STUDIES ON THE NATURE AND CHEMISTRY OF SEDIMENTS AND WATER OF PERIYAR AND CHALAKUDY RIVERS, KERALA, INDIA

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By

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CERTIFICATE

This is to certify that this thesis work entitled **"STUDIES ON THE NATURE AND CHEMISTRY OF SEDIMENTS AND WATER OF PERIYAR AND CHALAKUDY RIVERS, KERALA, INDIA"** is an authentic record of the research work done by **MAYA. K**, under my scientific supervision and guidance, for the partial fulfilment and the requirement for the Degree of Doctor of Philosophy 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 or associateship in any other University.

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PREFACE

Among various geological agents at work, rivers have been receiving special attention from the beginning of mankind. Rivers are the chief carriers of water, dissolved salts and organic matter from land to the sea. They are the prime architect in shaping the geomorphic features of tropics and subtropics. The natural channels and flowing waters that form the essential components of rivers act as corridors for the free movement of organisms among various aquatic ecosystems. But, it is unfortunate that, increased human interventions consequent to economic development in the past 3- 4 decades have imposed tremendous pressure on these life support systems. Recent studies reveal that human interventions have caused world-wide increase in river input of geochemical constituents, especially nutrient elements, to the coastal ecosystem by many folds. This in turn leads to imposed eutrophication incidences in many parts of the coastal areas. Construction of dams / reservoirs and associated structures, on the other hand, causes considerable reduction in the supply of water and sediments downstream, thereby affecting the natural river processes and also its stability. The scenario is being complicated further by the huge discharge of toxic contaminants from point and non-point sources. As a result of all these interventions / processes, the river systems of tropics and sub-tropics have been altered to levels often beyond their natural productive capacity.

Kerala State is blessed with 44 small rivers with catchment area <10000 km^2. Estimates show that these rivers together transfer about 78000 million m^3 of water into the Lakshadweep Sea every year. Uncontrolled discharge of pollutants from urban, agricultural and industrial sources, indiscriminate mining of construction materials (clay and sand) from instream and floodplain areas, damming of rivers, inter-basin water transfer, etc., have adversely affected the natural processes of these river systems. The recurring incidences of fish diseases and ecosystem disorders are nothing but the signals of man-imposed stresses in these ecosystems, which obviously need immediate attention and corrective measures.

The present study is an attempt to address issues related to sediment properties like texture, mineralogy and geochemistry as well as water quality of two important rivers of central Kerala – the Periyar (River length : 244 km, Catchment area : 5398km^2) and the Chalakudy (River length 130 km, catchment area 1704 km^2) rivers. These river basins are located between North latitudes 9^{0}15'50" & 10^{0}32'53" and East longitudes 76^{0}7'38" & 77^{0}24'32".

The entire thesis is addressed in seven chapters. Chapter 1 comprises the general introduction of the study area with its location, drainage, river discharge, physiography, geology, structure, climate, landuse, population, environmental degradation and the objectives of the study. The various methods employed in the study, consisting of fieldwork, sampling, laboratory investigation and computation of data are presented in Chapter 2. Chapter 3 deals with textural characteristics like, grain size and statistical parameters, bivariate plots, CM pattern and classification of sediments. Mineralogical parameters such as heavy mineral assemblage and correlation matrix of heavy minerals etc. are incorporated in Chapter 4. Chapter 5 is devoted to geochemistry and pollution assessment using statistical parameters like enrichment factor and contamination factor. Chapter 6 deals with a detailed analysis of water quality and nutrient fluxes of these rivers. The summary and conclusions of this study are dealt in Chapter 7. The relevant literature cited is given at the end of the thesis.

CONTENTS

CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

Rivers are the major geological agents in tropical and sub-tropical regions. Year by year, rivers transport about 37000 km^3 of water (Meybeck, 1976) and 13.5×10^9 tonnes of sediments (Milliman and Meade, 1983) from terrestrial environments to the world oceans. During transportation, water and sediments undergo considerable changes in their physico-chemical properties depending on terrain characteristics and climate of the region through which the river flows (Gibbs, 1977a; Lal, 1977; Subramanian, 1979; Sajan et al., 1992; Walling, 1999; Somayajulu et al., 2002; Ankers et al., 2003; Turner and Rabalais, 2004). It is now well understood that river transport of particulates, nutrients and minerals plays a major role in maintaining the productivity of the coastal and the nearshore environments of the world. Rivers and its estuaries provide connectivity between terrestrial and marine environments and also act as corridors for free movement of aquatic organisms among various sub-environments. But, unfortunately, increased human interventions consequent to the economic development in recent years have imposed tremendous pressure on the river systems. Several studies reveal that human interventions have caused worldwide increase in river input of geochemical constituents, especially nutrient elements to the coastal ecosystem by many folds leading to 'imposed eutrophication' incidences in many parts of the coastal areas. Construction of engineering structures like dams, spillways etc. are also responsible for changes in natural processes of river environments. The scenario is being complicated further by the huge discharge of toxic contaminants from point and non-point sources. All these, in one way or the other, have negatively affected the natural productive capacity of these life support systems of tropics and sub-tropics.

The situation is not so different in the river systems of Kerala, especially in the Periyar and Chalakudy rivers draining, respectively, the industrial and cultural capitals of the State. Discharge of pollutants from urban, agricultural and industrial sources, indiscriminate mining of construction grade materials (clay and sand) from instream and floodplain areas, damming of rivers, inter-basin transfer of water etc., have adversely affected the natural processes of these river systems. The recurring incidences of fish diseases and ecosystem disorders are signals of man-imposed stresses in these ecosystems, which obviously need immediate attention and corrective measures based on careful observations and studies.

The present study is an attempt to address certain aspects of the sediment and water systems of the Periyar and the Chalakudy rivers flowing through Idukki, Ernakulam and Thrissur districts of Kerala. The study includes a systematic analysis of sediment properties like texture, mineralogy and geochemistry and also the quality of overlying waters of these river systems. An attempt has also been made to evaluate the pollution status of the area.

1.2 STUDY AREA

1.2.1 Location

The area selected for the present study, the Periyar and Chalakudy river basins, falls within the central part of Kerala (Fig.1.1) and lies between North latitudes $9^0 15'50''$ - $10^0 32'53''$ and East longitudes $76^0 07'38''$ - $77^0 24'32''$. The area spreads in the Idukki, Ernakulam and Thrissur districts and comprises 16 taluks – 5 in Thrissur, 7 in Ernakulam and 4 in Idukki.

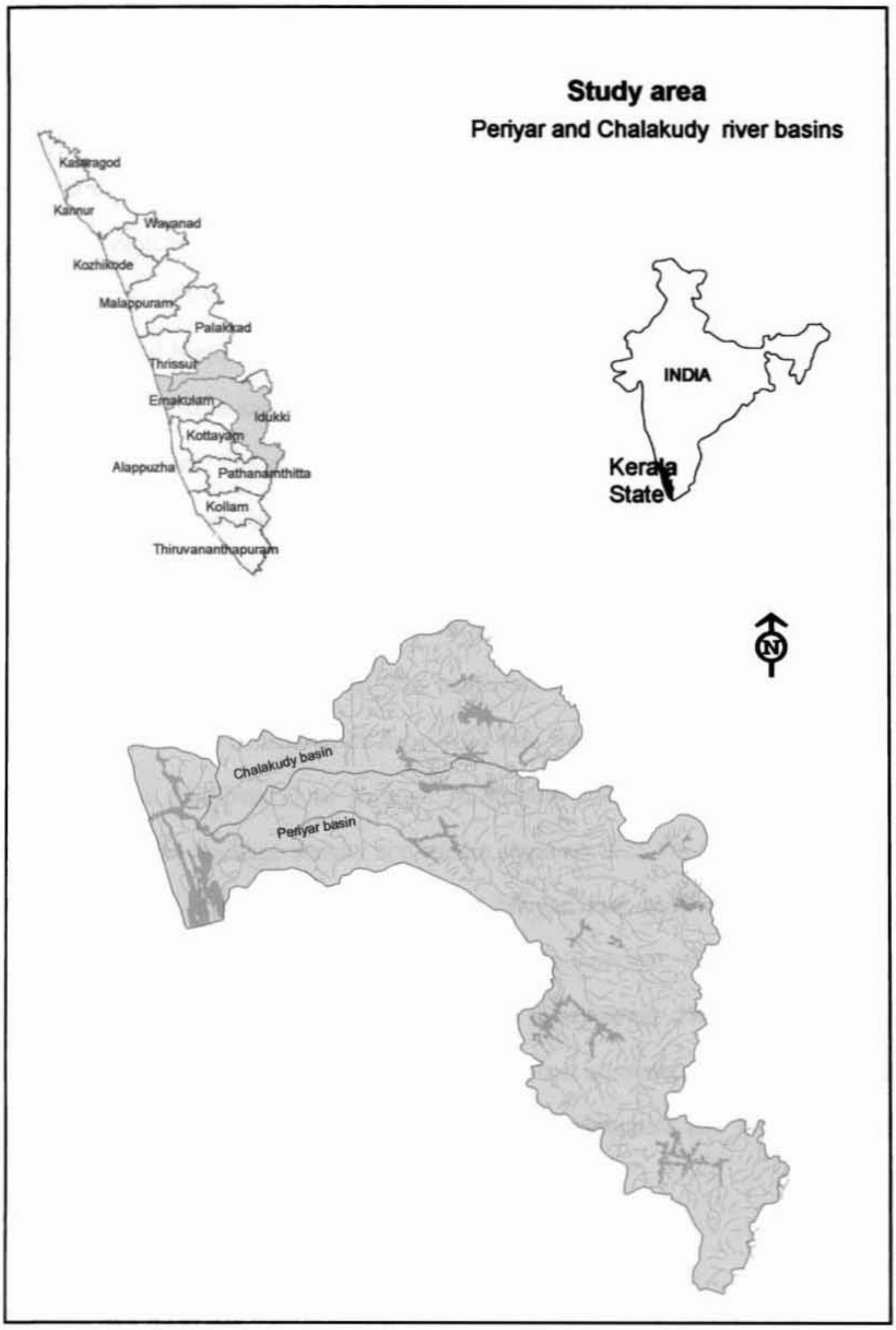


Fig. 1.1 Location map of the study area

1.2.2 Drainage

Periyar river

The Periyar river other wise called the *Poorna nadi*, is the longest river of Kerala and also the largest in water discharge potential (Kerala State Gazetteer, 1986). Fig 1.2 depicts the drainage characteristics of the river which has a length of about 244 km and a catchment area of 5398 km^2; out of which a total of 5284 km^2 lies in the Kerala State and rest in the Tamil Nadu State. The river originates from the Sivagiri hills at an elevation of about 1830 m above mean sea level (msl) and flows through highly varied geologic and geomorphic regions. The major channel supplying water and sediments to Periyar river are the Muthirapuzha, Perinjankutty, Edamalayar and Mangalampuzha tributaries. The river bifurcates near Aluva township into two major distributaries: the southwesterly branch is called as the Marthanda Varma distributary (flowing through Eloor-Kalamassery industrial belt) and the northwesterly branch as the Mangalapuzha distributary. Both the distributaries debouches into the Lakshadweep Sea either directly (Mangalapuzha distributary) or through backwaters (Marthanda Varma distributary); (Annexure I). The drainage density and stream slope are 0.21 km / km^2 and 7.14 m / km, respectively. The important reservoirs in the Periyar river basin are Bhoothathankettu, Idukki, Lower Periyar, Kallarkutti, Ponmudi, Mullaperiyar, Mattupetti, Anayiragal, Kundla and Idamalayar. Table 1.1 summarises the relevant details of some of these reservoirs whose information is available in published accounts. The longitudinal profile of the river is depicted in Fig. 1.3a. The river is perennial and generally exhibit a dendritic drainage pattern.

Chalakudy river

The Chalakudy river is a comparatively smaller perennial river than the Periyar. Though Chalakudy river in strict geological sense is a tributary of Periyar river, for all

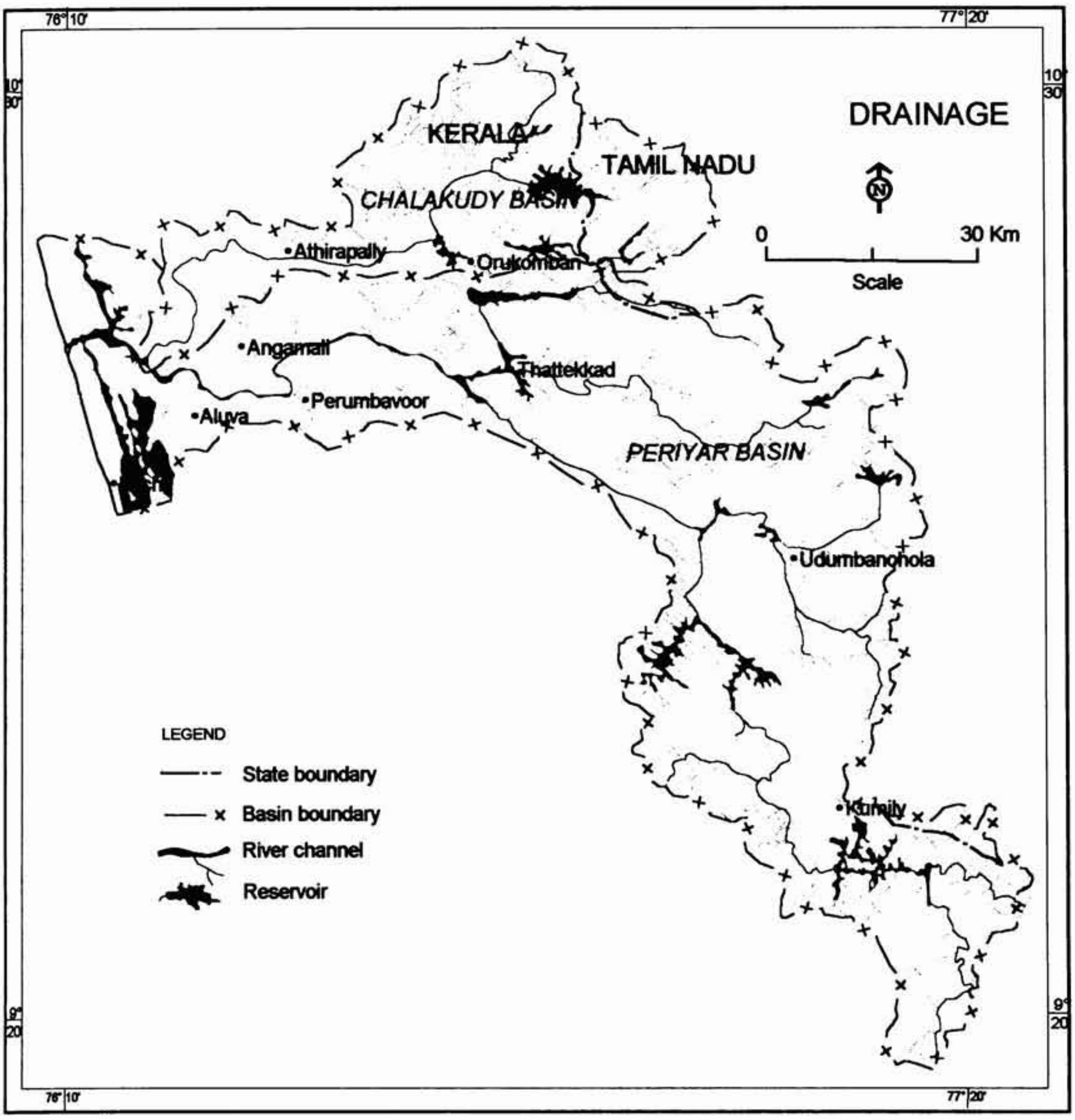


Fig. 1.2 Drainage map of the study area (Periyar and Chalakudy river basins)

Table 1.1 Important reservoirs in the Periyar and Chalakudy river basins

Sl. No.	Name of Reservoir	Year of completion	Height of dam (m)	Length (m)	Volume of content (×1000m^3)	Reservoir			Designed spill way capacity (m^3/s)
						Area at FRL (km^3)	Gross capacity (million m^3)	Effective capacity (million m^3)	
I PERIYAR RIVER BASIN									
1	Kundala	1946	32.30	259	54	0.47	7.79	7.65	184.06
2	Mattupetty	1956	85.34	237	155	3.24	55.23	55.23	-
3	Sengulam	1957	26.80	144	18	0.29	0.71	0.71	70.80
4	Kallarkutty	1961	43.00	183	40	0.65	6.88	6.51	1982.40
5	Ponmudy	1963	59.00	294	181	2.79	51.54	47.40	1416.03
6	Anayirangal	1965	34.00	292	462	4.86	49.84	48.99	348.00
7	Idukki	1974	168.90	366	46	59.83	1996.30	1459.50	5100.50
8	Cheruthoni	1976	138.20	650	1700	59.83	1996.30	1459.50	5100.50
9	Kulamavu	1977	100.00	385	450	59.83	1996.30	1459.50	5100.50
10	Idamalayar	1985	12.20	58	4	0.25	0.79	0.77	1014.00
11	Kallar	1989	20.00	146	16	0.97	5.35	5.09	507.00
12	Erattayar	1989	102.80	373	880	28.30	1089.80	1017.80	3012.80
13	Lower Periyar	1995	39.00	244	140	0.45	5.30	4.50	14200.00
II CHALAKUDY RIVER BASIN									
1	Peringalkuttu	1957	36.90	366	63	2.85	32.00	30.30	2266.00
2	Sholayar- Maindam	1965	66.00	430	303	8.71	153.60	15.20	1825.00
3	Sholayar- Flanking	1964	28.00	259	44	8.71	153.60	15.20	1825.00
4	Sholayar-saddledam	1965	19.00	109	18	8.71	153.60	15.20	1825.00

Source: KSEB (1996), FRL- Full Reservoir Level practical purposes it is treated as a separate river by Government and other agencies. The river joins the Periyar river near its mouth. It originates from the Anamalai hills of the Western Ghat mountain ranges and flows through the northern part of Periyar river. After draining through varied physiographic and geologic terrains of Tamil Nadu (minor portion) and Kerala (major portion) States, the river merges with the Periyar river at Elanthikkara located about 10 km upstream of the Periyar river confluence at Munambam. The Chalakudy river has a length of about 130 km and a catchment area of about 1704 km^2. Out of the total catchment area, about 300 km^2 lies in Tamil Nadu and the remaining in Kerala. The river is formed by the confluence of 5 major tributaries: Parambikulam, Sholayar, Kuriyarkutti, Karappara and Anakkayam. Out of these, the first two tributaries originate from the Tamil Nadu State and the remaining from the Kerala State. The Chalakudy river hosts several waterfalls, of which Peringalkuttu and Athirappalli are the major ones. The reservoirs constructed in the river basin are Peruvarippallam, Tunakadavu, Parambikulam, Sholayar and Peringalkuttu (Table.1.1). The river, in general, exhibits a dendritic drainage pattern. The longitudinal profile of the river is given in Fig.1.3b.

