6.13 Quantity of sand extraction from the river reaches falling within the highland, midland and lowland physiographic zones of the study area

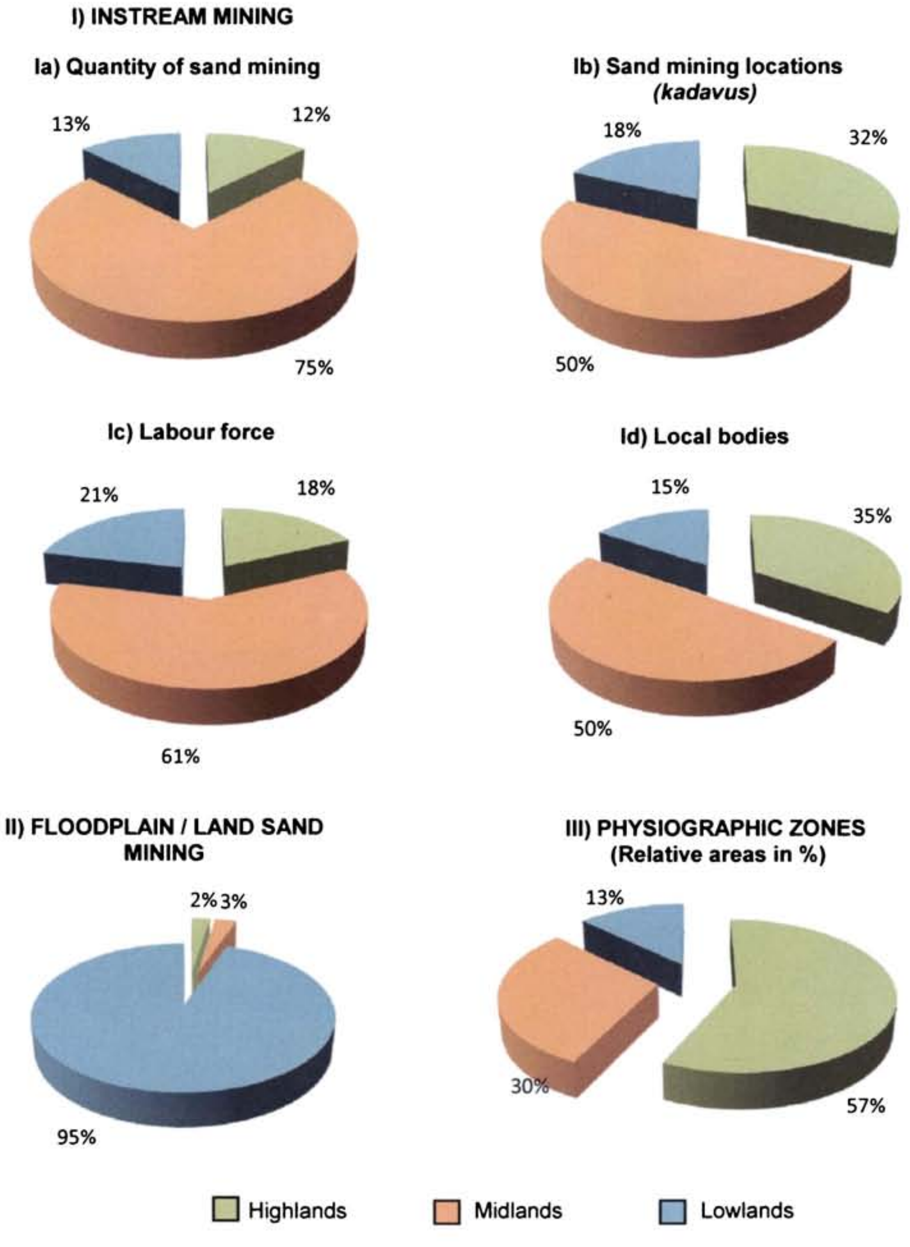


Fig. 6.14 Details of sand mining (instream and floodplain) within different physiographic zones in the study area

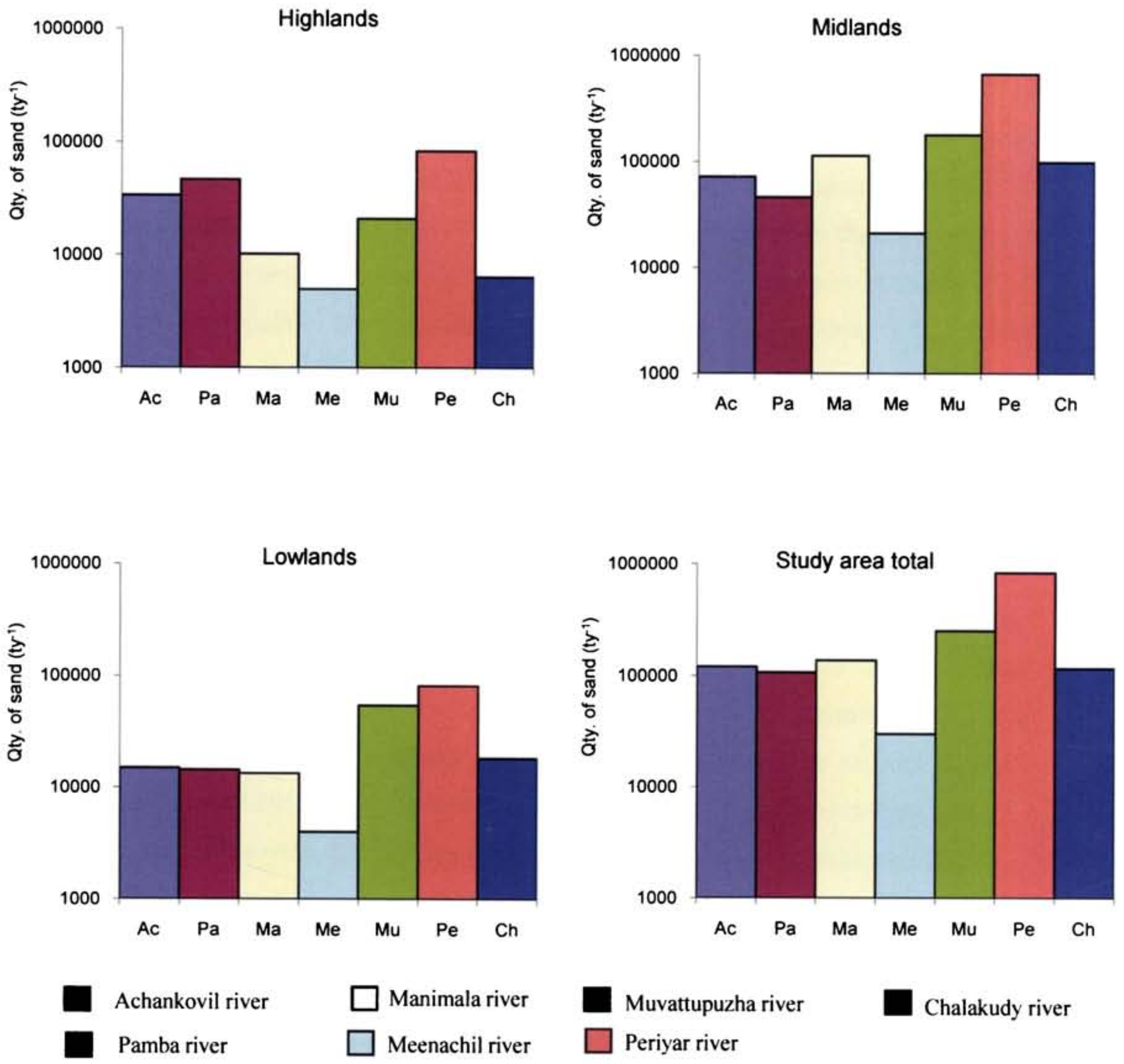


Fig. 6.15 Interbasinal comparison of sand mining in the study area

in the highlands are widely exploited for sand, except in the Achankovil river, where sand mining is confined to the main channel only. From Fig. 6.15, it is seen that a greater quantity of sand is mined from the midland part of the Periyar river (5.315 x 10^6 ty^{-1}) in spite of the less number of sand mining locations. The Periyar river accounts for about 55% of the total quantity of sand extracted from the midland region followed by Muvattupuzha (15%) and Manimala (9%) rivers. Mining of sand from the river channel in the midlands is in the increasing order of Meenachil < Pamba < Achankovil < Chalakudy < Manimala < Muvattupuzha < Periyar. Similarly in the lowlands, Periyar (40.52%) and Muvattupuzha (27.11%) rivers register the first and second positions in sand mining. The Chalakudy (9.14%), Achankovil (7.45%), Pamba (7.15%) and Manimala (6.65%) rivers exhibit the next successive positions in their ranks. The Meenachil river figures in the last position as it contributes only a minimal quantity (1.99%) of construction grade sand.

An intrabasinal comparison of the river basins shows that in the Achankovil river, the mining activities are severe in the midlands than the highlands and lowlands. Estimates show that, nearly 60% of the total quantity of sand extracted from the Achankovil river is from the midland part of the river channel. The amount of sand extraction is more (0.096 x 10^6 ty^{-1}) in the Thumpamon grama panchayat in the midlands. In the case of Pamba river, the highlands (0.374 x 10^6 ty^{-1}; 43%) and midlands (0.368 x 10^6 ty^{-1}; 42%) together constitute about 85% of the total quantity of sand extraction. Thottapuzhassery grama panchayat in the downstream part of the midlands contribute the maximum quantity of sand (0.12 x 10^6 $ty^{-1)}$ in the basin. A comparative evaluation of the quantity of sand mining among three physiographic zones of Manimala river basin reveals that more than 80% of the sand being mined is from its midlands. A quantity of 0.264 x 10^6 ty^{-1} of sand is extracted from the river channel flowing through Vellavoor grama panchayat in the midlands, which is the highest quantity in the basin. In Meenachil river basin, midlands contribute 70% of the total quantity of sand extracted out of the three physiographic regions. An amount of 0.032 x 10^6 ty^{-1} of sand is extracted from the Nattakom grama panchayat in the lowlands of the basin followed by 0.026 x 10^6 ty^{-1} from Ayarkunnam grama panchayat in the midlands. Like Meenachil river basin, out of the total quantity of sand extracted from the three physiographic zones of Muvattupuzha river, about 70% is from the midlands of the basin. The quantity of sand extraction is highest in the Piravom grama panchayat (0.216×10^6 ty^{-1}) in the downstream part of the midlands followed by Vellur and Thalayolaparambu grama panchayats (0.202×10^6 ty^{-1}) in which the latter is situated in the lowlands of the basin. In Periyar river basin, of the three physiographic provinces, midlands constitute 80% of the quantity of sand extraction. An amount of 0.96×10^6 ty^{-1} of sand is extracted from Kalady grama panchayat which is the highest in the basin. Nearly 84% of the total quantity of sand extracted is from the midlands of the Chalakudy river basin. In the Chalakudy river basin, the Melur grama panchayat constitutes the highest amount of sand extraction (0.176×10^6 ty^{-1}).

Table 6.13 shows the intensity of annual sand extraction from each river segment in the midlands. In the midland part of the Periyar river, the maximum amount of sand is extracted from the downstream channel segment between Kottamom and Thuruttu (0.175×10^6 $ty^{-1}km^{-1}$) followed by the upstream channel segment from Bhagavathikulam to Kottamom (0.06×10^6 $ty^{-1}km^{-1}$). Similarly in the Muvattupuzha river, the quantity of sand extraction is high (0.032×10^6 $ty^{-1}km^{-1}$) in the downstream segment between Pazhur and Vettikattumukku. A quantity of 0.031×10^6 $ty^{-1}km^{-1}$ of sand is extracted from the channel segment between Kanjirapalli and West Chalakudy in the midlands of Chalakudy river. In the Manimala river, the amount of sand extraction in the river reach between Kottangal to Madathumbhagom is to the tune of 0.025×10^6 $ty^{-1}km^{-1}$. In the Achankovil river, the quantity of extraction in the segment between Thumpamon to Venmoni is very high and is at a rate of 0.023×10^6 $ty^{-1}km^{-1}$. In the Pamba river, the rate of extraction is high in the upstream segment between Puthiyakavu temple to Malakkara (0.017×10^6 $ty^{-1}km^{-1}$). The quantity of sand extraction in the midland part of the Meenachil river is high in the river reach between Pala and Punnathara (0.003×10^6 $ty^{-1}km^{-1}$). From the analysis, it is clear that the rivers in the northern part of the study area (especially in the drainage basins of Muvattupuzha, Periyar and Chalakudy) centred around the major developmental centre Kochi City and its satellite towns, are affected by intense sand mining and hold a major share (~ 75%) in the amount of sand extraction. Also, the river channels, especially in the midland-lowland areas are under severe degradation due to indiscriminate mining activities.

Table 6.13 Intensity of annual sand extraction in the midlands of the rivers draining the Vembanad lake catchments

Sl.No.	River / River segments	Length (km)	Sand extraction ($x10^6 ty^{-1} km^{-1}$)
I	**Achankovil river**		
1.	Pramadom to Thumpamon	13.55	0.009
2.	Thumpamon to Venmoni	13.45	0.023
3.	Venmoni to Kunnam	10.75	0.011
II	**Pamba river**		
4.	Puthiyakavu temple to Malakkara	12.80	0.017
5.	Malakkara to Pandanad	13.30	0.012
III	**Manimala river**		
6.	Chenappadi to Kottangal	12.15	0.024
7.	Kottangal to Madathumbhagom	19.50	0.025
8.	Madathumbhagom to Kallungal	17.75	0.006
IV	**Meenachil river**		
9.	Kondur to Pala	10.20	0.005
10.	Pala to Punnathara	15.20	0.003
11.	Punnathara to Govindapuram	15.15	0.003
V	**Muvattupuzha river**		
12.	Muvattupuzha to Urayam	12.15	0.021
13.	Urayam to Pazhur	19.00	0.014
14.	Pazhur to Vettikkattumukku	14.25	0.032
VI	**Periyar river**		
15.	Bhagavathikulam to Kottamom	25.60	0.060
16.	Kottamom to Thuruthu	28.40	0.175
VII	**Chalakudy river**		
17.	Kanjirapalli to West Chalakudy	14.50	0.031
18.	West Chalakudy to Puvathissery	12.30	0.020

In addition to instream sand mining, a significant quantity of sand is extracted from the floodplains and / or overbank areas of the rivers as well. As the study area is subjected to tectonic uplifts in different geological periods, sand rich overbank areas and other wetlands exists even in certain regions of the midlands and highlands. The sand deposits in these areas are also extracted in addition to the floodplains in the lowlands. But the quantity of sand extracted from the former two cases is meager compared to the floodplain part of the lowlands (Fig. 6.14). Estimates show that the quantity of floodplain mining in the study area has increased notably from 2002-03 to 2006-07 consequent to the rise in demand of construction grade sand. The Muvattupuzha river basin holds a major stake (94%) in floodplain mining compared to the other rivers in the study area. The Achankovil, Pamba and Manimala river basins together accounts for 2% of floodplain sand extraction. The remaining 4% of the quantity of sand is contributed by rest of the river basins in the area.

Because of continued and indiscriminate sand mining, the sand resource in the study area has been decreased to a considerable extent. Also, sand mining can cause disruptions in the longitudinal connectivity of the rivers and alterations in the flow regime and sediment loads. It is well understood that when the extraction rate exceeds the replenishment rate, significant and potentially irreversible changes occur in the hydraulic conditions and channel stability (Kitetu and Rowan, 1997). This instability has already begun to surface in the form of environmental problems in the land, water and biotic systems of the area. Therefore, measures are to be taken to mitigate the impacts and reset all our developmental initiatives environment-inclusive. This is utmost essential to rescue the Kerala State - God's own country - from the potential environmental disaster that could be triggered by unscientific developments.

Chapter 7

ENVIRONMENTAL PROBLEMS AND DATA INTERPRETATION

7.1 Introduction

Large scale mining of sand and gravel several folds higher than the natural replenishments, has led to irreparable damages to the land, water, biotic and social / human environments related to many of the world's river systems. The problem is serious in the case of the rivers in the southwest coast of India, especially in Kerala, where the rivers are small with limited river bed resources. At the same time, the mining of sand is on the rise to meet its ever increasing demand in the construction sector. It is now widely realized that, in spite of the short term benefits, the indiscriminate sand mining from the rivers is detrimental to these life sustaining systems, in the long run. Moreover, the effects of instream sand mining may not be visible immediately because it requires continuous monitoring and takes a decade or more to surface and propagate the effects along the river channel in measurable units. In other words, mining may continue for years without apparent effects upstream or downstream, only to have geomorphic effects manifest later during high flows. Similarly, rivers are often said to have 'long memories', meaning that the channel adjustments to instream extraction or comparable perturbations may persist long after the activity has ceased (Kondolf, 1998a).

Sand mining disturbs the equilibrium of a river channel because it intercepts material load moving within a dynamic system and triggers an initial morphological response to regain the balance between supply and transport. Habitat alteration is also inevitable when morphological adjustments take place. Eventhough some literature exists on river sand mining, no detailed studies have hitherto been made to unfold its effects on physical, biological and social environments. Most of the better documented studies on the geomorphic effects of river sand mining have involved extraction rates lasting over a decade or more, resulting in large, measurable changes in channel form, that are quite enough to be clearly detected. Studies have documented the direct ecological effects of suspended sediments from sand mining sites, but the long term, indirect and cumulative effects of mining upon the food chain are harder to study, and have not really been tackled. To study site–specific effects of instream mining would require careful measurement of mining-induced changes to baseline conditions (Kondolf et al., 2002).

The present chapter deals with the effects of sand mining on various components of the river and its adjoining environments of the study area. The extent of these effects depends upon the type and scale of sand extraction, the channel's resistance to erosion, and watershed differences in hydrology and sediment transport. The various effects of sand mining encountered in the study area are numerous and the important ones are discussed in detail in the following sections with examples and / or case studies.

7.2 Changes in bed forms

The river channels are naturally modified into different bed forms depending on the changes in flow energy and sediment discharge. But the river systems of the study area especially in the midlands and lowlands, have notably changed due to anthropogenic activities rather than natural processes. The most destructive anthropogenic activity in the past 3-4 decades is the indiscriminate extraction of construction grade sand from the river channels and adjoining areas. A better understanding of the general distribution, sources and fates of sediments is necessary to discriminate the effects of sand mining from the other anthropogenic and natural processes.

River channels transport sediments and water from headwaters to its mouth. They are built up and maintained by erosion and deposition of sediments during river flows (Heede, 1986; Whiting, 1998). Current velocity varies from one part of a given cross-section to another. Most rivers experience a wide range of flows along its river course. In relatively undisturbed river systems a condition known as dynamic equilibrium exists where gradual erosion of outside bends of river meanders and deposition of eroded material on inside bends occurs. Lane in 1955 put forth the empirical relation $Q_S d \sim Q_W S$ to explain the dynamic equilibrium existing within alluvial channels. In this equation, Q_S is the quantity of sediment, d is the particle diameter or size of the sediment, Q_W is the water discharge and S is the slope of the stream (Lane, 1955). If any one of these four variables is altered, the river looses its equilibrium, which ultimately leads to channel instability. Channel stability in a given river reach occurs from a delicate balance among river flow, channel form, influx of sediment from the watershed and loss of sediment to downstream reaches. This 'conveyor belt' effect, where rivers transport eroded materials from headwaters toward the oceans, provides the necessary quantities and sizes of sediment during channel-forming flows such that channels remain in a dynamically stable condition (Kondolf, 1997).

Instream mining can result in channel instability through the direct disruption of pre-existing channel geometry or through the effects of incision and related undercutting of banks (Collins and Dunne, 1989). Mining aggravates widespread instability because the discontinuity in the sediment supply-transport balance tends to migrate upstream as the river bed is eroded to make up for the supply deficiency (Knighton, 1984). Thus sand mining from a relatively confined area triggers erosion of bed and banks, which in turn, increases sediment delivery to the site of original sediment removal. Bed degradation is caused by pit excavation and bar skimming, the two general types of sand mining. Bed degradation occurs through two primary means: headcutting and "hungry" water effects. In the first, excavation of a mining pit in the active channel lowers the stream bed, creating a nick point that locally steepens channel slope and increases flow energy (Kondolf 1998). During high flows, a nick point becomes a location of bed erosion that gradually moves upstream through headcutting (Bull and Scott 1974; Hartfield 1993; Kondolf 1997). Headcutting mobilizes substantial quantities of stream bed sediments that are then transported downstream to deposit in the excavated area and locations further downstream. Headcuts often move long distances upstream and into the tributaries (Hartfield 1993; Kondolf 1997). Of the two forms of bed degradation, headcutting is more recognizable in the field and represents greater risk to aquatic resources.

Among the two types of instream sand mining, pit excavation locally increases channel depth by creating deep pits (Fig. 7.1) and bar skimming increases channel width. Both conditions produce slower stream flow velocities and lower flow energies, causing

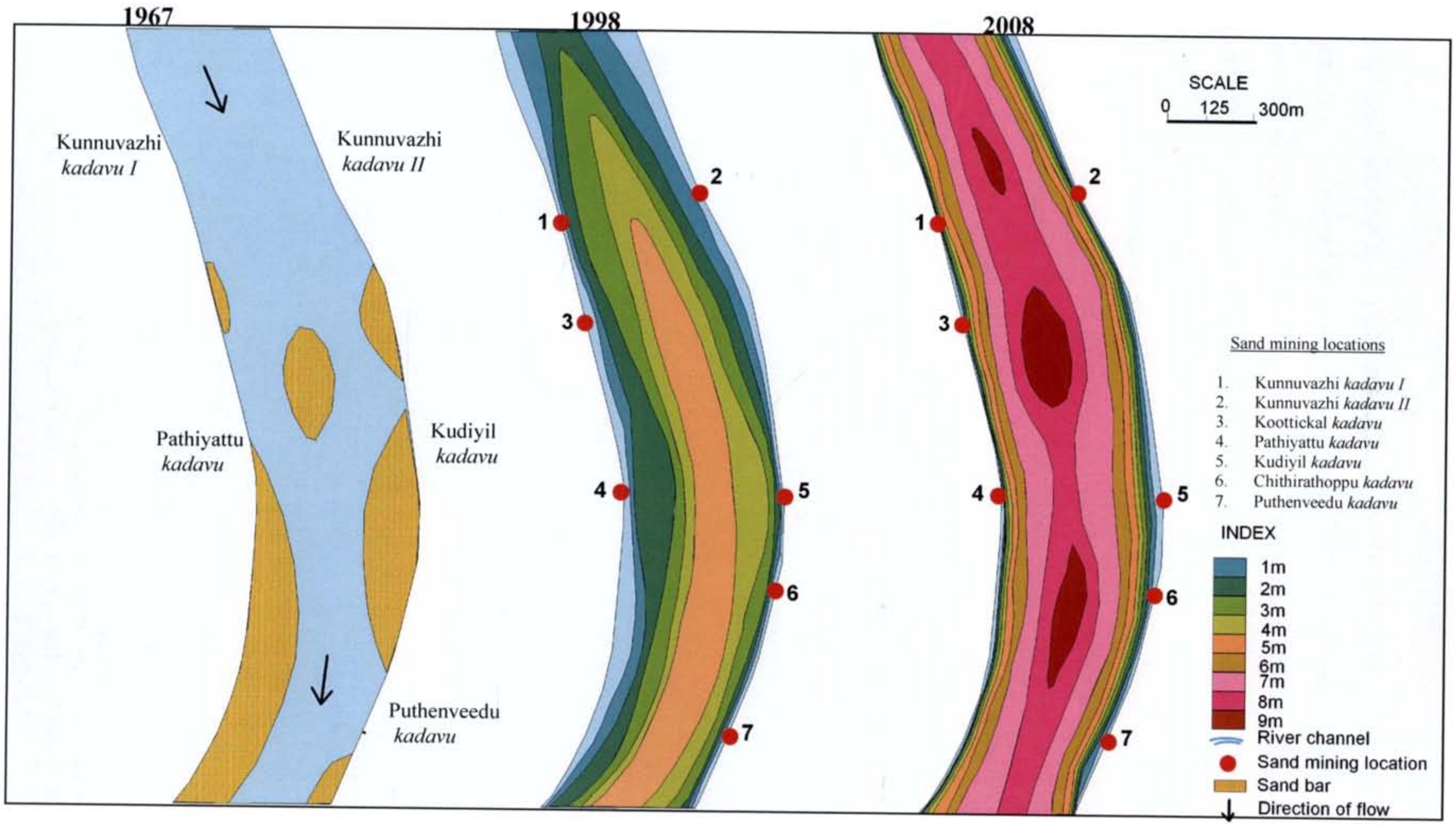


Fig. 7.1 **Changes in the bottom configuration of Periyar river consequent to indiscriminate sand mining in a stretch between Vazhakkulam and Sreemoolanagaram**

sediments arriving from upstream to deposit at the mine site. As stream waters leave the area, the flow energy increases in response to the "normal" channel flow downstream, the amount of transported sediments leaving the site is now less than the sediment carrying capacity of the flow. This sediment-deficient flow of 'hungry' water picks up more sediment from the stream reach below the mine site, furthering the bed degradation process. This condition continues until the balance between input and output of sediments in the site is re-established (Williams and Wolman, 1984; Kondolf, 1997). The interplay of these two means of bed degradation and consequent river bed lowering will be visible even in the mining prohibited areas of bridges and water intake structures. Plate 7.1 is a typical evidence of erosion of sand from prohibited areas of Ranni bridge in Pamba river (downstream view; photograph is taken from the bridge) and water intake structure at Thelappuzha *kadavu* (Anicaud grama panchayat) in Manimala river due to clandestine sand mining from the downstream reaches of these rivers over the years.

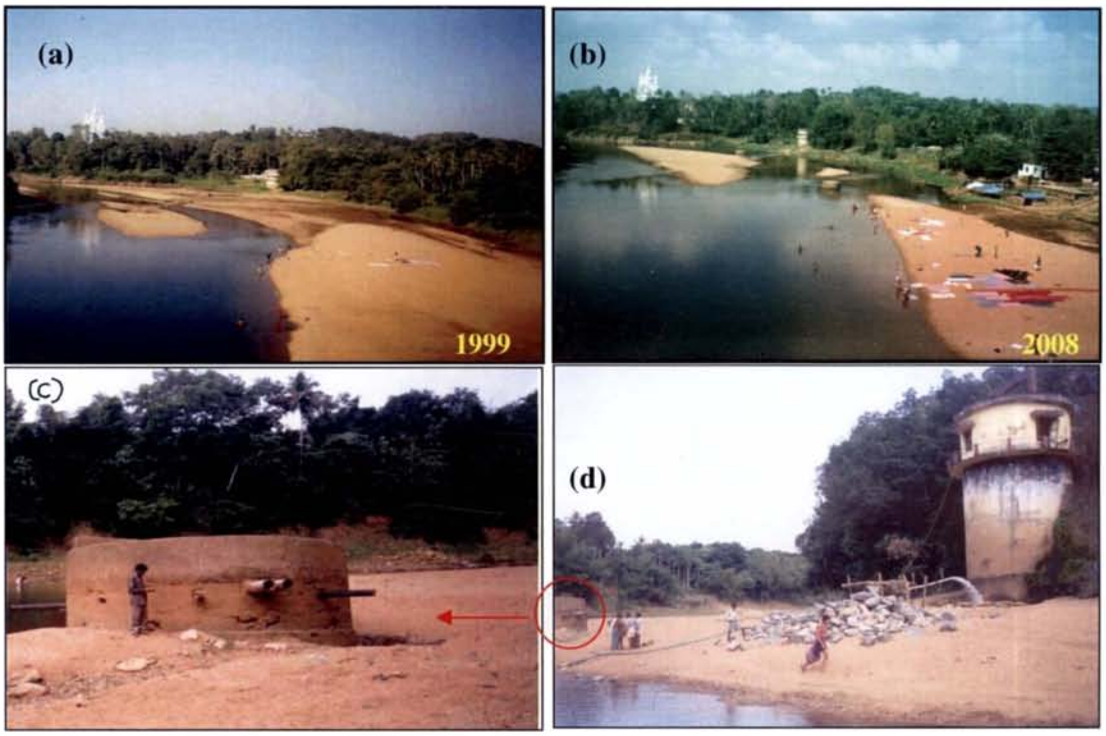


Plate 7.1 Erosion of sand and channel incision are the direct effects of clandestine river sand mining from the downstream reaches. Many of the structures constructed for rural water supply schemes and pier foundations of bridges are affected by this process. (a) and (b) Decadal change in river bed morphology and channel incision noticed in Pamba river; (c) The exposed water intake structure in the Manimala river bed near Anicaud panchayat; (d) Direct pumping of water is in progress.

The shape of the cross-section of a river channel in a given site is a function of flow velocity, the quantity and character of the sediment in movement through cross-section, and the character of the materials that make up the river bank and bed of the channel (Leopold et al., 1964). The following section deals with systematic analysis of river cross-section data to understand the changes occurred in the bed profile during the last two decades. Data on water and sediment discharges and cross profile measurements obtained from the Central Water Commission's (CWC) gauging stations are used extensively for the study. River gauging stations of CWC are located at Thumpamon in Achankovil river, Malakkara in Pamba river, Kallooppara in Manimala river, Kidangoor in Meenachil river, Ramamangalam in Muvattupuzha river, Neeleeswaram in Periyar river and Arangali in Chalakudy river.

The CWC gauging station in the Achankovil river at Thumpamon is located about 38 km upstream of the river confluence with Pamba river at Viyapuram. Data for the period of 1980-2005 has been analysed to know about the extent of channel incision due to sand mining. Fig. 7.2 shows the bed changes in the cross-sectional profiles of the river during the period 1980-2005. The average rate of channel incision and the incision noticed in the deepest point in the river at the gauging station (i.e., 80 m from the reference point of CWC station) are shown in Fig. 7.2 b and c. During 2005, the deepest point in river bed was at 6.32 m above msl during 1980 which sunk to the level of 3.72 m amsl (net incision: 2.6 m). The mean channel incision estimated for the entire section was 160 cm (rate of incision: 6.4 cmy^{-1}) during the period 1980-2005. The rate of incision was a maximum of 11.14 cmy^{-1} during the period 1985-90, which was almost double the rate of channel incision recorded during the previous period (i.e., 1980-85; rate of channel incision: 5.26 cmy^{-1}). The river bed subsided 9.52 cmy^{-1} during the next 5 year period. Surprisingly, the rate of incision was minimal (1.08 cmy^{-1}) during 1995-2000 period because of stringent regulatory efforts enforced by the District Administration. A detailed yearly analysis reveals that, on an average, the river bed at Thumpamon is getting lowered at a rate of 5.04 cmy^{-1} during the period 2000-04 and the year 2005 witnessed a period of sand deposition. The deepest point in the channel exhibited almost

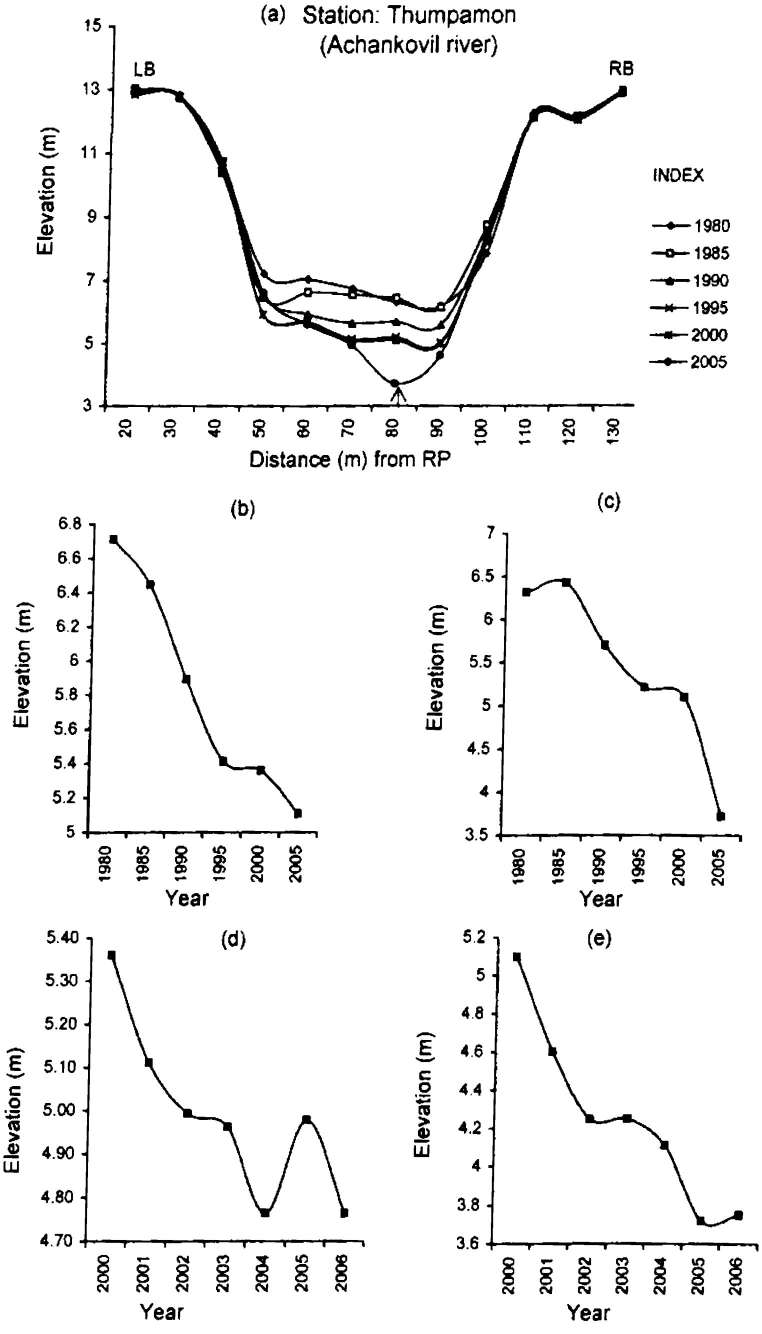


Fig. 7.2 Channel cross-profile changes noticed in the Achankovil river at Thumpamon CWC gauging station. (a) River bed lowering of Achankovil river during 1980-2005; (b) Average bed lowering estimated for the entire cross section during 1980-2005; (c) Bed lowering noticed at the deepest point of the channel (80 m) away from RP of CWC during 1980-2005; (d) Yearly average bed lowering during the period 2000-2006; (e) Yearly bed lowering in the deepest point during the period 2000-2006. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. *(Data source: Central Water Commission (CWC), Kochi)*

stabilization during 2005-06. Fig. 7.2 e depicts the channel incision noticed in the deepest point of the channel during 2000-06.

The changes noticed in cross-sectional profiles of the Pamba river at CWC gauging station, Malakkara (located about 27 km upstream of the river confluence with Achankovil and Manimala rivers at Mannar) is presented in Fig. 7.3. The channel incision noticed in the deepest point at 80 m from the reference point of CWC is given in Fig. 7.3 c. This point was at 0.75 m below msl (i.e., -0.75 m) during 1985, which was lowered (incision) to about 2.43 m and touched 3.18 m below msl (i.e., -3.18 m) during 2005. On an average, the river bed has lowered to 212 cm (rate of incision = 10.63 cmy^{-1}) during 1985-2005. A detailed analysis shows that the period 1985-90, witnessed a low rate of channel incision (2.98 cmy^{-1}) which changed markedly during 1990-95 with a rate of incision of 20.98 cmy^{-1}. In the subsequent 5 year period (1995-2000), the rate of channel incision was reduced marginally with a lowering of 15.48 cmy^{-1}. The pace of incision was reduced further during the period 2000-05 (3.06 cmy^{-1}). The continued and devoted works of NGO's like Pampa Parirakshina Samithi (PPS), District Administration, etc. were responsible for the awareness creation and effective enforcement of the sand mining law and regulations in the Pamba basin. The detailed yearly analysis carried out during the period 2000-06 reveals minor aggradation of bed materials in the year 2001, followed by bed erosion till 2004. Like Achankovil river, the Pamba river also shows an aggradational phase for about 14 cm in the year 2005, followed by an erosive phase in 2006. The deepest point located at 80 m away from the reference point of CWC shows a lowering trend except for minor aggradational events in 2001 and 2004.