1.2.3 River discharge

Analysis of 8 years of water and sediment discharge data (1987/88 – 1994/95) collected from the offices of the Central Water Commission (CWC) located at Malayattoor-Neeleeswaram (Ernakulam district) in Periyar river and Arangali (Thrissur district) in Chalakudy river reveals that, on an average, 6613 million m^3 of water and 346089 tonnes of sediment (sand = 83603 tonnes; mud = 262486 tonnes) are discharged through Periyar river every year. The corresponding water and sediment discharges of the

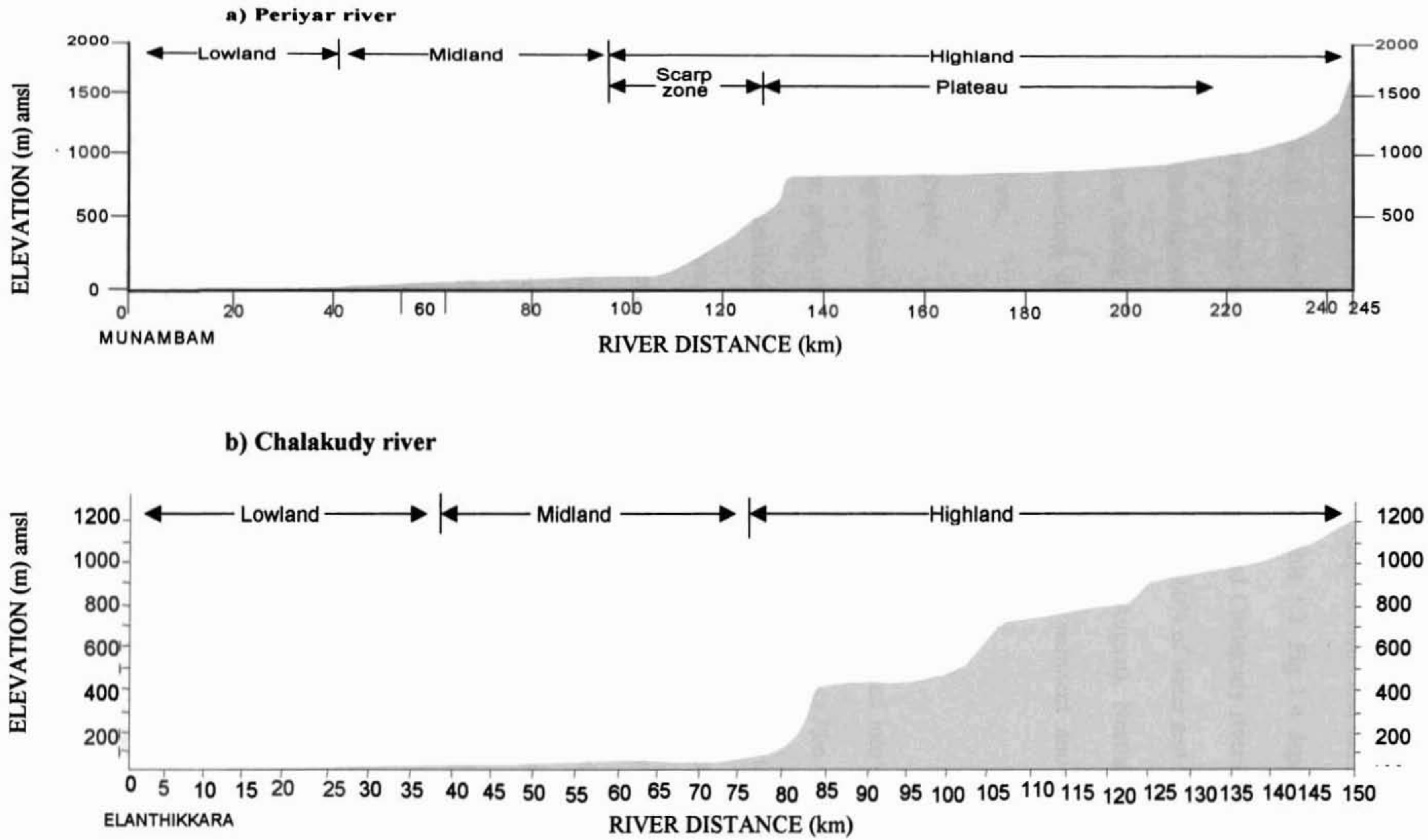


Fig. 1.3 Longitudinal profiles of Periyar (a) and Chalakudy (b) rivers; amsl- above mean sea level.

Chalakudy river are 1903 million m^3 and 59917 tonnes (sand = 13060 tonnes; mud = 46857 tonnes), respectively. The year - wise discharge of water and sediments during the period 1987/88 – 1994/95 are summarized in Table 1.2. Fig 1.4 depicts the monthly discharge of water and sediment through Periyar and Chalakudy rivers during the year 1987. From these figures it is very evident that about 60% of water and 65% of sediment discharge occur during southwest monsoon (June - August). Northeast (September-November) monsoon discharges only about 30% of sediment and water into the Lakshadweep sea.

1.2.4 Physiography

Physiographically, the study area can be broadly divided into 3 major zones - lowland (< 8m amsl), midland (8 – 75m amsl) and highland (>75m amsl); (Fig.1.5). Fig.1.6 depicts a detailed relief map of the region. The lowland has a width ranging from 10 to 15 km. The area close to the coast is dominated by a network of backwater channels. The midland region is characterized by an almost rugged topography comprising small flat-topped low mounts and broad valleys. The midlands are intensely cultivated. The highland is characterized by scarp, valleys, plateau and mountains. The highland host many reservoirs. The highest mountain peak in Kerala, the Anamudi run in a north-south direction in the eastern border of Periyar river basin. Plates 1 and 2 depict a few geomorphic features related to the Periyar and the Chalakudy river basins.

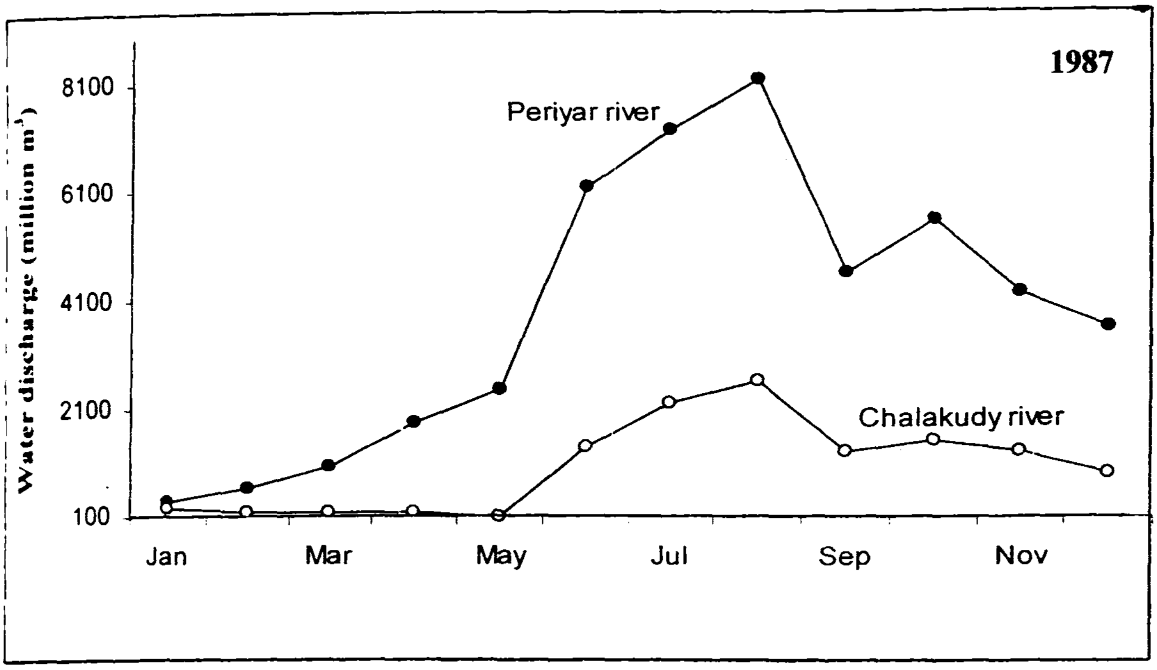
1.2.5 Geology

Kerala State forms a part of the peninsular shield, comprising the major rock units: Pre-Cambrian crystallines, Tertiary sedimentaries, laterites developed over the Pre-Cambrian crystallines, Tertiary sedimentaries and Recent to Sub-Recent (late Quaternary)

Table 1.2 Annual discharge of water and sediments through Periyar and Chalakudy rivers

Sl. No.	Year	Periyar river				Chalakudy river			
		Water discharge (million m^3)	Sediment discharge (tonnes)			Water discharge (million m^3)	Sediment discharge (tonnes)		
			Sand	Mud	Total		Sand	Mud	Total
1	1987- 88	4939	29540	102174	131714	1297	4604	20788	25392
2	1988-89	5569	70440	198467	268911	1835	10784	31306	42090
3	1989-90	7563	154545	480995	635540	1739	15344	44722	60066
4	1990-91	6074	41141	168924	210065	1665	7504	22682	30186
5	1991-92	6627	87648	295713	383361	1961	16935	53718	70653
6	1992-93	8062	144963	350013	494976	2362	24289	59271	83560
7	1993-94	6578	42470	163610	206080	1599	6049	31216	37265
8	1994-95	7495	98079	339994	438073	2765	18969	111151	130120
Average		**6613**	**83603**	**262486**	**346089**	**1903**	**13060**	**46857**	**59917**

Source: Central Water Commission (CWC), Kochi



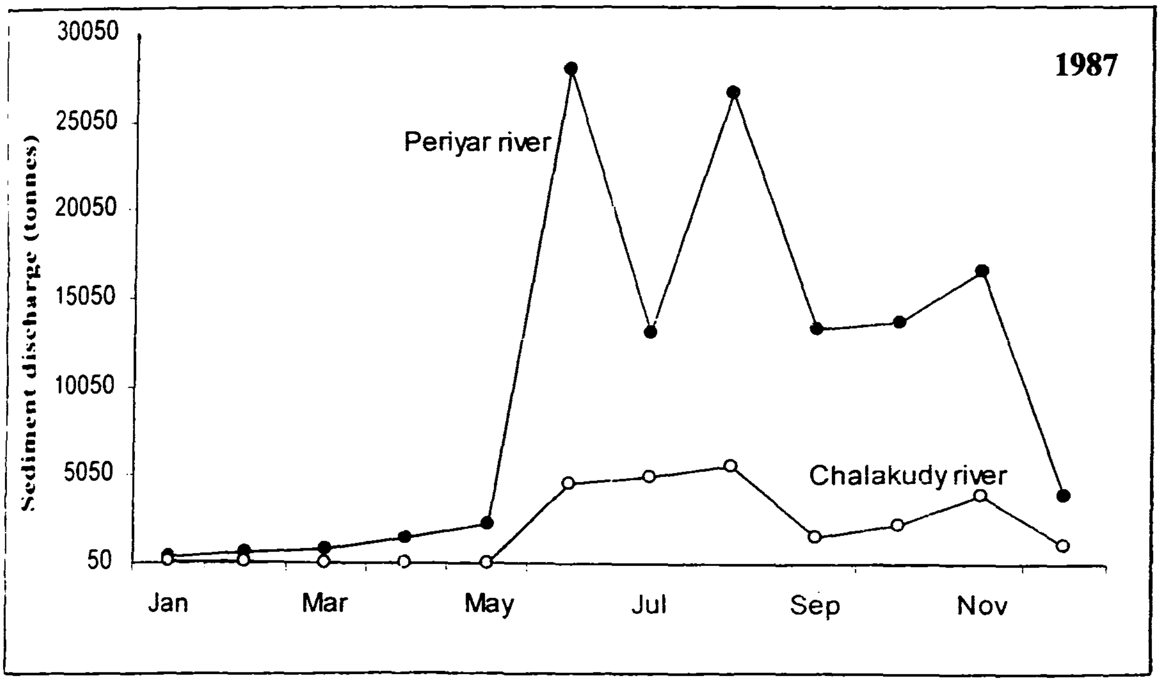


Fig. 1.4 Monthly sediment and water discharges of Periyar and Chalakudy rivers

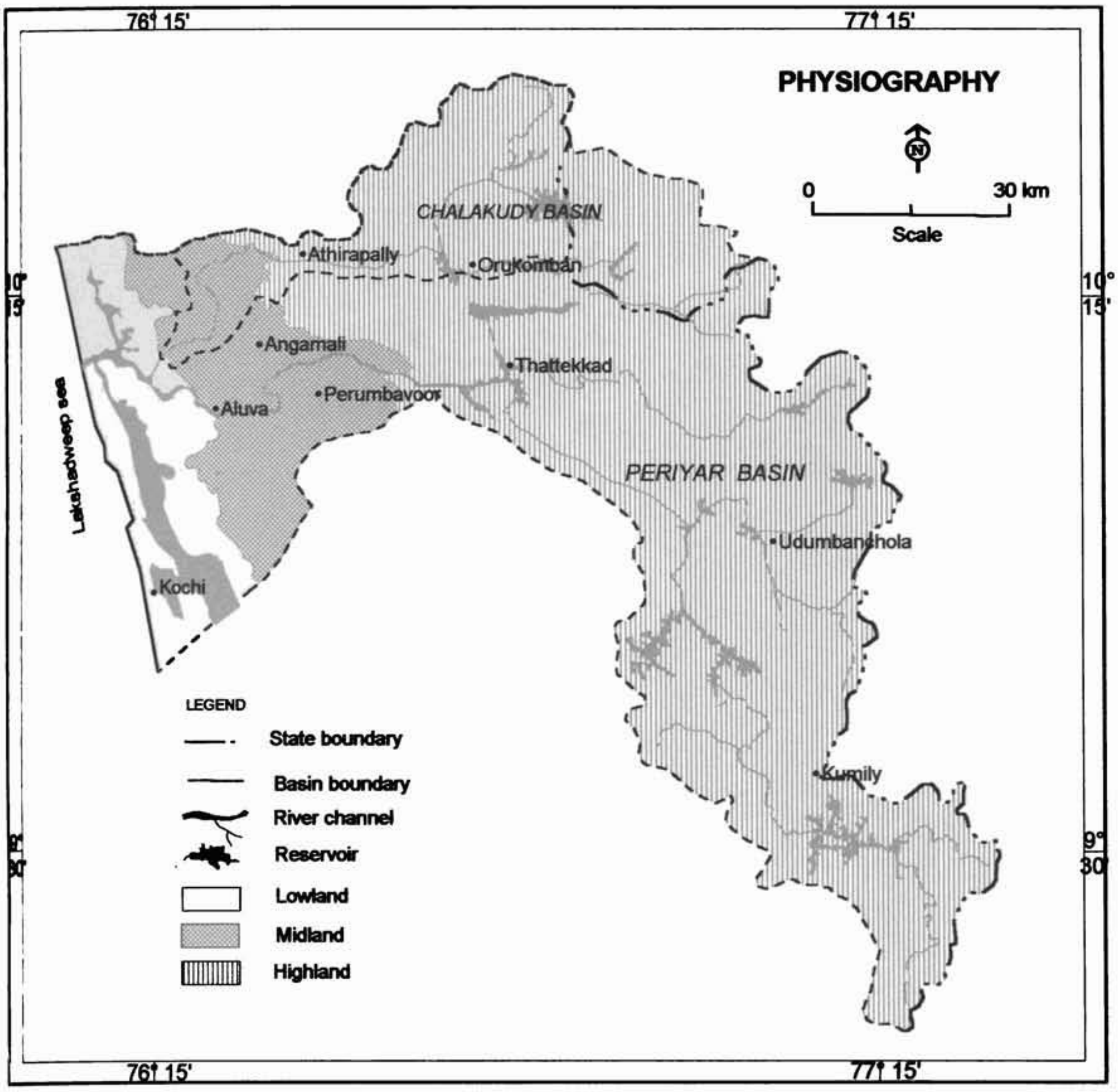


Fig. 1.5 Physiography of the study area (CESS, 1984)