The cross-profile measurements of Manimala river at CWC gauging station, Kallooppara show that the river bed is getting lowered at notable levels during the period 1990-2005 (Fig. 7.4). The gauging station is located about 20 km upstream of river confluence with the Pamba river near Thiruvalla. Fig. 7.4 b presents the extent of channel incision noticed at the river gauging station. The river bed was lowered to 169 cm during the last 15 years with an average of 11.27 cmy^{-1}. The rate of incision was 13.84 cmy^{-1}

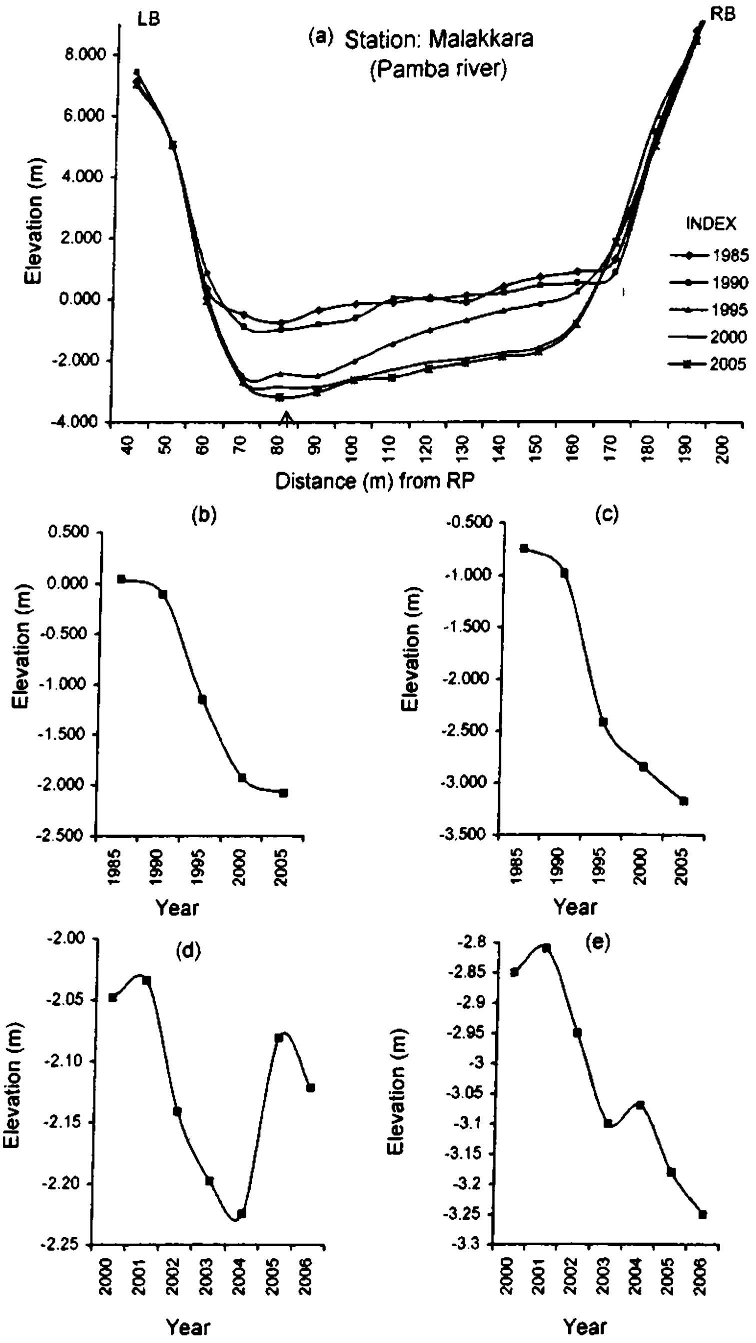


Fig. 7.3 Channel cross-profile changes noticed in the Pamba river at Malakkara CWC gauging station. (a) River bed lowering of Pamba river during 1985-2005; (b) Average bed lowering estimated for the entire cross section during 1985-2005; (c) Bed lowering noticed at the deepest point of the channel (80 m) away from RP of CWC during 1985-2005; (d) Yearly average bed lowering during the period 2000-2006; (e) Yearly bed lowering in the deepest point during the period 2000-2006. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. *(Data source: Central Water Commission (CWC), Kochi)*

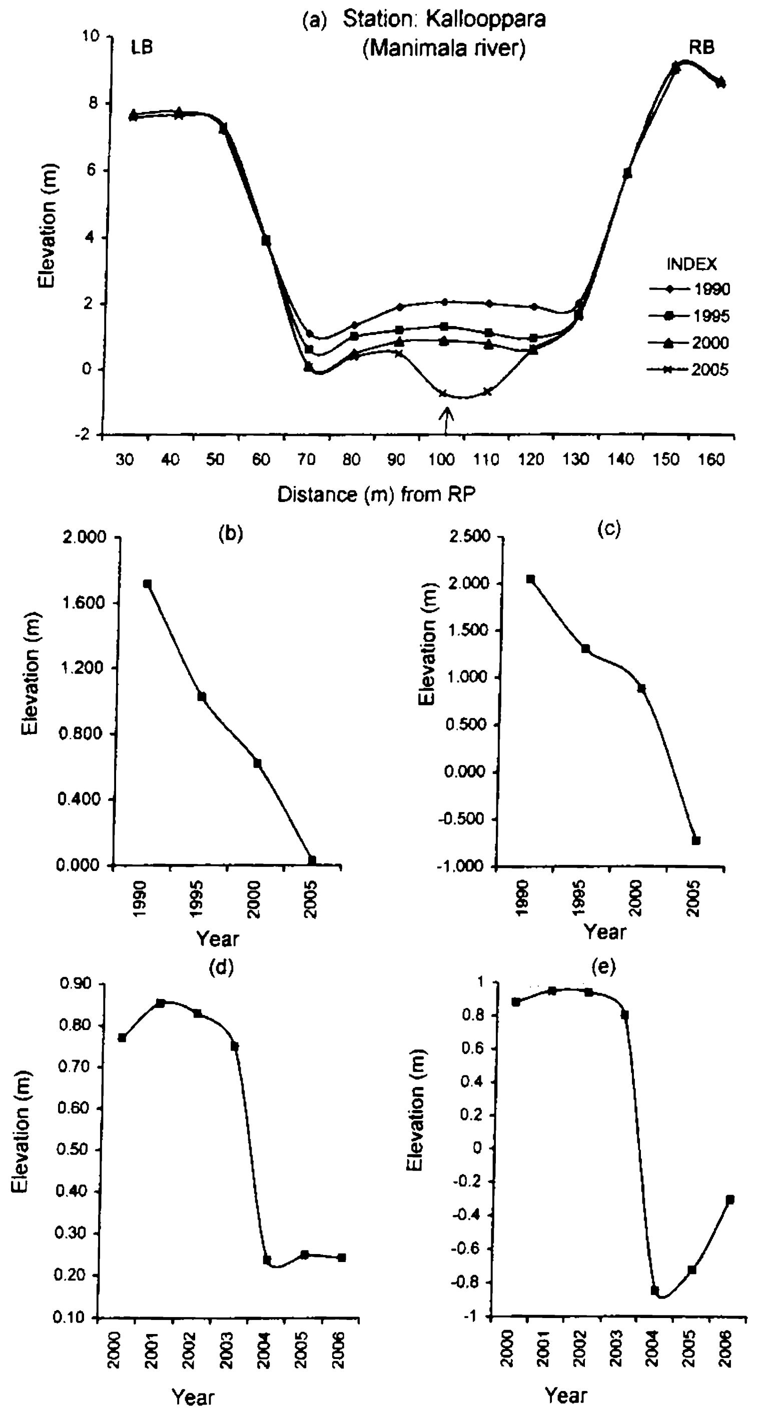


Fig. 7.4 Channel cross-profile changes noticed in the Manimala river at Kallooppara CWC gauging station. (a) River bed lowering of Manimala river during 1990-2005; (b) Average bed lowering estimated for the entire cross section during 1990-2005; (c) Bed lowering noticed at the deepest point of the channel (100 m) away from RP of CWC during 1990-2005; (d) Yearly average bed lowering during the period 2000-2006; (e) Yearly bed lowering in the deepest point during the period 2000-2006. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. *(Data source: Central Water Commission (CWC), Kochi)*

during the period 1990-95. But, in the next 5-year period (i.e., 1995-2000), the channel erosion was reduced substantially and the incision was to the tune of 8.14 cmy^{-1}. During 2000-05, the channel incision was again increased marginally with a rate of 11.82 cmy^{-1}. In Manimala river, the point 100 m from the reference point of CWC gauging station was the deepest point. The channel incision noticed at this point is presented in Fig. 7.4 c. The deepest point in the river bed was at 2 m above msl in the year 1990. The river bed has been lowered to 0.7 m below msl (i.e., -0.7 m) in 2005. During the period 2000-05, the river recorded the maximum channel incision of 32.1 cmy^{-1}. The detailed yearly analysis of Manimala river for the period 2000-06 for the entire cross-section and the deepest point is given in Fig. 7.4 d and e, respectively. During the period 2003-04, the river bed has been degraded to its maximum extent (channel incision = 51 cm).

In Meenachil river, the cross-profile measurements at CWC gauging station, Kidangoor (located about 24 km upstream of the river confluence with Vembanad lake) have been studied for assessing the extent of channel incision consequent to indiscriminate sand mining. Fig. 7.5 shows the cross-profile variations of Meenachil river for the period 1986-2005. The general trend of river bed lowering is given in Fig. 7.5 b. The net channel incision during the period 1986-2005 was 324 cm with a rate of incision of 16.19 cmy^{-1}. The deepest point in the river channel was located at 40 m away from the reference point of CWC station working at Kidangoor. The channel incision recorded at this point is shown in Fig 7.5 c. This point was 1 m above msl in 1986 and later lowered to 2 m below msl (i.e., -2 m) in 2005. Compared to the other rivers in the study area, the rate of incision was far higher in Meenachil river during the period 1986-1990 with a rate of 19.75 cmy^{-1}. However, the rate of incision dipped to 4.46 cmy^{-1} during 1990-95, perhaps due to the strict enforcement of the rules and regulations of river sand extraction by the District Administration. It is quite interesting to note that during the period 1995-2000, the incision rate attained its maximum level of 27.48 cmy^{-1} which was six times higher than that in the previous period. During the period 2000-05, the rate of channel incision again decreased to 13.06 cmy^{-1}. The deepest point also behaves in the same fashion as that of the average cross profile measurements. The detailed yearly analysis

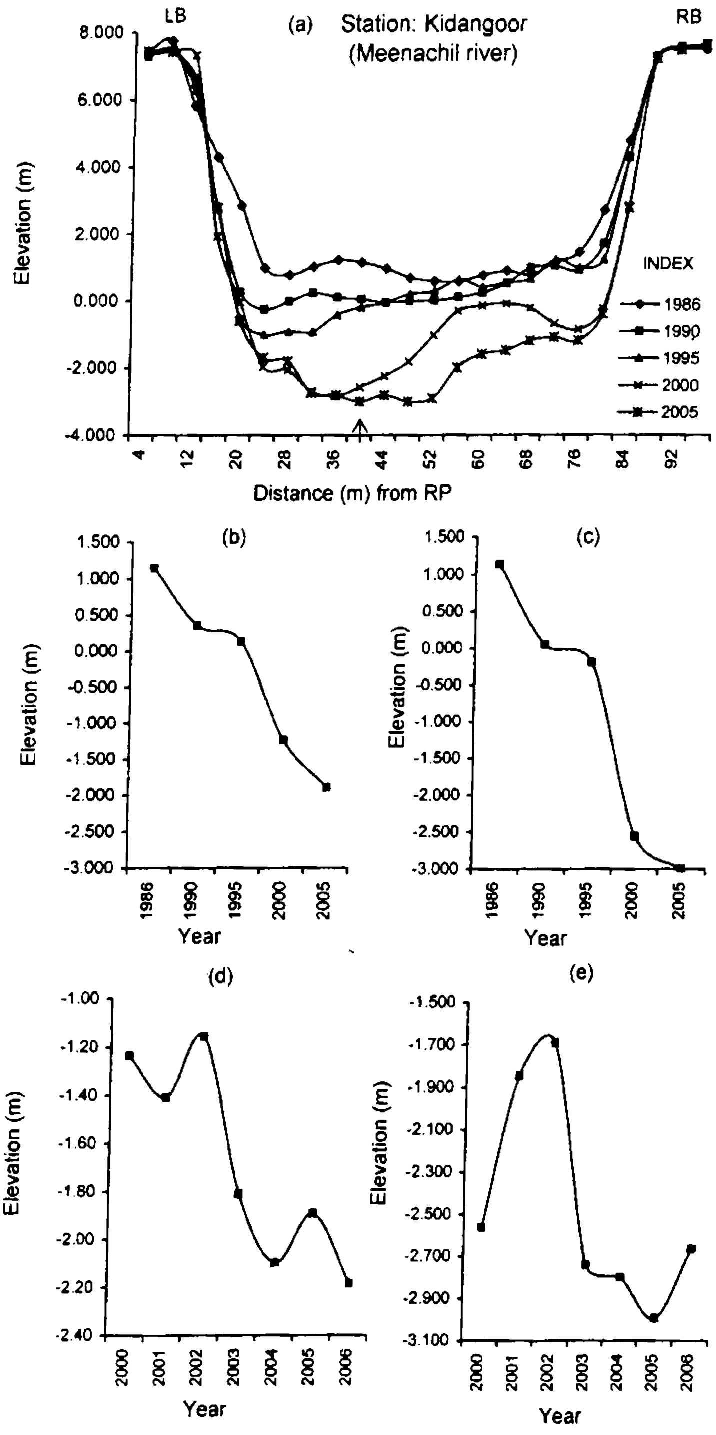


Fig. 7.5 Channel cross-profile changes noticed in the cross section of Meenachil river at Kidangoor CWC gauging station. (a) River bed lowering of Meenachil river during 1986-2005; (b) Average bed lowering estimated for the entire cross section during 1986-2005; (c) Bed lowering noticed at the deepest point of the channel (40 m) away from RP of CWC during 1986-2005; (d) Yearly average bed lowering during the period 2000-2006; (e) Yearly bed lowering in the deepest point during the period 2000-2006. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. *(Data source: Central Water Commission (CWC), Kochi)*

carried out for the entire cross-section and the deepest point for the period 2000-06 is given in Fig. 7.5 d and e. Fig. 7.5 d shows cycles of erosion and deposition in the consecutive years 2000-02 and 2004-06. The channel incision was noticed at maximum level during 2002-04. At the same time, the deepest point 40 m away from reference point shows an aggrading trend during 2000-02 and 2005-06 periods.

Fig. 7.6 shows the river bed changes noticed in the CWC gauging station of Muvattupuzha river at Ramamangalam, located ~ 35 km upstream of the Ittupuzha distributary confluence with the Vembanad lake. The general trends of channel incision for the entire cross-section as well as the deepest point in the river cross-section (80 m from zero reference point of CWC) are represented in Fig. 7.6 b and c. On an average, the river bed has lowered to 105 cm during 1986-2005 period with a rate of incision of 5.24 cmy^{-1}. The rate of incision was 5.5 cmy^{-1} during the period 1986-90. But the pace of channel incision marginally declined (4.2 cmy^{-1}) in 1990-95. During the period 1995-2000, the river bed has lowered to its maximum level with a rate of 9.4 cmy^{-1}. The rate of incision has again decreased to 6.6 cmy^{-1} during 2000-05. The deepest point in the river showed a marginal aggradation of 3.13 cmy^{-1} during the period 1986-1990 (Fig 7.6 c). But, the successive 5-year periods of assessment showed erosion of river channel at a rate of 5.1, 15.4 and 3.6 cmy^{-1} during 1990-95, 1995-2000 and 2000-05, respectively. Fig. 7.6 d and e represents detailed yearly assessments carried out for the entire cross-section of the channel and the deepest point during the period 2000-06. Though the river bed shows deposition or bed stabilization for certain short periods, the net effect is erosion (channel incision) of the river channel. A similar, but more pronounced effect is observed in the deepest point in the channel section, as well.

The analysis of cross-profile data of the Periyar river for the period 1980-2005 monitored at the CWC gauging station, Neeleeswaram located at 50 km upstream of the river mouth is given in Fig. 7.7. The river bed has been lowered to 296 cm with an estimated average incision rate of 11.84 cmy^{-1} during the period 1980-2005. The deepest point in the channel cross-sectional profile was sited at 80 m from the reference point of CWC. The trend of channel incision in the deepest point is given in Fig. 7.7 c. In the year

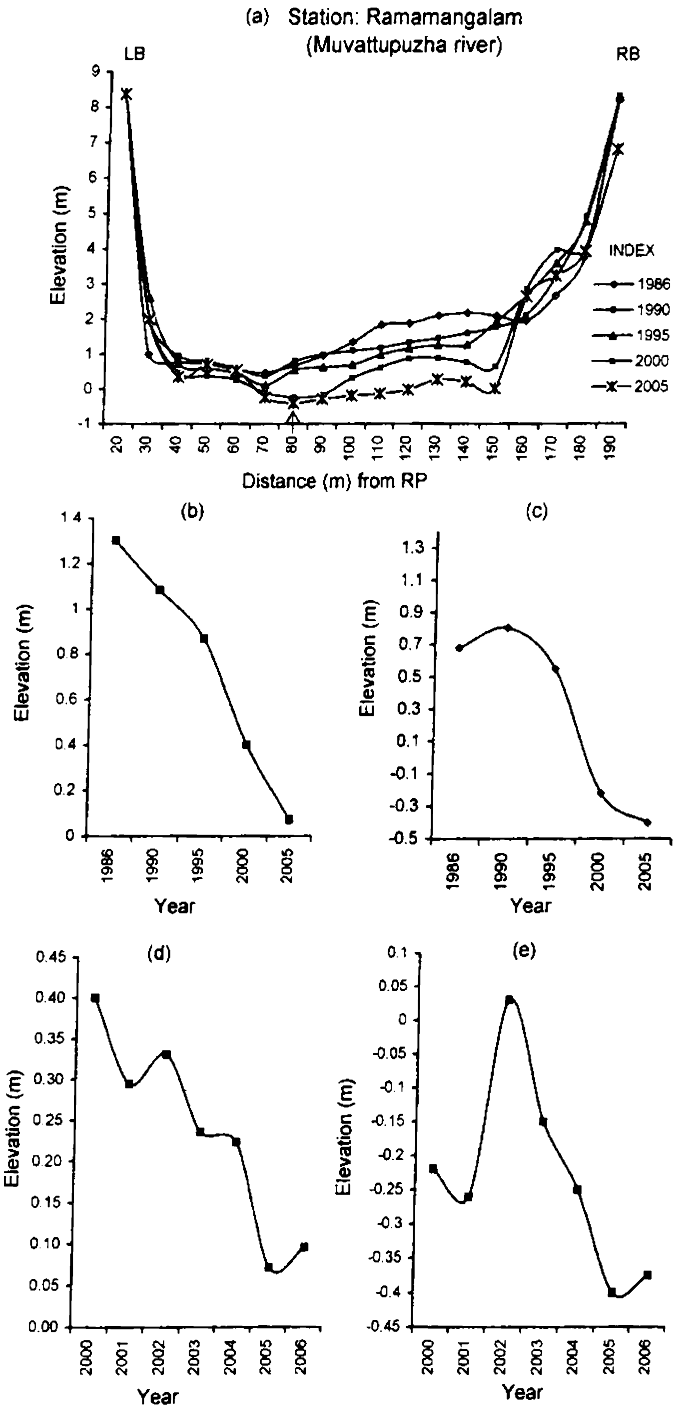


Fig. 7.6 Channel cross-profile changes noticed in the Muvattupuzha river at Ramamangalam CWC gauging station. (a) River bed lowering of Muvattupuzha river during 1986-2005; (b) Average bed lowering estimated for the entire cross sectionduring 1986-2005; (c) Bed lowering noticed at the deepest point of the channel (80 m) away from RP of CWC during 1986-2005; (d) Yearly average bed lowering during the period 2000-2006; (e) Yearly bed lowering in the deepest point during the period 2000-2006. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. *(Data source: Central Water Commission (CWC), Kochi)*

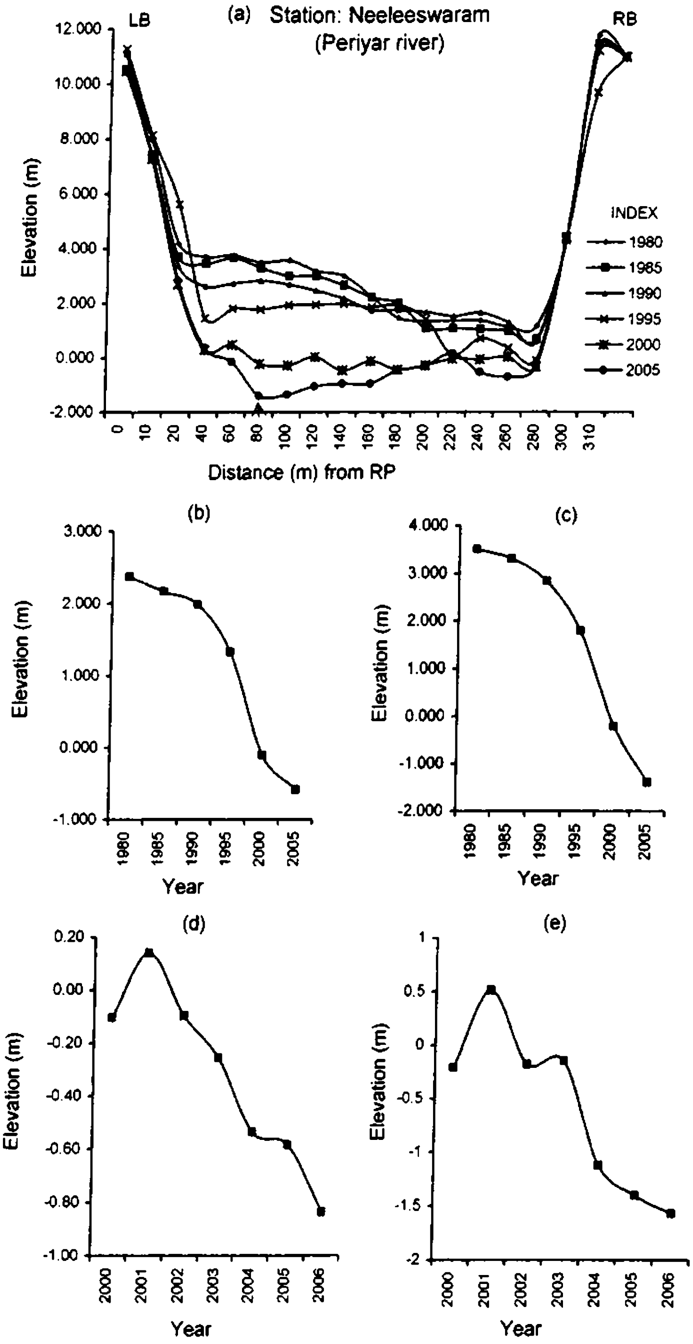


Fig. 7.7 Channel cross-profile changes noticed in the cross section of Periyar river at Neeleeswaram CWC gauging station. (a) River bed lowering of Periyar river during 1980-2005; (b) Average bed lowering estimated for the entire cross section during 1980-2005; (c) Bed lowering noticed at the deepest point of the channel (80 m) away from RP of CWC during 1980-2005; (d) Yearly average bed lowering during the period 2000-2006; (e) Yearly bed lowering in the deepest point during the period 2000-2006. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. *(Data source: Central Water Commission (CWC), Kochi)*

1980, this point was at 3.5 m amsl and later lowered to 1.4 m below mean sea level (i.e., -1.4 m). Analysis of the cross-sectional profile measurements shows that the rate of channel incision was 4.1 cmy^{-1} and 3.64 cmy^{-1} during the periods 1980-85 and 1985-90, respectively. In the subsequent 5 year periods, the rate of incision increased to about 3 times during 1990-95 (13.2 cmy^{-1}) and 7 times during 1995-2000 (28.64 cmy^{-1}) compared to the rate of incision of 1985-90 period. During the period 2000-05, the channel incision rate decreased considerably (9.64 cmy^{-1}) than the previous 5-year period (i.e.1995-2000). The deepest point also showed the same trend as that of the average channel incision. The detailed yearly analysis for the period 2000-06 for the entire cross-section and the deepest point is presented in Fig. 7.7 d and e, respectively. A small peak of deposition is observed in both the figures in the year 2001. After that, the river bed has been subjected to continuous erosion from 2002 to 2006. The same trend has observed in the deepest point as well, with an exception in the year 2003.

Channel bed changes of the Chalakudy river observed during the period 1985-2005 at the Arangali CWC gauging station, located about 27 km upstream of the confluence point with the river Periyar is given in Fig. 7.8. The analysis of the cross profile changes of Chalakudy river is performed in slightly different way from the other rivers in the study area. The river has a well developed sand bar – the Arangali sand bed - at this station, which is protected by the Non-Governmental Organisations (NGO's) in the area. Since the sand bed is almost stable throughout the observation period, two types of analyses are carried out to find out the actual rate of channel incision – (1) Analysis of cross-section including sand bed (i.e. the entire cross section) and (2) Analysis excluding the sand bed (i.e., the channel portion from 110 m to 200 m with respect to reference point of CWC). Fig. 7.8 b-d represents the channel incision analysed for the entire cross-section with sand bed and without sand bed (110 m - 200 m), respectively. The rate of incision during the period 1985-90 in the entire cross-section was 4.46 cmy^{-1} and was double the rate in the cross-section without sand bed (8.68 cmy^{-1}). Similar trends have been observed except for the period 1995-2000 where not much variation occurred in the net channel incision. The channel incision is not much pronounced when the entire cross-

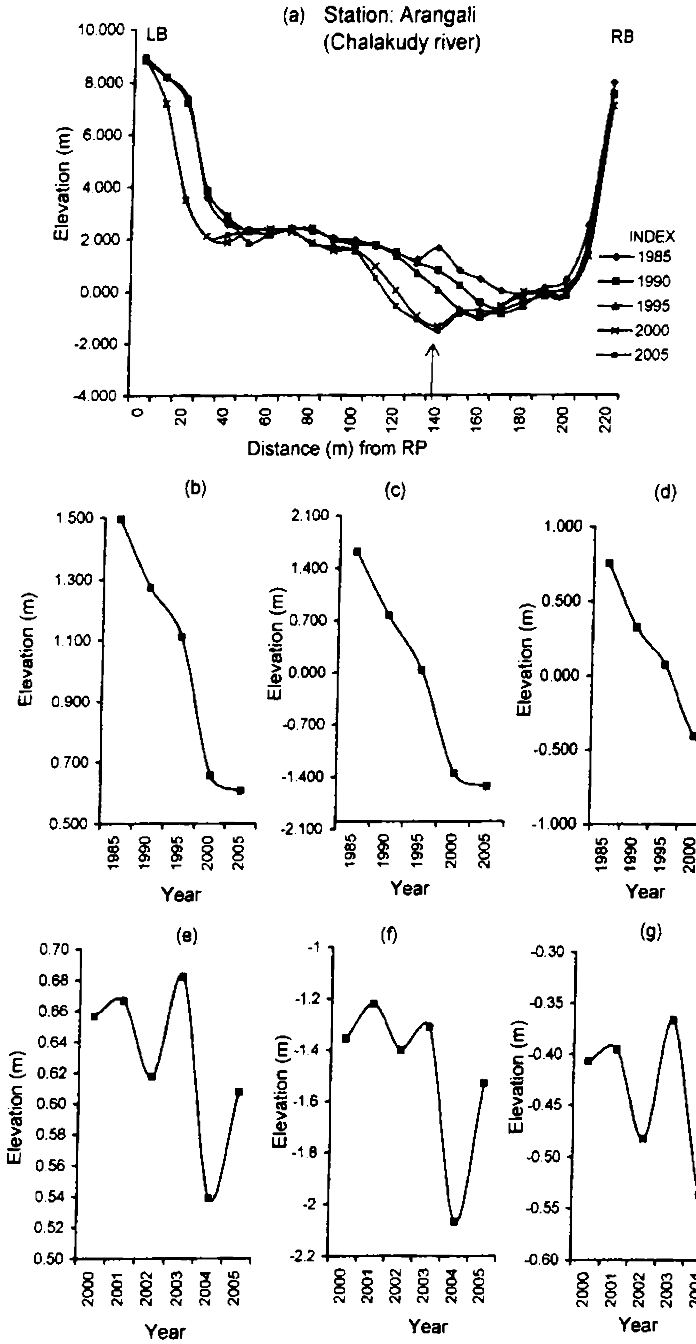


Fig. 7.8 Channel cross-profile changes noticed in the Chalakudy river at Arangali CWC gauging station. (a) River bed lowering of Chalakudy river during 1985-2005; (b) Average bed lowering estimated for the entire cross section with sand bed during 1985-2005; (c) Average bed lowering in the deepest point of the channel (140 m) away from RP of CWC during 1985-2005; (d) Average bed lowering estimated for the active channel between 110 m and 200 m away from RP of CWC during 1985-2005; (e) Yearly bed lowering during the period 2000-2005; (f) Yearly bed lowering in the deepest point during the period 2000-2005; (g) Yearly bed lowering along the active channel between 110 m and 200 m away from RP during 2000-2005. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. *(Data source: Central Water Commission (CWC), Kochi)*

section including the sand bed is taken into consideration. Like Meenachil, Muvattupuzha and Periyar rivers, this river also experienced maximum incision during the period 1995-2000. The deepest point in the river channel sited was at 140 m from the reference point of CWC. Fig. 7.8 c shows the channel incision noticed in the deepest point during 1985-2005. During the period of observation this point was 1.6 m amsl in the year 1985 which sunk to 1.5 m below msl (i.e., -1.5 m) in the year 2005. The detailed yearly analysis of river bed changes carried out for the river including sand bed, deepest point and active channel excluding sand bed during the period 2000-05 are given in Fig. 7.8 e-g. The analysis shows that there is a similar trend in the behaviour in the cross sections with sand bed, without sand bed and the deepest point. The maximum incision of the bed was observed during the period 2003-04.

The rivers in the Vembanad lake catchments exhibit marked changes in their bed profiles over the years consequent to human interventions, especially river sand mining and construction of impoundments. The cross-profile measurements for the period 1990-95 reveal that the sand bed of Pamba river has lowered to 105 cm with an average incision rate of 20.98 cmy^{-1} (Table 7.1).

Table 7.1 Channel incision (cmy^{-1}) in the storage zones of the rivers in the study area

Sl.No.	River	Channel incision (cmy^{-1})				
		1980-85	1985-90	1990-95	1995-2000	2000-2005
1	Achankovil	5.26	11.14	9.52	1.08	5.04
2	Pamba	NA	2.98	20.98	15.48	3.06
3	Manimala	NA	NA	13.84	8.14	11.82
4	Meenachil	NA	19.75	4.46	27.48	13.06
5	Muvattupuzha	NA	5.50	4.20	9.40	6.60
6	Periyar	4.10	3.64	13.20	28.64	9.64
7	Chalakudy	NA	4.46	3.24	9.08	1.00

The lowest rate of channel incision was noticed in the Muvattupuzha river (4.2 cmy^{-1}) during the period 1990-95 The next five year period (1995-2000) witnessed maximum channel incision in the river Periyar (28.64 cmy^{-1}) followed by Meenachil river (27.48 cmy^{-1}). The channel incision in the other rivers are in the order Pamba > Muvattupuzha > Chalakudy > Manimala > Achankovil (Table 7.1). It is quite interesting to note that after the year 2000 (during 2000-05), the rate of channel incision has been substantially reduced nine times in Chalakudy river, five times in Pamba river, three times in Periyar river, two times in Meenachil river and less than two times in Muvattupuzha river with respect to 1995-2000 period. It can be related to the effective regulatory measures taken by Government after the implementation of 'Kerala Protection of River Banks and Regulation of Removal of Sand Act, 2001'. At the same time, the rate of channel incision has been increased in the Achankovil and the Manimala rivers. The maximum rate of channel incision observed was in the Meenachil (13.06 cmy^{-1}) river during the period 2000-05 compared to other rivers (Table 7.1).

All the rivers in the study area are subjected to unabated instream sand mining over the years. However, the other human interferences like construction of reservoirs, check dams, etc., can also induce changes to the river bed characteristics including channel incision. The present level of bed degradation noticed in the rivers in the Vembanad lake catchments is mainly due to sand mining. This is because the scale of sand extraction exceeds many folds higher than the natural replenishment (See Chapter 6; section 6.6). The positive correlation existing between the quantity of sand mining and the rate of channel incision (r = 0.79; Fig. 7.9) reiterates this view.

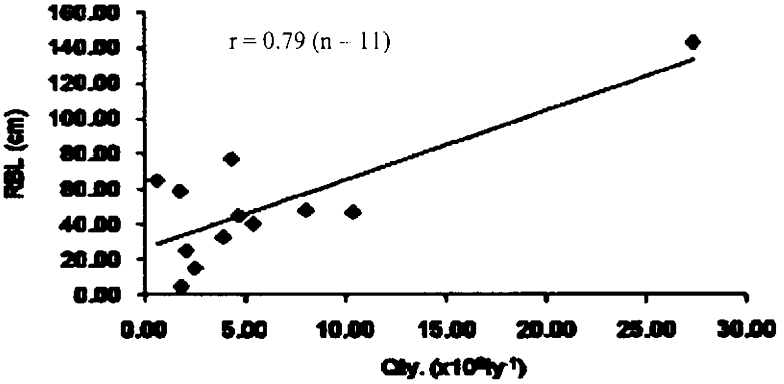


Fig. 7.9 Interrelationship between quantity of sand mining and river bed lowering noticed in the rivers draining the Vembanad lake catchments

Indiscriminate sand extraction from the river beds often aggravates bank erosion incidences (US Army Corps of Engineers, 1981; Neill and Yaremko, 1989). Mining reduces the strength of river banks and resistance to erosion by enlarging channel cross-sections and by damages to bank integrity and riparian vegetation at access points. A case of bank erosion in the Muvattupuzha river noticed by Ramamangalam CWC gauging station (185 - 190 m away from the reference point of CWC) is illustrated in Fig. 7.10. It can be seen that the right bank of Muvattupuzha river has been degraded in recent years consequent to indiscriminate sand mining.

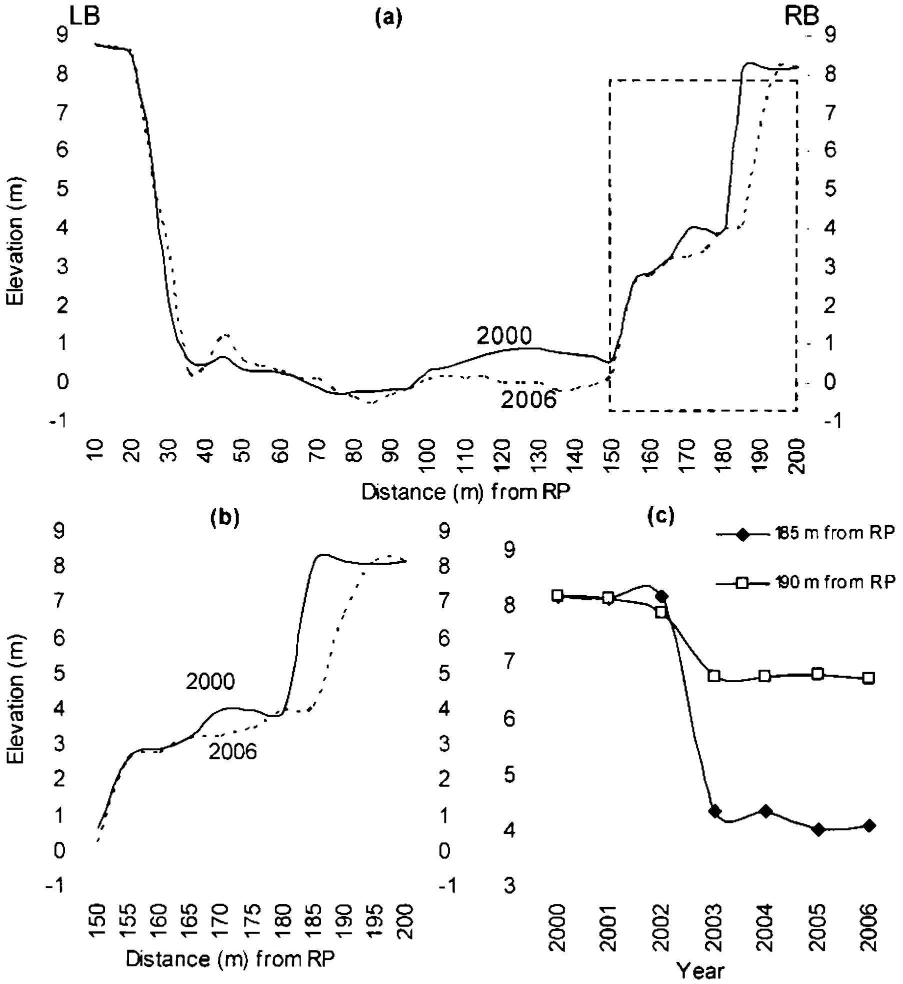


Fig. 7.10 River bank changes in the Muvattupuzha river near CWC gauging station at Ramamangalam during 2000-06. (a) Cross section of the Muvattupuzha river showing slumping of RB between 150 - 200 m away from RP of CWC; (b) A close view of instability of the river bank and subsequent valley widening; (c) River bank changes noticed at 185 m and 190 m from RP of CWC during the period 2000-06. LB = Left Bank; RB = Right Bank; RP = Reference Point; Elevation is measured with respect to mean sea level. [Data source: Central Water Commission (CWC), Kochi]

The rate of erosion at the point 185 m was 0.68 my^{-1} and 190 m was 0.25 my^{-1} during the 2000-06 period. The material composing the river bank is acted upon by two forces tending to produce down slope movements. One of these is gravity, which tends to make the material roll or slide down. The gravity force is the component that acts downward along the side slopes of the bank. The other force acting is the movement of the water through the channel, which tends to drag or push the material in a downstream direction. The magnitude of this force depends upon the velocity of water. The pits formed in the channel bed due to illegal sand mining trap the sediments (Fig. 6.2 in Chapter 6) leaving sediment deficient water (i.e., hungry water) to flow downstream. This hungry water would aggravate the erosion of the banks.

When changes of channel width and depth as well as of sinuosity and meander wavelength are required to compensate for a hydrologic change, then a long period of channel instability can be envisioned with considerable bank erosion and lateral shifting of the channel occurring before stability is restored (Schumm, 1971). Bank erosion and bank retreat are commonly observed at long-term sand extraction areas. The river banks derive their strength and resistance to erosion largely from vegetation (Yang, 2003) and to lesser degrees from their composition, height, and slope. The removal of riparian vegetation as a result of indiscriminate mining of sand can induce bank slumping to a great extent. Plate 7.2 shows examples of bank failure incidents recorded in the downstream reaches of the rivers in the study area.

Plate 7.2 A close-up of the river bank in the lowlands showing bank failure incidences due to river bed lowering and indiscriminate sand mining

7.3 Changes in sediment characteristics

Studies reveal that indiscriminate and continued mining of sand from the alluvial reaches of river systems could impose marked changes in the grain size characteristics of river beds, in the long run (Scott, 1973; Sandecki, 1989; Stevens et al., 1990). As bed materials form an important abiotic component of a river ecosystem, changes in grain size characteristics may lead to changes in biodiversity of the system. (Starnes, 1983; Thomas, 1985; Kondolf and Matthews, 1993). Therefore, an understanding of the changes in the bed characteristics is important in any analysis related to river environments. Here, to understand the effects of sand extraction on grain size changes of river beds in the study area, two cases are examined – (1) the Muvattupuzha river where previous database on grain size characteristics of the year 1988, documented by Padmalal (1992), is available for comparative evaluation and (2) the Valanchuzhi point bar of the Achankovil river, near Pathanamthitta town where a detailed granulometric mapping has been carried out as a part of the present study. Of these two rivers, the Muvattupuzha river is draining close to the Kochi City, a fast developing urban-cum-industrial centre in the study area. The river experiences severe stress due to indiscriminate exploitation of sand from instream and floodplain areas to meet the rising demand in the construction sector of Kochi City and its surrounding areas. The sand resource in the Achankovil river is used to cater to the construction activities in Pathanamthitta, Chengannur, Thiruvalla and Kollam townships.

7.3.1 Case study 1: Muvattupuzha river

A total of 10 bed sediment samples were collected in the premonsoon (February) period of 2008 from the sampling points in the Muvattupuzha river where information on grain size data of the year 1988 (pre-monsoon) is available (Padmalal, 1992). The results of the grain size characteristics of the year 2008 are given in Table 7.2 along with that of the previous reports (i.e., 1988). Fig. 7.11 shows a comparative evaluation of the grain size frequency curve of the present study with that of Padmalal (1992). Except the sediments collected from Vettikkattumukku and Ittupuzha, all the other samples show a marked coarsening compared to earlier record. The contents of coarser particles like Very Coarse Sand (VCS) and Coarse Sand (CS) are generally higher compared to the reported

Table 7.2 A comparative evaluation of the percent content of various grain size classes of bed sediments of Muvattupuzha river collected in 2008 (present study) with that of an earlier survey conducted in 1988 (given in parenthesis; Padmalal, 1992)

Sample No.	Pebble (a)	Granule (b)	Very coarse sand (c)	Coarse sand (d)	Medium sand (e)	Fine sand (f)	Very fine sand (g)	Gravel (a+b)	Sand (c+d+e+f+g)	Mud
1	9.008 (36.64)	12.728 (12.320)	26.741 (6.870)	30.428 (15.000)	15.328 (16.230)	3.762 (9.510)	0.857 (2.100)	21.737 (48.960)	77.119 (49.710)	1.142 (1.330)
2	15.101 (20.980)	7.923 (16.670)	23.156 (12.430)	29.446 (12.950)	19.175 (21.280)	4.281 (11.980)	0.241 (1.920)	23.025 (37.650)	76.301 (60.560)	0.673 (1.790)
3	0 (0.000)	3.277 (0.000)	8.709 (0.240)	17.902 (6.080)	29.281 (65.700)	15.923 (25.270)	2.053 (1.870)	3.277 (0.000)	73.868 (99.160)	22.853 (0.840)
4	54.933 (17.030)	15.509 (6.100)	9.653 (5.630)	8.511 (12.130)	8.823 (31.200)	2.393 (25.240)	0.070 (1.470)	70.443 (23.130)	29.452 (75.670)	0.104 (1.200)
5	30.490 (18.630)	22.203 (19.170)	23.994 (11.680)	17.309 (17.110)	4.910 (26.500)	0.888 (5.820)	0.090 (0.660)	52.694 (37.800)	47.193 (61.770)	0.112 (0.430)
6	8.810 (3.340)	16.054 (16.330)	30.193 (11.940)	22.270 (17.440)	10.223 (28.580)	9.087 (19.620)	1.413 (2.390)	24.864 (19.670)	73.189 (79.970)	1.945 (0.360)
7	0 (2.73)	18.557 (19.45)	46.339 (34.11)	30.619 (32.9)	4.053 (9.53)	0.242 (0.57)	0.038 (0.26)	18.557 (22.18)	81.292 (78.27)	0.152 (0.45)
8	4.541 (1.180)	8.314 (15.320)	18.122 (29.610)	28.975 (33.720)	27.736 (16.400)	9.781 (2.400)	0.879 (0.780)	12.856 (16.500)	85.494 (82.910)	1.648 (0.590)
9	5.424 (8.860)	6.085 (22.370)	12.552 (26.370)	27.353 (30.320)	31.313 (3.330)	12.589 (1.070)	2.848 (0.450)	11.510 (31.230)	86.658 (61.540)	1.829 (2.250)
10	10.055 (15.890)	28.904 (21.750)	23.622 (17.950)	18.103 (17.750)	9.512 (20.880)	7.881 (5.280)	0.791 (0.220)	38.960 (37.640)	59.911 (62.080)	1.128 (0.280)

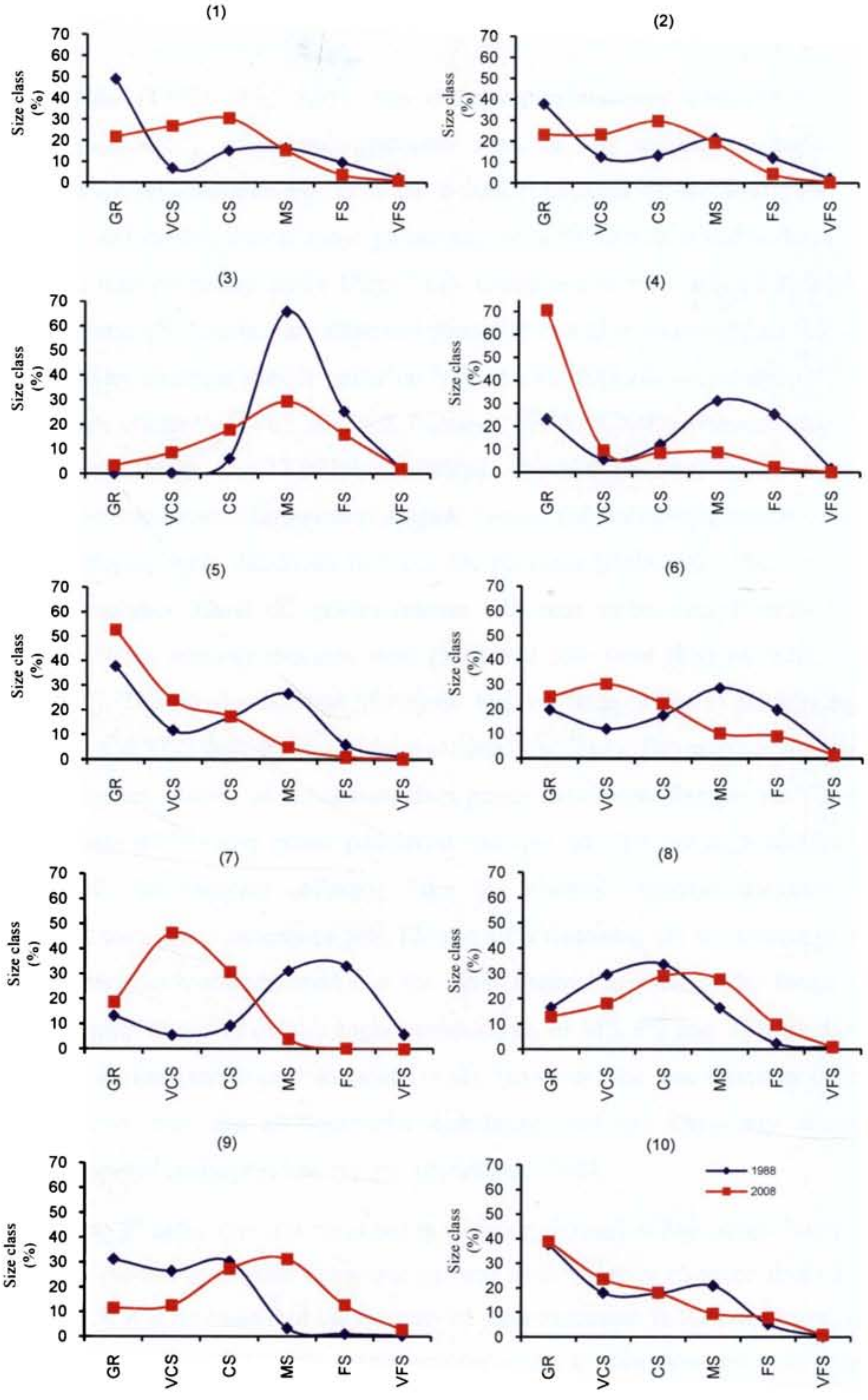


Fig. 7.11 Comparative evaluation of grain size frequency curve of the sediments of Muvattupuzha river during 2008 (present study) and 1988. (Refer Table 7.2 for details)

values of Padmalal (1992); (Fig. 7.11). The two samples analysed from the Kaliyar tributary (Sample No. 1 from the upstream area of the confluence point of Kothamangalam *Ar* and Sample No. 2 in the downstream area of the confluence of Kothamangalam *Ar*) exhibit almost same granulometric behaviour as revealed from the similarity of the size frequency curve (Fig. 7.11). Compared to the study of Padmalal (1992), the VCS and CS fractions are observed generally in higher amounts than the rest of the fractions. The sediment sample collected from the Thodupuzha *Ar* (Sample No. 3) also exhibits high content of VCS and CS fractions [VCS: 8.709% (Present study) / 0.240% (Padmalal, 1992); CS: 17.902% / 6.080%]. The size fractions in the sample collected from the main river channel near Angadi *kadavu* (Muvattupuzha municipality; Sample No. 4) display wide variations between the previous (Padmalal, 1992) and the present (2008) analyses. Here, the gravel content was seen to be exceptionally high (70.443% / 23.130%) whereas medium sand (MS) and fine sand (FS) recorded low values (Table 7.2). The site downstream of Angadi *kadavu* (Sample No. 5) exhibits high content of gravel and VCS than the rest of the fractions (Fig. 7.11). The samples collected from the Mamalasseri *kadavu* of Ramamangalam grama panchayat (Sample no. 6) and Kallidumbil *kadavu* of Piravom grama panchayat (Sample no. 7) show high content of VCS. In general, the samples collected from the channel segment upstream of Vettikattumukku show low contents of MS, FS and VFS fractions. On the contrary, the samples collected from Vettikattumukku in the main channel as well as the Ittupuzha distributary (Samples 8 and 9) exhibit higher proportions of MS, FS and VFS fractions compared to the earlier reports of Padmalal (1992). However, the size fractions in the sediments collected from the Murinjapuzha distributary did not show any marked difference as compared to the previous reports (Padmalal, 1992).

The coarsening of bed sediments observed in the main channel of Muvattupuzha river can be related to the indiscriminate extraction of sand from the river channel. From Fig. 7.12 and Table 7.3, it is revealed that the quantity of sand extraction in the river increases downstream. The quantity of mining is comparatively less in tributaries than the main channel and distributaries. Texturally, coarser grains are seggregated upstream of the Piravom sector (Table 7.3); whereas, the river reach downstream of Piravom sector is characterized by the dominance of finer sediments. The quantity of mining is much higher in the Vettikattumukku reach (0.346 x 10^6 ty^{-1}), where mining is generally taking place to the tune of 0.041 x 10^6 $ty^{-1}km^{-1}$. Among the 2 distributaries (Ittupuzha and Murinjapuzha sectors), mining is more prevalent in Ittupuzha with an estimated sand extraction of 0.192x 10^6 ty^{-1}. In the main channel, mining activities are concentrated more in the Piravom reach (0.277 x 10^6 ty^{-1}) followed by Marady (0.227 x 10^6 ty^{-1}) and Ramamangalam reaches (0.130 x 10^6 ty^{-1}). An overall evaluation of the rate of sand mining reveals that the river stretch from upstream of Pazhur to Vettikattumukku (~ 17 km) along the main channel records intense sand mining (0.07 x 10^6 $ty^{-1}km^{-1}$) than the upstream counterparts (0.02 x 10^6 $ty^{-1}km^{-1}$). It is now well understood that the physical composition and stability of substrate are changed significantly as a result of instream sand mining. And, most of these physical effects exacerbate sediment entrainment in the channel.

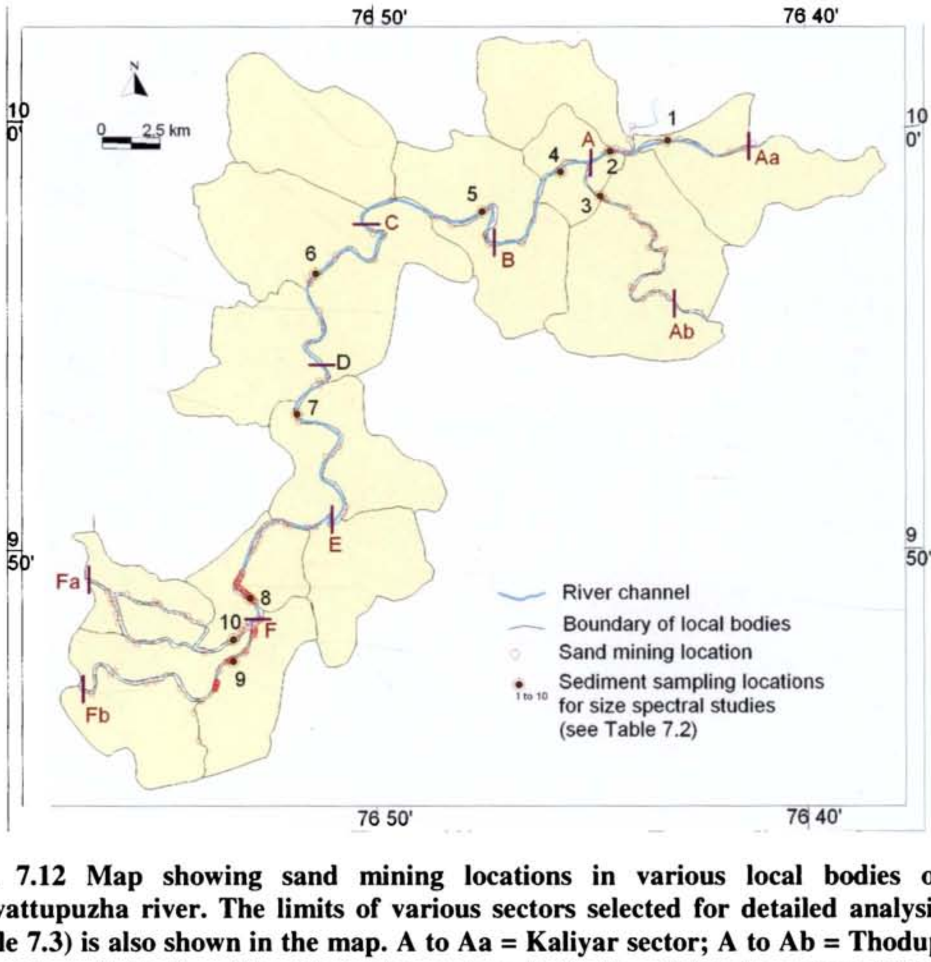


Fig. 7.12 Map showing sand mining locations in various local bodies of the Muvattupuzha river. The limits of various sectors selected for detailed analysis (see Table 7.3) is also shown in the map. A to Aa = Kaliyar sector; A to Ab = Thodupuzha Ar sector; A to B = Muvattupuzha sector; B to C = Marady sector; C to D = Ramamangalam sector; D to E = Piravom sector; E to F = Vettikattumukku sector; F to Fa = Murinjapuzha sector and F to Fb = Ittupuzha sector.

Table 7.3 Sand extraction and other relevant details of Muvattupuzha river – a sector wise presentation

Sl. No.	Sectors*	Length of the channel (km)	Qty. of mining ($\times 10^6 ty^{-1}$)	Qty. of mining ($\times 10^6 ty^{-1}km^{-1}$)	No. of sand mining locations	Observations
1.	Aa to A	8.00	0.496	0.006	9	Sediment texture is dominated by very coarse sand and coarse sand that results in bed coarsening.
2.	Ab to A	11.1	0.083	0.008	16	Here also, very coarse sand and coarse sand is present in high amount compared to other size fractions with coarsened bed.
3.	A to B	6.90	0.070	0.010	3	The amount of gravel is exceptionally high in this segment indicating coarsening of river bed.
4.	B to C	8.25	0.227	0.028	11	The river bed is characterized by gravel and very coarse sand fraction that dominates the sediment texture.
5.	C to D	11.50	0.130	0.011	7	The content of gravel, very coarse sand and coarse sand is high in this segment with coarsened river bed.
6.	D to E	8.75	0.277	0.032	17	This sector is dominated by very coarse sand fraction which indicates bed coarsening.
7.	E to F	8.50	0.346	0.041	61	Medium sand, fine sand and very fine sand dominates in this sector too. Here also, water lilies are seen on the river bank side.
8.	F to Fa	9.60	0.095	0.010	9	Fine sand and very fine sand shows a marginal increase compared to previous study.
9.	F to Fb	12.70	0.192	0.015	37	Medium sand, fine sand and very fine sand dominates in this sector. The presence of silted sediments was evident from the water lilies that flourished in the channel.

**Refer Fig. 7.12 for locations of individual sectors*

As explained earlier in section 7.2, the deep pits created in the channel as a result of pit excavation method of sand mining (Fig. 7.1), act as sediment traps and the hungry water leaving the pits could selectively entrain sand particles in the finer entities and deposit further downstream. Continuation of this process, in the long run could result in bed coarsening with high percent content of coarser particles in the upstream. Occurrence of granules in the sampling location in Thodupuzha *Ar* (Sample No. 3) in the present study and its absence in the previous reports (Padmalal, 1992) also supports the size based sorting triggered by indiscriminate sand mining. A comparative evaluation of the grain size characteristics of the present study with that of Padmalal (1992) revealed that VCS and CS fractions are higher in majority of the samples except for a slight variation in CS in the downstream reaches. Indiscriminate extraction of sand from the lower reaches at a rate of 0.07 x 10^6 $ty^{-1}km^{-1}$ could impose marked changes in the sediment distribution pattern in this fluvial environment. The sand mining activates the selective removal of medium to very fine sands from the upstream and their deposition in the subsequent downstream stations. This processes of selective sorting based on grain size, aggravated many folds by indiscriminate sand mining, is responsible for bed coarsening in the upstream reaches of the rivers in the study area. (Plate 7.3).

Plate 7.3 Concentration of coarser particles left after selective entrainment and transportation of finer entities.

On the contrary, continued removal of construction grade sand from the downstream reaches around Vettikkattumukku and subsequent replacement by finer sands from the upstream stations could attribute fining of grain size population in the downstream reaches. This might be the reasons for the observed increase in MS and FS in samples 8 and 9 collected from the intense mining locations of Ittupuzha and Murinjapuzha distributaries of Muvattupuzha river.

7.3.1 Case study 2: Valanchuzhi point bar of Achankovil river

Bed coarsening noticed in the sandy plains (point bars) used for holding religious congregations is a serious problem threatening the smooth conduct of these annual events. Many point bars in the study area shown in Table 7.4 have been degraded due to indiscriminate sand mining and subsequent bed coarsening phenomenon. People in the area opine that these point bars were composed entirely of sand 3-4 decades ago. But the point bars are later transformed to gravelly sand or sandy gravel due to selective entrainment of medium to very fine sands from the sediment population. The particles that are removed from the point bars will later be deposited in the deep pools in the downstream part of the river channel developed as a result of pit excavation.

Table 7.4 Important sand deposits / sandy plains in the study area used for holding festivals / religious conventions

Sl. No.	Point / Sand bar	River	Festival / religious convention
1	Valanchuzhi	Achankovil	Festival in connection with Valanchuzhi Devi temple
2	Cherukole	Pamba	Cherukolpuzha Hindu Convention
3	Maramon	Pamba	Maramon Christian Convention
4	Mallapally	Manimala	Mallapally Charismatic Convention
5	Aluva	Periyar	Aluva Sivarathri Rituals
6	Kalady	Periyar	Kalady Sivarathri Rituals
7	Mambra	Chalakudy	Sivarathri festival in connection with Annamanada Siva Temple.

The surface and core sediments collected from the Valanchuzhi point bar of the Achankovil river reiterate that bed coarsening is resulted from the 'imposed' removal of finer particles from the upstream end of the point bar and its subsequent deposition in its downstream end. The sand mining location - Vyazhi *kadavu* - which is in operation in the downstream side of the Valanchuzhi point bar is one of the beneficiaries of the bed coarsening of the Valanchuzhi point bar.

The granulometric results of the surface sediments of Valanchuzhi point bar are furnished in Table 7.5. Fig. 7.13 a and b depict the sediment types and sand isoliths of the Valanchuzhi point bar. From Fig. 7.13 a, it is evident that the sediments in the Valanchuzhi point bar show a wide range of textural patterns. Gravel, sandy gravel, muddy sandy gravel, gravelly sand and sand are the different sediment types noticed in the point bar deposit. The river channel is floored by gravel in the upstream part followed by sandy gravel in the middle and gravelly sand in the downstream area. Muddy sandy gravel is confined to the central portion of the point bar deposit. Sand is confined only to a small portion in the point bar (Fig. 7.13 a). From Table 7.5, it is revealed that the content of pebble and gravel show a decreasing trend downstream whereas, the content of sand shows an opposite trend. The various size fractions of pebble such as coarse and medium pebbles are lacking in the downstream end whereas fine pebble occur in marginal quantities. Granule also shows a similar variation to that of the pebble fractions. Fig. 7.13 b shows the variation of sand content in the study area. The VCS, CS, MS, FS and VFS show marked deviation from the gravel entity by exhibiting a general increase towards the downstream part of the river channel as well as Valanchuzhi point bar. In other words, a progressive increase in the sand fraction is noticed towards the lower part of the point bar and also the river channel.

The percentage content of various grain size fractions in the borehole sample is given in Table 7.6. The sediment type and grain size characteristics are depicted in Fig. 7.14. The core with a total length of 60 cm is composed of 2 litho-units. The surface of the core (VC1; 0-5 cm) is rich in gravel (97.413%) with very low content of sand

Table 7.5 Grain size characteristics of the sediments of the Valanchuzhi point bar in Achankovil river

Sample No.	Coarse pebble (a)	Medium pebble (b)	Fine pebble (c)	Granule (d)	Very coarse sand (e)	Coarse sand (f)	Medium sand (g)	Fine sand (h)	Very fine sand (i)	Pebble (a+b+c)	Gravel (a+b+c+d)	Sand (e+f+g+h+i)	Mud
1	7.463	27.037	35.955	20.256	1.942	0.316	0.322	3.826	1.278	70.455	90.712	7.684	1.604
2	26.966	22.831	23.582	17.068	5.309	0.862	0.650	1.401	0.817	73.379	90.447	9.039	0.514
3	25.449	43.018	20.078	10.584	0.708	0.033	0.027	0.032	0.029	88.545	99.129	0.828	0.043
4	14.518	22.563	20.452	35.816	6.319	0.083	0.020	0.028	0.015	57.533	93.349	6.465	0.186
5	21.246	23.282	17.853	16.661	7.335	4.809	1.553	3.295	1.458	62.381	79.042	18.451	2.508
6	0.000	9.593	10.431	23.670	14.421	7.422	4.058	11.789	7.246	20.024	43.694	44.936	11.370
7	0.000	8.492	16.187	26.616	14.408	9.828	9.948	8.263	2.956	24.679	51.295	45.403	3.302
8	0.000	9.186	12.749	40.988	11.972	4.386	3.220	12.545	2.775	21.935	62.923	34.898	2.178
9	0.000	0.000	16.530	51.978	21.410	3.302	0.905	3.112	1.219	16.530	68.508	29.948	1.544
10	0.000	41.750	23.218	17.374	6.549	3.749	2.706	2.244	0.870	64.968	82.342	16.117	1.541
11	15.786	17.950	22.060	17.629	7.139	5.133	8.945	3.942	0.824	55.796	73.424	25.984	0.591
12	9.586	27.368	17.248	13.719	5.754	6.467	10.416	5.237	0.404	54.202	67.920	28.277	3.803
13	13.850	39.337	12.917	17.088	8.420	3.724	3.485	1.107	0.051	66.104	83.192	16.788	0.020
14	0.000	9.214	7.845	23.966	19.826	10.677	6.645	9.776	3.300	17.059	41.025	50.224	8.751
15	0.000	1.917	10.855	20.344	12.500	8.708	9.305	21.921	6.974	12.772	33.116	59.409	7.475
16	0.000	10.113	7.061	18.995	22.191	7.920	12.477	17.021	2.538	17.174	36.169	62.147	1.684
17	0.000	11.655	5.570	7.001	12.055	28.950	27.277	5.618	0.592	17.225	24.226	74.492	1.282
18	0.000	7.255	12.997	21.362	11.255	7.002	4.749	16.831	7.259	20.252	41.615	47.096	11.290
19	17.946	18.605	10.936	13.256	11.076	4.106	3.046	11.217	4.347	47.487	60.743	33.792	5.465
20	0.000	6.125	8.081	23.756	13.167	7.079	19.440	18.320	1.872	14.206	37.962	59.879	2.160
21	0.000	9.446	14.457	18.403	12.784	19.889	17.409	6.101	0.675	23.902	42.305	56.858	0.837
22	0.000	0.000	2.999	13.143	11.507	5.011	20.873	38.121	3.034	2.999	16.142	78.547	5.311
23	0.000	0.000	1.024	11.591	11.943	8.855	29.258	28.601	2.449	1.024	12.615	81.105	6.280
24	0.000	0.000	4.732	14.938	26.366	29.021	19.414	4.703	0.357	4.732	19.670	79.861	0.469

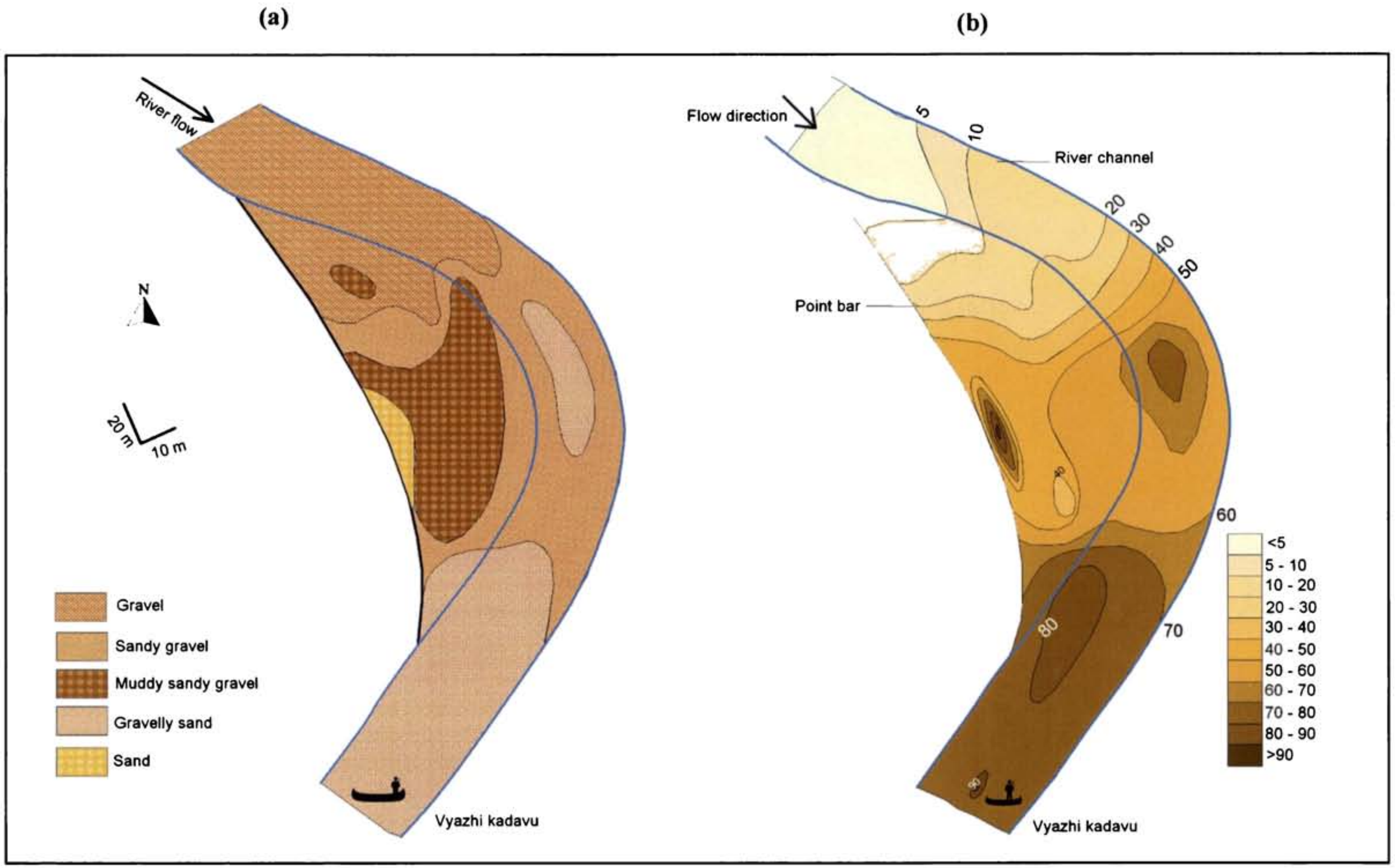
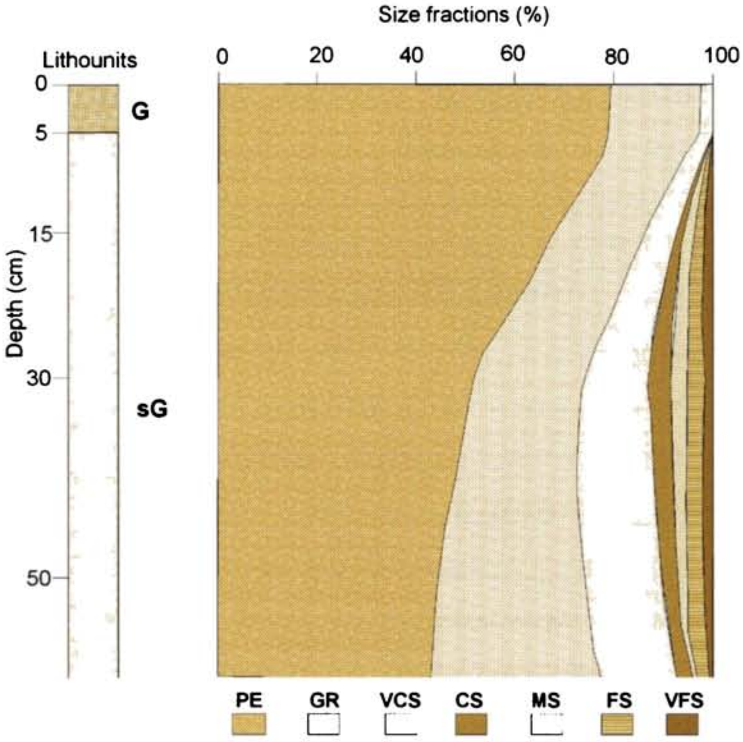


Fig. 7.13 Sediment types (a) and sand isoliths (b) of the Valanchuzhi point bar and adjoining river channel of the Achankovil river. (a) Type of surface sediments in the sand bar and river channel; (b) Variations of sand isolith in the study area.

Table 7.6 Particle size categories in the sediment core recovered from the Valanchuzhi point bar, Achankovil river

Sl. No.	Size class	VC1 (0-5cm)	VC2 (5-30cm)	VC3 (30-60cm)
1	CP	11.461	19.335	0
2	MP	31.691	17.588	25.217
3	FP	36.038	14.760	18.147
4	GR	18.233	23.049	33.893
5	VCS	2.479	11.906	16.430
6	CS	0.045	5.004	2.744
7	MS	0.019	3.311	0.574
8	FS	0.014	4.241	2.126
9	VFS	0.010	0.514	0.461
10	Pebble	79.180	51.684	43.364
11	Gravel	97.413	74.733	77.257
12	Sand	2.566	24.976	22.335
13	Mud	0.021	0.291	0.407

VC: Valanchuzhi Core; CP: Coarse pebble; MP: Medium pebble; FP: Fine pebble; GR: Granule; VCS: Very coarse sand; CS: Coarse sand; MS: Medium sand; FS: Fine sand; VFS: Very fine sand



Gravel with high content of pebbles and trace amounts of coarse to very fine sands

Sandy gravel dominated by pebbles and granules, and with low content of coarse to very fine sands.

Sandy gravel with pebbles, granules and sand fractions.

Fig. 7.14 Sediment type and particle size characteristics of the sediment core collected from the Valanchuzhi point bar of the Achankovil river. Note Fig. 4.3 for location of the core. G – Gravel; sG – Sandy gravel; PE – Pebble; GR – Granule; VCS - Very coarse sand; CS - Coarse sand; MS - Medium sand; FS - Fine sand; VFS - Very fine sand

(2.566%). Of the various sand fractions, VCS dominates in this layer of core (2.479%). This is followed downward by sandy gravel (5-60 cm). The gravel, sand and mud fractions in the samples VC2 and VC3 are 74.733%, 24.976%, 0.291% and 77.257%, 22.335%, 0.404% respectively. In the surface layer (0-5 cm), the sand is present only in trace amounts due to the selective removal of sand and its subsequent deposition downstream. This can ultimately lead to coarsening of sediments in the surface layer which is evident in Fig. 7.14. Continued extraction of sand from the Vyazhi *kadavu* located in the downstream end of the Valanchuzhi point bar aggravates winnowing and selective removal of finer sediments from the deposit in high flow regimes and its subsequent deposition in the sand mining area / pit of the Vyazhi *kadavu*. This, in the long run, transforms the original sandy point bar to a new bar with lag concentrates of pebbles and cobbles. Development of such a feature through natural processes requires hundreds or thousands of years (geologic time scale-dependent process), but anthropogenic processes like intensive sand mining activities, construction of impoundments, etc., can transform river bed features within a couple of decades (human life scale-dependent process) as in the case of Valanchuzhi point bar.

7.4 Changes in water quality / quantity

Indiscriminate mining for construction grade sand and gravel from the active channels and floodplains of river systems can impose serious problems in the surface and sub-surface (groundwater) water resources. Information on these issues is important for a proper environmental impact assessment of the mining activity. A cursory glance of literature reveals that investigations on this angle are scarce in the case of the small catchment rivers in the southwest coast of India. Therefore, a few case analyses have been attempted here to illustrate the effects of river sand mining on the surface and ground (sub-surface) water resources of the study area.

7.4.1 Surface water

High content of suspended particulates in the water column arising as a result of clandestine sand mining operations can cause severe impairments to the river ecosystems.

The disturbance caused by indiscriminate sand and gravel mining stirs up clouds of fine organic and inorganic particulates in the overlying waters (Plate 7.4). The suspended solids may be carried downstream by river waters and will settle out blanketing the river bed, under favourable environmental conditions. In high concentrations, suspended sediments could block the gills of fishes and also create problems in the filter mechanisms of animals like bivalves. Further, the suspended sediments may impair the respiration and photosynthesis of instream flora which ultimately lead to reduced growth rate and finally its total destruction (Thrivikramaji, 1986; UNEP, 1990).