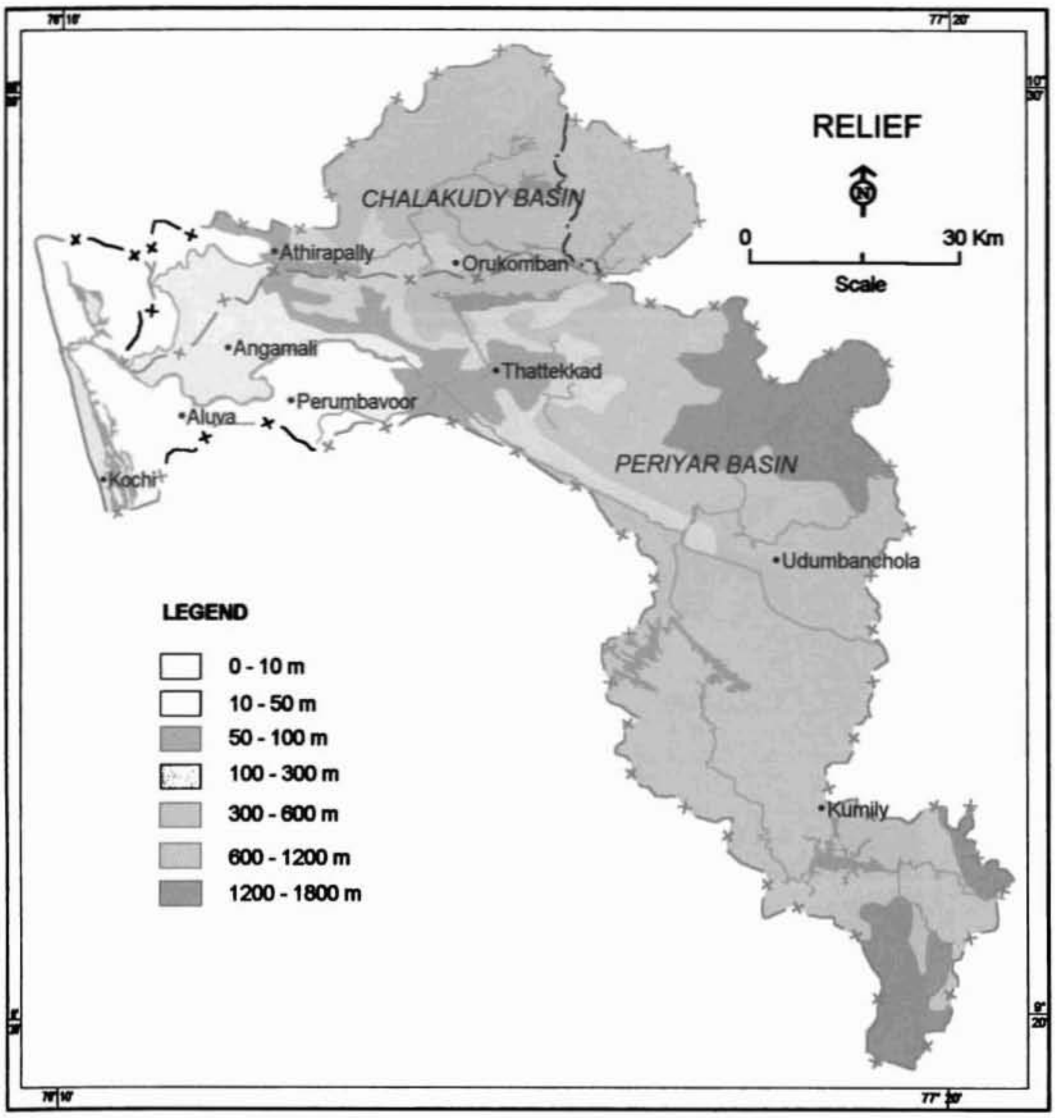


Fig. 1.6 Relief map of the study area (CESS, 1984). Measurements are from the mean sea level (msl)

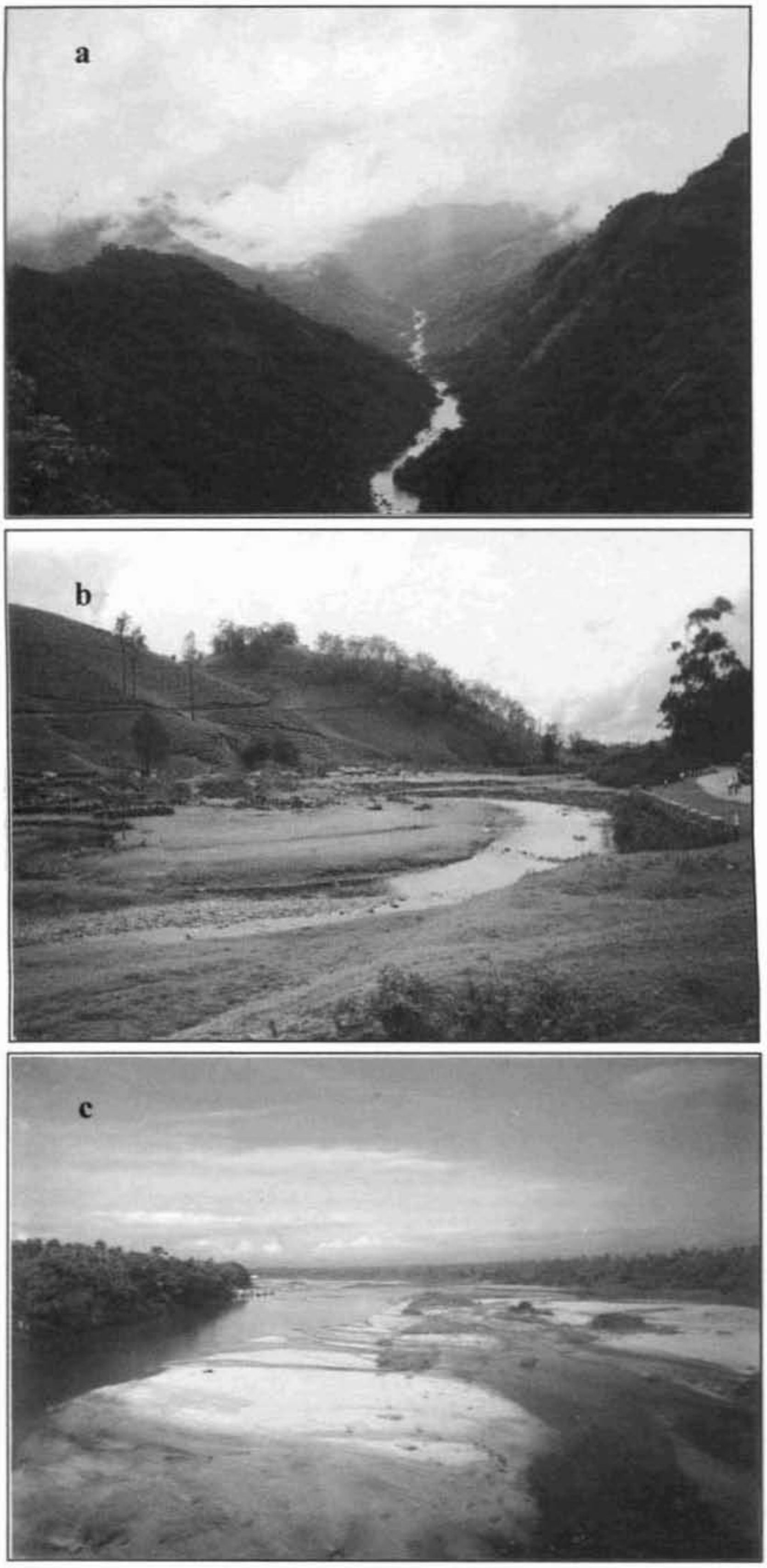


Plate 1 : Some selected scenes from the Periyar basin.
a) Muthirapuzha tributary - a distant view;
b) Sand deposits within channel near Munnar;
c) Sand deposit of Periyar near Kalady town

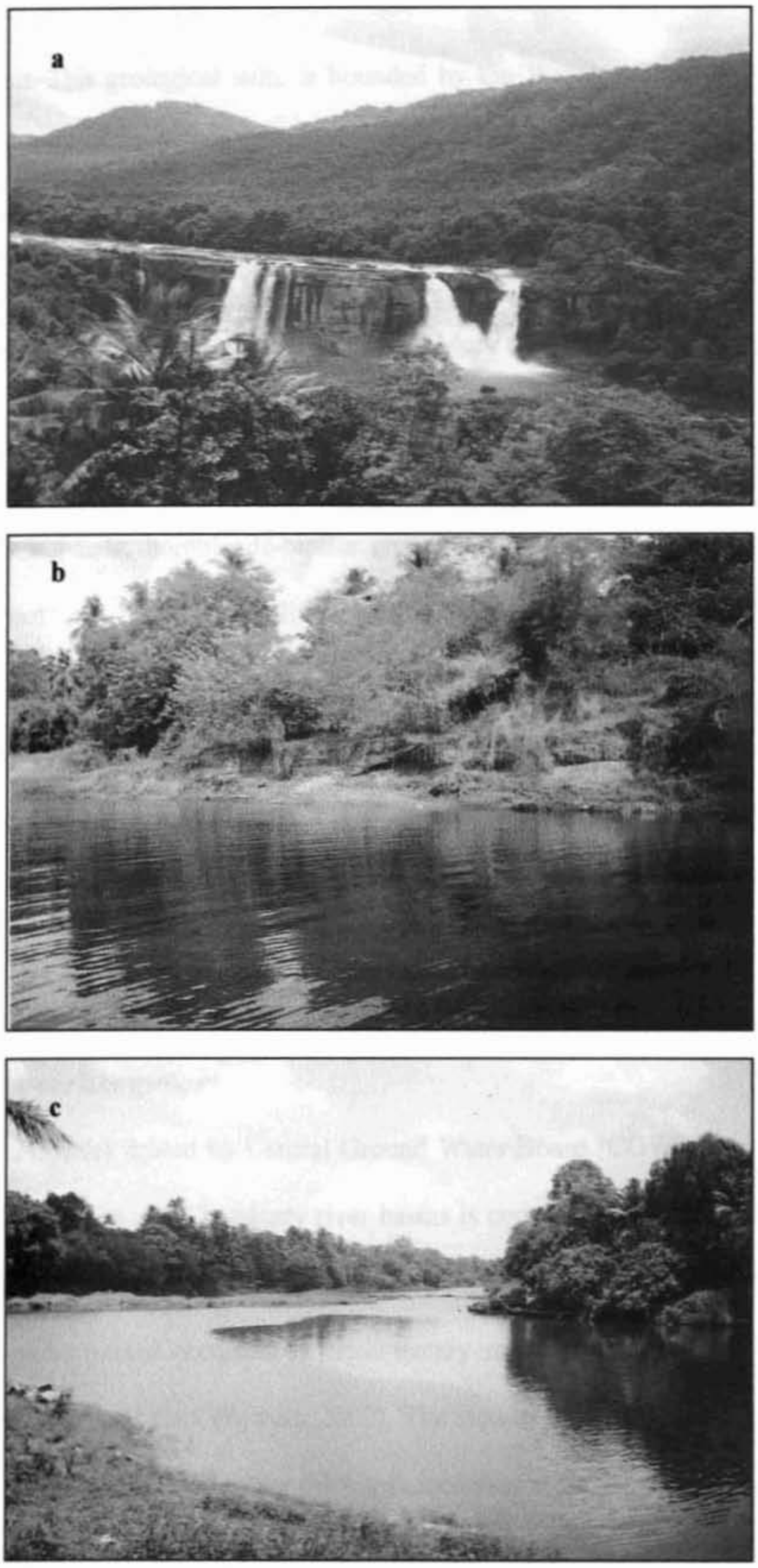


Plate 2 Some selected scenes from the Chalakudy river.
a) The Athirappally water falls;
b) Chalakudy river near Chalakudy town;
c) Chalakudy river with luxuriant riparian vegetation near Kadukutty.

sediments. This geological suite is bounded by the Western Ghats on the east and the Lakshadweep Sea on the west.

Geologically, the Periyar and Chalakudy river basins are occupied by a spectrum of rock types, which include crystalline rocks of Pre-Cambrian age and the sedimentaries of Tertiary and Quaternary Periods (Fig.1.7). More than 95% of the study area is covered by Pre-Cambrian crystallines. The crystallines are comprised of 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 Pre-Cambrian crystallines. Pegmatitic intrusions are recorded at many places. Tertiary sedimentaries occur as sub-surface formation especially in the coastal area. The Pre-Cambrian crystallines and Tertiary sedimentaries are covered at many places by laterites. Recent to Sub-Recent sediments of Quaternary age overlie the Tertiaries in the lowland, especially near coastal zones.