Plate 7.4 Problems related to suspended solids generation and settling. (a) A scene from Manimala river showing suspended particulate matter in the overlying waters derived from sand mining and (b) Processing activities; (c) and (d) Morphological changes occurred over ten years in Periyar river due to deposition of silted sediments from upstream areas as a result of indiscriminate mining activities – View upstream of Kalady bridge.

To understand the impact of sand mining in the overlying waters of the rivers in the study area, a case analysis has been carried out in one of the mining - hit rivers in the study area, the Manimala river. A total of 5 water samples were collected from the Manimala river between Vellavoor and Thondara during sand mining periods (March 2006 and April 2006) and mining prohibition periods (August 2006). The results of the analysis are given in Table 7.7, and their spatial and temporal variations are shown in Fig. 7.15. As seen from Fig. 7.15, during the months of March and April 2006, the river waters in reach close to the clustered mining centres (Samples 1 to 3; upper part) are loaded with high concentrations of suspended particulates (av. TSS in March: 54.60 mg/l; April: 153.71 mg/l) than the lower reaches (av. TSS in March: 26.50 mg/l; April: 7.87 mg/l). But the content of particulates was comparatively low in the entire stretch during August 2006, the period when the sand mining was banned in the entire rivers of the Pathanamthitta district.

During the processes of mining, the sand particles are selectively removed using specially fabricated porous scoopers. This process not only increases the turbidity level, but also enhances the silt and clay concentrations in the overlying waters (Plate 7.4). The turbidity introduced by mining of sand is a havoc to the instream plants and animals in the river ecosystem. The coating of fine materials over leaves adversely affects the photosynthesis of aquatic macrophytes and benthic algae. For filter feeders in the water column as well as on the substrate, the solids may interfere with the filtration process. Some solids clog on to gills of fishes and invertebrates leading to asphyxiation. Deposition of silt on river bed can smother diatoms, benthic algae, macro invertebrates and fish eggs (Kanehl and Lyons, 1992; Nelson, 1993; Meador and Layher, 1998; Lake and Hinch, 1999).

Another problem that may arise in due course is the imposed changes in river bed characteristics. As mentioned earlier, the silt and clay particles generated from the mining and cleaning sites may be carried to downstream reaches and often blanket the sand bars escaped from the mining activities. This, in turn, leads to stabilization of sand bars by thick vegetative growth. Pure sand deposits (i.e., sand bars) cannot sustain vegetation, but

Table 7.7 Total Suspended Sediment (TSS) concentrations (mg/l) of the Manimala river between Vellavoor and Thondara during three different sampling periods in the year 2006 (see Fig. 7.15 for sampling locations)

Site no.	Sampling location	TSS (mg/l)		
		March '06	April '06	August '06
1	Vellavoor	54.90	259.76	3.80
2	Anicaud	60.30	135.40	13.80
3	Mallapally	48.60	66.12	13.16
4	Vallamkulam	21	7.80	7.04
5	Thondara	32	7.94	7.36

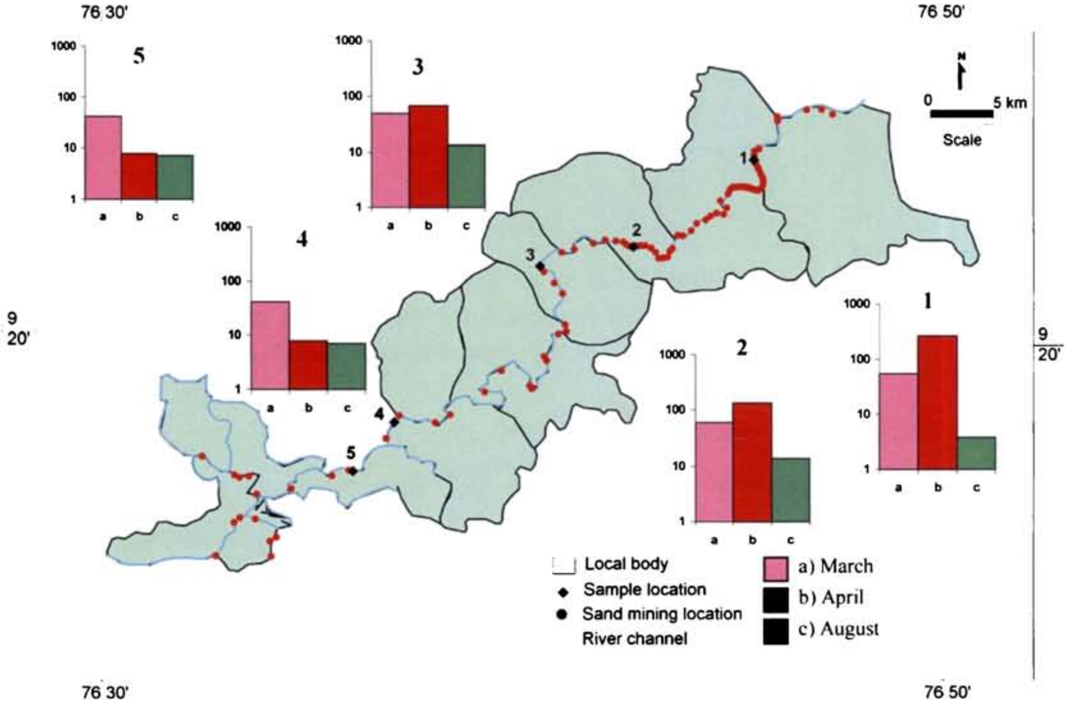


Fig. 7.15 Concentrations of Total Suspended Solids (TSS) in various sampling points (1-5) of Manimala river. (See Table 7.7 for the name of the sampling sites). Note the intensity of sand mining sites in this stretch of the river course

the silt-clay blanketed sand bars promote vegetative growth. Plate 7.4 c and d show mud blanketing and stabilization noticed in Periyar river near Kalady due to clandestine sand mining over the past several years.

In the study area, the mining of sand is taking place at alarming rates at many locations in the midlands (See Chapter 6). In an earlier study, Babu and Sreebha (2004) reported that a positive correlation exists (r = 0.63) between the TSS contents in the overlying waters and the quantity of sand mining (Fig. 7.16).

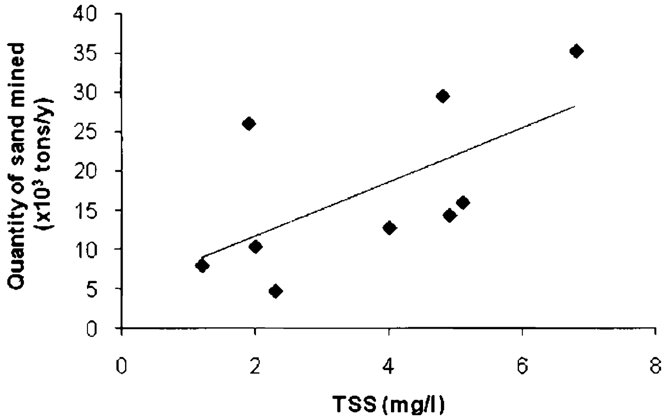


Fig. 7.16 Scatter plots of TSS *vs* Quantity of sand mining from the river channels in the intense sand mining (midlands) reaches of the study area during non-monsoon period

This also corroborates well with the above observation that mining is a significant contributor for the rise in TSS contents in the midlands and lowlands, especially in the non-monsoon season. As particulate sediments is one of the efficient carrier phases of nutrients, the variations in suspended particulate levels in river waters can alter its net flux to the nearshore waters in the marine environment. It is a fact that the large pits in the lowland part of the river channels developed as a result of rampant sand mining, often trap the finer sediments loaded with nutrient elements and metals (Table 7.8; Fig. 7.17 a and Fig. 7.17 b). The pit excavation and trapping of nutrient loaded fine particulates including the TSS within it ultimately leads to reduction in nutrient supply from terrestrial environments to ocean realm.

Table 7.8 Total Suspended Solids (TSS), Particulate Iron [$Fe_{(par)}$] and Particulate Phosphorus [$P_{(par)}$] in the river water samples of the study area along with the quantity of sand mining during active mining (non-monsoon) season

Sl.No.	Location no.	River / Location	TSS (ppm)	$Fe_{(par)}$ (ppb)	$P_{(par)}$ (ppb)	Quantity of sand mined (x 10^6 ty^{-1})
		Achankovil river				
1.	Ac.R1	Konni	6.6	488	12	0.010
2.	Ac.R2	Omallur	12.0	677	20	0.010
3.	Ac.R3	Pandalam	6.2	569	13	0.005
4.	Ac.R4	Mavelikkara	48	800	12	0.008
		Pamba river				
5.	Pa.R1	Mukkam	1.9	387	12	0.025
6.	Pa.R2	Vadasserikkara	2.1	305	7	0.022
7.	Pa.R3	Kozhenchery	1.2	363	8	0.024
8.	Pa.R4	Chengannur	4.9	550	11	0.014
9.	Pa.R5	Mannar	7.3	692	10	0.016
		Manimala river				
10.	Ma.R1	Mannarakayam	3.9	563	20	0.011
11.	Ma.R2	Manimala	1.2	192	7	0.008
12.	Ma.R3	Mallapally	4.8	388	17	0.030
13.	Ma.R4	Nedumbram	5.9	630	12	0.025
		Meenachil river				
14.	Me.R1	Erattupetta	6.8	429	18	0.006
15.	Me.R2	Pala	9.8	770	26	0.008
16.	Me.R3	Ettumanoor	2.3	396	13	0.005
17.	Me.R4	Thazhathangadi	5.8	710	12	0.006
18.	Me.R5	Nattakom	1.8	281	4	0.003

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Sl.No.	Location no.	Name of the location	TSS (ppm)	$Fe_{(par)}$ (ppb)	$P_{(par)}$ (ppb)	Quantity of sand mined (x 10^6 ty^{-1})
		Muvattupuzha river				
19.	Mu.R1	Avoli (TT)	3.5	349	6	0.018
20.	Mu.R2	Muvattupuzha	5.1	259	8	0.016
21.	Mu.R3	Ramamangalam	3.8	286	12	0.056
22.	Mu.R4	Vellur	6.8	823	16	0.035
23.	Mu.R5	Vadayar (ID)	4.9	773	5	0.067
		Periyar river				
24.	Pe.R1	Kuttampuzha (PT)	1.2	79	10	0.030
25.	Pe.R2	Bhoothathankettu	1.9	361	9	0.026
26.	Pe.R3	Perumbavoor	1.1	132	3	0.093
27.	Pe.R4	Aluva	1.5	1005	19	0.024
28.	Pe.R5	Kadungallur (MVD)	2.3	218	2	0.048
29.	Pe.R6	Eloor (MVD)	5.0	859	35	0.024
		Chalakudy river				
30.	Ch.R1	Athirapally	2.6	113	8	0.007
31.	Ch.R2	Chalakudy	2.0	137	6	0.010
32.	Ch.R3	Kadukutty	4.0	237	6	0.013
33.	Ch.R4	Parakkadavu	9.2	347	6	0.011
34.	Ch.R5	Kanakkankadavu	11.2	228	4	0.008

TT: Thodupuzha Tributary; ID: Ittupuzha Distributary; PT: Pooyamkutty Tributary; MVD: Marthanda Varma Distributary; ty^{-1}*: tonnes per year*

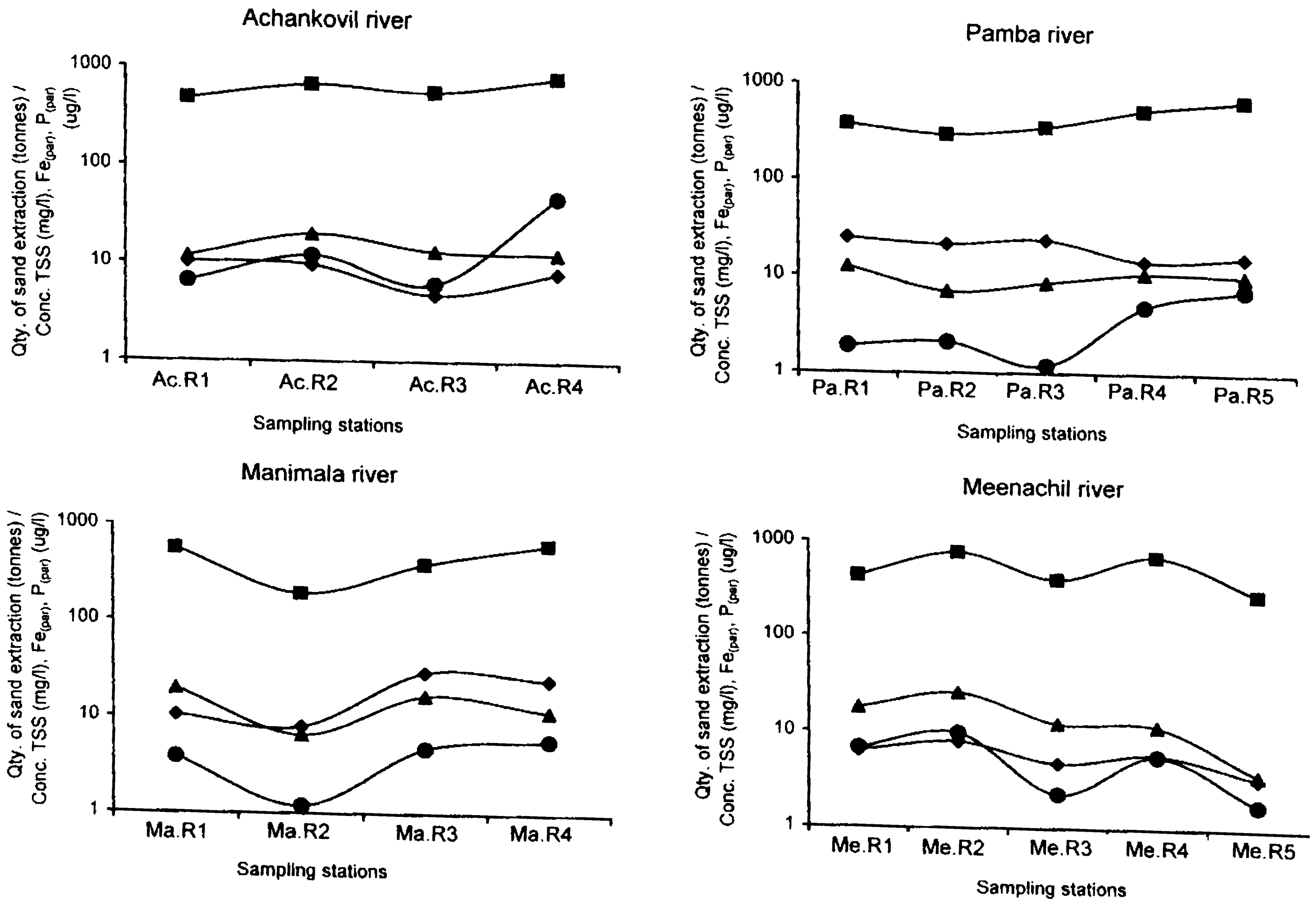

Fig. 7.17a Variation of TSS, $Fe_{(par)}$, $P_{(par)}$ and quantity of sand extraction in different sampling sites of the rivers draining the study area during active sand mining (non-monsoon) season

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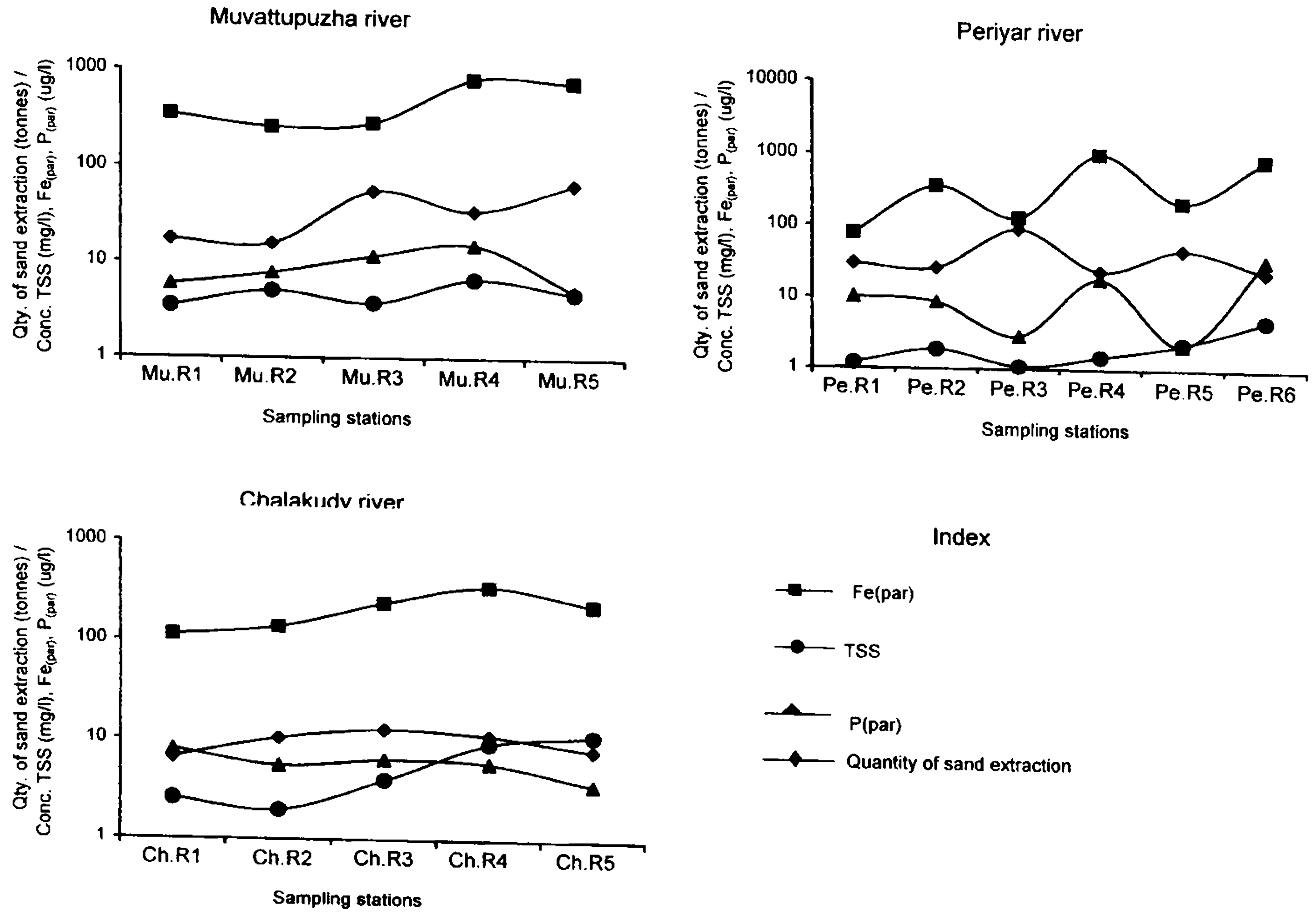

Fig. 7.17b Variation of TSS, $Fe_{(par)}$, $P_{(par)}$ and quantity of sand extraction in different sampling sites of the rivers draining the study area during active sand mining (non-monsoon) season

7.4.2 Groundwater

Cases of water table lowering consequent to sand and gravel mining have been documented by several investigators. Planning Department of the Lake County, California in 1992 has estimated that the potential reduction in alluvial aquifer storage consequent to channel incision caused by instream mining ranges from 1 to 16%, depending on local geology and aquifer geometry (Lake County, 1992). Lowering of groundwater table has been documented along the Russian River of the Sonoma County in the year 1992 (Kondolf, 1998). Kondolf et al. (2002) while reviewing the effects of sand and gravel mining on various environmental components, opined that channel incision consequent to indiscriminate sand mining can accelerate the pace of groundwater lowering in areas adjacent to river channels. Mitchell (2006) has also made an attempt to study the relation between gravel mining and water supply wells in Maine, U.S.A., and found that mining processes have a direct bearing on water table levels in the area.

The drinking water shortage has gained wide attention in Kerala also, as groundwater forms the major drinking water source, especially in the midland and lowland areas of the State. The study carried out by Prasad and Nair (2004) in Achankovil river basin near Thumpamon grama panchayat (midland region) has highlighted that indiscriminate sand mining from the river channel and consequent channel incision are the major causative factors of drinking water problems in areas adjoining the river channels in the midlands and certain parts of the lowlands.

The Thumpamon grama panchayat is located in the midland physiographic region of the Achankovil river. The households are located on hillocks of the region irrespective of topography or water availability. The valleys in the area are cultivated for paddy and the flanks of the hillocks are used for growing rubber. Virtually all the households depend on dug wells for drinking water. Fig. 7.18 shows the lithological cross section of the area showing the connectivity of aquifer with the river channel. The aquifer lithology of alluvial sand and alluvial clay in Fig. 7.18, consists of ~2 m thick ferruginous fine sand, underlain successively by 5m of fine sand, 2-3 m of unconsolidated clay and the weathered zone with open fractures and boulders of basement. This unique lithological

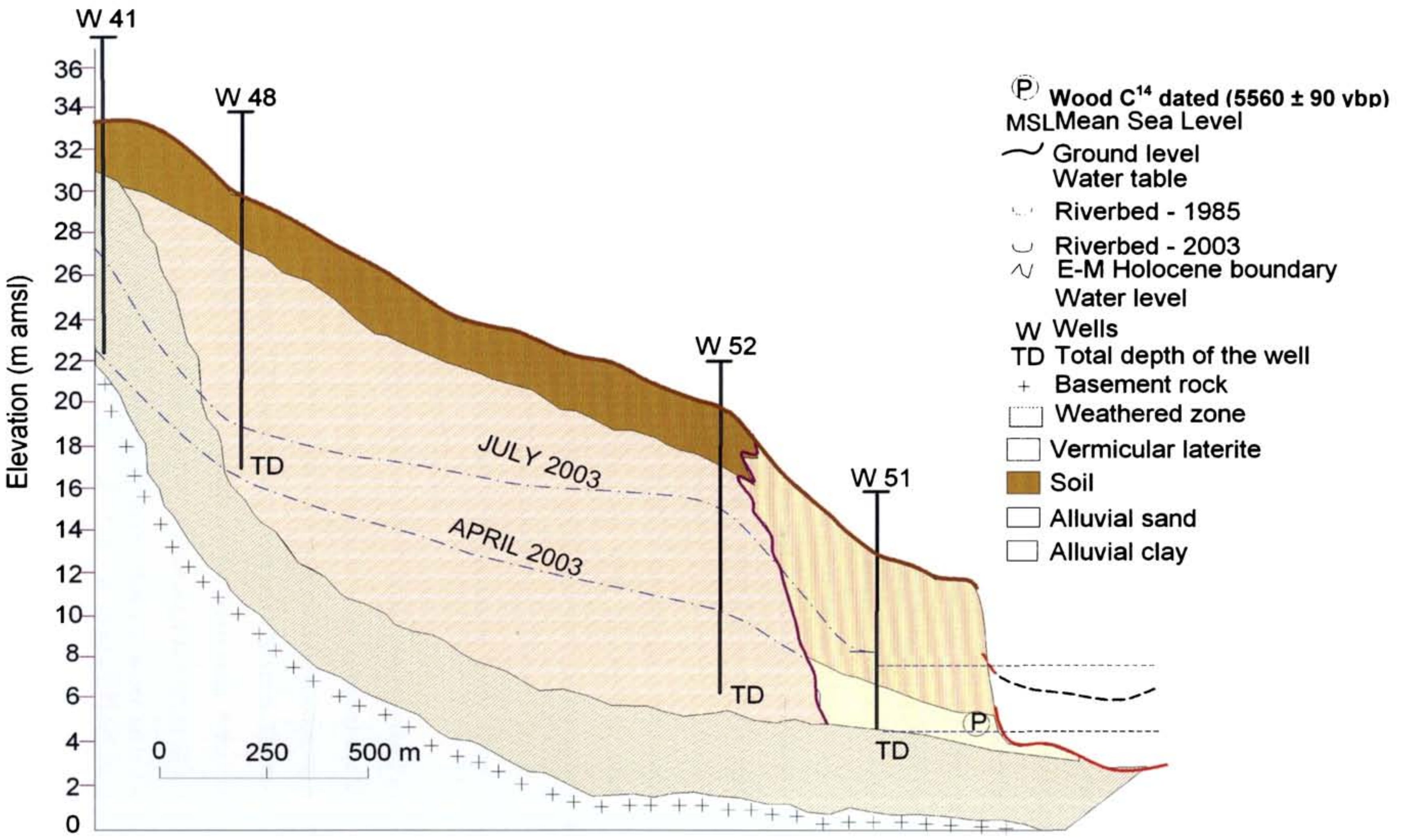

Fig. 7.18 Cross section depicting the connectivity between the water supply wells and the river bed

assemblage has some advantages to areas with thick vermicular laterite upslope. When the river is in flood, the water level rises above the sand-clay interface. A major part of the sand thickness gets saturated. When the water saturated sand is in contact with vermicular laterite upslope, the water potential of the latter increases. However, when the floodwaters recede and reach its level of January to May virtually the entire sand is drained of its water and escapes as baseflow to the river leaving the wells along the river bank virtually dry. However, the water table in the vermicular laterite does not get lowered correspondingly. The well located in the river bank side (Well No. 51) experiences profound effect of sand mining due to the channel incision. The river bed which was at 6.43 m above sea level during the year 1985 has been lowered to 4.25 m during the year 2003. The water table along the river bank plunges steeply to the riverbed, which has undergone incision to the extent of about 2 m or more during the past 18 years. Channel incision due to sand mining, typically lowers the alluvial water table as the channel itself determines the level down to which the alluvial groundwater drains (Galay, 1983; Creuz des Chatelliers and Reygrobellet, 1990; Mas-Pla et al., 1999). This results in loss of groundwater storage and influences alluvial groundwater-surface water exchanges along the river system. Generally, in the local body, the wells that have gone dry due to channel incision have been deepened to the practicable levels. Despite this, a large number of wells face water shortage in the area.

The survey conducted by Prasad and Nair (2004) in the area between Panthalam and Thumpamon reveals that out of the total 53 wells, 36% are perennial and 64% are seasonal, drying up for varying durations. The wells were classified according to their year of construction i.e. <5 years, 5-10 years, 10-20 years and >20 years. The maximum percentage of wells that go dry for various periods are the oldest ones. It may be noted that the wells are dug during dry months and they are bottomed in a zone, which yields the required quantity of water. This obviously shows that the water table has been lowered. When a well goes dry the consequential action is to deepen it and obviously many wells under all categories have been deepened to the extent practicable. It may also be noted that the percentage of wells that do not dry up is under the category of <5 years.

These wells were dug when the riverbed had reached closer to the present level. Deepening of many older wells to the level of the present summer riverbed level is not practicable due to the presence of massive basement or fear of collapse on account of caving in the zone of weathering. All these supplement the fact that channel incision has a profound role in the water availability of wells that are close to the river channels and also constructed on older alluvium with sand-clay intercalations.

7.5 Changes in biological environment

Human activities have disrupted the natural flow patterns and ecological processes of rivers with adverse affects on their biological wealth (Petts, 1984; Moyle and Leidy, 1992). General forms of river degradation due to increasing human population includes physical conversion of natural habitats, water pollution, development of freshwater resources, introduction of exotic species and overfishing. Yet, river supports an extraordinary array of species, many of which are under threat due to habitat destruction. During the past 3-4 decades, river systems of the world have been altered significantly due to indiscriminate sand mining. Sand mining has many deleterious direct and indirect effects on the physical, chemical and biological environments of river systems. However, relatively little attention has so far been made to unravel the effects of sand mining on the riverine biota. And, only a few studies are available on the composition of benthic and fish communities affected by changes in sediment texture and habitat loss arising from selective removal of fine aggregates from the river bed deposit. Therefore, an attempt has been made here to document the effects of river sand mining on instream biota and riparian vegetation of some selected cases in the river catchments of Vembanad lake.

7.5.1 Benthic community

Indiscriminate sand mining from active channels of rivers causes many adverse effects on the benthic fauna, which inhabits the bottom sandy substratum. Excessive sand extraction from rivers affects the eco-biology of many terrestrial insects whose initial life history begins in aquatic environments. As advised by CESS, Sunilkumar (2002b) conducted a study on the impact of sand mining on benthic fauna of the Achankovil river reach around Maroor. The study brought out the fact that many aquatic organisms, especially the benthos, are affected severely by clandestine sand mining. The organisms include different species of mayfly, dragonfly, chironomids, caddisfly and other insects of the order Diptera. There is a drastic decrease in the population of dragonfly in the area in recent years (Table 7.9; Fig. 7.19). The dwindling of the numerical abundance of benthic fauna might be attributed to indiscriminate sand mining, an activity responsible for the destruction of habitats for their early development in the life cycle. Dragonfly is a beneficial insect to mankind as it is a mosquito predator. But it is unfortunate that, the biological control of mosquitoes is decreasing due to destruction of dragon fly nymphs (due to sand extraction) before their emergence from riverine habitats in adult forms. Sand mining can also negatively affect the survival and dispersal of benthic organisms belonging to the groups Polychaeta, Crustacea and Mollusca. Dispersal of eggs and larvae is an important aspect of the biological processes of aquatic organisms. In the fisheries point of view, loss of food in the form of benthic invertebrates is a major negative impact which will ultimately end up in the decline of inland fishery resource of the area.

7.5.2 Fish community

Although many studies on the freshwater fishes of Kerala are available in literature, most of them are either concerned with taxonomy or with capture fisheries / aquaculture. It is unfortunate that the effect of sand mining on fish fauna and habitat loss has hitherto not been studied in detail though the issues became a major concern to fishery biologists and environmental scientists as any decline in fish population can cause far reaching adverse implications in future. A few studies on biodiversity, ecological structure and functional processes of fishes are highlighted here to reveal the role of sediment characteristics and habitat alteration on fish population in aquatic ecosystems, especially rivers. The first and foremost reason for using fishes in riverine biodiversity monitoring is that they are enormously diverse, with different species reflecting different environmental conditions (Moyle and Cech, 1996). Secondly, fishes often have major

Table 7.9 Distribution and density (0.1 m^2 area) of benthic organisms in the Achankovil river near Maroor, Pathanamthitta district

Phylum / Class	**Undisturbed area**							**Disturbed area**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
ARTHROPODA										
Insecta	-	-	-	-	-	-	-	-	-	-
Chironomus larvae	108	99	167	135	98	217	182	39	18	35
May fly nymph (Sp. 1)	15	3	7	7	7	29	7	2	11	7
May fly nymph (Sp. 2)	12	4	4	-	-	-	-	-	-	-
May fly nymph (Sp. 3)	-	-	-	-	2	3	-	-	-	-
Heptagenia sp.	-	-	-	-	-	2	-	-	-	-
Dragon fly nymph (Sp. 1)	2	3	2	-	-	-	-	-	-	-
Dragon fly nymph (Sp. 2)	2	4	-	-	2	4	2	2	-	-
Dragon fly nymph (Sp. 3)	-	2	-	1	-	-	-	-	-	-
Diptera larvae	24	21	17	4	9	13	13	-	4	4
Chironomus pupa	1	2	7	17	4	7	238	4	-	1
Caddis worm (larvae)	-	1	20	1	50	20	13	2	-	1
Insect larvae (unidentified)	3	4	4	-	6	2	9	-	-	-
Crustacea	-	-	2	-	-	2	-	-	-	-
ANNELIDA	-	-	-	-	-	-	-	-	-	-
Polychaete	-	-	4	-	-	9	-	-	-	-
MOLLUSCA	-	-	-	-	-	-	-	-	-	-
Fresh water mussel	5	2	-	-	-	3	6	-	-	-
Bivalve	-	-	-	-	2	-	-	-	-	-
Gastropod	-	-	-	-	-	-	2	-	-	-
VERTEBRATA	-	-	-	-	-	-	-	-	-	-
Pisces	-	-	-	-	-	-	-	-	-	-
Noemacheilus sp.	2	1	2	-	-	-	-	-	-	-
Unidentified species	-	2	-	3	-	-	-	-	-	-
Total number of species	**10**	**13**	**11**	**7**	**9**	**12**	**9**	**6**	**3**	**5**

Source: Sunilkumar (2002b)

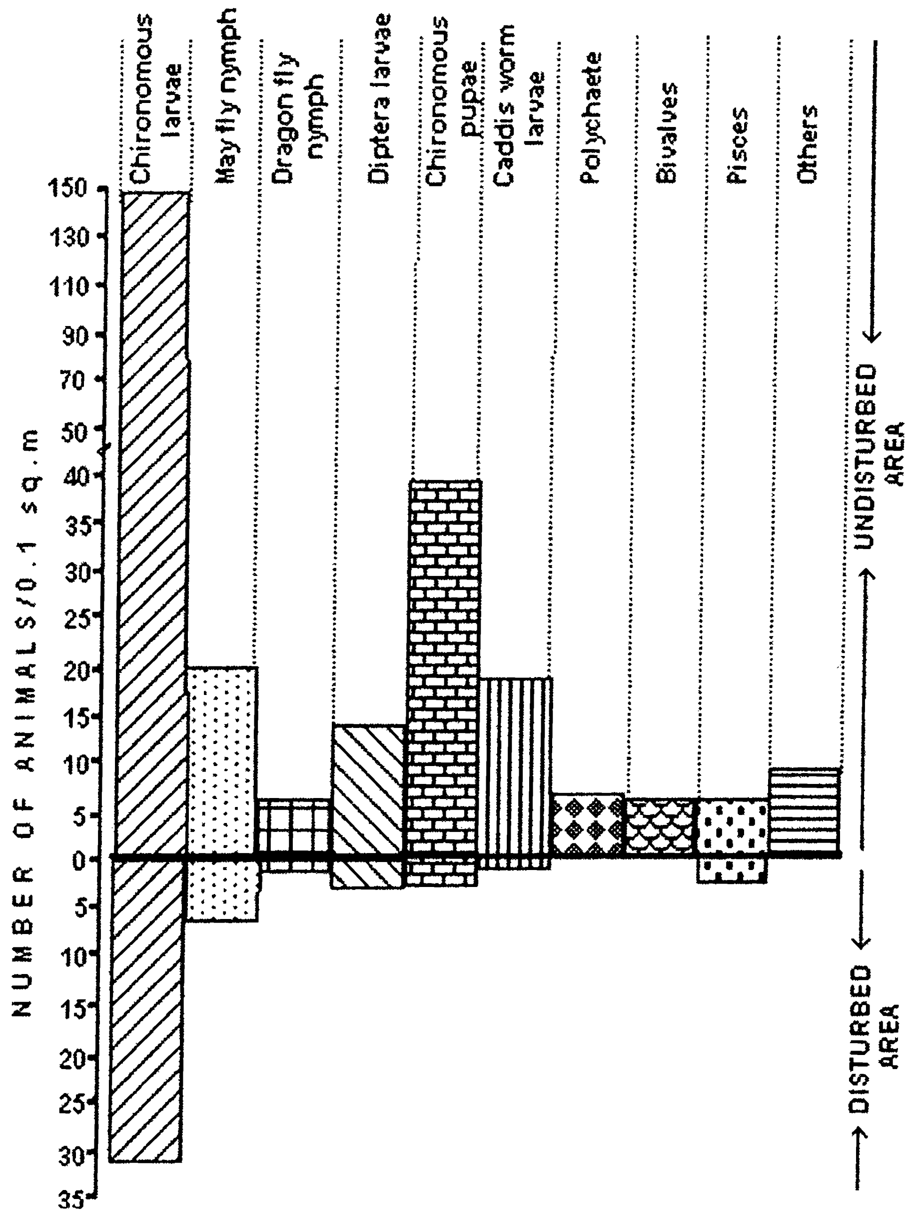

Fig 7.19 Average abundance (0.1m^2 area) of benthic organisms in the Achankovil river
Data source: Sunilkumar (2002b)

bearing on the distribution and abundance of other organisms in the waters they inhabit. Third, fishes form an important ecological link between aquatic and terrestrial environments as it form food for many terrestrial organisms including aves. Most of the fishes are open substrate spawners that do not guard their eggs (FAO, 1998). The spawning substrata of fishes can be grouped into five categories – (a) Pelagophils: Eggs are non-adhesive, naturally buoyant and develop whilst being carried by the water current. Larvae are strongly phototropic and swim actively; (b) Lithophils: Eggs stick to stones and gravel; (c) Phytolithophils: Eggs stick to submerged plants but other substrata are utilized in their absence; (d) Phytophils: Eggs adhere to submerged macrophytes and (e) Psammophils: Eggs are laid on sand or fine roots associated with sand, washed by running water. According to Freeman et al. (1997), fishes preferably occupy areas that best support survival, growth or reproduction.