1.2.6 Sub-surface geology

Boreholes drilled by Central Ground Water Board (CGWB) reveal that a greater part of the Periyar and Chalakudy river basins is composed of Pre-Cambrian crystallines such as charnockites (major occurrence), hornblende gneiss, garnet biotite gneiss and biotite gneiss (minor occurrence). Sedimentary rocks of Tertiary and Quaternary ages occur in the coastal tract (Soman, 2002). The studies of ONGC in the offshore basin of Kerala indicate that sedimentary thickness increases steadly from north to south. As per CGWB (1993), the Tertiaries are represented mainly by Warkalli, Quilon and Vaikom

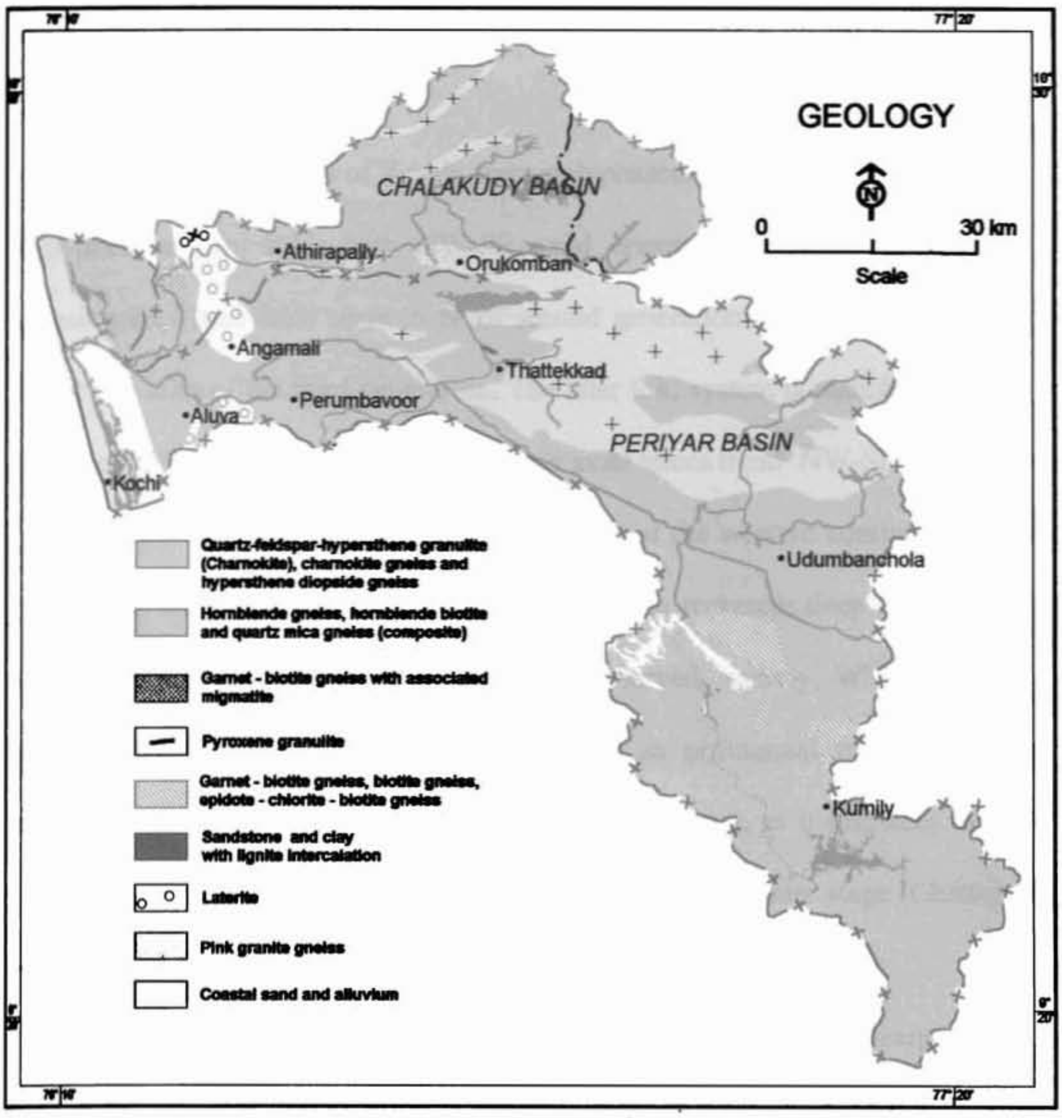


Fig. 1.7 Geology of the study area (after GSI, 1995)

Formations (Fig.1.8). Minor occurrence of Quilon Formation is recorded at the Chellanam borehole. The Tertiaries overlay laterites at many places. The thickness of Quaternary sediments varied between 20 m and 54.3 m. The Tertiaries and Quaternaries are composed of alternate layers of sand and clays.

1.2.7 Structure and tectonics

The crystalline rocks of Kerala were polyphasedly deformed. In the present area, fairly tilted isoclinal folds with NW-SE axial orientations can be demarcated on a regional scale. These folds seem to be of second generation whose orientation has been modified by folds of the third generation. The later fold system is manifested in the form of large upright synforms and antiforms whose axial traces trend NW-SE (Nair, 1990).

The Kerala region covers a significant part of the western continental margin of India and the major lineaments here are considered to represent deep fractures or shear zones. Three major lineament orientations are observed, namely, WNW-ESE, NW-SE and NE-SW. The NE-SW sets, which maintain an orthogonal relationship, can be considered as conjugate pairs and also seems to be younger, as it displaces the NW-SE set. It may be that the NE trending ones were reactivated at a later stage (Chattopadhyay and Chattopadhyay, 2004).

There is rough parallelism between the general trend of lineaments and the foliation. The NW trending foliation in the central part of the area runs parallel to the NW trending major lineaments. In the southern part of the area, to the south of intersection of the NE and NW oriented major lineaments, the foliation has a N to NE trend. In the area of maximum intersection of the lineaments, a major synclinal structure is defined by the foliation.

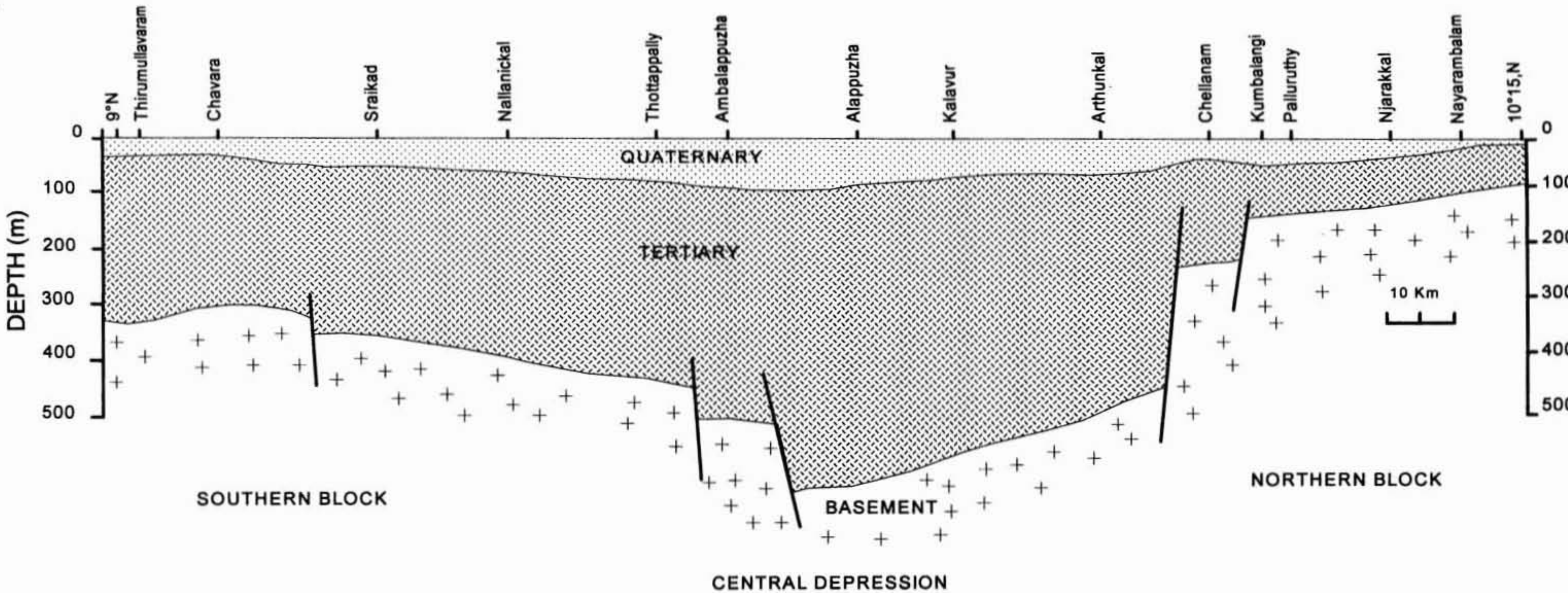


Fig. 1.8 Geological cross section along the coast; Quaternary includes laterite also. (after Nair and Padmalal, 2003)

In regard to the relationship of the lineament with the geology, it is seen that the major lineaments are either located at the boundaries of the rock formations or they cut across the rock formations. The composite gneiss trending NW-SE and the granite bodies elongated in the NE-SW direction are sub-parallel to the major lineament directions. The basic dykes are parallel to the WNW-ESE trending lineaments (Sinha Roy, 1981).

1.2.8 Soils

Soils of the Periyar and Chalakudy river basins fall within 6 broad categories. They are: 1) lateritic soil 2) hydromorphic saline soil 3) brown hydromorphic soil 4) riverine alluvium 5) coastal alluvium and 6) forest loam. Of these, lateritic soils are the predominant soil type of the midland region. The brown hydromorphic soil is mostly confined to valley bottom of undulating topography of the midland. They are formed as a result of the deposition of material derived from the adjoining hills and slopes. A major portion of the upland is covered by forest loam having the surface layer rich in organic matter. The riverine alluvium occurs mostly along the river channels and their tributaries. The coastal alluvium is believed to be developed from marine and estuarine processes.

1.2.9 Climate

The study area is characterized by a tropical humid climate with summer season from March to May, and rainy season from June to September. Wet type of climate prevails in the higher hill ranges. The area receives an average annual rainfall of 3000 mm. The rainfall increases from west to east. Nearly 68.2% of the total rainfall occurs from June to August (southwest monsoon) period. The period September –November (northeast monsoon) contributes about 17.5 % of the total rainfall. A total of 13% of rainfall is received during March to May and the balance is obtained during January to February. Out of the total 133 rainy days 83 days are during southwest monsoon.

The relative humidity is higher during monsoon months. Wind speed records the highest mark during May (10.9 km/h). The area experiences almost uniform temperature throughout the year. However, the maximum temperature is in the month of March and minimum in December.

1.2.10 Landuse / land cover

The study area occupies landuse classes, like tea / coffee plantations, forests, open scrub, mixed crops, rubber plantations, paddy fields and water bodies (Fig 1.9). The landuse / land cover of the area can broadly be grouped into agricultural land, forest land, wastelands and water bodies.

The upper region consists of forest land, agricultural land, wastelands and water bodies. The forest land consists of forest plantations, ever green / semi-ever green forests, deciduous forests and degraded forests. Of the forest land, nearly 10% is covered by forest plantation, 12% by degraded forest, about 8% by deciduous forest and 5% by evergreen / semi evergreen forest. Nearly 40% of the upland is agricultural land, which is mainly under mixed agricultural / horticultural plantations. About 10% of upper region is wasteland which is occupied equally by barren rock and land with or without scrub. Rest of the area is occupied by water bodies.

The midland is occupied by agricultural land, forest land and wasteland. Nearly 85% of the area is agricultural land which is mainly under mixed agricultural / horticultural plantations. Forest land is occupied by evergreen / semi-evergreen forest and

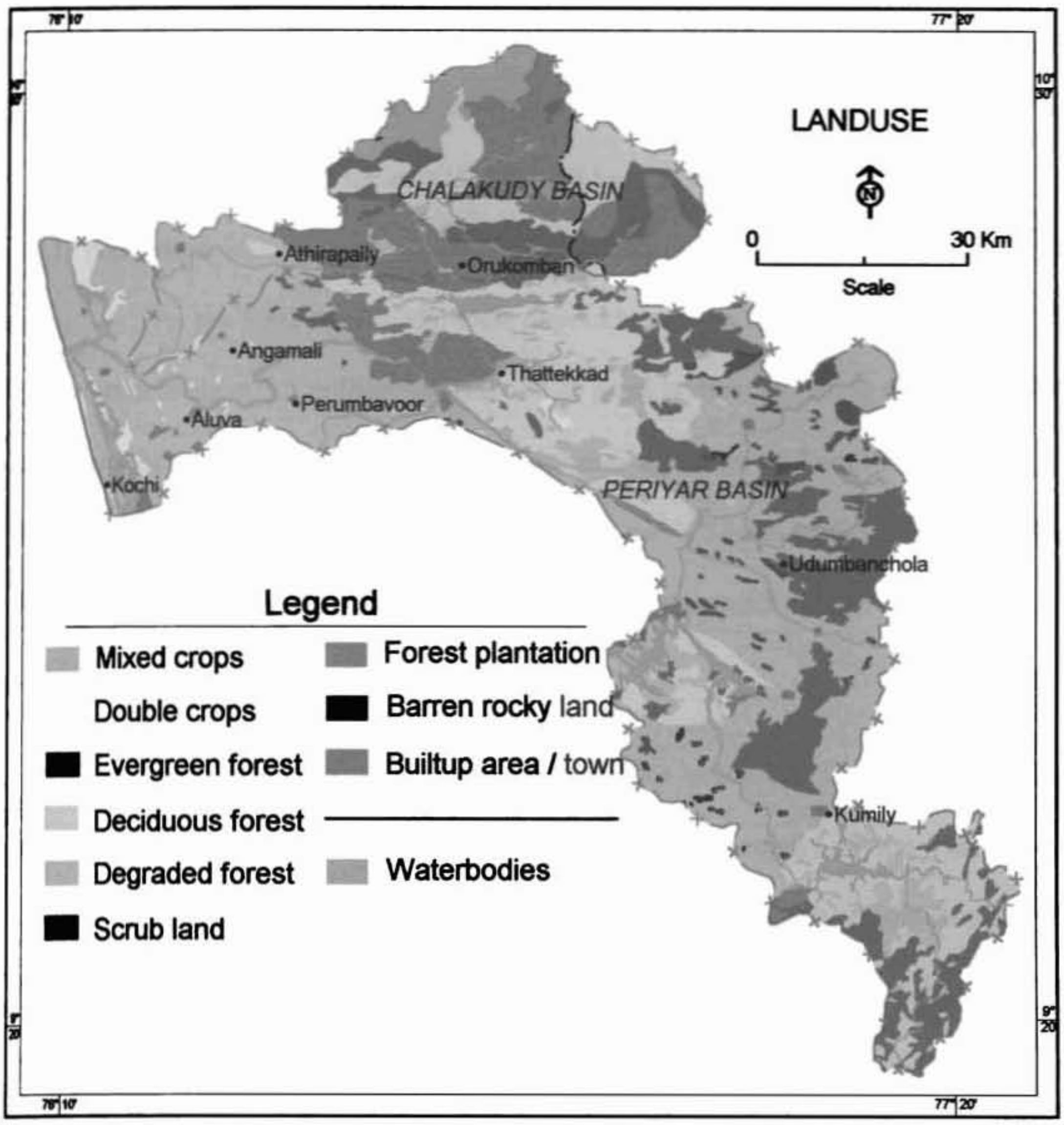


Fig. 1.9 Landuse map of the study area (after KSLUB, 1995)

degraded forest. Rest of the area comes under wasteland, which is land with or without scrub.

The lowland is occupied by agricultural land and water bodies. Nearly 75% is occupied by mixed agricultural / horticultural plantations and about 15% by double cropped paddy lands. Rest of the area is occupied by water bodies.

1.2.11 Population

As per 1991 census, the total population in the Periyar and the Chalakudy basins comes to about 3.5 million. A total of 125 local bodies, including 6 municipalities fall within these basinal areas. In addition to these, a portion of Tamil Nadu State also falls within the eastern part of the study area. Of these 125 local bodies of Kerala State, 95 fall completely within the study area and the remaining comes only in part.

1.2.12 Environmental degradation

Population explosion and rise in demand for resources has lead to serious environmental problems in the river basins of Kerala, especially in the Periyar and Chalakudy river basins. The Periyar river near Eloor – Kalamassery regions hosts many fertilizer and chemical industries (Plate 3). All these industries together discharge an amount of about 260 million m^3 of liquid wastes into the river channel, annually (Dineshkumar, 1997). Additionally, an amount of 113000 tonnes/year of urban wastes is also added in Periyar and Chalakudy basins from various urban local bodies (CESS, 1999). The unscientific disposal of these wastes could enhance the level of pollution in the area. Analysis of secondary data from Agricultural Department, Government of Kerala reveals that an amount of 46000 tonnes/ year of chemical fertilizers are applied for

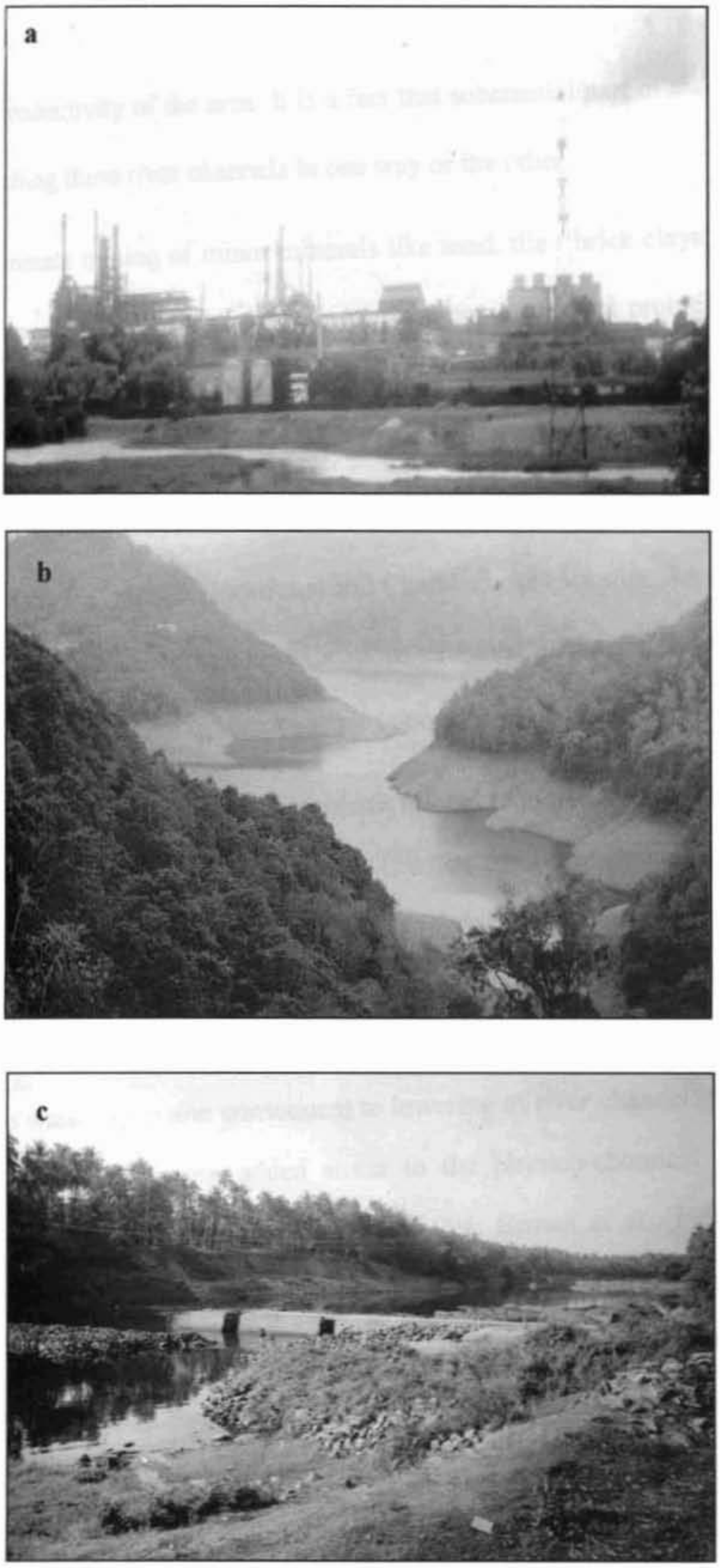


Plate 3: Field photographs from Periyar and Chalakudy basins
(a) Cluster of industries in the Periyar basins;
(b) An arm of Idukki reservoir near Cheruthoni (Periyar river basin);
(c) Check dam constructed in the Chalakudy river near Chalakudy town

enhancing the productivity of the area. It is a fact that substantial part of these chemicals will also be reaching these river channels in one way or the other.

Indiscriminate mining of minor minerals like sand, tile / brick clays, hard rocks / dimension stones, soil, etc. are also imposing severe environmental problems in Periyar and Chalakudy river basins. River sand mining is reported from the entire channel networks. A total of 40 local bodies of Periyar and 9 local bodies of Chalakudy river are engaged in sand mining. About 364 sand mining locations (locally known as '*kadavus*') are identified in the Periyar (320 locations) and Chalakudy (44 locations) rivers. The total quantity of sand being mined from these locations amounts to 7.8 million tonnes / year. It is estimated that the sand mining sector sustains about 11500 laboures in two river basins.

There are many environmental problems related to indiscriminate mining of sand. The river bank is cut deeply at many locations (particularly downstream stretches) for the passage of vehicles into the riverbed. Incidents of river bank slumping, weakening of engineering structures, lowering of water table in wells adjacent to sand mining sites, etc., are common in the area (Padmalal et al., 2003). There are several reports of aggravated sea water ingression consequent to lowering of river channel in areas close to river mouth. All these impose added stress to the physico-chemical and biological environment of the river ecosystem (Kondolf, 1994; Brown et al., 1998; Sheeba and Arun, 2003; Sreeja et al., 2003). Fig 1.10 depicts the riverbed lowering in the Periyar and Chalakudy rivers near the gauging stations at Malayattoor – Neeleswaram (Periyar river) and Arangali (Chalakudy river). Plate 4 potrays some selected scenes from the sand mining sectors of these two rivers.

Apart from river sand mining, indiscriminate clay mining from paddy fields for manufacture of roofing tiles, bricks and other clay articles is another serious

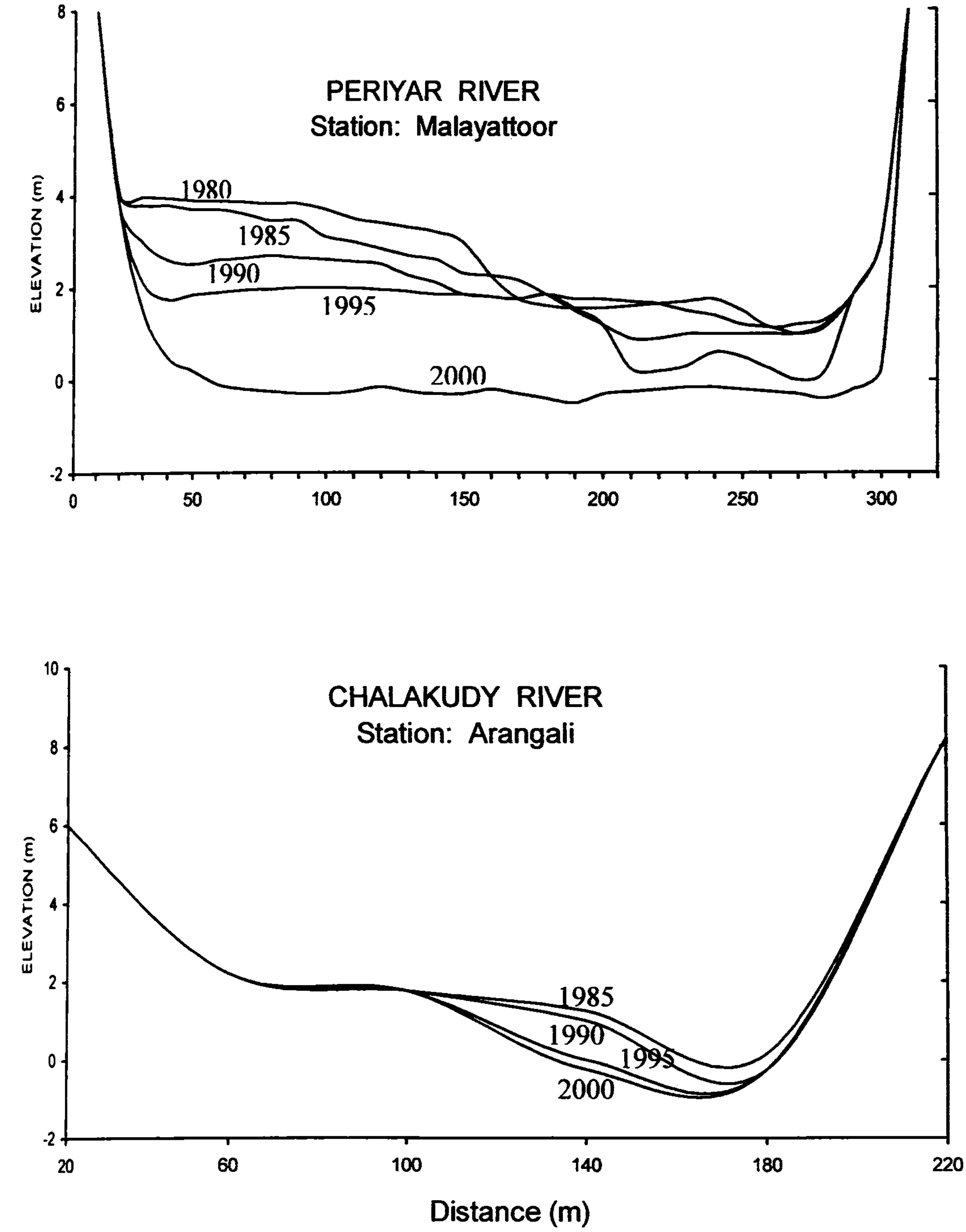


Fig. 1.10 Riverbed lowering of Periyar and Chalakudy rivers (Data source: CWC, Kochi)

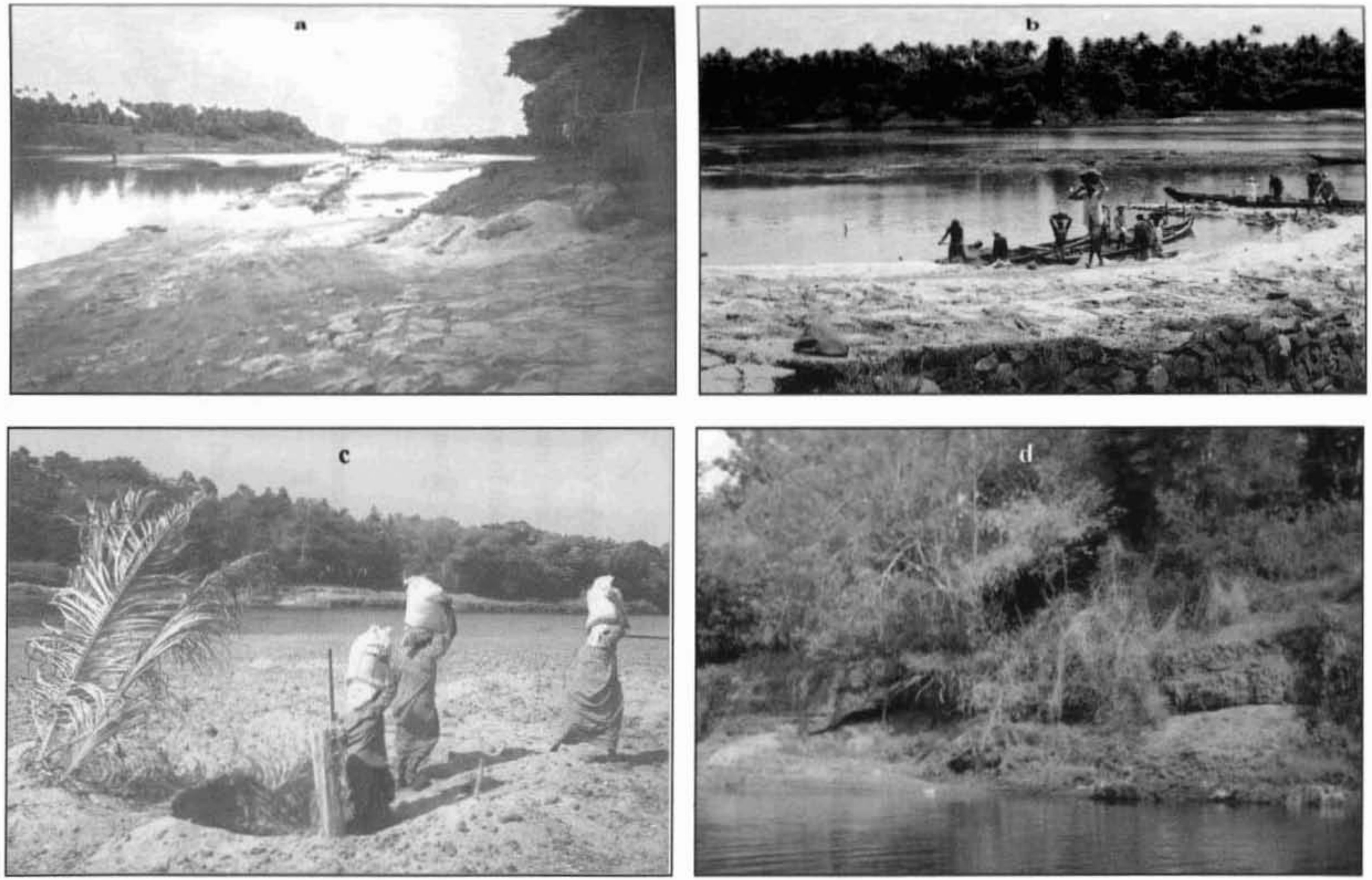


Plate 4: Field photographs showing river sand mining from Periyar (a & b) and Chalakudy (c & d) rivers

environmental problem in the area. The process, generally confined to the wetland systems of the area, has a direct impact on paddy production of the State. From the borehole sampling and analysis, it is revealed that, tile and brick clay occur to about 5m below ground level, on an average level. Further, active clay mining is recorded from an area of about 0.96 km^2. About 135975 tonnes / year of clay is being scooped from the area and used by various industrial establishments (Padmalal et al., 2004a). Some selected scenes from clay mining sector of the Periyar and Chalakudy rivers are displayed in Plate 5.

1.3 OBJECTIVES OF THE PRESENT STUDY

Considering the significance of the socio-economic and environmental scenario of the two river basins and in the overall development of Kerala, a detailed investigation on the sediment and water quality aspects of Periyar and Chalakudy rivers have been attempted. The following are the specific objectives of the study.

- To investigate the textural and mineralogical characteristics as well as transportation and depositional mechanisms of the sediments of Periyar and Chalakudy rivers.
- To find out the geochemical variability of organic carbon, phosphorus and certain major (Na, K, Ca and Mg) and minor / trace (Mn, Pb, Ni, Cr, and Zn) elements in the bulk sediments and mud fraction of these rivers.
- To evaluate the status of heavy metal pollution registered in the sediments of these rivers.
- To assess the physico-chemical characteristics and water quality of Periyar and Chalakudy rivers.
- To estimate the dissolved nutrient flux through the Periyar and Chalakudy rivers into the receiving coastal waters.

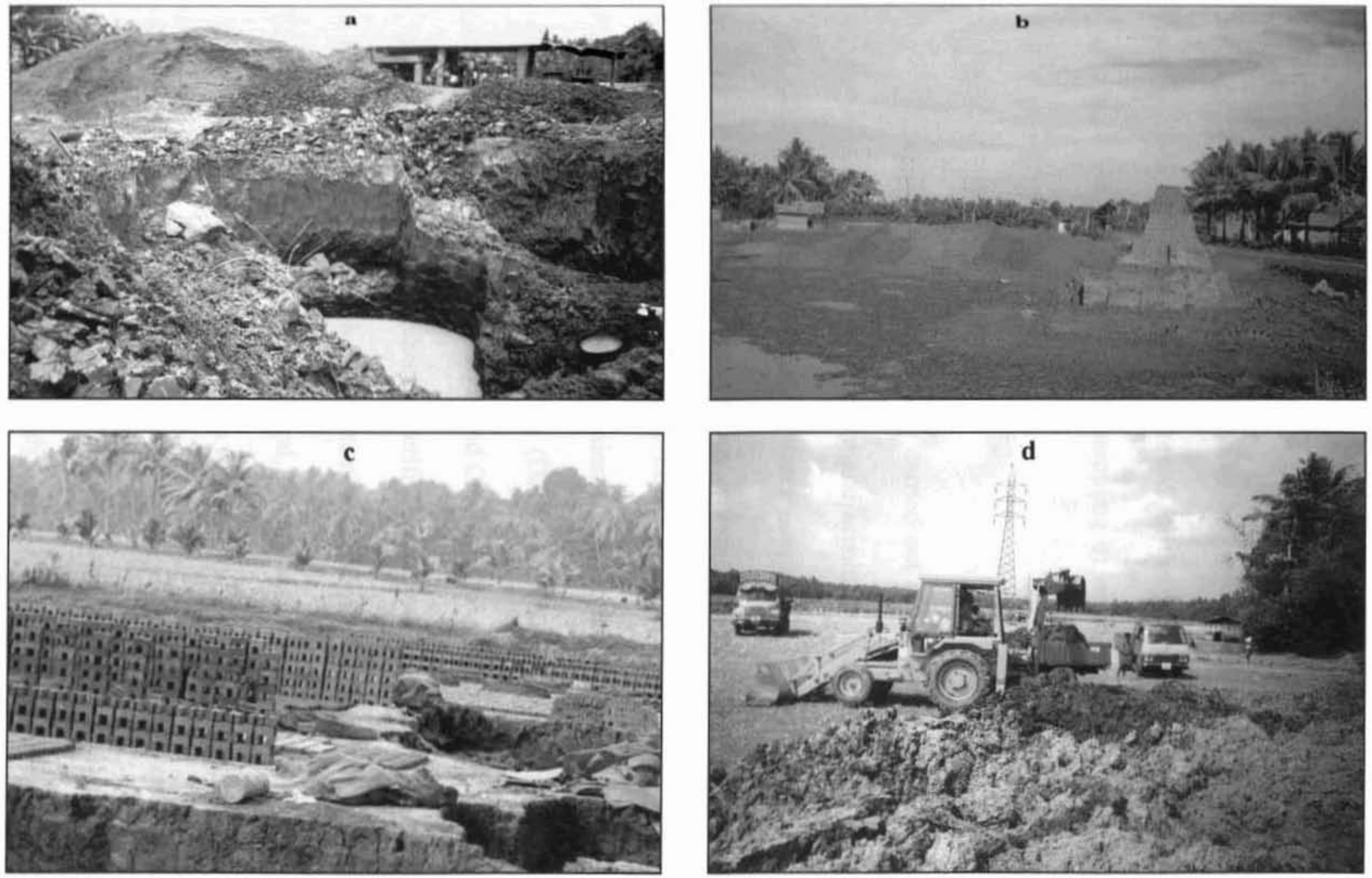


Plate 5: Field photographs showing clay mining from Periyar (a & b) and Chalakudy (c & d) river basins

CHAPTER 2

MATERIALS AND METHODS

2.1. INTRODUCTION

This study covers a spectrum of subject components such as texture, mineralogy and geochemistry of sediments, and hydrochemistry of Periyar and Chalakudy rivers. Various procedures adopted for the present study can broadly be grouped into three: a) field survey and sampling b) laboratory investigation and c) computation and compilation of results.