In a study on the ecological structure and functional processes of fish assemblages in Periyar lake and stream systems, Arun (1999) noted loss of about 16 species from this aquatic system when he compared his study results with the list of fishes recorded in a previous study by John (1948). Resource requirements based on habitat associations like depth, flow, substrate and food were assessed for endemic and threatened fishes. Most of the endemic and threatened fishes of the study area preferred stream habitat than lake habitat. This is an indication to the fact that pit excavation (through sand mining) and creation of lentic sub environments in rivers is an adverse situation for such fishes. Fig. 7.20 a-f shows the substrate association of fishes in the Periyar lake-stream system. The most preferred substrate for fishes in the stream habitat was boulders followed by pebbles / or cobbles. Sand mining is prevalent in the tributaries of the rivers in the study area, including the Periyar river. Pebbles and cobbles are also mined from the river reaches for decorative purposes. These processes will definitely alter the substrate characteristics. Dietary analyses show that the major food bases of fishes were algae, diatoms, terrestrial insects, aquatic insects (both macro and microinvertebrates), crustaceans and molluscs, plankton and detritus. Detritus is the major pathway of energy and material flow in most ecosystems, supports higher trophic levels, and is a major source of inorganic nutrient

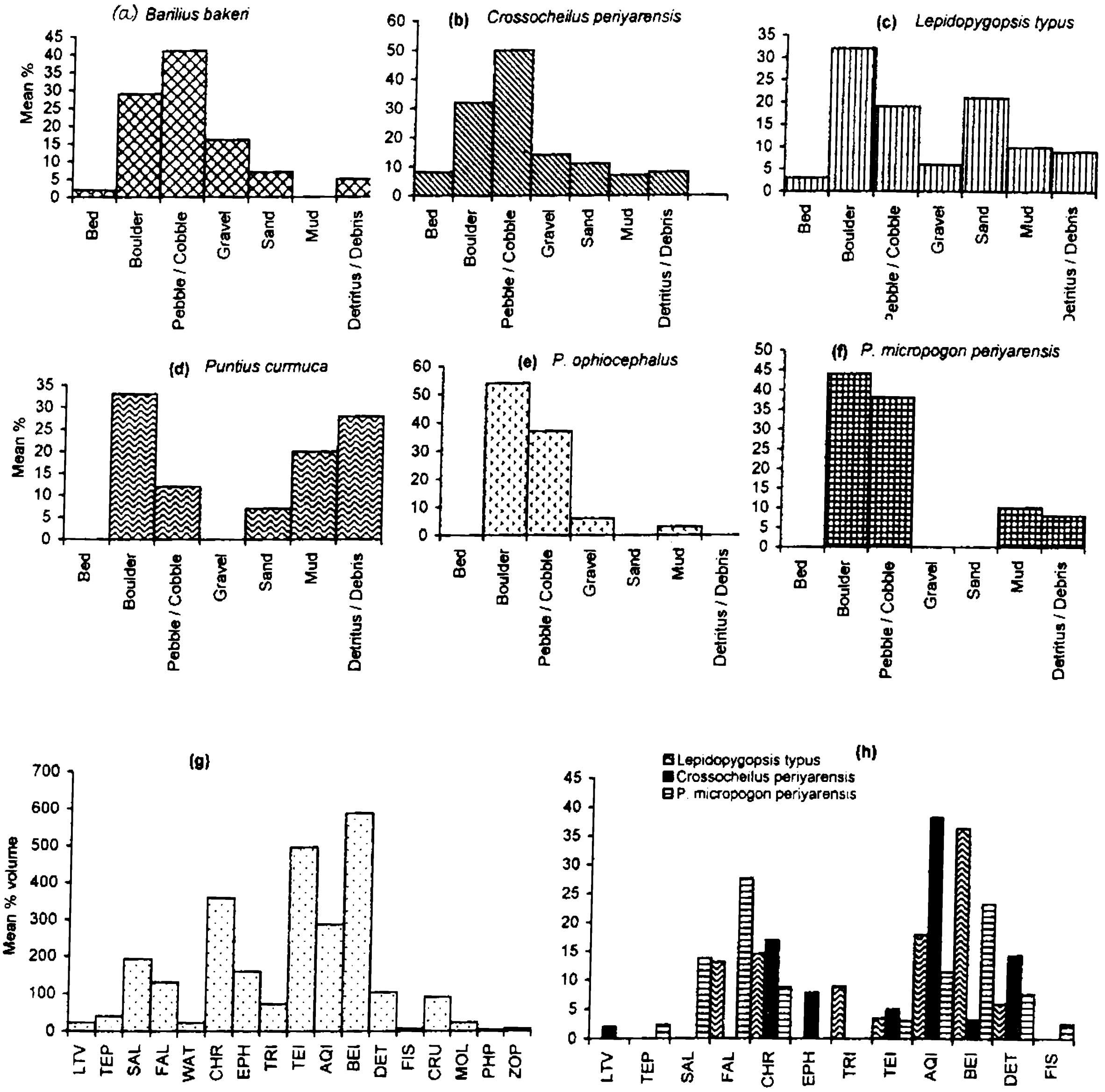

Fig. 7.20 Habitat associations and dietary composition of fish species in Periyar streams in the reservoir catchments (after Arun, 1999). (a) - (f) Substrate type associations of endemic and threatened fishes (mean %); (g) and (h) Dietary composition of fish species along with endemic species.LTV: Littoral vegetation; TEP: Higher terrestrial plant matter, their remains such as seeds, flowers etc.; SAL: Small algae including diatoms; FAL: Filamentous algae; WAT: Water mites; CHR: Chironomids; EPH: Ephemeropterans; TRI: Trichopterans; TEI: Insects of terrestrial origin such as ants; AQI: Adult aquatic insects; BEI: Benthic microinvertebrates; DET: Detritus including debris, mud / clay particles; FIS: Fish or parts of fishes like scales, fins etc.; CRU: Crustaceans and its parts; MOL: Molluscs and its parts; PHP: All phytoplankton species; ZOP: All zooplankton species

regeneration and uptake. The composition of diet of fishes in the Periyar lake-stream system is given in Fig. 7.20 g and h. In a recent study, Taylor et al. (2006) found that loss of a detrital feeding fish species alters ecosystem metabolism and organic carbon flow in the system.

Kurup et al. (2005) listed 175 freshwater fishes from some of the major river systems of Kerala. Out of this, a total of 143 species are recorded in the rivers draining the Vembanad lake catchments. The study shows that the rivers and streams in the State have exceptional fish biodiversity with a high degree of endemism due to the presence of many rare and localized forms. The biodiversity status of these fishes was assessed as per the International Union for Conservation of Nature and Natural Resources (IUCN); (Table 7.10). The IUCN list puts threatened fishes into the categories (1) Extinct (E), (2) Extinct in the Wild (EW), (3) Critically Endangered (CR), (4) Endangered (EN), (5) Vulnerable (VU), (6) Lower Risk (LR), (7) Data-Deficient (DD) and (8) Not Evaluated (NE). The category LR can be separated into conservation-dependant (LRcd), near-threatened (LRnt) and least concern (LRlc).

Table 7.10 Number of fish species in the study area falling in the Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Low Risk Near-Threatened (LRnt), Low Risk Least Concern (LRlc) and Data Deficient (DD) categories of the IUCN

River	**IUCN status categories***						**Total species in each river**
	CR	**EN**	**VU**	**LRnt**	**LRlc**	**DD**	
Achankovil	-	4	4	3	15	3	29
Pamba	1	2	3	4	5	1	16
Manimala	-	1	1	1	2	-	5
Meenachil	-	1	-	4	8	-	13
Muvattupuzha	-	-	2	1	1	-	4
Periyar	3	11	6	5	5	4	32
Chalakudy	4	7	9	10	10	4	44
Total in the study area	**8**	**26**	**26**	**28**	**46**	**12**	**143#**

Source: Kurup et al. (2005); #Fishes in the reservoirs are not considered in this category as it may contain introduced / exotic species.

About 125 research papers on the freshwater fish fauna of Kerala available during the period 1965-2000 were reviewed by Kurup et al. (2005) while compiling the past data on abundance and availability of fishes in Kerala. The population of the majority of fish species shows drastic decline over the past five decades. The serious threats faced by the freshwater fishes of Kerala are mostly in the form of human interventions and consequent habitat alterations (Kurup et al., 2005). From Table 7.10, it is clear that the Chalakudy river have the greatest diversity of fishes followed by Periyar and Achankovil rivers. Among the 8 critically endangered species 4 are confined to the Chalakudy river. While Periyar river ranks first in the case of endangered species, the Chalakudy river occupies first position in vulnerable species. A list of some of the threatened fishes of the study area and causes for threat are presented in Table 7.11.

In a recent study, Kurup and Radhakrishnan (2006) noted that a total of 31 species of freshwater fishes were found missing from the total of 175 species reported earlier (Kurup et al., 2005). The natural populations of these fishes might have undergone drastic depletion due to various types of anthropogenic activities, first and foremost being river sand mining. A population reduction of 99% of most of the critically endangered species was recorded due to serious anthropogenic activities. They not only showed high habitat specificity but also found in specific microhabitats of certain river systems. The destruction of the critical habitat parameters of these specific microhabitats is the main cause for the depletion in their natural population. The rivers in the study area are characterized by the presence of varied types of habitats and the fishes are adapted to live in these habitats (Table 7.12). Reports suggested that the indiscriminate sand mining has changed the ecology of the river systems along vast stretches during the past few decades (Anon, 2005). All these strengthen the view that any change in the habitat structure can contribute to the decline of the fish population. All these, in other words, reveal that any change in these natural fluvial setting would adversely affect these fishes. It is a fact that indiscriminate sand mining is an anthropogenic factor that would change the natural fluvial system.

Among the major threats faced by the fish populations in Chalakudy river system, disappearance of riparian vegetation and extensive sand mining plays an important role along with the other factors (Ajithkumar, et al., 1999; 2000). Gopalakrishnan and

Table 7.11 Threatened freshwater fishes in the study area and reasons for threat as per IUCN (1990)

Sl.No.	Name of fish	Threat	IUCN Category
1.	*Anabas testudineus*	Damming, Fishing, Human interference, Over exploitation, Trade (local, domestic, commercial)	VU
2.	*Barilius bakeri*	Fishing, Loss of habitat, Pesticides, Poisoning, Siltation, Trade (local)	VU
3.	*Channa striatus*	Fishing, Trade (commercial)	LRlc
4.	*Glossogobius giuris*	Hunting, Trade (local)	LRnt
5.	*Gonoproktopterus kolus*	Disease, Dynamiting and other destructive method of fishing, Loss of habitat due to exotic animals, Over exploitation, Predation, Predation by exotic animals, Trade (local, domestic)	EN
6.	*Noemacheilus pulchellus*	Damming, Fishing, Human interference, Loss of habitat, Over exploitation, Poisoning, Pollution, Trade (local)	DD
7.	*Puntius ticto punctatus*	Fishing, Genetic problems, Over exploitation, Trade (local)	CR
8.	*Puntius vittatus*	Fishing, Human interference, Loss of habitat, Over exploitation, Pollution, Trade (commercial)	VU
9.	*Puntius denisonii*	Fishing, Human interference, Loss of habitat, Over exploitation, Trade (commercial)	EN

Modified after Sheeba and Arun (2003)

VU – Vulnerable; LRlc – Lower Risk least concern; LRnt – Lower Risk near threatened; CR – Critically Endangered; EN – Endangered; DD – Data Deficient

Table 7.12 Critically endangered and endangered freshwater fishes in the study area along with their habitats, relative abundance and importance

Sl.No.	Name of the species	River source	Habitat		Relative abundance*	Degree of importance	Category	Endemism
			Alluvial reach	Substrate type$^{\#}$				
1	*Horabagrus nigricollaris*	Chalakudy	Pool-riffle	Sand, mud	A2	Highly important	Food fish	EWG
2	*Lepidopygopsis typus*	Periyar	Riffles	Boulder, cobble, pebble, sand	A1	Highly important	Ornamental	ENK
3	*Labeo ariza*	Periyar	-	-	A2	Important	Food fish	EWG
4	*Osteochilichthys longidorsalis*	Chalakudy	Riffles	-	A2	Important	Ornamental	ENK
5	*Pangasius pangasius*	Pamba	Pools	-	-	Important	Ornamental	-
6	*Tor mussullah*	Chalakudy	Rapids	Boulder, cobble	A1	Highly important	Food fish	EWG
7	*Channa micropeltes*	Pamba	Pools	Sand, mud	A1	Highly important	Food fish	ENK
8	*Dayella malabarica*	Achankovil, Chalakudy	-	-	-	Important	Ornamental	EWG
9	*Puntius ophicephalus*	Pamba, Periyar	Rocky pools	Cobble, pebble, gravel	A1	Important	Food fish	EWG
10	*Gonoproktopterus micopogon periyarensis*	Periyar	Riffles and runs	Cobble, pebble	A1	Highly important	Food fish	ENK
11	*Osteochilus thomassi*	Periyar	-	-	-	Highly important	Food fish	EWG
12	*Silonia childreni*	Periyar	Pools	-	-	Not categorised		EWG
13	*Travancoria elongata*	Chalakudy	Rapids	Boulder, cobble	A1	Highly important	Ornamental	EWG
14	*Travancoria jonesi*	Chalakudy	-	-	A1	Highly important	Ornamental	EWG
15	*Anguilla bengalensis*	Periyar	Pools	Mud	A2	Highly important	Food fish	EWG
16	*Garra mcClellandi*	Periyar	Riffles and runs	Boulder, cobble, pebble, gravel	A2	Important	Ornamental	EWG
17	*Garra surendranathinii*	Periyar, Chalakudy	Riffles and runs	Boulder, cobble, pebble, gravel	A3	Very highly important	Ornamental	ENK

Contd...

...Contd

Sl.No.	Name of the species	River source	Habitat		Relative abundance*	Degree of importance	Category	Endemism
			Alluvial reach	Substrate type$^{\#}$				
18	*Gonoproktopterus kolus*	Periyar, Chalakudy	Runs and pools	Cobble, pebble, gravel	-	Highly important	Food fish	EWG
19	*Gonoproktopterus thomassi*	Chalakudy	Runs	Cobble, pebble	A1	Highly important	Food fish	EWG
20	*Gonoproktopterus kurali*	Periyar	Runs and pools	Gravel, sand, mud	A2	Highly important	Food fish	EWG
21	*Labeo dussumieri*	Achankovil, Pamba	Runs and pools	Sand, mud	A1	Highly important	Food fish	ENK
22	*Osteobrama bakeri*	Achankovil	Runs and pools	-	A1	Very highly important	Ornamental	ENK
23	*Pangio goensis*	Manimala	-	-	A1	Important	Ornamental	EWG
24	*Puntius lithopidos*	Periyar	-	-	-	Highly important	Ornamental	EWG
25	*Sicyopterus griseus*	Chalakudy	Riffles and pools	-	-	Highly important	Ornamental	EWG
26	*Batasio travancoria*	Pamba, Manimala, Chalakudy	-	-	A2	Important	Ornamental	ENK
27	*Glyptothorax annandali*	Muvattupuzha	-	-	A3	Important	Ornamental	EWG
28	*Gonoproktopterus curmuca*	Chalakudy	Runs and pools	Cobble, pebble, gravel	A3	Highly important	Food fish	EWG
29	*Horabagrus brachysoma*	Achankovil, Periyar, Chalakudy	Runs and pools	-	A3	Highly important	Food fish	ENK
30	*Puntius denisonii*	Achankovil	Rocky pools	Boulder, cobble, pebble	A1	Very highly important	Ornamental	ENK
31	*Nemacheilus keralensis*	Meenachil	-	-	A1	Very highly important	Ornamental	ENK

Modified after Kurup et al. (2005); Sl.No. 1 to 9: Critically endangered and rest are endangered; EWG: Endemic to Western Ghats; ENK: Narrowly endemic to Kerala
Relative abundance (A1 to A3): A1: Very rare; A2: Rare; A3: Abundant
**Data source: Gopi (2000); #Source: Daniels (2002); Arun (1999)*

Ponniah (2000) identified upstream areas of Periyar and Chalakudy rivers and selected stretches of Vembanad lake as potential areas for developing into fish sanctuaries. In the case of Periyar, between 774 – 968 m altitude, biodiversity showed an unusually increasing trend due to the dominance of some critically endangered endemic species such as *Lepidopygopsis typus*, *Gonoproktopterus micropogon periyarensis* and *Crossocheilus periyarensis*. Abundance of *L. typus* showed a positive correlation with amount of bedrock substrate, chute type microhabitat, overhanging boulders, overhanging vegetation, total shade and stream cover. The latter two species also showed affinity to overhanging vegetation and excellent shade. The Periyar river system requires special conservation measures due to the presence of endemic and critically endangered species in its upstream region. Fish diversity is found to be less in the midland and highland regions of these rivers probably due to habitat alteration on account of various human interventions. Padmakumar and Krishnan (2000) identified deep pools in Meenachil and Pamba rivers adjoining the Vembanad lake could be protected as sanctuaries for threatened species such as *Labeo dussumieri* and *Horabagrus brachysoma*. In short, fishes and other organisms of the rivers of Kerala are under severe stress due to drastic changes in habitat alteration for mining of construction grade sand from active channels, river banks (Plate 7.5) and also floodplains. A strict regulation of this activity is utmost essential for reviving the health of the river ecosystems of the State.

Plate 7.5 Loss of riparian vegetation as a result of indiscriminate sand mining activities is a major threat to aquatic organisms, especially fishes. Two scenes showing degraded river banks devoid of riparian vegetation

7.5.3 Riparian vegetation

The riparian habitats comprise a transition between the river and the upland portion of the watershed. Vegetation that grows at the interface of the river and adjacent riparian habitat and shades the water is known as Shaded Riverine Aquatic habitat (SRA). The SRA vegetation is composed of overhead cover and instream cover. The overhead cover comprises overhanging riparian vegetation and the instream cover comprises woody debris, such as roots and trunks, and aquatic plants.

Sand mining has deleterious effects on the riparian vegetation seen along the banks of the rivers. The riparian canopy regulates stream temperature through shadowing and provides organic matter via litter fall, while their root systems stabilize the bank and filter lateral sediment and nutrient inputs, thereby controlling stream sediment and nutrient dynamics (Gregory et al., 1991; Naiman and Decamps, 1997). Riparian zone is a very important habitat when rivers in the study area are considered. Bachan (2003) studied in detail the riparian vegetation along the Chalakudy river and found that lower stretches of the river are highly degraded with less number of vegetation. He emphasized that river sand mining is the most destructive human activity threatening the river environment. The river banks were severely eroded and the common riparian lands were disappeared. According to Vijith and Satheesh (2006), riparian vegetation seen along the banks of Meenachil river is rich in medicinal plant species. The indiscriminate sand mining activities prevalent in the highland areas of Meenachil river basin is a major threat to these floral resources. In short, the destruction of riparian vegetation is a real threat to the river environment.

7.5.4 Aquatic / Instream vegetation

Aquatic vegetation plays an important role in maintaining and improving the health of the river environment. However, these are more likely to be of greatest significance for fisheries when a watercourse has little or no variation in physical structure. The surfaces of submerged leaves are sites of primary and secondary production by micro algae and bacteria, which can rival that of phytoplankton and bacterophils in water column. The community serves as food for grazing invertebrates and protozoa, it contributes to bio-purification of organically polluted water courses, and can be a substantial source of planktonic micro-organism (Murphy, 1998). Nutrient recycling is an important function accomplished by instream vegetation. They act as physical link between water and air for many invertebrates, eg., caddis, which are food for fish have aquatic larval stages and aerial adults. As discussed in subsection 7.4.1, TSS introduced in the water column by sand mining can have profound effect on instream vegetation. Turbidity due to the carriage of silt in the water mass may physically block out light penetration through the water column thus reducing the activity of photosynthesis and thereby lowering the levels of primary production. Nandan (2005) opined that in Pamba river, the algal and benthic biomass and diversity was generally low. The major planktonic organisms collected from various stretches in the river were *Anabaena, Ankistrodesmus, Chlorella, Navicula, Tintinnids, Pleurosigma* and *Microcystis*. In Periyar river, phytoplankton community comprised of Chlorophyceae, especially desmids in the freshwater region of river (Joy et al., 1992). Rise in turbidity level in water column due to sand mining could adversely affect the phytoplankton population in the water column. This will naturally affect the secondary productivity and ultimately the trophic level in the Periyar river waters.

7.6 Changes in social environment

Social effects are a hybrid form of environmental, social and economic factors. However, it should be emphasized that quantifying the socio-economic effects is a difficult task. However, an assessment of socio-economic effects of river sand mining would be helpful in wise-decision making in river management. Though some sub-components of sand mining may improve the social condition (eg., generation of income, local revenue, employment etc.), majority of the activities will have negative effects on the environment as well as on society. Those who are worst affected by the mining activities include the local people residing close to river channels (Plate 7.6).

Plate 7.6 Socio-economic effects of sand mining on riparian land owners. (a) A scene from Achankovil river; (b) A scene from Periyar river

Documentary evidences and file photos from archives are extensively used for illustrating this section. In this section, an attempt has been made to describe the social effects of river sand mining in the study area. For convenience of description, social effects are classified into 4 types, namely, socio-economics, socio-health, socio-cultural and socio-livelihood (Macfarlane and Mitchell, 2003).

7.6.1 Socio-economics

The potential socio-economic effects of river sand mining inferred from this study are largely negative. However, common arguments favouring river sand mining, are that the mining activity do create positive socio-economic impacts in the area through employment and revenue generations. The income can entail a dramatic rise in material living standards. River mining can potentially provide a significant source of revenue through profit related royalty payments and through fixed taxation (Waelde, 1992). The most significant incremental socioeconomic impact will relate to some small employment generation locally and further a field for drivers and to suppliers of driver goods and services. Additionally, it should be noted that the potential for vehicle movement to degrade roads is high. This cost is arguably borne by the vehicle operators in their additional road tax. Nevertheless, it is unlikely this revenue will be fed back to the mining areas where their impact is greatest.

The magnitude of river channel incision measured in the storage zones in about 20-25 years are already explained in Section 7.2. The drastic depletion of the groundwater table due to excessive removal of river sand had already made many rural water supply schemes defunct. It was found that indiscriminate sand mining close to the bridges and the filtration tanks of many drinking water schemes is continuing without much interruption even today. Pumping facilities and water scarcity during dry periods has become a serious issue in the Vembanad lake catchments. Furthermore, many houses on the sides of river banks have developed cracks on the walls and floors due to the primary and secondary effects of sand mining. The bridges in the study area are in peril due to incision of river beds and hungry water effects consequent to indiscriminate sand mining. The construction of a number of check dams are now necessitated to hold up the water level and prevent the undermining of bridges, exposure of water intake structures etc. The costs to repair or replace structures damaged by river bed lowering from sand mining activities will be a huge amount and it will be far higher than the revenue generated from the mining activities.

7.6.2 Socio-health

As in the case of biological effects described earlier (Section 7.5), impact on human health is also typically mediated through physical impacts of river sand mining. For example, changes in water flow and water quality may increase the prevalence of communicable diseases. Deterioration of the quality of water used for drinking, bathing and other domestic purposes is a serious problem in the study area. These effects can ultimately result in permanent and irreversible ecological transformations, rendering mined stretches of rivers useless for subsequent development or use. Parker (1996) states that any adverse effects on the hydrological environment of developing countries will tend to have a corresponding affect on the health of local communities. In many parts of the developing world, communities near to extractive operations depend on untreated surface and ground waters as their main water supplies, used for drinking, washing and food preparation. Extraction from riverbanks and beds and the resultant generation of particulates, chemical pollutants such as diesel in the water therefore pose a particular health risk to workers involved in mining.

In highlands and midlands, alterations by extraction to the hydrological environment can increase the risk of diseases, especially during summer where low flow exists. The excavations associated with river mining can create stagnant waters that may favour the multiplication of waterborne disease vectors such as flies, mosquitoes and other parasites and the introduction of new ones. Resurgence in the incidence of vector borne diseases like Dengue fever, Chikungunya, Japanese encephalitis etc., is one of the most worrying changes in disease patterns in recent years in the study area, where mining activities are more prevalent. This had a particularly devastating effect on the populations, who have no resistance to the emerging strains and little access to modern medical facilities. Recent reports show that *Anopheles culicifacies* thrive in river bed pools, borrow pits, sluggish streams with sandy margins (KSCSTE, 2007). Larvivorous fishes like *Puntius amphibius*, which can be used as biocide for mosquitoes, are disappearing from the streams due to habitat degradation consequent to extensive mining activities (Jameelabeevi, 2004).

The field survey made in connection with this study revealed that workers of sand mining sector are suffering from occupational hazards like skin allergies, eye and respiratory problems etc. Further, the deep pits created in the channel also can contribute to an increase in accidents in the working environment. This creates serious threat to residents in the area who depend on river water for their domestic purposes. From Table 7.13, it is evident that a total of 248 people got drowned in the deep excavation pits developed by sand mining processes during 2002-06. Drowning incidents of livestock are also common in midland and lowland areas, but there is no account exists to highlight the loss of life of livestock and other pet animals. No doubt, the rivers in the study area have turned into death traps due to pit excavation and migration of the pits upstream and downstream during high flow regimes of the monsoon periods. The major source of socio-health impacts of transportation will stem from truck fumes, dust generation and movement. Increase in accidents as a result of rash driving of lorries carrying sand

Table 7.13 Various types of accidents and death toll of people in the study area as a result of sand mining activities

Rivers	Years														
	2002			2003			2004			2005			2006		
	DA	VA	PA	DA	VA	PA	DA	VA	PA	DA	VA	PA	DA	VA	PA
Achankovil	2	-	-	2	-	-	8	-	-	5	-	-	3	2	-
Pamba	-	-	-	8	2	-	7	3	-	9	1	-	12	1	-
Manimala	3	-	-	2	-	-	1	-	-	5	-	-	2	-	-
Meenachil	1	-	-	1	-	-	2	-	-	7	-	-	5	-	-
Muvattupuzha	3	-	1	9	-	1	5	1	-	6	-	-	14	1	-
Periyar	24	-	1	15	6	-	20	1	1	24	9	-	16	2	3
Chalakudy	9	-	-	3	-	-	8	-	-	3	-	-	4	3	1
Total	**42**	**-**	**2**	**40**	**8**	**1**	**51**	**5**	**1**	**59**	**10**	**-**	**56**	**9**	**4**

DA: Drowning accident; VA: Vehicle accident; PA: Pedestrian accident through the roads is frequent in recent years (Table 7.13). Many people lost their lives through this means as well.

7.6.3 Socio-culture

River sand extraction is linked to some small population increases as a result of its potential direct and indirect employment opportunities. The wages they receive can cause huge disparities of wealth in a concentrated area (Clark, 1996, Warhurst and Macfarlane, 1999). This analysis shows that illegal river sand mining is a brisk business in many parts of the area. This has led to degradation of cultural and moral values as well. The so-called sand mafia has reportedly gained in strength along the banks of the rivers in the study area. Incidents of the mafia goons extending their criminal activities to nearby towns have also been reported in various regional and national dailies (The Hindu, Mathrubhumi, etc.), during the period of this study.

At many places in the downstream, the river enfolds well developed sand bodies. The vast sandy plains in river beds are used traditionally to hold religious conventions. The river bed of Pamba river at Maramon, near Kozhenchery has been the traditional venue for holding the Maramon convention for the past hundreds of years or so. And, the sand bed at Cherukolpuzha forms the venue for the annual Hindu convention for the last 9 decades. In addition, many places of worship of the various religious communities of Kerala are also situated on the banks of rivers. The sand beds in Periyar river near Aluva town hosts religious congregations in connection with the Sivarathri festival. The history and cultural activities of any area is invariably associated with the rivers and their river beds of that area. The famous Hindu conventions in connection with the festivals of the Thirumalida Mahadeva temple at Mallappally and the Devi temple at Kallooppara, the Catholic and CSI Christian conventions etc. are being celebrated annually on the river beds of Manimala river. The Lord *Ayyappa* temple is another religiously important spot in Pamba basin. Reports say that during pilgrim season millions of *Ayyappa* devotees from various districts of south and central India reach at Sabarimala for worship and holy dip at Pamba river. The famous *Uthruttathi* boat race is held at Aranmula every year, as a part of Onam festival. Illegal mining activities cause grave threat to these culturally /

religiously significant places and events. The extensive sand beds in the river channels of the study area have been found shrinking due to indiscriminate sand mining. The degradation of the river systems will definitely impose far-reaching implications in the socio-economic and cultural environment of the study area.

7.6.4 Socio-livelihood

Besides the river sand mining's potential for employment creation that is particularly important with regard to livelihoods of workers engaged in mining, it is also related to the livelihood issue of local people in the form of resource availability. Effects of sand mining on resource availability include: a) Loss of access to clean water – used for drinking, bathing, cleaning, irrigation, etc. b) Loss of land and access to land, c) Reduced access to food and d) Loss of trees and vegetation.

Loss of productive agricultural lands in the physiographic provinces like highland, midland and lowland, loss of livestock etc., can have adverse effects on livelihood issues of inhabitants along the river side. Impacts of sand mining on sediment characteristics and water quality can also have marked effects on the levels of fish stock ultimately leading to local food security. The fishermen communities in the lowlands of the river basins are in difficulty due to drastic decline in fish catch during the past several years. Most of them are traditionally engaged in fishing. But, indiscriminate scooping of river sand which offers the breeding and spawning grounds for many economically important fish species is one of the major factors for the observed decline. Conflict between the miners and fishermen communities is frequent in the upstream reaches where the river bank failure incidents are also very severe. People's opposition against mining is also reported from the area.

7.7 Discussion

All the seven rivers (Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy rivers) draining the Vembanad lake catchments are degrading at alarming rate consequent to indiscriminate sand mining, construction of impoundments and other means (urbanization, industrialization, etc.) that obstruct movements of sand downstream. Among these, sand mining is the most notable one as the activity became rampant throughout the river system. As a consequence, the channel beds in the storage zones of these rivers are lowering (channel incision) fast posing instability problems to river banks and associated engineering structures, loss of habitat of riverine biota, etc. The rate of channel incision responds well to interventions of Honourable Courts and the Government from time to time. This was clearly evident during 2000-05 period, in which the rate of incision was considerably reduced in many of the rivers of the study area. Unfortunately, such interventions could not sustain for long because of the rising demand for construction grade sand and also ineffective implementation of regulatory procedures. By removing sediment from the channel, disrupting the pre-existing balance between sediment supplies and transporting capacity, and in some cases creating a locally steeper gradient upon entering the pit, instream gravel mining typically induces channel incision upstream and downstream of the extraction site (Sandecki, 1989).

The continued extraction of sand taking place over the past 3-4 decades has imposed notable changes in the composition and stability of bed sediments of rivers. Local hydrodynamics may, of course, played an important role in imparting notable textural variations along the profile of the rivers. From Fig. 5.7 c in Chapter 5, it is evident that the water discharge through the Muvattupuzha river channel was found constant without much fluctuation. This clearly indicate that the observed variations of granulometric image in sediments as evidenced in Fig. 7.11 is attributed due to human interventions consequent to river sand mining rather than the natural processes. The river bed characteristics of the point bars, like the one at Valanchuzhi in Achankovil river, will be worsened markedly if effective steps are not been taken to protect the entire river system from rampant river sand mining. Simultaneously scientific management practices are also to be adopted to restore the ecological and environmental scenario of the system. Many of such point bars are used for holding the annual religious / cultural congregations.

In an aquatic environment, the transport of elements is controlled generally by the size spectrum of clastic sediments (De Groot et al., 1982 and Forstner, 1990). A large part of fluvial transport of matter occurs in the form of suspended sediments. During low flow regime, these geochemical carriers sink to the bottom as bed sediments. Geochemical studies of the river transported materials, especially bed and suspended sediments, have been extended in the past few decades due to the growing awareness of its impact on the ecosystem. Longer residence of TSS in the water in non-monsoon season favours the fine clay and silt particles in TSS adsorb nutrient elements onto its surface. Since the sand mining operation generates large excavation pits in river channels, the flocculated fine particles enriched with nutrients ultimately find their way into these pits. The net result will be substantial reduction in the net flux of nutrients to the marine environments. Sand and gravel mining can considerably limit the delivery of sediment to the coastal environment, in a manner similar to that of damming, as also observed elsewhere by Brownlie and Taylor (1981), Inman (1985) and Frihy et al. (1991).

During periods of base flow, alluvial banks commonly drain to the river level. Channel incision can induce fall in the alluvial water table, since the banks are effectively drained to a lowered level, potentially affecting water supply in nearby wells as well as riparian vegetation (Galay, 1983; Mas-Pla et al., 1999). The lowering of groundwater table also results in economic loss among the people who survives along the river banks by lowering the wells and pumping water from greater depths, increasing water costs significantly. The water table lowering will extend farther from the channel in highly permeable alluvium such as gravel and sand, a short distance in finer grained alluvium with lower permeability. Alluvial aquifers with fine grained alluvium that receives substantial recharge from valley sides and tributaries may maintain a water table that slopes steeply toward the channel despite incision. Water table lowering can induce profound ecological and landscape changes, including loss of hyporheic habitat as adjacent banks are dewatered (Creuze des Chatelliers and Reygrobellet, 1990). More widely documented has been the loss of riparian vegetation as the water table drops below the root zone of riparian plants (Reilly and Johnson, 1982; De Bano and Schmidt, 1989). Another potential effect in the fall of alluvial groundwater storage is reduced summer base flow due to reduced contributions to the stream from the adjacent alluvial aquifer. This effect is particularly strong for lowered channels in coarse grained alluvium with high permeability. Reduced base flow may lower water quality by reducing the effect of dilution. In general, channel incision changes the pattern of ground water-surface flow interactions in alluvial streams, including the extent and flux of groundwater upwelling zones that provide important habitat for fish and benthic invertebrates and regulate stream temperature (Ward and Stanford, 1995). From this, it can be concluded that the lowering of water table in the wells close to the midland and lowland part of river channels during summer season will be in tune with the channel incision consequent to indiscriminate sand mining in the area.

It is now well established that extensive sand mining results in habitat destruction of aquatic organisms. The elimination of benthic fauna consequent to indiscriminate sand mining can adversely affect survival of carnivorous and omnivorous fishes. At the same time it also forms food for a group of terrestrial animals when matured. Therefore these insects constitute an important component of both food chain of aquatic and terrestrial environments and thereby playing an important role in maintaining the ecological balance intact. Benthic fauna of river systems are biological indicators of an area. Occurrence and distribution of these organisms not only indicate good ecological conditions but also the water quality of the river system. Examination of trends in freshwater fish fauna from different parts of the study area points to the fact that most fauna are markedly declining which in turn, stress the need for immediate conservation. Anthropogenic activities are the main cause for the alarming decline of fish populations in the rivers of the study area. Habitat destruction of natural spawning and breeding grounds of fishes through sand extraction and construction of physical obstructions across rivers has contributed to drastic decline in population of fishes. Information regarding migration, breeding behaviour and spawning grounds of threatened fishes should be generated through extensive field studies. Aquatic and riparian vegetation is a prime factor in determining the value of a riverine fishery and its potential. The direct scooping of sand from active channels and overbank areas can have major negative impacts. Efforts should be made to control the various human interventions in freshwater environments.

The social effects of sand mining are complex and cannot be considered separately from environmental issues. The social impacts stemming from river sand mining activities can have positive and negative effects. The river sand mining, generally, is an ambivalent phenomenon presenting, on the one hand, opportunities for the production of substantial wealth, and on the other hand, social breakdown (Macfarlane and Mitchell, 2003). The environmental degradation of river systems due to sand mining perhaps emerges out over the other possible causes like inter-basin water transfer, pollution, construction of dams etc. In the study area, the effects of sand mining over the years are visible on the river bed topography, bank instability, granulometry, water quality, biota and finally on the various socio-environmental components. All these issues are to be properly assessed and addressed for framing sustainable development strategies that not only strengthen the economic well being of the society but also ensure ecological security of the area.

Chapter 8

ENVIRONMENTAL IMPACT ASSESSMENT (EIA) OF SAND MINING

8.1 Introduction

River channels and its adjoining areas have long been exploited for construction grade aggregates like sand and gravel. But it is now well understood that indiscriminate sand mining from rivers and its basin areas imposes many harmful effects (see Chapter 7) on the environment. The impact of sand mining may vary depending upon geologic and geomorphic settings, river size, resource availability, climatic conditions, etc. In order to mitigate the impact of sand mining on the environment, a scientific evaluation / assessment is a pre-requisite for framing sustainable development strategies for the mining-hit areas. As most of the rivers in the State are severely affected by indiscriminate sand mining from instream and floodplain areas, an attempt has been made in this chapter to assess the environmental impact of sand mining from the river catchments of Vembanad lake, as an example. Based on the study, an Environmental Impact Statement (EIS) is prepared and is followed by an Environmental Management Plan (EMP) for the conservation and sustainable use of river ecosystems.