2.2. FIELD WORK AND SAMPLING

A detailed fieldwork has been carried out in the Periyar and Chalakudy river basins for the collection of primary and secondary data (from the field and various offices) as well as sediment and water samples for laboratory investigation. Secondary information was collected from various State and Central Government Departments like Kerala State Land Use Board (KSLUB), Central Ground Water Board (CGWB), Central Water Commission (CWC), State Planning Board (SPB), Department of Economics and Statistics (DES), Agricultural Directorate and also from various local bodies in the Periyar and Chalakudy river basins. This information is updated using necessary field checks / verifications as and when required. A total of 56 sediment samples were collected systematically from the Periyar (34) and the Chalakudy (22) rivers for detailed textural, mineralogical and geochemical studies (Fig. 2.1). A stainless steel van Veen Grab was used to collect bottom sediments from the two river basins. All samples were carefully transferred to neatly labeled polythene bags and preserved for further analysis. Additionally, a total of 19 water samples were also collected from the study area (11 in Periyar and 8 in Chalakudy river) during monsoon (in the month of July) and non - monsoon (February) periods

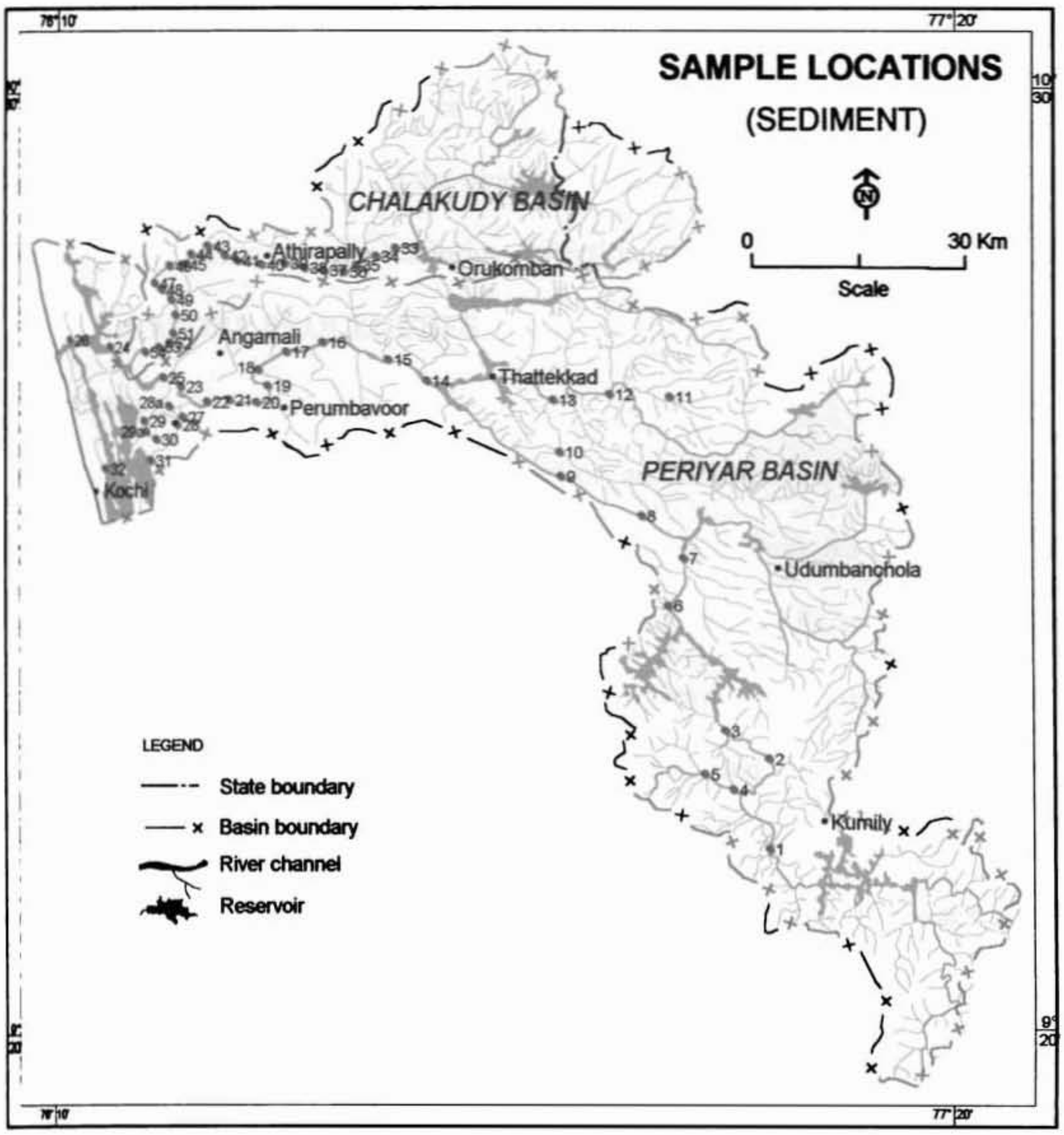


Fig. 2.1 Sediment sampling locations in the Periyar and Chalakudy rivers

for hydrochemical analyses (Fig. 2.2). The water samples (2 liters) were collected from each location using a well cleaned plastic bucket. The pH and temperature of water samples were noted in the field itself. In addition to these, separate samples were collected for Dissolved Oxygen (DO) and Bio-chemical Oxygen Demand (BOD) estimations. All the samples were brought to laboratory and analysed for various parameters for achieving the objectives of the study. Utmost care was taken for not to contaminate the samples during collection and handling.

2.3 LABORATORY PROCEDURES

2.3.1. Texture

The sediment samples were dried on an air oven at 55±2^{0}C to constant weight. Representative portions of the samples were sieved for 15 minutes on mechanical Ro-Tap sieve shaker using a standard set of ASTM Endicott sieves at half phi (1/2 ϕ) intervals. The fractions left over in each sieves were carefully transferred, weighed and cumulative weight percentages were calculated. The cumulative weight percentages of the above analyses were plotted against the respective grain sizes in ϕ units on a probability chart. The cumulative frequency curve is drawn for each sample and values of 1, 5, 16, 25, 50, 75, 84 and 95 percentiles were recorded. The statistical parameters such as phi mean, median, standard deviation, skewness and kurtosis were calculated following Folk and Ward (1957):

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

$$\text{Median} = \phi 50$$

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

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

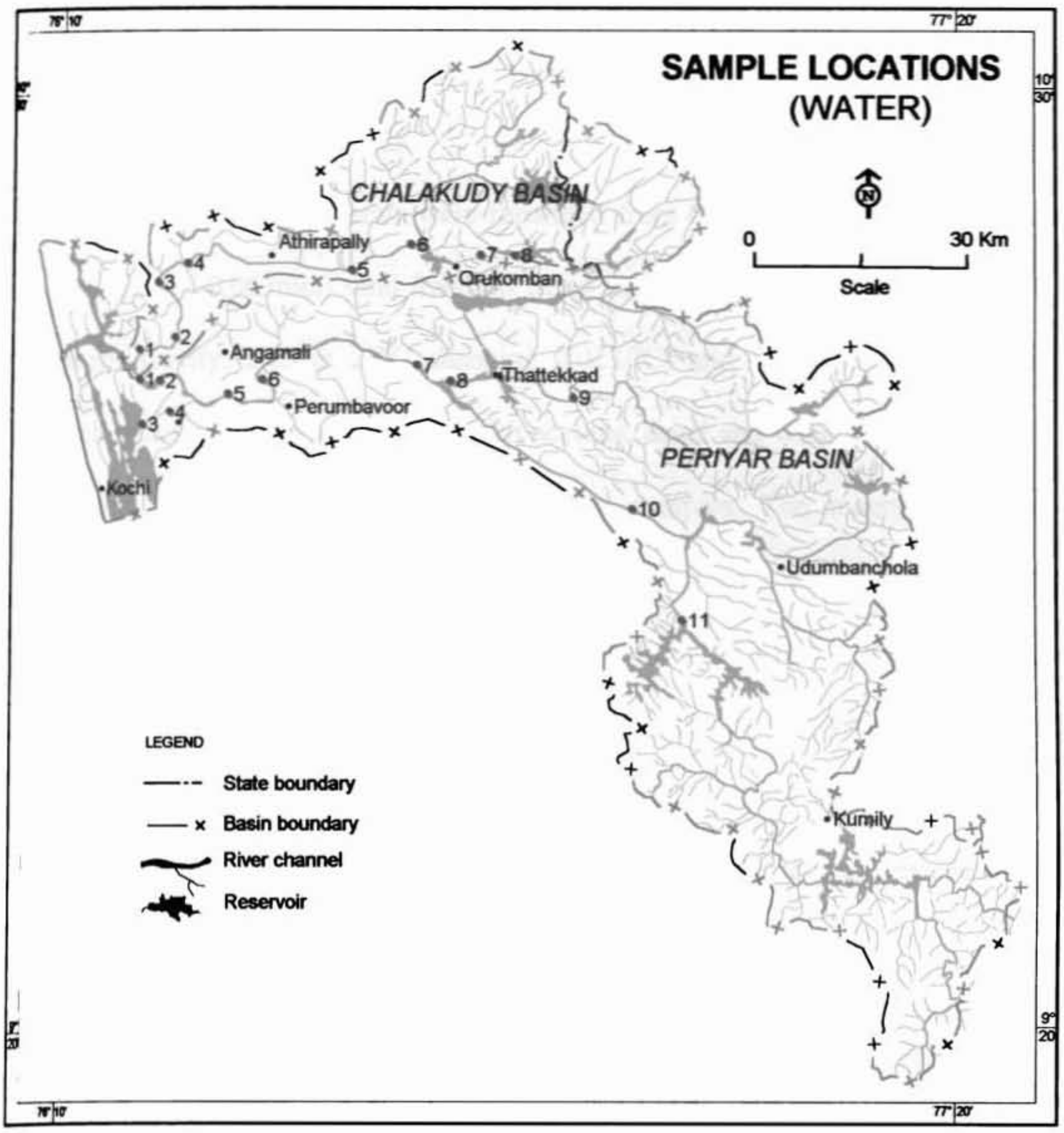


Fig. 2.2 Water sampling locations in the Periyar and Chalakudy rivers

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

The grain size classes like pebbles, granules, sand (various size grades) and mud were separated following the size limits of Wentworth and studied for their differential segregation along the profile of the Periyar and Chalakudy river systems.

2.3.2 Heavy and Light minerals

Heavy and light minerals were separated from coarser (1mm – 0.25mm) and finer (0.25mm – 0.063mm) sand fractions using the heavy liquid, bromoform ($CHBr_3$ - specific gravity: 2.85 at 20^{0}C changing 0.023/^{0}C) and a separating funnel. The minerals thus separated were washed with acetone, dried and weighed to find out the total heavy and light mineral contents in the samples. The magnetic fractions (magnetite) in the heavy mineral suite were separated using a hand magnet. The heavy minerals were then boiled for a few minutes with dilute HCl and a tinge of stannous chloride crystals to remove Fe / Mn coating over the detrital heavy grains. A total of 300 - 400 grains from each residue were mounted on glass slides using canada balsam. The individual minerals in each slide were studied under a Leitz petrologic microscope.

2.3.3 Clay minerals

The mineralogy of clay fraction was identified by X-ray diffraction technique. The organic matter in the samples was eliminated by treating with H_2O_2. Oriented smear slides as suggested by Gibbs (1967) were prepared for clay fraction (<2 μm) and run on Philips X – ray diffractometer using Kα radiation and Ni filter. The slides were then glycolated and repeated the experiment. The chart drive 1cu/min, goniometer 1°/min and intensity 2 x 10^2 were maintained.

(1) Kaolinite will give peaks at the same spacing as that of the mineral chlorite and hence their identification is really a difficult task. However, Biscaye (1964)

pointed out that kaolinite in addition to two strong peaks at 7.16A° and 3.58A° gives always very small peak at 2.38A°.

(2) Gibbsite gives distinct peak at 4.85A°.

(3) Montmorillonite is identified by its (001) peak at 14A° which expands to 17A° on glycolation.

2.3.4 Geochemistry

An amount of 0.5g of very finely powdered bulk sediments as well as the mud fractions were digested with perchloric acid and hydrofluoric acid in 1:3 proportion in a clean dry Teflon crucible and heated on a sand bath till no fumes come out of it. An amount of 5 ml of double distilled water was added to it and filtered the solution until the digestion of the sample is completed. Made this upto a known volume (50 ml) and was then used for geochemical analysis following various techniques (Table 2.1).

Table 2.1 Various analytical methods / instrument / make / model employed in the geochemical study

Sl. No.	Parameters	Method	Instrument Make/Model	Reference
1	Sediment organic carbon	Titrimetric	-	El Wakeel and Riley(1957)
2	Phosphorus	Colorimetric	SHIMADSU 15A Double Beam Spectrophotometer	Murphy and Riley(1962)
3	Sodium and Potassium	Flame photometric	Systronics FPM Digital Model	APHA(1985)
4	Calcium	Titrimetric	-	APHA(1985)
5	Iron	Colorimetric	SHIMADSU 15A Double Beam Spectrophotometer	APHA(1985)
6	Manganese and trace elements	Atomic Absorption Spectrophotometric	Perkin Elmer Model 2380	Rantala and Loring(1975)

A brief description of the methods employed for geochemical estimations is given below:

Organic Carbon

The organic carbon in the bulk sediments and mud fraction were determined by wet oxidation method following El Wakeel and Riley (1957). The principle is that the organic matter in the sample is oxidized by a known quantity of chromic acid and the amount of chromic acid consumed is estimated by back titration against ferrous ammonium sulphate to obtain percentage of organic carbon.

Phosphorus

Phosphorous as $PO_4 - P$ was determinant based on the reaction of the ions with an acidified molybdate reagent to yield a phosphomolybdate complex (Murphy and Riley, 1962). It was then reduced to a highly blue coloured compound. The concentration of the $PO_4 - P$ in the solution will be proportional to the intensity of the colour developed. The maximum absorption at 880 nm, shows the blue colour. The amount of $PO_4 - P$ was determined by comparing with a set of standard samples.

Sodium and Potassium

Sodium and Potassium were determined using Flame Photometer, based on the procedure described in APHA (1985). In order to avoid the inter element and anionic effects, Fe and Al were removed from solution by precipitating with ammonia solution. It was then aspirated for the estimation of Na and K. Calibration curve for Na and K was drawn separately and concentration of the metals was estimated from the calibration curves.

Iron (Fe)

Fe was determined colorimetrically following APHA (1985). The experiment was based on the formation of pink-red coloured complex between Fe^{2+}

and orthophenanthrolin. A 10% hydroxylammonium hydrochloride was used to reduce Fe at a pH 4.8 to 5. The intensity of the colour was measured at 510 nm by spectrophotometer (Model SHIMADZU 15A). The amount of total Fe was estimated from standard calibrated values.

Manganese and Tracemetals

Manganese and tracemetals (Ni, Zn Pb and Cr) were analysed using Atomic Absorption Spectrophotometer (AAS; Model PE 2380) following the method of Rantala and Loring (1975).

Precision and Accuracy

The precision and accuracy of heavy metal estimation were checked against the USGS standard rock sample W_1 (Table 2.2). All the metal values were in agreement with the published values of Rantala and Loring (1975) and Flanagan (1976).

Table 2.2 Heavy metal concentration of USGS standard rock W_1 (Fe in percentage; others in ppm)

	Fe	Mn	Zn	Cr	Ni	Pb
W_1						
Observed	7.85	135	88	119	73	34.28
	(0.02)	(0.002)	(1.3)	(1.2)	(0.82)	(0.32)
(1) Published	7.76	132	86	114	76	31.20
(2) Published	7.96	127	86	116	66	34

Parenthesis – standard deviation of triplicate analyses (1) Flanagan (2) Rantala and Loring

2.3.5. Water quality analysis

The water samples were analysed for various physico-chemical parameters following standard methods (APHA, 1985 and Grasshoff, 1976). Nutrients and Fe were determined after filtering the samples through 0.45 μm millipore membrane filter paper. All colorimetric determinations were made using a double beam spectrophotometer (SHIMADZU UV 160A). The various methods used for the analyses are furnished in the Table 2.3.