8.2 Drivers of river sand mining and the need for impact assessments

The three prominent factors affecting environmental changes are population, standard of living and technology (Rubin, 2001). Standard of living or the level of affluence of the population is usually measured in terms of economics such as Gross Domestic Product (GDP) per capita. The more affluent the population, the more goods and services demanded, and the greater the resulting environmental impacts. Third critical factor is technology – the vehicle for delivering goods and services that people demand. These three factors are closely interrelated with each other. They are the principal drivers determining future land use patterns, natural resource requirements and pollutant emissions to air, water and land (Fig. 8.1). However, the environmental impacts of human activities, including sand and gravel mining, depend directly on the number of people inhabiting in the area. Ehrlich and Ehrlich (1990) gave the following formula regarding the environmental impact of man: I = P x A x T, where P = Population, A = Per capita consumption of resources and T = Technology. A review of historical records shows that as standards of living improve, there is a concomitant increase in the use of natural resources for energy and raw materials (Rubin, 2001).

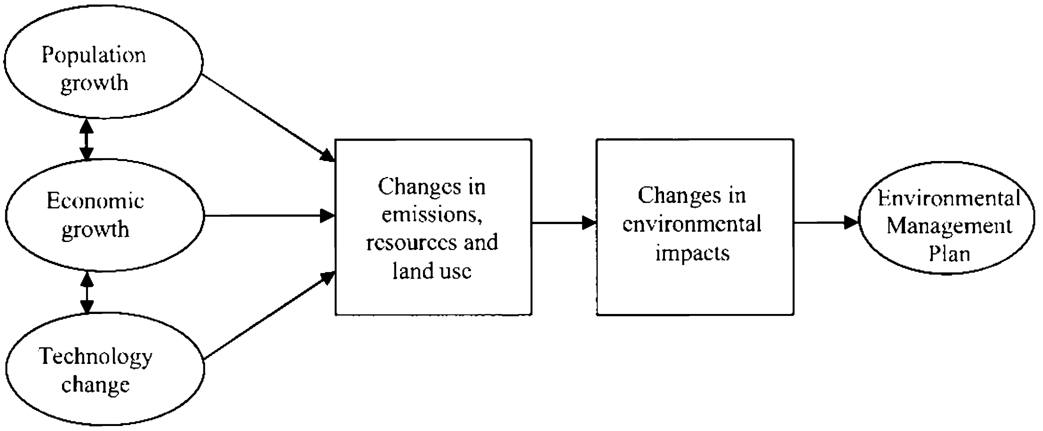

Fig. 8.1 Schematic representation showing the relation among three main drivers that cause environmental changes.

In Kerala State, the interplay of the three main drivers mentioned in Fig. 8.1 gains considerable significance. Fig 8.2 a shows the decadal addition of houses and population growth in the State during the last century. The rise in foreign remittance was one of the most influential factors responsible for the increase in the dwelling places (Fig. 8.2 b). Unscientific resource consumption and unplanned construction of houses and other infrastructural facilities have already made disturbances in the State's natural environmental setting. However, estimates show that the growth in population will attain stable phase within a couple of decades (Kannan, 2004) as the population control measures in the State are yielding significant positive results (Table 8.1). As the per capita addition of new ones within a square km area is on the decline (Table 8.1), the population will be reaching to a stable figure of around 35 million (currently 31 million) by around early thirties in this century (Kannan, 2004). It is quite interesting to note that Kerala has gained this position after attaining one of the highest densities of population in the world.

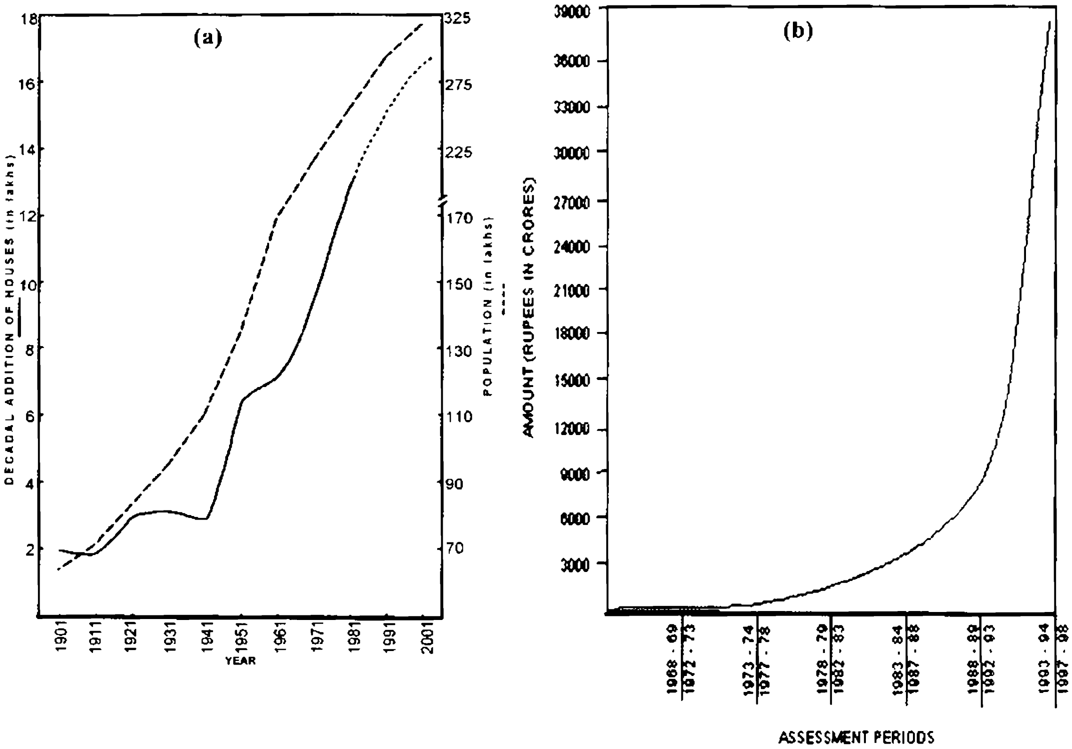

Fig. 8.2 The major drivers of environmental degradation in Kerala. Population growth curve and decadal addition of occupied houses during the period 1901 to 2001 (modified after Harilal and Andrews, 2000); (a) and Foreign remittance of Kerala during the period 1968/69 to 1997/98 (updated after Nair, 1994); (b)

The international labour migration to Gulf countries contributed and continues to contribute to the State economy in a very significant manner. Globalisation has opened up a wider set of opportunities in the State. Foreign remittances are the principal means by which emigration impacts upon the economy (Zachariah and Rajan, 2004). The remittances account for nearly a quarter (23 percent) of the State income. All these notably enhanced the pace of economic growth in the State, leading to increased resource consumption and consequent environmental degradation.

Table 8.1 Population density and decadal addition of persons in Kerala from 1901-2001

Sl.No.	Year	Population density (inh.km^{-2})	Decadal addition (inh.km^{-2})
1.	1901	165	-
2.	1911	184	19
3.	1921	201	17
4.	1931	245	44
5.	1941	284	39
6.	1951	349	65
7.	1961	435	86
8.	1971	549	114
9.	1981	655	106
10.	1991	749	94
11.	2001	819	70

Added to these are the problems arising out of the reduction in household size. Studies show that, even when the size of the population remains constant, more households imply a larger demand for resources (Keilman, 2003). Rapid increase in household numbers, often manifested as urban sprawl, and resultant higher per capita consumption of resources in smaller households pose serious challenges to aquatic ecosystems especially, the rivers (Liu et al., 2003). Fig. 8.3 shows a comparative evaluation in the decline of household sizes in the world with that of the Kerala State.

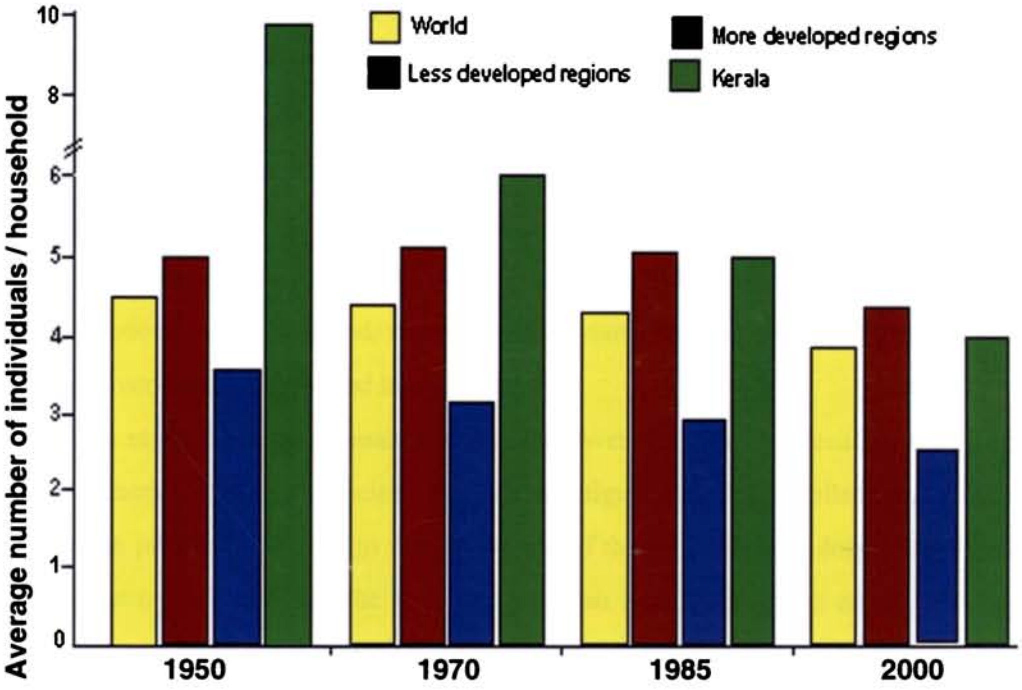

Fig. 8.3 Household sizes – a comparative evaluation. Note the recent trend of Kerala which is almost similar to world average. Modified after Keilman (2003)

There are two general categories of natural resources - renewable and non-renewable. River sand is a non-renewable natural resource in terms of human life scale, but renewable resource in terms of geological time scale. If one extracts sand to the level of natural replenishments, then the resulting environmental problems of sand mining will be minimal. But it is unfortunate that the indiscriminate extraction of river sand has turned the rivers of Kerala to such a level that they are not able to reinstate their natural ecosystem functioning. The situation demands for high priority and specific intervention to restore the natural riverine character of the already disfigured rivers of the State. In this context, role of micro-level studies and assessment of environmental impact of sand mining are extremely important not only to ameliorate the situation but also to sustain both economic development and environmental quality of the mining-affected areas.

8.3 State of river environment in the study area

The rivers in the Vembanad lake catchments are degraded severely consequent to indiscriminate sand and gravel mining. The intensity of degradation varies markedly with respect to physiography and geologic setting. The lowlands and parts of midlands close to the lowlands, that act as the storage zones of these rivers are affected severely by sand mining compared to the rest of the areas. Table 8.2 summarises the environmental problems noticed in the highland, midland and lowland physiographic provinces of the individual rivers in the Vembanad lake catchments.

As a result of indiscriminate sand mining over the past 3–4 decades, the rivers experience marked changes in their channel bed configuration. Uncontrolled extraction of sand through pit excavation led to transformation of the river bed into deep pools (Figs. 6.2 & 7.1) at many locations. The river bed has been incised to a great extent exposing many water intake structures constructed for rural water supplies and creating damages to bridges and other engineering structures (side protection structures, spillways, subsurface dykes, etc.). The luxuriant riparian vegetation bordering the rivers is affected severely by the sand mining activities. Uprooting of trees and riparian vegetation is frequent all along the river channels. The sand beds in the rivers are found to be shrinking at alarming rates year after year due to indiscriminate sand extraction and other human interventions. Ramps are constructed in the river channel at certain places for trapping sands reaching from the upstream areas as well as for providing free passage of vehicles into the river bed for loading sands directly from the river channel. Sand mining also adds to the water pollution problems in the rivers, especially in the urbanized areas. It is sure that all these activities ultimately end up in the degradation of the rivers.

8.4 Environmental Impact Assessment (EIA)

Environmental Impact Assessment (EIA) is an activity designed to identify and predict the impact on the biophysical environment and on social environment (man's health and well-being). EIA has become established worldwide as an environmental management tool used by government agencies, companies and other organizations. In its

Table 8.2 Sand mining related environmental problems in the rivers draining the Vembanad lake catchments

Sl. No.	River / Physiography	Channel type	Major environmental problems / issues and field observations	Extent of degradation (After Arun et al., 2003)
1	**Achankovil river**			
	Highland	Main channel	Bank failure incidences, uprooting of trees, parking of vehicles inside the river channel, marked changes in river bed configuration, damage to engineering structures, etc.	Low - Moderate
	Midland	Main channel	Uprooting of trees and riparian vegetation, formation of deep pools, undermining of bridge piers, channel incision and lowering of water table, damages of water intake structures and side protection structures in river bank areas, etc.	Moderate - High
	Lowland	Main channel, distributaries	River bank slumping, marked changes in the river bed configuration, channel widening, undermining of engineering structures, lowering of water table, dwindling of riverine habitats, floodplain mining of sand, etc.	Moderate - High
2.	**Pamba river**			
	Highland	Main channel, tributaries	Damage to luxuriant riparian vegetation, instream biota, bank failure incidences, etc.	Low
	Midland	Main channel	River bank slumping, severe threat to sandy plains used to hold religious conventions, channel incision, undermining of engineering structures, etc	Moderate - High
	Lowland	Main channel	River bank slumping, undermining of engineering structures, formation of deep pits, lowering of water table, floodplain mining, etc	Moderate - High
3.	**Manimala river**			
	Highland	Main channel, tributaries	River bank slumping, changes of channel morphometry, etc.	Low - Moderate
	Midland	Main channel, tributaries	Shrinking of sandy cover of the river channel and subsequent exposure of bedrocks, construction of ramps in the river bed, river bank slumping and uprooting of trees, channel incision and lowering of water table, undermining, exposure of water intake structures, etc.	High - Severe
	Lowland	Main channel, distributaries	Caving of river banks, development of deep pits in the river channel, lowering of water table, pit capturing by the river during high flow regime, undermining, floodplain sand mining, etc.	High - Severe
4.	**Meenachil river**			
	Highland	Main channel, tributaries	River bank slumping, changes in the natural configuration of river bed, undermining, encroachments, etc.	Low - Moderate
	Midland	Main channel, tributaries	Incidences of river bank slumping, over deepening of river channel, marked changes in the natural configuration of river beds, channel incision and lowering of groundwater table, encroachments, etc.	Moderate - High
	Lowland	Main channel	Wet pit and dry pit mining of sand from floodplain areas, collapse of wells during monsoon season, lowering of water table, etc.	Moderate - High

Contd..

Contd

Sl. No.	River / Physiography	Channel type	Major environmental problems / issues and field observations	Extent of degradation (After Arun et al., 2003)
5.	**Muvattupuzha river**			
	Highland	Main channel, tributaries	River bank slumping, changes in riverbed configuration, damages to engineering structures, etc.	Moderate - High
	Midland	Main channel, tributaries	River bank slumping, caving of river banks, changes in riverbed configuration, formation of deep pits of variable dimensions in the river channel, construction of temporary roads in the river bed, channel incision and lowering of water table, damages to engineering structures, encroachments, etc.	High - Severe
	Lowland	Main channel, distributaries	Incidences of river bank slumping, caving, drastic changes in river bed configuration, mining activities close to engineering structures like bridges, overdeepening of channels, lowering of water table, floodplain mining of sand, etc.	High - Severe
6.	**Periyar river**			
	Highland	Main channel, tributaries	River bank slumping, changes in channel morphometry, encroachments and reclamation, etc.	Low - Moderate
	Midland	Main channel	River bank slumping, lowering of river bed, drastic changes in river bed configuration, formation of deep pits in the river channel, dreadful dissection of river banks as a result of passage of vehicles into the river bed, vanishing sand beds, channel incision and lowering of water table, damage to engineering structures, etc.	High - Severe
	Lowland	Distributaries	Changes in bottom configuration of the river channel, river bank slumping, undermining of engineering structures, encroachment of river channel, lowering of groundwater table, saline water intrusion, etc.	High - Severe
7.	**Chalakudy river**			
	Highland	Main channel	Damage to luxuriant riparian vegetation, instream biota, bank failure incidences, etc.	Low - Moderate
	Midland	Main channel	River bank slumping and extensive damage to riparian vegetation, channel incision and lowering of water table, marked changes in river bed configuration, undermining of engineering structures close to the mining sites, shrinking of sand beds, salt-water ingression, etc.	High - Severe
	Lowland	Main channel	Lowering of groundwater table, salinity intrusion, floodplain mining of sand, etc.	Moderate - High

most simple form, an EIA represents the process of identifying, estimating and evaluating the environmental consequences of current or proposed actions (Vanclay and Bronstein, 1995). EIA is essentially about optimizing resources through an allocation of all resources, to achieve a balance between development and environmental protection (Gilpin, 1995). In other words, an EIA is a process of analyzing the various *pros* and *cons* of an action or a set of actions as it would affect the environmental conditions / parameters that have been considered as significant in a given scenario. EIA was introduced in the United States in 1969 as a requirement of their National Environmental Policy Act (NEPA). Since then, many countries are following the EIA procedures by introducing appropriate legislation and also establishing Agencies / Departments with responsibility for its implementation.

An 'environmental impact' is any alteration of environmental conditions or creation of a new set of environmental conditions, adverse or beneficial, caused or induced by the action or set of actions of any particular activity under consideration (Rau and Wooten, 1980). It is an event or effect, which results from a prior event. It can have both spatial and temporal components and can be described as the change in an environmental parameter, over a specific period and within a defined area, resulting from a particular activity (Wathern, 1989). The impact is the difference between the with-project and without-project condition, which may be possible to quantify, for example, a predicted change in an environmental parameter such as noise level.

EIA is a key component in the environmental planning process, which should be used at an earlier stage to identify and to consider projects or activities likely to cause significant adverse impacts on the environment and to ensure that such potential impacts are evaluated, minimized and mitigated appropriately. Broadly, an action or a set of actions would include such activities that have been proposed in a project at its implementation stage (Ramachandran and Padmalal, 1997). The vehicle that would convey the impact of a particular activity is the Environmental Impact Statement (EIS). The main purpose of the EIS is to provide environmental quality in planning and decision making processes. The EIS should embody the impacts that would generate on the quality of the biophysical and the social environments, in terms of both short and long-term perspectives.

8.5 EIA studies – a brief review

EIA is an effective tool to assess the effects of developmental processes on various components of environment. It is an emerging area in the field of environmental studies. Bilateral and multilateral agencies have recognized the value of EIA as a decision-making tool. The Organization for Economic Co-operation and Development (OECD) issued guidelines for good practices in EIA (OECD, 1992). United Nations Environment Programme in 1980 provided guidance on EIA of the development proposals (UNEP, 1980) and on basic procedures for EIA (UNEP, 1988). The World Conservation Strategy pinpointed the need to integrate environmental considerations with development (IUCN, 1980). Importance of EIA was echoed in the Brundtland Report (WCED, 1987), and at United Nations Earth Summit on Environment and Development held at Rio de Janerio (UNCED, 1992). The evolution and procedures of EIA in various countries is reviewed by Munn (1975), Canter (1977), Jain et al. (1977), Htun (1988), Wathern (1989), Wood (1994) and many others.

Some of the valuable contributions made by various researchers in EIA studies are reviewed here. Harm (1974) in his book 'Man shapes the Earth' defines earth as 'finite earth' and humanity as 'infinite humanity' and looks into the human impact and humanity interaction with various environments. There are very few studies, which concisely deal with EIA in a spatial perspective. Most of the studies confine themselves to impact assessment of some specific proposed project. A good number of researches in estuarine studies and inputs of different human activities on the ecosystem have been reported from U.S. There are studies using Cost Benefit Analysis (CBA) for assessing environmental impacts. Nijkamp and Peter (1977) have developed a CBA technique to assess the impact of development projects. In this method all the *pros* and *cons* of the project including environmental effects are evaluated in monetory terms and are transferred to a common time point. Though it is widely accepted as an indirect monetory valuation method of social projects, the use of CBA in environmental and social issues has been criticized on account of the selection of discounting rate and irreversibility of environmental impacts.

Mukhina et al. (1981) in their research article 'System of planning for the study of interaction between economy and nature' have classified human impacts, transformations and consequences into different subgroups for examination, study and modelling. According to them, for studying regional socio-economic systems, the economic factors viz., industrial nodes, agricultural regions, cities and agglomerations, settlements and transport systems and recreation zones are to be treated as sources of impacts. They also prepared separate indices for the classification, and the absolute indices were transferred into relative ones in order to evaluate the ecological, social and economic consequences of the human impact on nature.

Shopley and Fuggle (1984) have made a comprehensive review of the current EIA practices. They elaborated the strengths and weaknesses of various methods and techniques, which could be incorporated in EIA procedures. They also attempted to highlight the unique contributions of each method and technique, and concluded with the comment that 'methods and techniques can be effective only if they are properly identified, combined and used'. Carley and Bustelo (1984) in their study noted that most of the Social Impact Assessments (SIA) has focused on resource development and on the large scale projects. Karin et al. (1986) have made a detailed study on the Hudson river, USA and adopted a system approach. The work deals with the impact of diverse human activities on the Hudson estuarine ecosystem. The various conceptual and methodological approaches of EIA are recognized for their social, economic and ecological values and also for possible effects on the structure and functions of the ecosystem. Selman (1986) in his work explains the impact of coal mining in Leicestershire, U.K., which had significant impact on agriculture. A 14 x 27 EIA matrix was prepared with workforce, transport, land and resource use and pollution against land use, housing, traffic, local economy, employment and community structure. A series of works have been published under the Chesapeake Bay monitoring programme as well. The nutrient studies by D'Eila

(1987), D'Eila et al. (1992) and the assessment of developmental pressures and land use changes by Clagget et al. (2004) are only a few among them. Many EIA studies have been carried out in India also. Since EIA became mandatory as per the Environment Protection Act (EPA), 1982, it has become a must for any proposed project for environmental clearance. EIA studies with special reference to sand and gravel mining are scarce in scientific literature. Some of the EIA studies on sand and gravel mining carried out across the world are already mentioned in Chapter 6 (See section 6.2).

There are a few studies on EIA conducted in Kerala State as well. The study conducted by Nair and Jain (1982), on the environmental and ecological impact of multipurpose river valley projects of Idukki was perhaps the first EIA study in Kerala. The impact study was performed with special reference to changes in forest landuse, fuelwood supply and the flora and fauna of the region. The Government of Kerala (1984), in a status paper on Western Ghats Development Programme (WGDP), stressed the need for studying the impact of mining activity, especially the quarrying on the landform of the region. Raha and Ghosh (1984) stated that the clay mining (without mentioning any) along the coastal tract of Kerala have affected the natural dynamic equilibrium in different ways such as loss of top soil, loss of agricultural land, depletion of groundwater resources and obliteration of natural landscapes. STEC (1987) went in some detail on the impact of mining of sand from the rivers and Revenue Department (1989) carried out EIA on the impact of hard rock quarrying on the prehistoric Edakkal cave in Ambalavayal, Wynad district. Ramachandran et al. (1989) made an EIA of limestone mining at Walayar. An EIA on soil quarrying at Thiruvallam near Thiruvananthapuram has been attempted by Ramachandran and Padmalal (1995). The latter two studies, however, were *ex post facto* impact assessments and were done at the direction of the Government of Kerala with the mandate of assessing the actual impacts of these activities. Ramachandran and Padmalal (1997) also made an attempt to assess the environmental impact of mineral based industries of Kerala and suggested environmental management plans for each mineral sector.

8.6 Environmental Assessment Process

The five activities involved in the environmental assessment processes are 1) basics, 2) description of environmental setting, 3) impact prediction and assessment, 4) selection of proposed action and 5) preparation of Environmental Impact Statement (EIS). Certain basics, that are required to accomplish an environmental assessment, are related to the description of the environmental setting, impact prediction and assessment and preparation of the EIS. In order to predict and assess the impacts associated with a proposed action, it is necessary to describe the environmental setting of the area in which the proposed action has to take place. This gives the baseline information against which prediction and assessment can be made. The next step is the identification of possible impacts, its magnitude and importance. The difficulty one would face here is the conversion of the impacts into certain common units for some of them are measurable (noise pollution, water pollution etc.) while some others are not. The most important step in the environmental assessment process, and the step that requires the greatest degree of scientific application of technology, is impact prediction and assessment. This particular step involves projecting the environmental setting into the future without the proposed action and then performing the necessary calculations or studying the approaches for actually predicting the impact of the proposed action and assessing the consequences arising out of the actions. Information from this step becomes a part of the next step of EIA involving aggregation of information. Based on this aggregate information, as well as on other factors such as technical and economic considerations, the proposed action is selected. Information about this step of the environmental assessment process also becomes a part of the EIS. Finally, a draft EIS is prepared. Based on the draft impact statement circulated for review and comments followed by the incorporation of the review comments, a final EIS is prepared.

Environmental systems are composed of complex inter-relationships between linked individual components and sub-systems. Consequently, impacts on one component may well have effects on other components, some of which may be spatially (and temporally) distant from the component immediately affected. Indirect impacts (also called secondary, higher-order or knock-on impacts) may be difficult to identify, evaluate and predict, but cannot be excluded from impact studies. The identification of impacts primarily requires description and understanding the baseline conditions of environment prior to an activity.

8.7 EIA methodologies

EIA is essentially a dimension of the planning process. The specific purpose of EIA is to influence the decisions made for the environment and its values. The methodology is the complex of procedures, techniques and tools that together help to fulfill this purpose of EIA. The preparation of EIS is only one element in this methodology (Anon, 1990). Because of the complexity of the various 'systems' concerned, one should expect an array of methodologies in EIA. Some of the important methodologies are: adhoc method, overlays, checklists, cause-condition-effect networks, matrices, quantitative or index methods and models (Munn, 1978; Rau and Wooten, 1980 and IBM, 1994). No method is foolproof and without blemishes. The following sections deal with a brief description of the methods commonly adopted for impact analysis.

8.7.1 Ad hoc method

This is the most commonly adopted method in the assessment of environmental impacts. This seems to be the oldest method. Basically, ad hoc method indicates broad areas of likely impacts by listing composite environmental parameters to be affected by a development activity. Ad hoc method involves assembling a team of specialists to identify impacts in their area of expertise. In this method, each environmental area (eg. air, water, etc.) is taken separately and the nature of the impacts such as no effect, short or long term, reversible or irreversible, etc., is considered. This method provides minimal guidance for the assessment of total impact giving the broad areas of possible impacts and the general nature of these impacts. For example, the impacts on animal and plant life may be stated as minimal but adverse, whereas, socio-economic impact may be stated as significant but extremely beneficial. Ad hoc method is more useful as a tool for pilot or reconnaissance survey. Details of the methods are rarely published separately as they are described in the individual EIS to which they relate.

8.7.2 Overlays

Overlays describe well-developed approaches used in planning and landscape architecture. This technique is based on the use of a series of overlay maps depicting environmental factors or land features. By overlaying these maps, areas possessing a preferred combination of these variables can be identified within the project area boundaries, the impacted areas and their relative geographical location. Overlay techniques utilizing computerization for more effective data analysis have been developed. Computers can be used not only to store comprehensive data on a local area, but also to provide composite maps incorporating a large number of characteristics of the proposed developments and the surrounding areas. This enables those carrying out assessments or route selection to introduce impact weightings into assessment. The computer can perform the complex mathematical operation required when a large number of variables are weighted. Overlay technique with the help of GIS is highly significant in the study of EIA. Any number of layers (themes) can be overlaid in the maps to assess the spatial changes and the relationships between them overtime by applying computer based GIS techniques. The overlay approach is generally effective in selecting alternatives and identifying certain types of impacts. This method is sometimes referred to as the McHarg method (McHarg, 1969).

8.7.3 Checklists

Checklists represent one of the basic methodologies used in environmental impact assessment. Of the various methodologies in EIA, checklists have intended to survive as a guide to the potential impacts of a project (Gilpin, 1995). Checklist method is often used to sort out complex situations that are strong in impact identification. All types of checklists – (a) simple, (b) descriptive, (c) scaling and (d) scaling-weighting – are valuable. Simple checklists are a list of environmental parameters; however, no guidelines are provided on how these parameters are to be measured and interpreted. Descriptive checklists include identification of environmental parameters and guidelines on how parameter values are to be measured. Scaling checklists are similar to descriptive checklists, with addition of information basic to subjective scaling of parameter values. Scaling-weighting checklists or Battelle Environmental Evaluation System (BEES) represent scaling checklists with information provided as to subjective evaluation of each parameter with respect to every other parameter. This was developed in 1972 at Battelle Laboratories for the Bureau of Reclamation. This system consists of a description of the environmental factors included in the checklist as well as instructions for scaling the values of each parameter and assigning importance units. BEES is a highly organized methodology, and as such, it helps to ensure systematic, all-inclusive approaches and to identify critical changes. As in the case of other methodologies, in this method also, very little emphasis is given to the socio-economic factors. Checklist method is an advanced ad hoc method in that they list environmental, social and economic components in great detail. Also, some checklists identify typical impacts resulting from certain types of development.

8.7.4 Networks

Network representation, otherwise called as flow diagram (Munn, 1975) and system diagrams (Bisset, 1984) helps to analyse the inter-dependencies of complex system. Network methods start with a list of project activities or actions and then establish cause-condition-effect relationships. This methodology attempts to recognize a series of impacts that may be triggered by a project action. The approach generally defines a set of possible networks and allows the user to identify impacts by selecting and tracing out appropriate project actions. Network methodology is based on known linkages within systems. Thus actions associated with a project can be related to both direct and indirect impacts. For example, impacts on one environmental factor may affect another environmental and / or socio-economic factor. And, such interactions are identified and listed on a network diagram. This diagram, subsequently, acts as a guide to impact identification and the presentation of results. The Sorenson network developed by Sorenson and Mitchell (1973) represents an early attempt to provide a method for tracing out impacts using a network format.

8.7.5 Matrices

Matrix method is basically, a generalized checklist and usually has two dimensions - one dimension of a matrix with a list of environmental, social and economic factors that are likely to be affected by a proposal and the other dimension with a list of actions that are associated with development. Impacts are identified by marking cells representing a likely impact resulting from the interaction of a facet of the development with an environmental feature. With some matrices, quantitative representations of impact importance and magnitude are inserted in individual cells. There are many variants of the matrix approach, but the best-known interaction matrix method was developed by Leopold et al. (1971). The Leopold matrix method involves the use of a matrix with 100 specified actions and 88 environmental items. The horizontal axis has 100 columns for activities that might cause positive or negative environmental impacts. The vertical axis consists of 88 rows of environmental quality variables grouped into four categories: 1) physical and chemical, 2) biological, 3) cultural and 4) ecological (Gilpin, 1995). In the use of a Leopold matrix, each action and its potential for creating an impact on each environmental item must be considered. The matrix is marked with a diagonal line in the interaction box where an impact is anticipated. The second step in using the matrix is to describe the interaction in terms of its magnitude and importance.

8.7.6 Quantitative or index methods

These methods are based on a list of factors thought to be relevant to a particular proposal which are differentially weighted for importance of impacts. Likely impacts are identified and assessed. Impact results are transformed into a common measurement unit, for example, a score on a scale of 'environmental quality'. The scores and the factor weightings are multiplied and then the resulting scores added to provide an aggregate impact score. By this means, beneficial and harmful impacts can be summed and total scores compared. Alternatively, all impact scores for two alternative sites can be aggregated and compared. The alternative giving the 'best' score is the preferred option. The development of quantitative or index methods has been given detailed consideration by the Battelle Columbus Laboratories (1974).

8.7.7 Models

Recently considerable attention has focused on the use of systems modelling in impact analysis. There are a few examples of models utilized in the assessment of a wide variety of impacts resulting from most major projects. Usually, only a particular impact of great significance or a number of key impacts is modelled, for example, the effects of a nuclear power station on a salmon population. Modelling is being used in the development and assessment of alternative strategies for resource management, but again only a few key issues are dealt with. However, in the future, the use of models in large-scale resource management problems may be the most fruitful application of this method.

8.8 Methodology adopted in the present study

The present study is an *ex-post-facto* EIA. This is to say that the impacting actions and the impacts on environment are largely known. What remains is its validation. This is not normally done in the actual process of EIA, where based on existing environmental factors and impacting actions, one makes predictions as to how the environment would behave, either positively or negatively, if various actions would become operational. EIA is the best tool in this respect, helping to select the best option among a set of alternatives such that the selected one will have the least negative impacts on the environment. In this context, the EIA being attempted here is different from the conventional one. While the conventional EIA is of predictive nature, the present assessment, as mentioned earlier, is a *de facto* record of the impacts, which have already happened in mining areas and its adjoining environs as a result of mining processes. This gives an added advantage of providing information to the decision maker as well as the general public about the actual picture of the environmental impacts incidental to mining of sand in the study area.

In the present study, the matrix method prescribed by Rau and Wooten (1980) is followed for assessing the impacts caused by sand mining. This is basically a method for presenting various impacts in an abstract way. It starts with a list of potential impact areas, which are normally environmental conditions and characteristics, and the nature of impacts as to whether negative (adverse) or positive (beneficial). These are assessed against various impacting actions. In this approach, the environmental conditions / characters are listed on the left hand side of the matrix and the impacting actions across the top.

8.9 Geo-environmental setting of areas selected for EIA studies

Growing environmental awareness and increasing public concern over the impacts of developmental activities on biophysical systems is a major impetus to the study of impact assessment. Although the environmental effects of sand and gravel mining noticed in all the rivers in the study area are taken into account for EIA, for better presentation of the impacts, three areas of the Pamba river basin representing 1) the highlands, 2) the midlands and 3) the lowlands have been chosen. For EIA of floodplain / overbank sand mining, the lowland areas of the Muvattupuzha river basin where the activity is very severe has been selected as an example. The purpose of this study is to promote efforts which will prevent or eliminate damage to the environment and biosphere using a systematic interdisciplinary approach.

Baseline studies include description of those aspects of the physical, biological and social environments, which could be affected by mining activities. These are fundamental to technical assessment studies to enable the level of significance of impact to be determined in relation to existing baseline conditions. Some of the major sources of baseline information are the following:

a) On-site collection of data relevant to physical, chemical, biological and socio-economic factors

b) Personal interviews with local people, representatives of various NGO’s, revenue officials, etc. Oral histories are of great values where no documentary materials exist. These are events described to interviewers by persons who directly experience the effects of mining. Information about attitudes, feelings and beliefs etc., are obtained through this method. The survey questionnaire used for data collection is given as Annexure I.

c) Information from various national / regional newspapers and other sources regarding mining and related activities and / or incidents.

8.9.1Pamba river basin

The location and other details of areas selected for EIA studies in the highlands, midlands and lowlands of the Pamba river basin are given in Table 8.3. The information relevant for this study was collected systematically from 0.5 km x 0.5 km grids. The investigation was conducted with an action to map the land use categories of each physiographic zones and to collect necessary field-level information on the sand mining activities prevailing in each area. Apart from assessing the environmental impacts, an attempt was also been made to analyse the impacts on the society as well. Its aim was not only to identify the socio-economic changes, but also to bring out peoples responses on various biophysical effects caused by the sand mining activities.

Table 8.3 Channel features of the areas selected in Pamba river for Environmental Impact Assessment

Physiography	Location	Channel length (km)	Channel width (m)	Bank height (m)	Nature of alluvial reach
Highland	9^{0}24’ – 9^{0}26’ N 76^{0}52’ – 76^{0}55’ E	7.75	50-150	3-4	Plane bed and riffle
Midland	9^{0}20’ – 9^{0}22’ N 76^{0}42’ 76^{0}45’ E	8.85	100-225	3-6	Pool-riffle
Lowland	9^{0}19’ – 9^{0}23’ N 76^{0}31’ - 76^{0}37’30” E	6.00	100-250	3-4	Dune-ripple

In the highland area, the river stretch is rocky in nature and the sand deposits are seen as sporadic patches. Thick vegetative cover is noticed at some places. Illicit mining of sand is frequent in the area. A major portion of the land on the left bank is covered by dense mixed jungle and on the right bank by rubber plantations and mixed crops. Perunthenaruvi waterfall, a major tourist attraction, in the Pamba river basin falls within this area. Fig. 8.4 a depicts the elevation model prepared for the highland part of the EIA study area. Only one authorized sand mining location of Vechoochira grama panchayat is working within the area. About 35 labourers are engaged in sand mining activities. The details of sand mining in the highlands along with other physiographic regions are given in Table 8.4. Sand mining is comparatively less in the highlands of Pamba river basin as most part of the river channels falls under dense forest cover.

Table 8.4 Details of sand mining in the river reaches selected for Environmental Impact Assessment

Sl.No.	Physiographic zone	Labour force	Sand mining locations	Quantity of sand mining (x 10^6 ty^{-1})	Number of households
1	Highland	35	1	0.032	14538
2	Midland	292	14	0.157	15560
3	Lowland	315	8	0.070	3042

The people in the highlands are engaged in different occupations like agriculture, rubber tapping, business, etc. A very small percentage of the people are engaged in fishing. A considerable portion of the people earns income from mining and construction activities. The people depend on river for bathing, drinking water requirements, irrigating agricultural lands, etc. The chances of pollution of river water by pesticides from rubber plantations are high during summer season. In the midlands, river bed is rocky at few places. Dense vegetation is seen on river banks and, sand deposits are thick at some parts

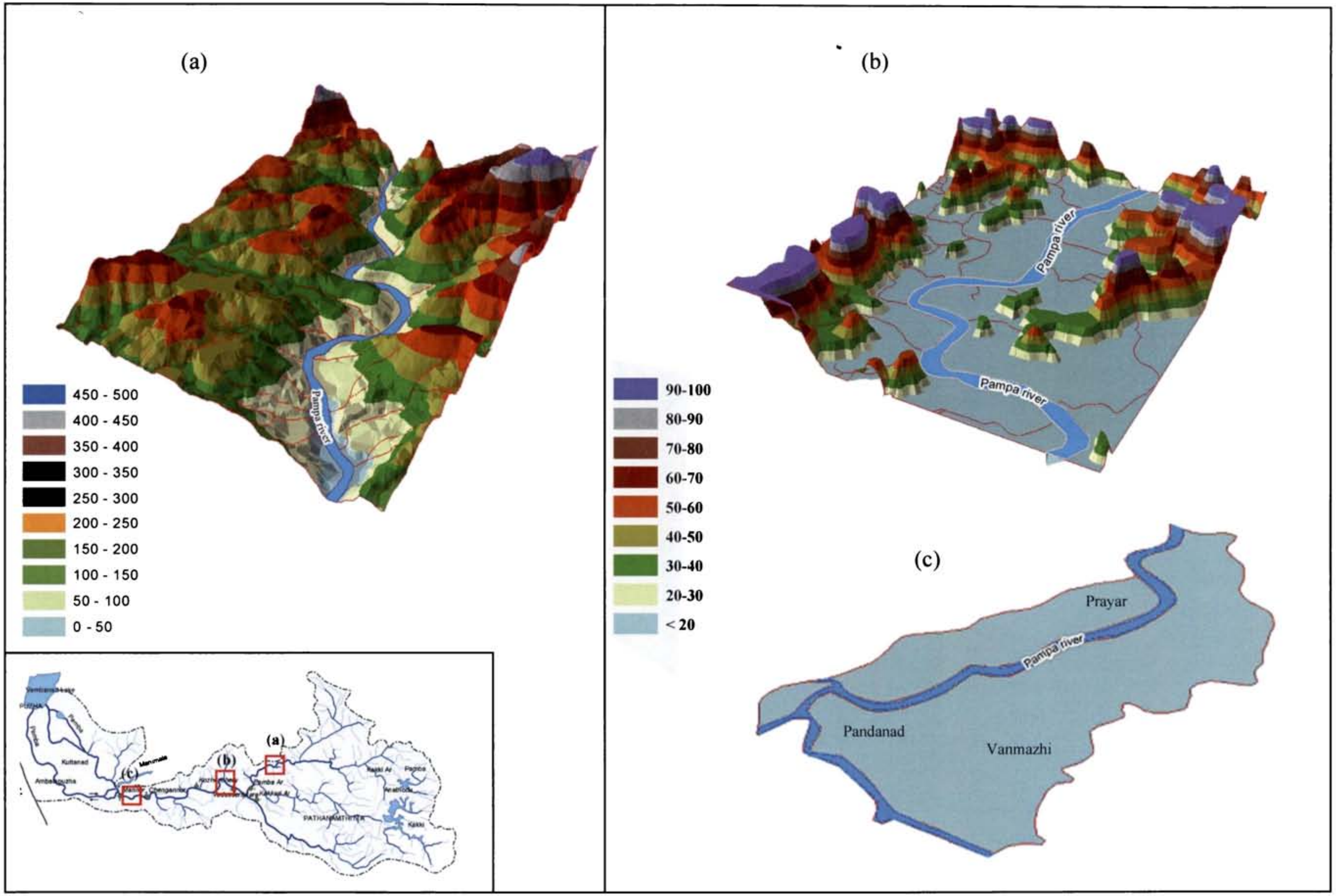

Fig. 8.4 Digital elevation model showing the altitudinal elevations in the (a) highland, (b) midland and (c) lowland areas of Pamba river basin selected for EIA study.

in the river stretch. Deep pools are seen in the channel bed at certain areas. These sand beds are often used for holding religious congregations like Maramon Christian Convention and Cherukolpuzha Hindu Convention, etc. The area is covered by mixed tree crops and settlements. Rubber plantations form another important land use category in the area. Fig. 8.4 b shows the digital elevation model developed for the midland part of the Pamba river selected for detailed EIA study. Table 8.4 shows the total strength of labour force in sand mining sector of midlands. Over 250 labourers are working in the 14 sand mining locations spread along the midland part. Nearly 0.16 x 10^6 ty^{-1} of sand is being transported from the area for various purposes.

The environmental problems in the lowlands are almost same as that of midlands. Valley widening, bank slumping and formation of deep pools in the river beds are common in the area. Encroachment of river banks is noticed at some places. Fig. 8.4 c shows the digital elevation model prepared for the lowland area of the Pamba river selected for the EIA study which is almost flat in nature. A total of 8 mining locations are located in the area. It is estimated that about 300 labourers are engaged in sand mining. The residents in the lowlands depend the river for their livelihood and domestic requirements. Traditional fishermen, farmers etc., also earns their income from sand mining activities. Lowering of water table in the wells adjacent to the mining sites during summer season is common in the study area. NGO's like Pamba *Parirakshana Samithi*, All Kerala River Protection Council and Pamba-Varattar *Samrakshana Samithi* are active in the area and campaigning against indiscriminate sand mining.

8.9.2 Muvattupuzha river basin

The downstream reaches of the Muvattupuzha river basin embed huge volumes of sand as floodplain deposits. Of the 6 local bodies in the downstream reaches, active floodplain mining is widespread in 4 local bodies. The locations of the active and abandoned floodplain mines are shown in Fig. 8.5. The relevant details on the sand mining activities are given in Table 8.5.

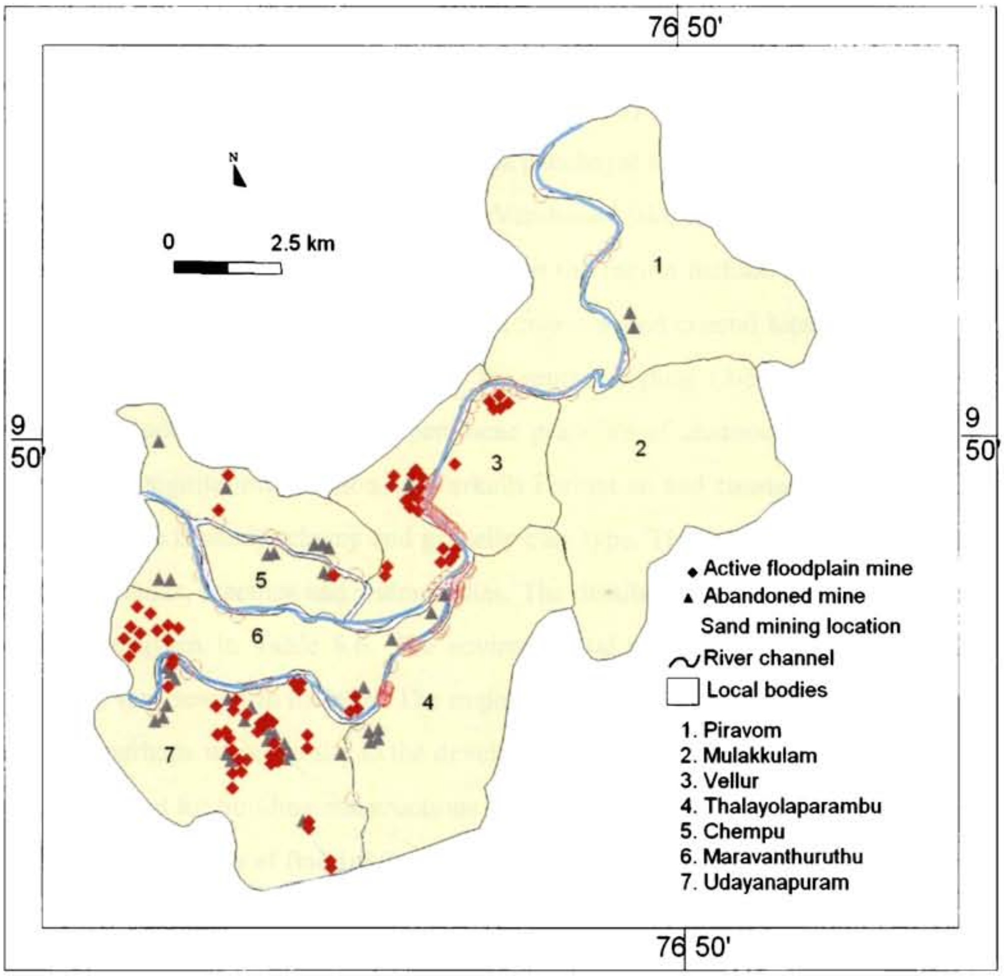

Fig. 8.5 Floodplain sand mining sites (active and abandoned sites) along with instream sand mining locations in the downstream reaches of Muvattupuzha river

Table 8.5 Characteristics of the area selected for EIA of floodplain mining

Sl. No.	Local bodies	Physiography	Area (km^2)	Population density	Number of households
1.	Piravom*	Midland	29.36	929	6279
2.	Vellur	Lowland	19.29	1218	5384
3.	Thalayolaparambu*	Lowland	20.63	1073	4974
4.	Chempu	Lowland	18.42	1111	4504
5.	Maravanthuruthu	Lowland	15.69	1357	4886
6.	Udayanapuram	Lowland	20.16	1263	5787

**Local bodies with no active floodplain sand mining areas*

The Muvattupuzha river drains through varied geological formations and terrain types (Chattopadhyay and Chattopadhyay, 1995). The river bifurcates near Vettikattumukku in Thalayolaparambu grama panchayat into Ittupuzha and Murinjapuzha distributaries. These distributaries join the Vembanad lake through a network of natural and artificial channels. The major landforms in the region include subdued sand dunes, beaches, submerged lands with swamps and marshes and coastal laterites. The slope of the area ranges between level (0-1%) to gently sloping (3-5%). Geologically, the lowlands include quartz-feldspar-hypersthene granulite of charnockite group, sandstone and clay with lignite intercalation of Warkalli Formation and coastal sand and alluvium. The soil texture is sandy, clayey and gravelly clay type. The area consists of agricultural lands, wastelands, marshes and water bodies. The details of floodplain mining of sand in the area are given in Table 8.6. The environmental problems due to floodplain sand mining are very severe in the area. The major factor promoting the clandestine mining in the area is perhaps its proximity to the developing centre, Kochi City which requires huge volumes of sand for building constructions and other developmental activities.

Table 8.6 Details of floodplain mining locations in the downstream areas of Muvattupuzha river basin

Sl. No.	Name of the local body	No. of floodplain mines		Qty. mined from active sites (x 10^6 ty^{-1})	No. of labourers in active mining sites
		Active	Abandoned		
1.	Piravom	-	2	-	-
2.	Vellur	24	1	0.780	984
3.	Thalayolaparambu	-	4	-	-
4.	Chempu	3	11	0.162	285
5.	Maravanthuruthu	16	4	0.612	670
6.	Udayanapuram	33	19	1.135	1383
	Total	**76**	**41**	**2.689**	**3322**

A total of 76 active and 41 abandoned floodplain locations are mapped in the area. Over 3000 labourers are engaged in the mining sector. About 2.689 x 10^6 ty^{-1} of sand is mined from the floodplain areas of Muvattupuzha river basin. Out of the 6 local bodies, sand mining locations are seen clustered in Udayanapuram (33 sand mining locations) and Vellur (24 sand mining locations) grama panchayats. Likewise, the quantity of mining is also high in these two local bodies (Udayanapuram: 1.135 x 10^6 ty^{-1}; Vellur: 0.780 x 10^6 ty^{-1}) compared to the other local bodies. Out of the total quantity of sand extraction, the Maravanthuruthu grama panchayat contributes nearly 23%. Only 3 active sites are located in Chempu grama panchayat and they together extract an amount of 0.162 x 10^6 ty^{-1} of sand. The labour force and other relevant details in the various local bodies are given in Table 8.6.

8.10 Environmental Impact Assessment (EIA) of sand mining

Sand extraction from river channels and overbank areas causes local disruptions which can be anticipated and prevented through appropriate EIA's (Chamley, 2003). After recording various environmental problems of river sand mining in various physiographic zones, an EIA was carried out to suggest appropriate Environmental Management Plan (EMP) for regulating the mining activities on a sustainable basis. The river environments in all the three physiographic zones such as highlands, midlands and lowlands are deteriorated drastically due to illicit scooping of sand even from prohibited areas close to bridges and water intake structures. Hence, an attempt has been made to analyse the environmental impacts caused by river sand mining to identify and address the key environmental issues that are resulted in from the activity. The main intention of the effort is to mitigate the negative impacts and enhance the positive ones. The environmental impacts must be evaluated on a case-by-case basis. Further, as the impacts of sand mining in the two different geo-environmental settings such as instream and floodplain zones are significantly different, two separate treatments are attempted in the present study.

Tables 8.7 - 8.9 illustrate the magnitude of impacts arising from instream sand mining activities prevalent in the highlands, midlands and lowlands of the study area. The impact magnitude and impacting actions of sand mining in these three physiographic zones are quite different. Impacting actions are those that are significantly affecting the quality of the environment in which the overall cumulative primary and secondary consequences alter the quality of the environment. Significant effects can include actions that have both beneficial and adverse effects. The significance of impacting actions may also vary with respect to the physiographic settings. The words 'low', 'medium' and 'high' are intended to imply thresholds of importance and impact that must be met before an Environmental Impact Statement (EIS) is prepared. The important impacting actions which have been considered here are the ones that have either 'high' positive or 'high' negative impacts on the environment. This, in no way, belittles the significance of lesser impacts. Cases of 'no appreciable impacts' or 'undetermined impacts' are also represented. The mode of mining is manual in the highlands and midlands. But in lowlands, in addition to manual mining, mechanical mining (sand extraction using diesel powered engines) is also being practiced (Plate 6.2b). Bar skimming and pit excavation are the commonly adopted methods of sand extraction in the highlands and midlands. But in lowlands, the widely practiced method is pit excavation. The extracted sand from the midlands and lowlands require cleaning as it contains clay lumps, decade wood and, in some cases, shells, whereas in highlands material cleaning is not required. Instead, in some cases, the bed materials have to be graded using frame screens of different mesh sizes to recover the desirable size grades (Fig. 6.2 c).

8.10.1 EIS of instream sand mining

The impacts would affect many environmental resources within the area, including land and water, biota, public health and safety. The database generated from the study and the conclusions drawn from it could be utilized for chalking out strategies for the conservation and sustainable management of resources. It can also be used for framing guidelines for regulating the mining activities of the area on an environment-friendly

Table 8.7 Environmental Impact Assessment (EIA) of river sand mining in the highlands using simple matrix method. The case is from Pamba river.

Components of environment			Impacting actions					
			Mining			Post-mining		
Environmental conditions / Parameters		Sub-components	Mode of Mining	Types of Mining		Processing	Transportation	
			MaE	BS	PE	SG	AR	VM
Physical & Chemical	Land / River channel	Land stability	•	✡	•	✡	✡	•
		Landuse / Land cover	✡	✡	✡	•	•	✡
		Soil	•	✡	•	•	✡	•
		Landform	✡	•	•	✡	✡	✡
		River bed	●	✡	•	✡	✡	✡
		Aesthetics	•	•	•	•	•	•
	Air	Air quality	✡	✡	✡	◇	✡	•
		Noise level	✡	✡	✡	◇	✡	•
	Water	Groundwater	✡	✡	✡	✡	✡	✡
		Surface water	●	•	●	✡	✡	•
Biological	Flora and fauna	Terrestrial	●	•	●	•	•	●
		Riparian	•	✡	•	•	•	✡
		Instream	⬤	•	⬤	✡	✡	✡
Social	Socio-economic	Employment	□	▫	□	▫	✡	▫
		Economic base	▫	▫	▫	▫	✡	▫
		Construction sector	▫	▫	▫	▫	✡	▫
		Land values and holdings	•	✡	•	•	□	▫
		Engineering structures	•	✡	•	✡	✡	•
		Agriculture/Plantations	•	✡	•	•	•	✡
	Socio-health	Accidents	•	✡	•	✡	✡	•
		Health impairment	•	✡	•	✡	✡	•
	Socio-cultural	Sand bars	✡	✡	✡	✡	✡	✡
		Heritage / Historical areas	•	✡	•	✡	✡	✡
	Socio-livelihood	Sustainable livelihoods (Fishing, farming etc.)	•	•	•	◇	✡	✡

•Low -ve impact; ●Medium -ve impact; ⬤High -ve impact; ✡ No appreciable impact
▫ Low +ve impact; □Medium +ve impact; ◇ Undetermined impact

Table 8.8 Environmental Impact Assessment (EIA) of river sand mining in the midlands using simple matrix method. The case is from Pamba river.

Components of environment			Impacting actions						
			Mining			Post-mining			
Environmental conditions / Parameters		Sub-components	Mode of Mining	Types of Mining		Processing		Transportation	
			MaE	BS	PE	SG	MC	AR	VM
Physical & Chemical	Land / River channel	Land stability	●	•	⬤	✡	✡	•	●
		Landuse / Land cover	✡	✡	✡	•	✡	•	✡
		Soil	●	•	⬤	•	✡	•	●
		Landform	●	•	●	✡	✡	•	•
		River bed	⬤	•	⬤	✡	•	●	✡
		Aesthetics	●	•	●	•	•	●	●
	Air	Air quality	✡	✡	✡	◇	✡	✡	●
		Noise level	✡	✡	✡	◇	◇	✡	●
	Water	Groundwater	●	✡	●	✡	✡	✡	✡
		Surface water	⬤	•	⬤	•	●	✡	●
Biological	Flora & fauna	Terrestrial	●	●	●	•	✡	•	•
		Riparian	●	•	●	●	•	•	●
		Instream	⬤	●	⬤	•	•	•	•
Social	Socio-economic	Employment	⬜	□	⬜	□	▫	▫	□
		Economic base	⬜	□	⬜	□	▫	▫	□
		Construction sector	⬜	□	⬜	□	▫	▫	□
		Land values and holdings	⬤	●	⬤	●	•	□	□
		Engineering structures	⬤	•	⬤	✡	✡	✡	●
		Agriculture/Plantations	●	✡	●	✡	✡	•	✡
	Socio-health	Accidents	●	•	●	✡	✡	✡	●
		Health impairment	●	•	●	◇	✡	✡	●
	Socio-cultural	Sand bars	⬤	•	⬤	✡	✡	•	•
		Heritage / Historical areas	●	•	●	✡	✡	✡	•
	Socio-livelihood	Sustainable livelihoods (Fishing, farming etc.)	⬤	•	⬤	◇	◇	•	✡

• Low -ve impact; ● Medium -ve impact; ⬤High -ve impact; ✡ No appreciable impact

▫Low +ve impact; □ Medium +ve impact; ⬜High +ve impact; ; ◇ Undetermined impact

MaE = Manual extraction; BS = Bar skimming; PE = Pit excavation; SG = Size grading; MC = Material cleaning; AR = Approach road; VM - Vehicular movement

Table 8.9 Environmental Impact Assessment (EIA) of river sand mining in the lowlands using simple matrix method. The case is from Pamba river.

Components of environment			Impacting actions						
			Mining			Post-mining			
Environmental conditions / Parameters		Sub-components	Mode of Mining		Type of mining	Processing		Transportation	
			MaE	MeE	PE	SG	MC	AR	VM
Physical & Chemical	Land / River channel	Land stability	●	⬤	⬤	✡	✡	•	●
		Landuse / Land cover	•	●	●	•	✡	•	•
		Soil	●	⬤	⬤	•	✡	•	●
		Landform	•	●	•	✡	✡	✡	✡
		River bed	●	⬤	⬤	✡	•	✡	✡
		Aesthetics	•	●	•	•	•	•	•
	Air	Air quality	✡	•	✡	✡	✡	✡	●
		Noise level	✡	•	✡	◇	✡	✡	●
	Water	Groundwater	●	⬤	⬤	✡	✡	✡	✡
		Surface water	⬤	⬤	⬤	✡	●	✡	•
Biological	Flora & fauna	Terrestrial	•	●	●	•	✡	•	•
		Riparian	●	⬤	⬤	•	✡	•	●
		Instream	●	⬤	⬤	✡	●	•	✡
Social	Socio-economic	Employment	☐	▫	☐	◻	◻	▫	◻
		Economic base	▫	☐	☐	◻	▫	▫	◻
		Construction sector	☐	☐	☐	◻	▫	◻	◻
		Land values and holdings	⬤	⬤	⬤	•	•	☐	✡
		Engineering structures	●	⬤	⬤	✡	✡	✡	●
		Agriculture/Plantations	●	⬤	⬤	✡	✡	•	✡
	Socio-health	Accidents	⬤	●	⬤	✡	✡	✡	●
		Health impairment	⬤	•	⬤	◇	✡	✡	●
	Socio-cultural	Sand bars	•	●	●	✡	✡	✡	✡
		Heritage / Historical areas	●	⬤	⬤	✡	✡	✡	✡
	Socio-livelihood	Sustainable livelihoods (Fishing, farming etc.)	●	⬤	⬤	✡	◇	✡	✡

•Low -ve impact; ● Medium -ve impact; ⬤High -ve impact; ✡ No appreciable impact

▫Low +ve impact; ◻Medium +ve impact; ☐High +ve impact; ◇Undetermined impact

MaE = Manual extraction; MeE = Mechanical extraction; PE = Pit excavation; SG = Size grading; MC = Material cleaning; AR = Approach road; VM - Vehicular movement basis. EIA performed here is an invaluable one by depicting the growing awareness and increasing public concerns over the impacts of river sand mining on the biophysical environment of riverine system. The following sections summarize the impact of sand mining on various components of the environment.

8.10.1a Physical and chemical components

Mining is the process of extraction of resources from the earth. The activity in the long run adversely affects the physical characteristics of the river environment. The accuracy with which one can assess physical impacts is dependent on the understanding of how the natural environment functions. Given perfect understanding it should be made to predict exactly the direction, degree and rate of change of the physical environment as it responds to a given stimulus. Depending on the type and amount of mining, the physical effects may vary from place to place in a river and from one river to the other. Physical effects like river bed degradation, river bank slumping, channel instability, etc., end up in the total degradation of riparian and aquatic ecology, in addition to undermining of engineering structures associated with the river environments. Fig. 8.6 a - c depicts the existing landuse pattern and other environmental features of the areas selected in the highlands, midlands and lowlands. The assessment of environmental impacts on various sub-components is given below:

Land / River channel: The manual mining practiced for the extraction of sand and gravel could induce negative changes on land stability, soil, landform, aesthetics and river bed characteristics. Manual mining imposes medium negative impacts on land stability, soil and landforms in midlands and lowlands. But in highlands, manual mining causes only a low negative impact on land stability and soil. On the contrary, in the midlands and lowlands, the stability of the river banks is seriously affected by intense sand mining as the banks are composed of incompact soil. Invariably, the fluvial landforms (alluvial / sand bars) within the river channel are removed from midland areas in the name of sand and gravel mining. Sand bars are common in the midlands and hence, the impact is much higher in this zone.

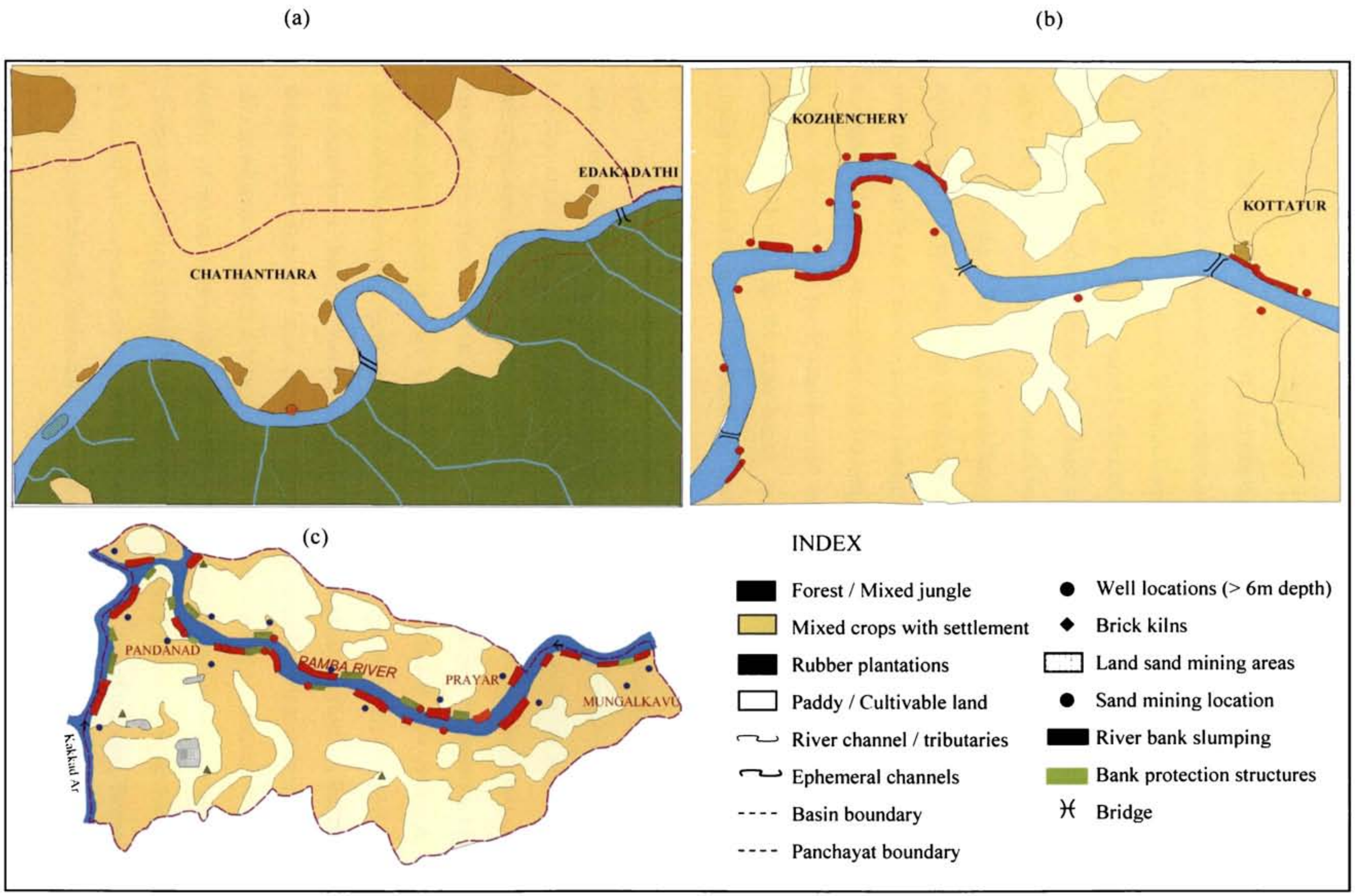

Fig. 8.6 Land use around the channel segments of Pamba river selected for the assessment of environmental impacts caused by sand mining in the (a) highland, (b) midland and (c) lowland areas. Location of sand mining sites and areas of bank slumping are also marked.

The secondary effects of sand mining, viz., river bank slumping, channel incision, etc., cause obvious physical disturbances on the land stability especially in areas close to the river banks. The situation is rather alarming in the midland and lowland areas (Fig. 8.6 b & c). The most widespread effect of instream mining is bed degradation. Manual mining in the midland areas causes high negative impact on the river bed. Among the three physiographic zones, the midlands are the most affected by manual mining as the quantity of mining is far higher in midlands compared to other physiographic zones. The records of the CWC station at Malakkara in Pamba river provides distinct evidences of river bed changes that have occurred during the past twenty years (see Fig. 7.3; Chapter 7 for further details). Mechanical sand mining using diesel powered suction pumps which is also taking place in the lowlands could impose high negative impact on the stability of land and soil close to the river banks, and also on river bed, in addition to marked changes (medium negative impacts) on land use, landform and aesthetics of the area. Of the two types of mining, bar skimming, practiced in highland and midland areas, imposes only low negative impacts on the land and river channel environments, whereas pit excavation shows dominance and imposes high negative impacts in the midland and lowland areas, although it is practiced in all the three physiographic provinces. Due to indiscriminate sand mining, pits of various dimensions have been formed on the river beds of the midlands and the lowlands. As mentioned in Chapter 7, formation of deep pits in the channel bed produce slower flow velocities and lower flow energies, causing sediments transported from upstream to deposit at mine site. The resultant sediment deficient water (hungry water) can have a very high erosive effect on the river banks downstream triggering bank erosion and damages to engineering structures. There are also downstream impacts arising from increased turbidity and sedimentation affecting the quality of water. It is quite evident that any type of mining process would drastically change the existing aesthetic environment and adversely affect the natural environment. If natural landscapes in any sector were eye catching, the loss of the same through mining would be aesthetically bad and a possible loss of tourism potential of the area.

Processing activities like size grading and material cleaning create a low negative impact on aesthetics. Plying of heavy vehicles to sand harvesting centres requires development of approach roads. Majority of such roads are following the same alignment of existing roads being used by pedestrians. Approach roads constructed for transportation of vehicles into the river bed create serious problems, especially in the midland areas. Vehicular movement into the river bed in some parts of the midlands and lowlands triggers land stability problems.

Air and Water: The impacting actions like manual mining would not produce much direct effect on air quality. However, the mining related activities like movement of vehicles through unplanned roads produces marked adverse effects in the ambient air quality, in addition to enhancing the noise level. Mechanical mining in the lowland areas can also cause negative impacts at lower levels on air quality and noise level (Table 8.9). The haulage of lorries into the riverbed through roads that are not well developed can cause soil compaction which, in turn, negatively affects the productivity of the land.

The after-effects of sand mining activities such as siltation and turbidity, creation of deep pits in the channel, transportation of vehicles into the riverbed for easy loading of the mined material, spillage of oil / gasoline from the vehicles, etc., can cause negative impacts on surface water quality. Bar skimming and pit excavation from the highlands create low negative - medium negative impacts in river water. In the highlands, there won't be any appreciable level of impacts on groundwater resources due to sand mining, whereas midlands and lowlands are the most affected river reaches by the mining processes. Manual mining in midland and lowland areas has medium negative impact on groundwater resources and high negative impact on river water. Among the two types of mining, pit excavation is more harmful as it badly affects the environmental setting of the midlands and lowlands. As described in Chapter 7, there exists a positive correlation between the quantity of sand mining and TSS loading in water during active mining seasons. These enhanced levels of suspended solids smother the benthic community, clogs the gills of fishes and as a result the fishes are forced to leave their habitat. Turbidity reduces vision and mask odours, both important for the survival of many fishes.

Sand conditioning (or processing) activities like material cleaning can also aggravate the TSS problem in overlying waters. Ground water quality is affected, when there is a connection exists between the aquifers and the river system. In addition to this, lowering of water table in the wells adjacent to the mining sites is noticed in many parts of the study area, especially lower parts of midlands and lowlands (Fig. 8.6 c; also refer section 7.4.2, Chapter 7).

8.10.1b Biological components

Environmental impacts vary in their directness, intensity and duration depending upon both the nature of the action and the type of the biotic community. The negative effects of mining are burdening on the biological communities. Of the different modes of mining, manual mining causes medium negative impact on terrestrial fauna in the highlands and midlands and low negative impact in the lowlands. Riparian flora and fauna in the highlands experience low negative impact from manual mining and those in the midland-lowland areas experience medium negative impact. The instream biota is the most affected by the manual mining processes. Among the types of mining, bar skimming in midland areas have medium negative impact on terrestrial and instream biota. Terrestrial (migratory) birds are a natural resource found at some time of the year in nearly all major habitat types in the study area including forests, sand bars and wetlands. Timing of season migration is species specific, but migration success is closely linked with appropriate food, shelter, nesting sites and material, as well as many other environmental factors. Indiscriminate mining from the sand bars during the past few decades leads to the destruction of resting and often nesting grounds of many migratory birds. Pit excavation creates negative impacts on biota in the instream and overbank areas. Riparian habitats comprise the transition between the river and the land portion of the watershed. Natural riparian habitats are characterized by variable radiant of moisture and light, lush vegetation, and very high biodiversity. Lowering of water table due to indiscriminate sand mining can induce loss of riparian vegetation along the banks of the rivers, if the water table drops below the root zone. Riparian flora and fauna suffer from serious effects caused by riverbank slumping, channel incision, lowering of water table etc., as a result of the direct removal of vegetation along the river banks, bank undercutting and channel incision (Kondolf, 1997; Brown et al., 1992; Price and Lovett, 2002a; 2002b). The deep pools shaded by the overhanging riparian shrubs and trees, are vital resting sites for instream fauna, especially fishes. Since aquatic ecosystems are among the most productive and diverse habitats, it is not surprising that they are easily upset by a variety of perturbations caused by human beings. The river itself has a variety of bottom characteristics, temperatures, velocities, bank features, riparian vegetation, and invertebrates that serve as fish food. Spawning must occur in the gravel / sand beds which act as incubators where eggs are well oxygenated and are hidden from predators. The newly hatched fish must escape from the gravel beds and seek out the stream nurseries. These are the shallow impoundments of quiet water in which there are warmer temperatures, protective vegetation cover, and abundant invertebrates for food. The distribution of instream biota is strongly related to physical habitat (Brown et al. 1998). Such a complex relationship between physical and biological factors can be easily upset through the various impacting actions of the sand mining. Therefore, fundamental changes in the total biotic community are to be expected when the physical structure of the river is altered. Studies reveal that the instream fish wealth of Pamba river is found decreasing year after year. Fishes (psammophilic) and benthic organisms are affected very well by the habitat loss (Nandan, 2005). Food fishes like *Labeo dussumieri, Wallago attu* etc. are critically endangered according to IUCN status. Siltation and turbidity in the river system can limit primary production by reducing light penetration (Nelson 1993; Waters 1995), which, in turn, will affect the aquatic food chain and limit production at higher trophic levels. Limited information exists about the effects of suspended sediment on benthic macroinvertebrates, although several studies have documented an increase in the drift response, a redistribution phenomenon where individuals temporarily enter the water column from the riverbed and move downstream, generally in response to lowering light levels (Waters, 1965). In addition to the effects of mining activities at the site of extraction, physical and biotic effects can extend far upstream and downstream (Brown et al., 1998). All of these adverse impacts can result in shifts in species composition, decrease in species diversity and abundance, and a loss of sensitive species and ecosystem integrity. The effects of sand mining on river ecosystem recovery time can be extensive. Further, as pointed out by Brown et al. (1998), a total restoration of severely affected rivers has been considered to be improbable.

8.10.1c Social components

Social impact assessment is an integral component of EIA as it provides a basis for protecting human environment from adverse effects of sand mining activities and for eliminating or reducing to minimum, those effects of mining that are known or likely to be hazardous to the social environment.

Sand is an important aggregate in the construction sector. Hence its mining causes a major positive impact in the socio-economic sector. Through mining activities, jobs and opportunities are created, and significant contributions are made to the State's economy. Mining can provide a significant source of revenue through profit related royalty payments and fixed taxation. However, these benefits are not without direct and indirect costs to the environment. Short term benefits are only counted. This is one side of the problem. On the other side, there is a heavy environmental cost together with economic and social costs for those residing on banks of rivers. Activities which provide socio-economic gains from the use of aggregate resources often result in the impairment of ecosystem functioning. Despite its positive phase, negative impacts dominate in the hazards, land holdings, infrastructure etc. Loss of human lives in the rivers has been increased nowadays due to creation of deep pits, channel incision etc. Channel incision causes undermining of bridge piers and other infrastructural facilities associated with river channels. Reports show that the Kozhenchery and Cherukolpuzha bridges in the Pamba river are under threat due to indiscriminate mining close to these structures. The cracks and holes developed on the well-foundations of the bridge and the exposure of bedrock at Cherukolpuzha is a clear indication of the alarming condition of the concrete structures on which thousands of vehicles ply everyday. Problems faced by small landholders residing on either side of the riverbanks are numerous. Limited land resources and houses of such landholders are always under threat of collapse, once mining proceeds unmindful of these issues. As a result, the poor riparian land owners are often forced to sell their property at throwaway prices (Ramachandran and Padmalal, 1995). The access road to the mining site should be designed for safe entry and exit of vehicles in order to minimise the accidents.

The drowning accidents are on the increase due to indiscriminate sand mining by pit excavation methods. The magnitude of the impact varies according to the physiographic zones and the intensity of mining. Added to these are the rapid movements of sand carrier vehicles through the roads. The death toll associated with various rivers together with those of the river Pamba is given in Chapter 7 (Table 7.13). The health of the people in the lowland area is greatly affected by manual mining compared to mechanical means of mining. The midlands experience medium negative impact on health impairment due to manual mining and pit excavation.