2.4. COMPUTATION AND COMPILATION

The voluminous data generated in this study has been processed using various statistical procedures / computational techniques. The results obtained were evaluated in the light of available published research works in India and abroad for drawing valuable conclusions.

Table 2.3 Details of hydrochemical parameters estimated in the water samples

Sl No.	Parameters	Methodology
[illegible]	pH	Measured using a portable pH meter, ELICO Water Quality Analyser PE 136, with an accuracy of 0.001 pH units.
[illegible]	Conductivity	Measured using a portable pH meter, ELICO Water Quality Analyser PE 136, with an accuracy of 0.1μs units.
[illegible]	Dissolved Oxygen	Winkler method with the azide modification.
4	BOD	Unseeded dilution technique and incubation at 20±1^{0}C for five days.
[illegible]	Alkalinity	Titration with standard acid using bromocresol green indicator.
[illegible]	Chloride	Argentometric titration with chromate ions as indicator.
[illegible]	Sulphate	Precipitation with barium chloride and measured the turbidity photometrically at 420 nm.
[illegible]	Nitrite-Nitrogen	Complexation with 4-amino benzene sulphanilamide and N-(1-naphthyl)-ethylene diamine dihydrochloride and measured the intensity of colour using spectrometer at 543 nm.
[illegible]	Nitrate-Nitrogen	Reduced quantitatively as nitrite in a cadmium column and estimated as in nitrite-nitrogen.
[illegible]	Ammonia-Nitrogen	Measured by the phenate method. The blue colour of indiphenol was measured photometrically at 630 nm.
	Total Nitrogen	Oxidised by autoclaving to inorganic nitrate forms, which further reduced to nitrite by passing through cadmium column and estimated as nitrite-nitrogen.
[illegible]	Inorganic Phosphorous	Converted to molybdenum blue by ammonium molybdate and ascorbic acid and the colour were measured photometrically at 882 nm.
	Total phosphorous	Converted all organic forms to inorganic forms by oxidation and estimated as molybdenum blue.
[illegible]	Silicate-Silicon	Converted to molybdosilicate and measured photometrically at 810 nm.
[illegible]	Hardness	EDTA titration using Eriochrome Black T indicator.
[illegible]	Calcium	EDTA titration using ammonium purpurate (Murexide) indicator.
[illegible]	Magnesium	EDTA titration (Total (Ca+Mg), from Hardness – Ca)
[illegible]	Iron	Complexation with 1-10 phenanthroline and the orange red complex was measured colourimetricaly at 510 nm.
[illegible]	TDS	Filtration through 0.45 μm Millipore membrane filter paper and evaporation of water in platinum dish and drying of the residue till constant weight.
	TSS	Drying and weighing of the residue left in 0.45 μm Millipore filter paper.

CHAPTER 3

TEXTURE

3.1 INTRODUCTION

Texture is one of the basic descriptive measures that refer to the relative proportions of various particle size classes (i.e., grain size classes), constituting sediments and sedimentary rocks. The grain size characteristics of sediments are studied for a variety of reasons. Knowledge in grain size is important in the understanding of the mechanisms operative during the transportation and deposition of sediments. Information on grain size classes of fluvial sediments is often used for unraveling the distance of sediment transport in both modern and ancient sedimentary deposits. Furthermore, it is widely accepted that variation in grain size is related to many aspects like channel morphology, source materials, and process of weathering, abrasion and corrosion of grains and sorting processes during transportation and deposition. Grain size also depends on properties like permeability of sedimentary aquifers, which in turn, have major economic and social implications. All these reasons have continued to make grain size analysis as an important tool for sediment related research areas.

3.2 PREVIOUS STUDIES

For the last five decades, granulometric researches witnessed an upboost, which brought out the intricate mechanisms of sediment transportation and deposition. Many studies on the size distribution of clastic sediments have revealed the existence of statistical relationships between the different size parameters such as mean size, sorting (standard deviation), skewness and kurtosis. The relation between mean size and sorting is particularly well established. The studies of Griffiths (1967), Allen (1970), Hakanson and Jansson (1983) and Pettijohn (1984), have revealed that the best-sorted sediments are generally those with mean size in the fine sand grade. The interrelationship between grain size frequency distribution and depositional environments has been used successfully in many earlier studies to identify the depositional agent and also to recognize the operative processes of sedimentation of ancient terrigenous deposits (Quidwai and Casshyap, 1978; Goldberg, 1980; Khan, 1984; Ramanamurthy, 1985; Mahendar and Banerji, 1989; Pandya, 1989; Joseph et al., 1997; Majumdar and Ganapathi, 1998). Several attempts have been made to differentiate various environments from size spectral analysis, because particle distribution is highly sensitive to the environment of deposition (Mason and Folk, 1958; Friedman, 1961; 1967; Griffiths, 1962; Moiola et al., 1974; Stapor and Tanner, 1975; Nordstrom, 1977; Goldberg, 1980; Sly et al., 1982; Seralathan, 1988; Padmalal, 1992; Badarudeen, 1997; Mohan, 2000 and Reji, 2002). The most noticeable distinction of sands in modern environments like beaches, dunes and rivers are depicted by a scatter diagram of moment standard deviation (sorting) *versus* moment skewness. Moment measure is a sensitive environmental discriminator, which incorporates the entire size frequency range population (Friedman, 1967).

In many of the earlier studies the image of grain size spectrum, its properties and the statistical parameters computed from size populations are used for getting insight into the transportation and depositional processes of sediments and sedimentary rocks (Friedman, 1961; 1967; Visher, 1969; Blatt et al., 1972; Sly et al., 1982; Pettijohn, 1984; Sajan et al., 1992; Seralathan and Padmalal, 1993 and many others). Exhaustive studies on global scale reveal existence of significant correlation between size frequency distribution and depositional processes. Proper selection and combination of statistical parameters can excellently be used to discriminate various environments of deposition of ancient as well as recent sediments (Folk, 1966; Griffiths, 1967; Friedman, 1967; Hails and Hoyt, 1969; Allen, 1970; Goldenberg, 1980; Pettijohn, 1984). Furthermore, the particle size distribution can invariably influence the mineralogical (Mishra, 1969; Patro et al., 1989) and chemical (Williams et al., 1978; Forstner and Wittmann, 1983) composition of sediments. The characteristics of grain size distribution of sediments may be related to the source materials, process of weathering, abrasion and corrosion of the grains and sorting processes during transport and deposition.

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

Textural attributes of sediments from the different environments in Indian scenario have been attempted by many researchers like Rajamanickam and Gujar (1985), Samsuddin (1986), Seralathan (1988), Jahan et al. (1990), Padmalal (1992), Badarudeen (1997) and Reji (2002). Rajamanickam (1983) and Rajamanickam and Gujar (1985) have investigated the grain size distribution of surficial sediments of west coast of India. Granulometric attributes of the beach, strand plain and inner shelf sediments of northern Kerala coast have been investigated by Samsuddin (1990). Textural characteristics of the fluviatile and estuarine sediments of the Nethravathy river basin has been studied by Narayana (1991). Studies on textural and sedimentological aspects of central Vembanad estuary were carried out by Padmalal (1992). Seetharamaiah and Swamy (1994) worked out the textural characteristics of inner shelf sediments of Pennar river, east coast of India. Seralathan and Padmalal (1994) carried out detailed textural studies of Muvattupuzha river and Vembanad estuary. Badarudeen (1997) has carried out a detailed study on sedimentology of some selected mangrove ecosystems of Kerala. A detailed study on geochemical and sedimentological aspects of Kayamkulam estuary has been carried out by Reji (2002).

Considering the importance of textural / grain size analysis in sedimentological studies, an attempt has been made here to study the particle size distribution of sediments of Periyar and Chalakudy rivers so as to have a better understanding of the fluvial processes of these river systems.

3.3 RESULTS

3.3.1 Grain size characteristics

River sediments are composed of a wide spectrum of particle sizes ranging from boulders to clay particles. Particles of coarser entities such as boulders and cobbles are confined mainly to the upland with high gradient physiographic characteristics. In river environments, there will be a progressive decrease in grain size downstream. Information on the relative proportions of grain size classes often is used as an efficient tool to unravel the energy conditions of the depositional environment.

The sediment samples of the Periyar and Chalakudy rivers exhibit a wide spectrum of particle sizes, ranging from pebbles to mud. The cobbles and boulders are excluded from the present study because of the difficulty in measuring the size of these larger particles. Tables 3.1 and 3.2 summarize the percentage content of various grain size classes of the Periyar and Chalakudy rivers. Figs. 3.1 and 3.2 depict the variation of grain size classes along the profiles of these rivers. The ranges of gravel (pebble + granule), sand and mud are 1.14% - 73.66% (av.15.92%), 25.06% - 98.39% (av. 82.17%) and 0.11% - 10.71% (av. 1.9%) in the Periyar river and 0.59% - 40.4% (av.13.6%), 58.71% - 97.53% (av. 84.78%) and 0.53% - 5.06% (av. 1.71%) in the Chalakudy river. Of the various size classes, pebbles and other coarser particles dominate in the river channel due to high gradient physiographic features. Coarser particles register high values in the river stretch between 100 and 132 km upstream of Periyar (50.23 %) and 60 km upstream of Chalakudy river (Figs. 3.1 and 3.2). These areas are with comparatively higher channel gradients and hard rock exposures within the river channel. Of the grain

Table 3.1 Percentage of various size grades in the sediments of Periyar river

Sample No.	PE (1)	GRAN (2)	GRAV (1+2)	VCS (3)	CS (4)	MS (5)	FS (6)	VFS (7)	SAND (3+4+5+6+7)	MUD (8)
1	5.49	12.07	17.56	35.02	35.14	9.72	1.67	0.11	81.66	0.79
2	4.00	3.50	7.50	2.00	37.00	35.00	10.50	2.00	86.50	6.00
3	7.09	5.97	1306	22.95	44.05	13.71	2.68	0.23	83.62	3.32
4	5.20	17.34	22.54	26.58	31.19	16.38	2.59	0.25	76.99	0.47
5	8.20	10.13	18.33	16.57	27.72	27.50	6.54	0.43	78.76	2.92
6	0.48	2.83	3.31	10.08	37.59	39.42	6.60	0.49	94.18	2.51
7	5.10	6.02	11.12	11.58	28.46	32.49	7.54	0.74	80.81	8.08
8	50.23	23.43	73.66	11.28	6.71	5.68	1.80	0.08	25.55	0.81
9	0.30	3.37	3.67	23.27	57.26	15.09	0.55	0.03	96.20	0.14
10	2.12	15.43	17.55	21.23	24.43	19.65	10.90	2.20	78.41	4.04
11	-	1.14	1.14	5.23	29.21	38.92	13.55	1.24	88.15	10.71
12	25.43	16.20	41.63	23.40	18.20	8.30	5.62	1.37	56.89	1.47
13	29.92	9.13	39.05	12.74	18.72	18.17	9.12	1.19	59.94	1.01
14	8.92	15.37	24.29	37.51	24.61	11.31	1.88	0.07	75.39	0.32
15	0.54	8.16	8.70	29.61	27.65	17.99	11.20	4.49	90.94	0.36
16	-	1.31	1.31	9.46	35.66	47.71	5.25	0.31	98.39	0.29
17	1.91	10.16	12.07	21.01	26.08	29.22	9.34	1.53	87.18	0.74
18	6.45	2.83	9.28	25.26	33.80	27.61	3.20	0.48	90.35	0.38
19	1.22	15.74	16.96	30.81	38.11	12.19	1.59	0.18	82.88	0.17
20	1.36	2.41	3.77	22.31	23.12	37.46	8.89	2.84	94.62	1.47
21	1.51	9.74	11.25	27.13	45.81	14.14	1.08	0.22	88.38	0.37
22	0.63	11.36	11.99	34.08	42.55	7.60	1.84	0.69	86.76	1.19
23	4.63	7.678	12.30	40.58	31.73	10.15	2.61	0.22	75.29	2.39
24	4.17	26.86	31.03	36.86	24.01	7.17	1.76	0.04	68.84	0.11
25	0.22	6.13	6.35	10.84	20.70	40.74	18.61	1.44	92.33	1.25
26	-	2.79	2.79	18.82	65.48	6.45	3.09	1.56	95.40	1.81
27	2.73	3.64	6.37	11.49	25.37	46.35	9.23	0.78	93.22	0.38
28	1.52	9.74	11.26	27.15	45.83	14.15	1.08	0.22	88.43	0.33
29	1.94	19.85	21.79	32.79	27.58	11.61	4.00	0.96	76.94	1.23
30	2.95	13.71	16.99	57.80	21.08	2.85	1.21	0.16	83.10	0.23
31	2.83	8.26	11.09	49.77	22.54	3.77	0.94	0.11	77.13	1.78
32	-	-	-	-	4.81	14.4	5.49	0.36	25.06	74.94

PE- Pebble, GRAN- Granule, GRAV- Gravel, VCS- Very coarse sand, CS- Coarse sand
MS- Medium sand, FS- Fine sand, VFS- Very fine sand

Table 3.2 Percentage of various size grades in the sediments of Chalakudy river

Sample No.	PE (1)	GRAN (2)	GRAV (1+2)	VCS (3)	CS (4)	MS (5)	FS (6)	VFS (7)	SAND (3+4+5+6+7)	MUD (8)
33	24.75	15.65	40.40	27.96	17.11	10.88	2.55	0.21	58.71	0.90
34	21.13	9.49	30.62	9.99	11.82	26.63	17.47	1.23	67.14	2.24
35	19.03	12.76	31.79	13.15	12.69	25.28	15.10	1.98	68.20	1.54
36	22.44	6.08	28.52	17.14	16.44	27.81	7.40	1.44	70.23	1.23
37	0.29	1.39	1.68	29.98	40.02	20.58	6.32	0.63	97.53	0.79
38	7.44	17.54	24.98	32.03	20.53	17.23	4.41	0.19	74.39	0.90
39	3.89	1.46	5.35	28.93	31.66	25.44	7.30	0.42	93.75	0.73
40	10.12	5.02	15.14	13.29	24.09	31.95	7.21	0.27	79.81	5.06
41	6.94	3.17	10.11	18.28	32.25	28.19	8.98	0.97	88.67	1.11
42	-	0.59	0.59	9.60	22.83	36.54	22.18	5.33	96.48	2.87
43	0.53	0.74	1.27	2.14	5.30	52.03	31.19	2.46	69.12	2.54
44	-	2.48	2.48	20.16	29.61	32.23	11.36	1.98	95.34	2.16
45	2.14	7.78	9.92	23.66	37.48	21.36	5.52	1.05	89.07	1.68
46	13.38	4.46	17.84	15.23	21.34	28.01	13.31	2.30	79.19	2.92
47	8.98	3.92	12.90	15.20	16.01	22.37	26.75	3.22	83.55	3.48
48	2.27	9.29	11.56	24.09	32.47	21.70	6.58	1.21	86.05	2.40
49	1.58	3.65	5.23	23.51	32.66	32.40	5.40	0.54	94.51	0.53
50	4.46	10.49	14.95	35.53	24.01	19.66	4.74	0.51	84.45	0.61
51	3.69	2.19	5.88	15.57	34.22	36.47	6.22	0.53	93.01	1.15
52	3.03	10.10	13.13	13.29	22.77	37.73	11.51	0.70	86.00	0.88
53	0.41	1.50	1.91	6.11	12.12	60.48	17.19	1.21	97.11	0.99
54	3.66	9.45	13.11	40.92	32.56	10.69	1.55	0.22	85.94	0.90

PE- Pebble, GRAN- Granule, GRAV- Gravel, VCS- Very coarse sand, CS- Coarse sand
MS- Medium sand, FS- Fine sand, VFS- Very fine sand