Sand bars prominent in some parts of the river reaches are used for holding annual religious / cultural congregations. But, as a result of indiscriminate river sand mining, the sand bars that are used for holding the annual religious conventions and religious ceremonies are vanishing or changing its texture which, in turn, affecting its desired use. Manual mining of sand through pit excavation is a major threat to the existence of these sand bars in the area (section 7.3 of Chapter 7).

Manual and mechanical mining interferes with the sustainable livelihoods like fishing, farming, etc., of the local people. Pit excavation creates high negative impact in midland and lowland areas. The mechanical mining creates high negative impact in the lowland area compared to manual mining. The loss of sustainable livelihoods can have a major impact on the economy of the area as well. The riparian land owners are affected severely as the river banks are prone to erosion consequent to indiscriminate sand mining. Their traditional livelihoods like agricultural farming, fishing, etc., are adversely affected through the loss of land. In addition, river use by public get disturbed due to mining and quality / quantity of water goes down. From the Tables 8.7 to 8.9, it is clear that the impacting actions have a significant effect on the quality of the environment including land, air, water, biological and social / human components. Mining of river sand and other associated activities are the main sources of environmental degradation in the area and the most serious ones are discussed here. In the highlands, though the physical impact is less compared to midlands and lowlands, impact on instream biota is considerably high. The midlands and lowlands of the study area are characterized by slumping of river banks, river bed lowering, damages to engineering structures and uprooting of trees. Transportation causes increased traffic and congestion levels on streets, roads and highways. It has a significantly detrimental impact on air, water quality, ambient noise levels in adjoining areas. Mining modes and types together with transportation involves contamination of public resources such as water supply system, groundwater, flooding, erosion or sedimentation. The impacting actions (manual and mechanical mining modes, pit excavation, construction of approach roads and vehicular movements) have a substantial aesthetic or visual effect which inflicts permanent damage on the landscape, especially in areas of unique interest or scenic beauty. These actions cause disturbance to the ecological balance of animal and vegetation habitats or the elimination of rare or endangered species and substantially alters the behaviour pattern of organisms or interferes with important breeding, nesting or feeding grounds.

8.10.2 EIS of floodplain sand mining

The impacts caused by floodplain mining of sand are identified and given in Table 8.10. Like instream sand mining, the modes of floodplain sand mining are also of two kinds – manual and mechanical (i.e., using diesel powered engines). The two common types of mining are wet pit mining and dry pit mining (See section 6.3 of Chapter 6 for description). The post mining operations can be phased into 3 groups, namely, processing (involving size grading or screening and material cleaning), transportation (including construction of approach road and vehicular movements) and reclamation (by land filling).

8.10.2a Physical and chemical components

Mechanical mining of floodplain sands generates many adverse effects on the land, air and water environments of the area. Of the two types of mining, wet pit mining induces medium negative impact on the land environment. Among the post mining

Table 8.10 Environmental Impact Assessment (EIA) of floodplain mining using simple matrix method.The case is from Muvattupuzha river.

Components of environment			Impacting actions								
			Mining				Post mining				
Environmental conditions / Parameters		Sub-components	Mode of Mining		Types of Mining		Processing		Transportation		Reclamation
			MaE	MeE	WPM	DPM	SG	MC	AR	VM	LF
Physical & Chemical	Land	Land stability	•	●	●	•	✡	✡	✡	●	☐
		Landuse / Land cover	•	●	●	•	•	•	•	✡	●
		Soil	•	●	●	•	•	•	✡	•	●
		Landform	•	●	●	•	✡	✡	✡	✡	•
		Aesthetics	●	●	●	●	•	•	•	•	•
	Air	Air quality	✡	•	◇	•	✡	✡	✡	●	•
		Noise level	✡	●	◇	✡	✡	✡	✡	●	✡
	Water	Groundwater	•	⬤	⬤	✡	✡	•	✡	•	•
		Surface water	✡	●	◇	✡	✡	•	✡	•	✡
Biological	Biota	Flora	•	●	●	•	✡	✡	•	•	✡
		Fauna	•	●	●	•	✡	✡	•	•	✡
Social	Socio-economic	Employment	☐	□	☐	□	▫	▫	✡	▫	▫
		Economic base	□	☐	☐	□	▫	▫	▫	□	✡
		Construction sector	□	☐	☐	□	▫	▫	▫	□	✡
		Land values and holdings	●	⬤	⬤	●	•	•	▫	•	□
		Infrastructure	•	●	●	•	✡	✡	✡	•	✡
		Agriculture	●	⬤	⬤	●	•	•	•	•	•
	Socio-health	Accidents	●	•	●	•	✡	✡	✡	●	✡
		Health impairment	●	•	●	•	✡	✡	✡	•	✡
	Socio-cultural	Heritage / Historical areas	•	●	●	•	✡	✡	✡	•	✡
	Socio-livelihood	Sustainable livelihoods (Fishing, farming etc.)	•	●	●	•	✡	✡	•	•	✡

•Low -ve impact; ●Medium -ve impact; ⬤High -ve impact; ✡ No appreciable impact

▫Low +ve impact; □Medium +ve impact; ☐High +ve impact ◇ Undetermined impact

MaE = Manual extraction; MeE = Mechanical extraction; WPM - Wet pit mining; DPM - Dry pit mining; SG - Size grading;
MC = Material cleaning; AR = Approach road; VM - Vehicular movement; LF - Land filling

activities, movement of vehicles causes medium negative impact on the stability of the land adjoining the river channel. During mining, the entire material, including the fertile top soil and subsurface soil, is removed. Due to continued and unscientific mining of floodplain sands, deep pits of different dimensions (> 6m bgl and several meters wide) are developed in the affected areas. These areas, in due course, are converted to water logged areas unsuitable for agricultural activities. Further, this type of artificial lakes created in undesirable locations due to mining operations can aggravate the land instability problems in the adjoining areas. The ugly scars of active mining sites and abandoned sites do significantly affect the aesthetics of the area. Land failure incidents / sliding of the walls left after mining in the neighbouring lands are also recorded at many places. The mining activity could cause perturbations in the general land use including settlements in the area. Despite the stability of land caused by land filling, negative effects persist on land use / land cover, soil, landform and aesthetics.

Mechanical extraction invariably causes air and noise pollution. The more the intensity of the activity, the greater the environmental pollution, especially in areas of dense human settlements. The sand transport of vehicles causes medium negative impact in air and acoustic environments. Wet pit mining and mechanical extraction of floodplain sands have high negative impacts on groundwater regime of the area. The subsurface sand layers that are being extracted for construction grade sand are the best aquifers in the region. Extraction of sand and loss / damage of these aquifers will have far reaching implications in the freshwater availability of the region. During mechanical extraction, water is often pumped out from the pits for further mining. This leads to draining of water and subsequent fall of groundwater table even from hinterlands too. Unscientific land filling using clayey materials (impervious characters) can totally disconnect the left out aquifers of the area. Depending upon the extent of reclamation, there would naturally be corresponding low recharge to the groundwater resource.

8.10.2b Biological components

Wet pit mining by mechanical extraction method causes medium negative impacts on flora and fauna of the area. The removal of natural vegetation has been the primary cause of habitat destruction, reduction in native plants and animals and species extinctions (Rau and Wooten, 1980). The major impacts caused by the removal of native vegetation for floodplain mining of sand include reduction in the amount of food and oxygen production (through photosynthesis) per unit area. The dissipation of heat and gases back to the atmosphere, soil erosion problems and reduction in normal nutrient recycling between vegetation and the soil are also negatively affected. Uninterrupted movement of vehicles for the collection of sands can enhance the concentration of Suspended Particulate Matter (SPM) in the atmosphere, a part of which settles on the leaves causing depletion of productivity. The fauna of an area is dependent on the vegetation and there are countless relationships between the species composing an animal community. Hence the same effects on flora are applicable to fauna also.

8.10.2c Social components

Manual mining generates more employment opportunities than mechanical mining. But mechanical mining could strengthen the economic base and the construction sector. The positive impact in the social sector persists only for a short period of time. In the long term, it can cause negative impacts on the environment, ultimately leading to total degradation of the environment. When manual and mechanical modes are opted for mining of floodplain sands, least consideration is given to the impacts on land values and holdings, infrastructure, heritage / historical areas and agricultural lands which form the livelihood of the people in the area. Post mining operation like land filling with nutrient deficient soil causes negative impact on agriculture. The pits in the mining area act as death traps for people residing in the area. Health problems to workers exposed to dust and noise generated by mechanical mining are common.

From the assessment of environmental impacts of floodplain mining, one can find that the wet pit mining using diesel powered engines is the most disastrous and can cause instability to land, changes in land use / land cover, soil, landform, aesthetics, groundwater, surface water, flora and fauna, land values, land holdings, infrastructure, agriculture, heritage / historical areas and sustainable livelihoods. Also, manual extraction of floodplain sands by creating wet pits is hazardous to humans. Several people and children lost their lives due to drowning in the water filled open pits left after mining. The rapid movement of vehicles for the collection of floodplain sand causes damage to roads, groundwater, surface water, flora and fauna, land stability, reduces air quality and increases noise levels.

Each activity in the instream and floodplain mining sector is to be carried out with the notion that the results will be of benefit to the humanity through the developmental activities which are in full swing in the study area. But the results already received are the initiation of most complex problems of environmental and ecological backlashes. Ultimately, responses to the negative impacts of river sand mining should be prioritized according to three criteria – environmental significance, social significance and economic significance. The full consequences of many impacts on environmental components may not be obvious, but the long-term impact may be more profound in the environment and overweighs the short-term benefits to society.

8.11 Environmental Management Plan (EMP)

Environmental management involves functions that determine and implement environmental policy. It involves identification of objectives, adoption of appropriate mitigation measures, protection of ecosystems, enhancement of the quality of life for those affected, and minimization of environmental costs (Barrow, 1999). Environmental Management Plan (EMP) will be formulated with an objective to mitigate the adverse impacts of any proposed project. This includes an environmental policy on protection of environment and public safety. One of the goals of EIA is to develop the implementation of a set of environmental protection measures. These measures are normally set in an EMP.

Understanding fully the various dimensions of river basin environment and its application to the conservation and management of freshwater systems is a daunting challenge to the mankind. The river management functions involve strategic planning, sustainable allocation of resources and environment compatible mining methods for protecting the health of the river system. Management of rivers includes legal, social and economic considerations, as well as scientific insights. Political will and development of institutional infrastructure that enables management of rivers to keep pace with the rapid growth in scientific information is a critical issue for the conservation and restoration of these key ecosystems. Rivers and their floodplains possess diverse and valuable ecosystems. Not only is the availability of freshwater in itself vital to sustaining life, but it also supports lush vegetation and abundant insect life that form the base of the food chain. In the river channel, fishes prey on the plants and insects, and are themselves eaten by birds, amphibians, reptiles, and mammals. Away from the channel, wetlands maintained by seepage and occasionally flooded by the river support rich and diverse habitats that are important for resident species, migrating birds and animals that use wetlands as staging posts while moving seasonally between different homes (domiciles). Riparian ecosystems are some of the key ecosystems in nature and they depend entirely on the regime of the river for their existence. In the uplands, rivers are nourished and nurtured by forests. Therefore, river conservation and management requires a balanced approach. Hence, great care must be exercised when altering this regime through basin and river management, as careless handling or over-exploitation of resources (both living and non-living) has catastrophic impacts on these ecosystems.

Kondolf (1994b) opined that aggregate extraction from rivers must be managed on a river basin-scale, while the demand for aggregate and the various sources of its supply must be managed on the scale of production-consumption regions. Strategies used to manage instream mining vary widely, and in many areas there is no effective management in practice. According to Kondolf et al. (2002), one strategy is to define a 'redline', a minimum elevation for the thalweg (the deepest point in a channel section) along the river, and to permit mining so long as the bed does not incise below this line (as determined by annual river bed surveys). The channel bars along some reaches of large rivers constitute a renewable resource of sand and gravel which can be harvested without significant damage to the channel if proper care is taken. Ill-planned and careless harvesting of sand from river channel bars can have deleterious effects on bar stability, channel evolution, and various other aspects of river characteristics. There may have impacts on fish habitat, aesthetics, and other river characteristics as an indirect result of the channel disturbance. Periodic field checking of river sand harvesting sites, recording total sand extraction, periodic environmental auditing etc., could prevent long-term degradation of river channels by regulating sand extraction to non-destructive levels. Current approaches to managing instream mining are based on empirical studies. While a theoretical approach to predict the effects of different levels of sand and gravel mining might be desirable, the inherent complexity of sediment transport and channel change and the lack of adequate data on channel form, sediment transport, and sand and gravel extraction overtime, make specific predictions impossible at present. Sediment transport models can provide an indication of potential channel incision and aggradation, but all such models are simplifications of a complex reality, and the utility of existing models is limited by unreliable formulation of sediment rating curves, variations in hydraulic roughness, and inadequate understanding of the mechanics of bed coarsening and bank erosion (NRC, 1983). Another approach to managing sand mining is to estimate the annual bedload sediment supply from upstream, the "replenishment rate", and to limit annual extraction to that value or some fraction thereof, considered the "safe yield". Future management of gravel mining should emphasize incentives to use alternative sources of construction grade aggregate.

Indiscriminate river sand and gravel mining over the years has imposed irreparable damages to the river ecosystems of Kerala. Lack of adequate scientific information on the mining processes and the impacts of mining on various environmental components is a major lacuna in properly addressing the problem. Therefore, there is an urgent need for strengthening and integrating studies on various disciplines on the human induced degradation of the small catchment rivers of Kerala. This is very much important not only for laying down strategies for regulating the mining activities on an environment-friendly basis, but also for creating awareness on the impact of river sand mining on the physical and biological environment of these life support systems of nature. It is well understood from the study that the storage zones of the rivers in the lowland-midland systems are widely exploited for construction grade sand. The impact assessment studies show that the mining activities can impose negative effects on the environment. Also, the intensity of environmental degradation varies from one region to another. The observations and analysis of the primary and secondary data of the present study stress the necessity of stringent efforts for reviving the environmental quality of the rivers in the study area.

Rivers in the study area can be properly managed by: (1) limiting extraction / use of resources and (2) restoration and rejuvenation. A river can be restored by bringing down the level of extraction and allowing the system to recuperation by itself. Restoration and rejuvenation require appropriate interventions. It is actually helping the system to recuperate fast. Restoration can be defined as the re-establishment of the structure, functions and natural diversity of an area that has been altered from its natural state (Cairns, 1988; NRC, 1992). It is often assumed that restoration projects are beneficial, but many well-intentioned projects are actually ineffective or detrimental (e.g. Frissell and Nawa, 1992; Iversen et al., 1993; Kondolf et al., 1996). It is in the context of actual geomorphological and ecological processes that restoration goals can be sensibly formulated and evaluated. A competent geomorphological analysis can shed light onto the fluvial processes and controls at a catchment scale, and a historical analysis can document the evolution of the channel and catchment, providing the manager with insight into the underlying causes of the channel's current condition (Sear, 1994). River geomorphology and ecology are complex, and one cannot predict precisely how the river will respond to a given treatment. From an environmental point of view the best restoration method is the one, which is absolutely necessary and involves the minimum modification of the natural channel. A restoration project is more likely to be successful if its design is based on an understanding of geomorphological and ecological processes, rather an imitation of channel forms believed to be suitable or prescribed by adherence to a classification scheme. Repairing excessive river bank erosion along downstream may be a waste of valuable resources if altered upstream or upslope conditions remain conducive to accelerated surface runoff, stream flows and sediment production rates (Pess et al., 2003).

Deep factual understanding of the system and learning its governing laws help in this process.

The Kerala Protection of River Banks and Regulation of Removal of Sand Act, 2001 comprising six chapters was enacted by the State Government to protect river banks and river beds from large scale mining / dredging of river sand and to protect their biophysical environment system and regulate the removal of river sand and for the matters connected therewith or incidental thereto. A River Bank Development Plan prepared by the District Expert Committee (DEC) is used for establishing, co-ordinating and protecting river banks within the district. The River Management Fund (RMF) maintained by the District Collector is meant for meeting all the expenses towards management of the mining location (locally known as *kadavu*) and river bank. In addition to the Act of 2001, provisions under the Kerala Land Conservancy Act, 1957 and The Kerala Minor Mineral Concession Rules, 1967 can effectively be used to contain illegal sand mining. The administrative structures of government are of fundamental importance for the effective regulation of mining of river sand. The administrative system also has a clear bearing on the degree to which there is confidence in the regulatory system and consensus over the mechanisms or procedures themselves and the decisions that result. Typically the local bodies cannot afford technical staff to evaluate the mining locations or to monitor the extractors. In addition, political pressure may exist to insure a steady supply of river sand for urban developments. In many areas, illegal mines continue to operate, with little enforcement by the lead agency. Failure to shut down illegal mines puts legitimate miners at a competitive disadvantage, since they pay permit fees and related charges evaded by illegal miners. Illegal extraction and over-extraction are rarely prosecuted by the court, irrespective of the cases filed by the public before the court.

Based on the present study, a schematic model was prepared showing the various mining scenarios and their environmental / economic impacts (Fig. 8.7). Instream mining can be managed by adopting any one of the four alternatives mentioned in the schematic model: (1) no mining in channels or floodplains, (2) bar skimming only, (3) floodplain mining only, and (4) no change to existing regulations. These alternatives range from best case (1) to worst case (4) in terms of river resource conservation and costs to society and from worst case to best case for economic effects on the industry. Of the different alternatives, bar skimming (extraction of sand from the exposed sand deposits / bars within river channels) can, to some extent, balance resource conservation and economic benefits to mining sector. Eventhough bar skimming is recommended as a means for advancing river conservation and maintaining a viable extraction industry, from the management plan, no mining scenario may be opted for the rivers in the study area for a certain period of time in order to restore them back to their natural condition. The management plan outlines environmental protection and other measures that will be undertaken to ensure compliance with environmental laws and regulations and to reduce or eliminate adverse impacts. The EMP is required to ensure sustainable development in the area, hence it needs to be an all encompassive plan for which the activity, Government, concerned authorities, River Management Committee and other statutory bodies and, more importantly, the affected people in the area need to extend their co-operation and contribution.

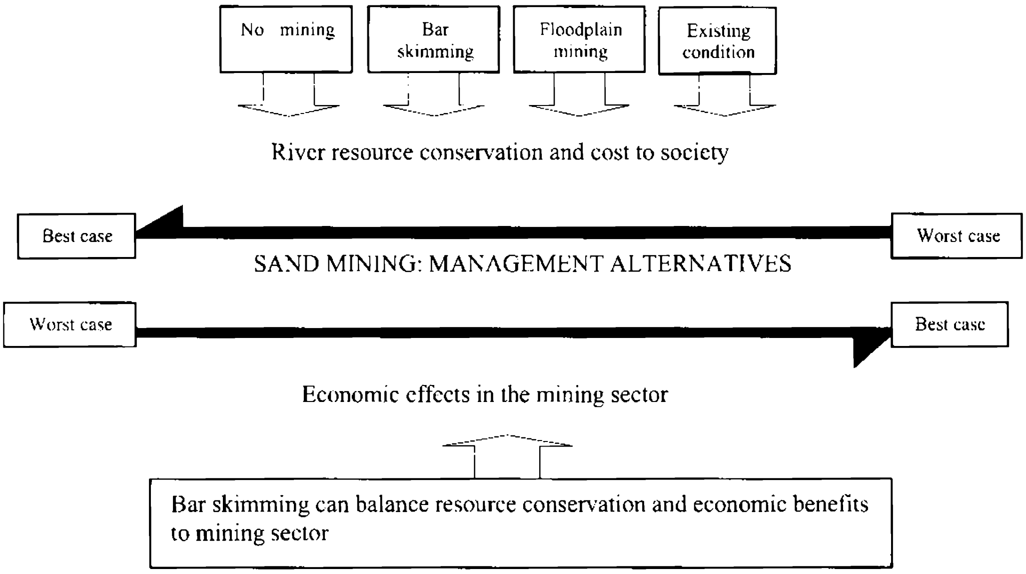

Fig. 8.7 Management alternatives of sand mining

At the same time, checking illegal sand mining is a major challenge, although several measures to regulate and control river sand mining have been in practice. The widespread demand of sand with the increasing construction / development activities, calls for an urgent need to look for alternative building materials available in the State. The conservation and creation of alternative resource system is the most important planning effort when the resource supply-demand mechanism is examined within the sustainable development framework. Initiatives must be taken by the Government and Institutions to promote alternatives and conservation *in lieu* of the conventional building materials. Awareness creation and use of alternate materials locally available have to be intensified with necessary Research and Development inputs. It is to be noted that the mining for alternatives that are not within the scientific stipulations can create severe environmental problems. The concept of "manufactured sand" (m-sand) is gaining more attention in the way that this technology can help in the substitution of river sand and thereby maintaining the ecological balance of rivers. It has to be promoted as an alternative resource system for the sustainable development in the State. The other alternatives include desilted sand from the reservoirs, importing sand from other States where there is surplus availability, mining palaeochannels and offshore mining.

The developmental activities taking place in the study area imposes pressure on the rivers draining the Vembanad lake catchments through over extraction of natural resources, particularly river sand. As a result, the rivers and its adjacent environments are degrading at a faster rate. Hence, every possible effort has to be made without much delay to rescue the rivers in the study area from the threats of indiscriminate sand mining.

Chapter 9

SUMMARY AND RECOMMENDATIONS

Throughout the developing world, river sand and gravel are widely exploited as aggregates for building constructions. As transportation and construction infrastructure expanded during the Post Independence Era, demands for construction grade sand also increased. Among the various sources, the river channels and its floodplains are major contributors of the construction grade sand. Sand is a non-renewable resource in human life scale and when extracted from river channels requires almost no processing other than size selection. Depending on the geological setting, this surface or subaqueous type of mining can cause serious environmental impacts, particularly if the river being mined is erosional. The in-channel or near channel extraction of sand inevitably alters the sediment budget and may substantially change channel hydraulics and ecosystem functioning. The impact of sand mining on the various environmental components such as land, water, biotic and social characteristics are typically severe and need indepth analysis for better conservation and management of the river ecosystem. Despite the importance of river sand mining in the construction sector, the details of its economic and environmental aspects and the impact of mining are not yet fully understood and do not adequately inform the decision makers and / or the authorities concerned with its regulation and environmental protection.

Kerala State, in the southwest coast of India, is characterised by fast pace of urbanisation and associated developmental activities, since early 1970's. This, in turn, led to the rise in demand for construction grade sand and gravel. Unfortunately, the 44 rivers in the State are small in size and sand resource capability, compared to neighbouring States. At the same time, indiscriminate mining of sand is booming in the State to meet its ever-increasing demand in the construction sector. Due to the extensive mining, the environmental problems associated with this are also emerging in the State. Now a stage has reached that the Kerala rivers are no longer able to assimilate the human interventions; instead the rivers need immediate attention and corrective measures. As rivers are the first to negatively affect to all developmental stressors, their monitoring and scientific recommendations based on systematic studies are very essential for tuning the activities within sustainable limits. In view of the above factors and also considering its likely impact in the sustainable development of the State, an attempt is made in this study to analyse the problems related to indiscriminate sand mining and to assess its environmental impacts taking the rivers draining the Vembanad lake catchments as a case study site.

The Vembanad lake and its hinterland areas (15100 km^2) drained by Achankovil, Pamba, Manimala, Meenachil, Muvattupuzha, Periyar and Chalakudy rivers occupies about 39% of the total area of Kerala State. The area is located between north latitudes $9^0 0'$ – $10^0 35'$ and east longitudes $76^0 05'$ - $77^0 25'$. The study area is known for its increased pace of urban and industrial developments. The coastal lands have the highest density of population (Population density of Kochi Corporation as per 2001 census = 6277 $inh.km^{-2}$). This region includes all the three major physiographic provinces of Kerala such as highlands (8625 km^2), midlands (4534 km^2) and lowlands (1941 km^2). The land use and settlement pattern varies considerably within the study area in tune of the physiographic settings.

The rivers in the study area reveal wide variations in their nature and characteristics. The segments in the main channel of Muvattupuzha river exhibit maximum average sinuosity index (1.71). Among the individual segments, Pamba (1.95) and Manimala (1.82) rivers exhibit high sinuosity index in the highlands whereas Achankovil (1.74), Meenachil (1.44), Muvattupuzha (1.9), Periyar and Chalakudy (1.59) rivers in the midlands. The majority of the river channel segments in the study area fall under the category of irregular meanders. Straight channel pattern is observed only in Periyar river that drains through Munnar-Peermedu plateau in the highland region. The average annual water and sediment discharges for the period 1987/88 to 1996/97 is highest in Periyar river (Water discharge: 83344 cumecs; Sediment discharge: 354870 tonnes), which has a greater basin area compared to other rivers in the study area. The analysis of sediment characteristics of the seven rivers reveals that, in general, there is a progressive decrease in grain size downstream. Sandy gravel dominates in the highlands and gravelly sand in the midlands and slightly gravelly sand or sand in the lowlands. An inter-comparison of all dissolved nutrient species reveals wide seasonal concentration differences. The rates of flux of nutrients like nitrate and phosphate through all rivers are considerably high during monsoon period compared to non-monsoon. Generally, rivers from the southern region reveal high seasonal difference of NO_3-N flux rate compared to the northern rivers of the study area.

Generally, two types of instream sand mining are practiced in the area - pit excavation and bar skimming. Deep pit excavation is widespread and is a common practice of sand mining in many parts of the river systems in the study area. The detailed examination on the extent of instream sand mining shows that the intensity of mining is high in the alluvial reaches. A physiography-wise analysis of sand mining reveals that in the highlands, the maximum quantity of sand is being mined from the Periyar river (0.667 x 10^6 ty^{-1}; 41.49%) followed by Pamba (0.374 x 10^6 ty^{-1}; 23.28%) and Achankovil (0.270 x 10^6 ty^{-1}; 16.82%) rivers. The main channel and tributaries of the entire rivers in the highlands are widely exploited for sand and gravel. A detailed examination of the extent of sand mining shows that river channels in the midlands are extensively mined for construction grade sand than the other two physiographic zones. The Periyar river holds a share of about 55% of the total quantity of sand extraction in the midlands followed by Muvattupuzha (15%) and Manimala (9%) rivers. Similarly in the lowlands, Periyar (40%) and Muvattupuzha (27%) rivers ranks the first and second positions in the total quantity of sand extraction. If one considers the study area as a whole, out of the total quantity of sand extraction, 50% is from the Periyar river, which flows through the most urbanized and industrialized areas. An overall analysis reveals that about 75% of the quantity of sand extraction is from the midlands. Also, rivers in the northern part of the study area (Muvattupuzha and Periyar rivers) close to the major developmental centres, like Kochi City, ranks top in the case of sand extraction. The sand mining locations are also higher in numbers in midlands than in the highland and lowland counterparts.

In addition to instream mining, floodplain mining is also widespread in the study area, especially in lowlands. Among the river basins, the downstream reach of Muvattupuzha river basin is widely exploited for floodplain sands often using diesel powered engines. In the Periyar river basin, land sand mining is widespread in the plateau region in the highlands. Mining of sands from these areas impose severe environmental problems to the river basin environment.

An apparent assessment of the quantity of sand extraction with respect to the sand input (replenishment) shows that mining in the river reaches down the gauging stations is of the order of 40 times higher than the input. The storage zones of the rivers are now transformed into deep pools due to pit excavation. The river segments at many places are devoid of mineable quantities of sand. This, in turn, has aggravated mining of sands from floodplain and over bank areas of river channels. Therefore, the quantity of sand allocated to mining should be strictly reduced in a phased manner (after normalizing the mechanism of mining), so that, over a period of time, the quantity of mining can be made in tune with natural replenishment.

The physical adverse effects of sand mining in the study area are numerous and need careful examination / analysis. The rivers in the Vembanad lake catchments exhibit marked 'human imposed' modifications in their bed profiles over the years consequent to sand mining and construction of embankments or dams upstream. The river cross sections over the years show that the channel beds are subjected to incision at faster rates (4.44 cmy^{-1} to 16.19 cmy^{-1}) due to indiscriminate sand mining. The present level of bed degradation in the rivers in the area can be attributed to sand mining activities because the scale of extraction of river sand exceeds the natural replenishment. Furthermore, the strong positive correlation existing between the quantity of sand mining and channel incision reiterates this view. Although timely interventions of Hon'ble Court and Government could yield positive results for short-term periods (which in turn, reflected well in the slow pace of channel incision at certain periods) the efforts could not sustain long due to illicit sand mining to meet the ever increasing demands in the construction sector.

Removal of sand by manual as well as mechanical means results in the generation of large pits in the river channels, which in turn, act as trap for sediments rich in nutrient elements. In addition, the pits trap much of the bedload sediment and sediment starved water (hungry water) that passes downstream of such pits not only aggravates erosion of river bed and banks with great vigour, but also undermines bridges and other engineering structures built in the river channel. Bank failure incidents are common in the midlands and lowlands and downstream areas of highlands of the entire rivers close to indiscriminate sand mining. The problem is very severe in the high flow periods of the monsoon season. The river stretch experiences marked changes in river bed configuration, damage to engineering structures constructed along and across the river channel, widening of river channel due to mining of sand close to river banks and adjoining areas, etc. Uprooting of trees is noticed at some places. Riparian vegetation is very scanty or totally absent on the banks in some areas.

The physical composition and stability of substrates are altered as a result of instream sand mining and most of these physical effects may exacerbate sediment entrainment in the channel. A comparative evaluation of the present study of changes in grain size characteristics in the Muvattupuzha river with the database of the year 1988, reveals that Very Coarse Sand (VCS) and Coarse Sand (CS) fractions are higher in majority of the samples in the upstream reaches. Indiscriminate extraction of sand from the lower reaches of the river has imposed marked changes in the sediment distribution pattern. Sand extraction has resulted in the imposed bed coarsening in the upstream areas by selective removal and transportation (entrainment) of medium to very fine sands from the upstream stations and their deposition in the subsequent stations downstream reaches. The surface and core sediments collected from the Valanchuzhi point bar of the Achankovil river reiterates the fact that bed coarsening phenomenon is also taking place in point bar deposits that are used for holding religious / cultural congregations. The variation of VCS, CS, Medium Sand (MS), Fine Sand (FS) and Very Fine Sand (VFS) shows a deviation from the gravel entity by exhibiting a general increase towards the downstream part of the river channel. Removal of sand and gravel taking place in the sand mining location (Vyazhi *kadavu*) situated downstream, as well as winnowing of gravels and sands from the incising river bed, has resulted in a kind of armouring (the development of a lag concentrates of pebbles) in the upstream side of the Valanchuzhi point bar.

The analysis of Total Suspended Sediments (TSS) in Manimala river reveals that during intense sand mining periods, the overlying waters close to mining centres are loaded heavily with TSS contents than sand mining prohibition periods. In addition, the positive correlation existing between TSS and quantity of sand extraction reiterates that the mining is one of the major causative factors in raising the suspended particulate contents in river environments. It can be noticed from the study that the lowering of water table in the wells constructed in the floodplains / older river terraces, especially during summer season, is in consonance with channel incision consequent to indiscriminate sand mining.

Sand mining from rivers has resulted in habitat destruction, which in turn, imposes negative effects on the fishes and benthic fauna that inhabit the sandy substratum. The elimination of benthic fauna consequent to indiscriminate sand mining can adversely affect the survival of carnivorous and omnivorous fishes. Examination of freshwater fish fauna from different parts of the study area indicates that most fauna are in serious decline and in need of immediate conservation measures. Sand mining also has deleterious effects on the riparian vegetation along the banks of the rivers.

Social effects are complex and cannot be considered separately from environmental effects. The potential socio-economic impacts of river sand mining inferred from this study are largely negative. Besides for its potential for employment creation, sand mining is also related to the livelihood issues of local people in the form of resource availability. The costs to repair or replacement of engineering structures damaged by channel incision consequent to sand mining account for a huge amount and are far higher than the revenue generated from the mining activities. At many places, people have to bear the cost of lowering the wells for correction of channel incision and thereby maintaining water availability, loss of productive lands, loss of access to clean water and increase in the risks of accidents and diseases. The deep pits created in the river channel now act as death traps for a number of people residing along the banks of the rivers. In highlands and midlands, alterations by extraction to the hydrological environment increase the risk of diseases, especially during summer where low flow exists. The excavations associated with river mining create stagnant waters that may favour the multiplication of vectors such as flies, mosquitoes and other parasites.

Environmental Impact Assessment (EIA) was carried out for instream mining to examine the magnitude of impacts in the three different physiographic settings. The impact magnitude and impacting actions of mining activities in the three physiographic zones - the highland, the midland and the lowland - are different. The EIA exposes the negative impacts of sand mining on various environmental components of the study area. Land, one of the major life-supporting components in the environment is affected adversely by mining. The effects of mining such as bank slumping, channel incision etc., cause physical disturbances on the land stability triggering bank erosion in previously stable areas. The transport of vehicles cause negative impacts on air quality and enhance the noise level. The after-effects of sand mining activities such as siltation and turbidity, creation of deep pits in the channel, transportation of vehicles into the riverbed for easy loading of the mined material etc., create negative impacts on surface water quality. Lowering of water table in the wells adjacent to the mining sites is also noted in the study area. The negative effects of mining impose severe stress on the biological communities as well. Through mining activities, jobs and opportunities are generated, and significant contributions are made to the State's economy. Despite its positive phase, negative impacts dominate in the aesthetics, hazards, land holdings, etc. In many circumstances, the poor riparian land holders are forced to sell their property at throwaway prices. EIA carried out for floodplain mining of sand reveals that the wet pit mining using diesel powered engines (i.e., mechanical mining) is most disastrous and cause land instability problem in the area. In addition to this, groundwater, surface water, flora and fauna and sustainable livelihoods are also adversely affected. Moreover, manual extraction of floodplain sands by creating wet pits is dangerous to humans.

A management plan is prepared to mitigate the impacts of mining. Among the various management alternatives of sand mining – no mining scenario, bar skimming, floodplain mining and pit excavation – no mining scenario may be opted for the river stretches in the lowlands and midlands. At the same time controlled bar skimming may be allowed in the river reaches of the highlands and upper part of midlands at places where sand bars are exposed. A share of the revenue collected from sand mining should be used for river restoration since the well being of a society is essentially a function of the environment.

Recommendations / suggestions

The following are the major recommendations / suggestions drawn from the present study.

- Aggregate management should be considered separately from river management. The present practice of combining these two should be stopped with immediate effect.
- An integrated environmental assessment, management and monitoring program should be part of the sand extraction processes. Individual extraction operations should be evaluated from a perspective that includes their potential secondary and cumulative impacts.
- Evaluate physical, chemical and biological effects of instream mining on a river basin scale, so that cumulative effects of sand extraction on the aquatic and riparian resources can be recognized.
- Mechanical forms of sand extraction are to be discouraged and manual removal of sand is strongly recommended subject to environmental safeguards.
- Incorporate costs of environmental impacts (to bridges and other resources) into price of instream sand and gravel.
- There is an urgent need for strengthening multidisciplinary studies on the rivers for providing adequate scientific information to river restoration and management activities.
- Examine and encourage alternatives to river sand for construction purposes. Import sand from areas where there is surplus availability.
- Immediate steps to be taken to intensify research activities leading to the finding of suitable, low cost and easily available alternatives to river sand. Simultaneously, alternative building technologies with low sand / no sand content to be developed and promoted to rescue the rivers of the study area from further deterioration.

- The abandoned pits left after floodplain mining of sand should be reclaimed by land filling using proper scientific methods.
- The top soil shall be stripped off and kept separately for replacement to a similar depth in the rehabilitated or landscaped area. Correspondingly, the natural vegetation and land use practices that existed before the mining shall be reintroduced.
- Prohibit mining in such areas where small landholders are settled.
- Regulate random mining and allow only location specific extraction of the floodplain sand under strict guidelines.
- Avoid mining below the level of depth of water table (with respect to the water table conditions of summer season) of adjacent areas.
- Awareness campaign should be conducted at various scales and levels about river sand mining, present state of environment of rivers, finite character of river sand, immediate need for control measures etc.
- Continued funding for R & D activities for updating the database, technologies and management.
- Enforce strictly the 'Kerala River Bank Protection and Regulation of Removal of Sand Act', 2001.

These suggestions / recommendations are to be taken into consideration while formulating strategies for the conservation and management of the fast degrading river ecosystems of Kerala.

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Annexure I

SURVEY FORMAT FOR ENVIRONMENTAL IMPACT ASSESSMENT

RESEARCH PERSON	PHYSIOGRAPHY	RIVER	GRID	DATE

LAND CHARACTERISTICS

1. Soil

2. Geology

3. Slope

4. Landuse / Landcover

5. Settlement pattern

WATER RESOURCES

6. Surface water

7. Groundwater

AIR

8. Information on air quality

CHANNEL CHARACTERISTICS

9. Channel morphology

10. Stability of riverbanks

11. Details of engineering structures

12. Colour / quality of water (physical observation)

13. Instream biota

14. Riparian vegetation