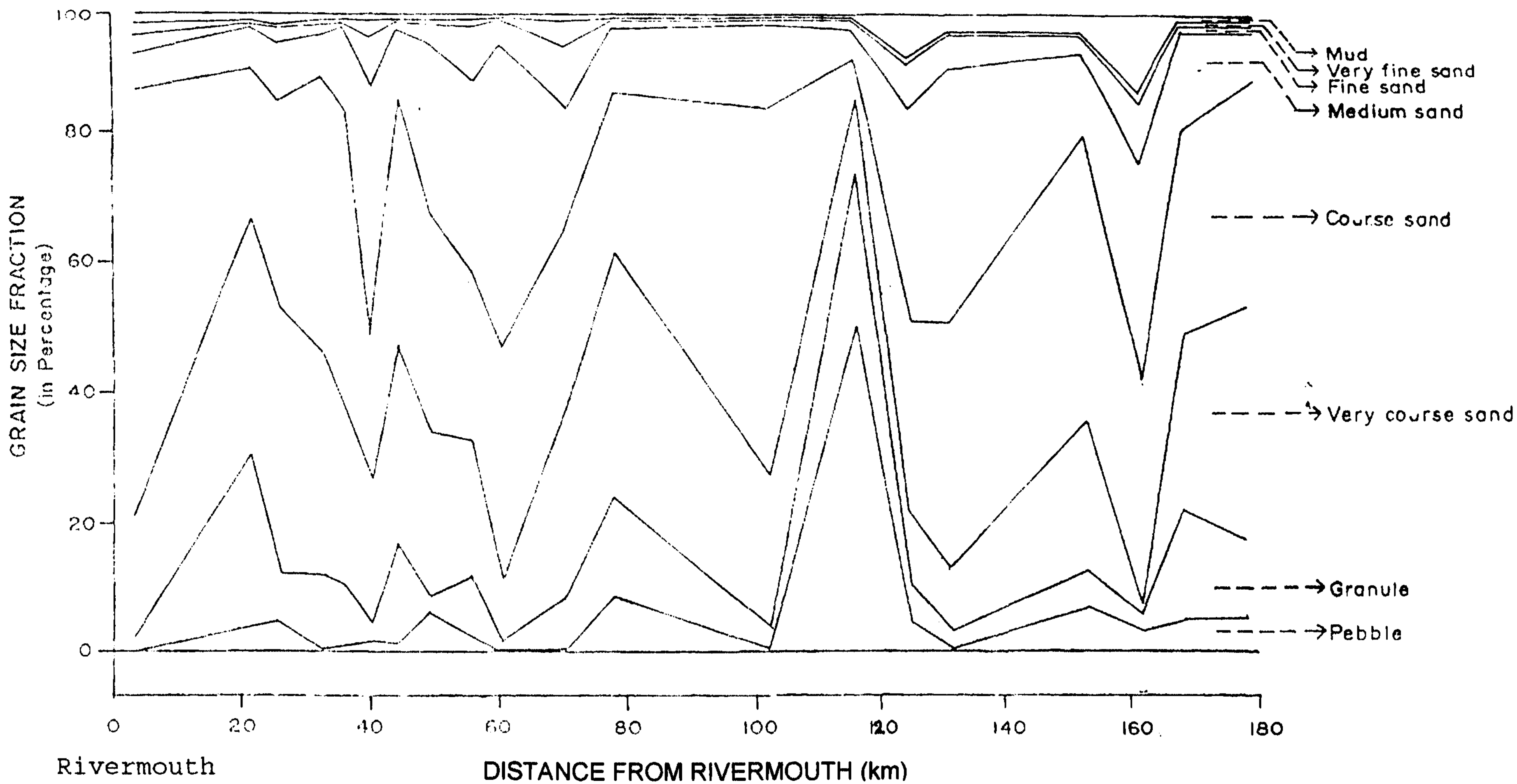


Fig. 3.1 Variation of grainsize fractions along the profile of Periyar river

size classes, sands of very coarse to medium categories dominate a greater part of the river channels, except in areas of high turbulence.

The grain size categories also follow the physiographic attributes of the terrain. This is especially true in the case of Periyar river. The granulometric composition of the sediments collected from the plateau region of the Periyar almost resembles to that of the lowland. Respective averages of gravel, sand and mud contents in the sediments are 11.82%, 83.82% and 4.3% in the plateau region and 13.29%, 84.52% and 1.11% in the lowland (also see Fig. 3.3). The difference in the size composition of the samples, if any, is related to difference in local geology or slope characteristics. The sample collected from Stn. 6, which is located about 132 km upstream of river confluence, exhibits subtle quantities of pebble (0.48%) and granule (2.83%). This sampling station is located downstream of Idukki dam and is now a comparatively low energy zone, which favoured the deposition of coarse and medium sands. From hereon, the content of pebble and granule (gravel) increases which reaches the highest values at Stn. 8 located in the scarp zone coinciding with the high energy condition (gravel = 73.66%, sand = 25.55% and mud =0.81%). Stn. 9, which is located at the base of the scarp zone, experiences comparatively low energy regime and characterized by nominal amount of gravel (3.67%) and high amount of very coarse to medium sands. From Stn. 8 there is a change in physiographic condition as the river enters into the midland and lowland which in turn are characterized by fluctuating energy conditions and varied granulometric compositions.

Unlike Periyar, the Chalakudy river exhibits marked fluctuations in grain size compositions. Here the sampling is done only from the foot hills of the first scarp

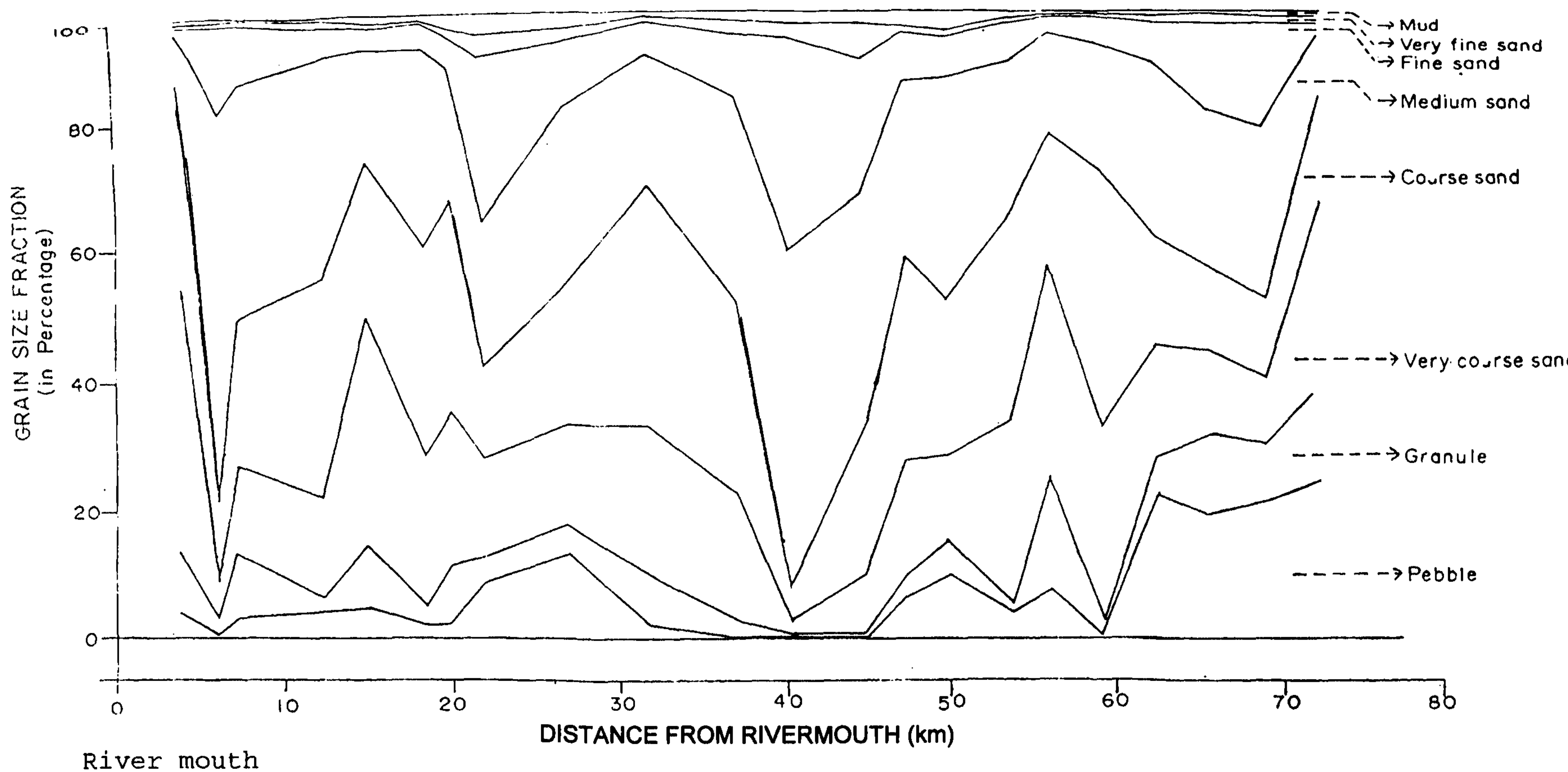


Fig. 3.2 Variation of grain size fractions along the profile of Chalakudy river

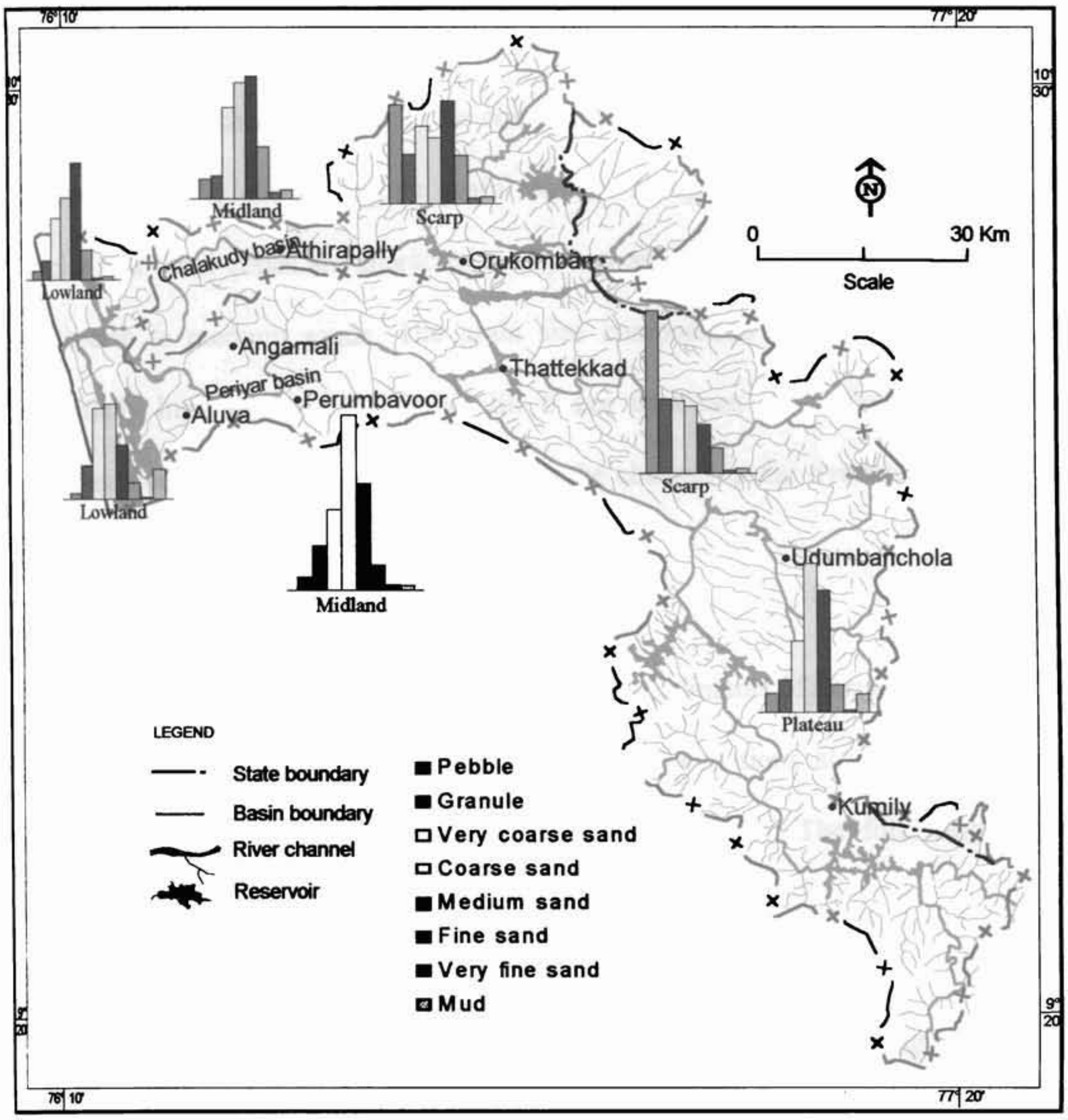


Fig. 3.3 Grain size image (average in %) of the sediments of plateau, scarp, midland and lowland of the study area

onwards (more precisely from 73 km onwards). The grain size composition exhibits the first marked variation at 60 km with low contents of gravel and high contents of very coarse to medium sands. This sampling Stn. is located downstream of the Athirappally waterfalls, where turbulence of water is comparatively lower. Thereon, the river again attains vigour, which is reflected in the comparatively high content of gravel in the grain size spectrum. The energy regime again changes abruptly at 40 km near Pulani. The samples near these zones are characterized by low amount of gravel and high content of very coarse to medium sands. The grain size composition once again changes with substantially high contents of gravel till 6 km upstream from river mouth. Minor variations observed in this zone are related to the changes in the riverbed characteristics or presence of meanders.

3.3.2 Statistical parameters

The statistical parameters computed for the sediments of Periyar and Chalakudy rivers are furnished in Tables 3.3 and 3.4 and their variations along the longitudinal profiles of these rivers are presented in Figs. 3.4 and 3.5. The following sections summarize the major observations drawn from this study.

Phi mean

Mean size expressed in phi (Φ) unit, represents the statistical average of grain size population. In the Periyar river, the phi mean varies from –1.8Φ to 1.26Φ. The sample collected from the Periyar confluence zone of Vembanad lake records high phi mean value of 6.67Φ. In general, the phi mean exhibits a fluctuating trend along the profile of the river system. However, as revealed in the case of granulometric analysis, there are similarities among the samples of each physiographic unit like plateau, scarp, midland

Table 3.3 Statistical parameters of the sediments of Periyar river

Sample No.	Mean (Φ)	Standard Deviation (Φ)	Skewness	Kurtosis
1	-0.07	1.01	-0.08	0.99
2	0.88	1.04	-0.15	1.76
2	0.20	1.10	-0.35	1.36
4	-0.06	1.17	-0.10	0.85
5	0.33	1.40	-0.36	1.00
6	0.92	0.81	0.17	1.55
7	0.65	1.24	-0.32	1.32
8	-1.80	1.61	0.20	1.19
9	0.43	0.67	-0.35	0.99
10	0.46	1.43	-0.07	0.90
11	1.26	0.78	0.08	1.30
12	-0.75	1.83	-0.04	0.95
13	-0.46	2.18	-0.22	0.80
14	-0.38	1.23	0.11	0.94
15	0.58	1.30	0.24	1.00
16	0.97	0.70	-0.17	1.15
17	0.52	1.23	0.10	0.96
18	-0.46	1.61	-0.05	0.82
19	0.01	0.97	-0.13	0.85
20	0.78	1.10	0.13	0.87
21	0.21	0.86	-0.26	0.96
22	0.05	0.84	-0.09	0.91
23	-0.01	0.95	0.04	1.11
24	1.11	1.16	-0.25	1.24
25	0.46	1.25	-0.24	0.92
26	0.40	0.77	0.18	2.14
27	0.91	1.01	-0.30	1.23
28	0.20	0.87	-0.22	1.07
29	-0.10	1.13	0.12	0.93
30	-0.36	0.79	0.29	1.33
31	-0.75	1.10	0.04	1.04
32	6.67	4.17	-0.10	0.76

Table 3.4 Statistical parameters of the sediments of Chalakudy river

Sample No.	Mean (Φ)	Standard Deviation (Φ)	Skewness	Kurtosis
33	-0.63	1.54	0.05	0.70
34	0.23	2.00	-0.36	0.17
35	0.20	2.00	-0.35	0.79
36	0.07	1.79	-0.23	0.69
37	0.56	0.88	0.09	1.02
38	-0.23	1.31	0.07	0.92
39	0.66	1.05	0.05	1.02
40	0.40	1.59	-0.51	1.12
41	0.63	1.39	-0.29	1.48
42	1.47	1.04	0.23	1.05
43	1.80	0.59	0.16	0.96
44	0.83	1.08	-0.03	1.01
45	-0.47	1.11	-0.13	1.08
46	0.40	1.39	-0.36	0.58
47	1.00	1.69	-0.28	0.92
48	0.43	1.18	-0.16	1.02
49	-0.56	0.80	0.04	0.64
50	0.03	1.18	0.23	0.96
51	0.77	1.02	-1.10	1.39
52	0.77	1.29	-0.65	1.15
53	1.47	0.80	-0.30	1.54
54	-0.03	0.93	-0.14	1.01

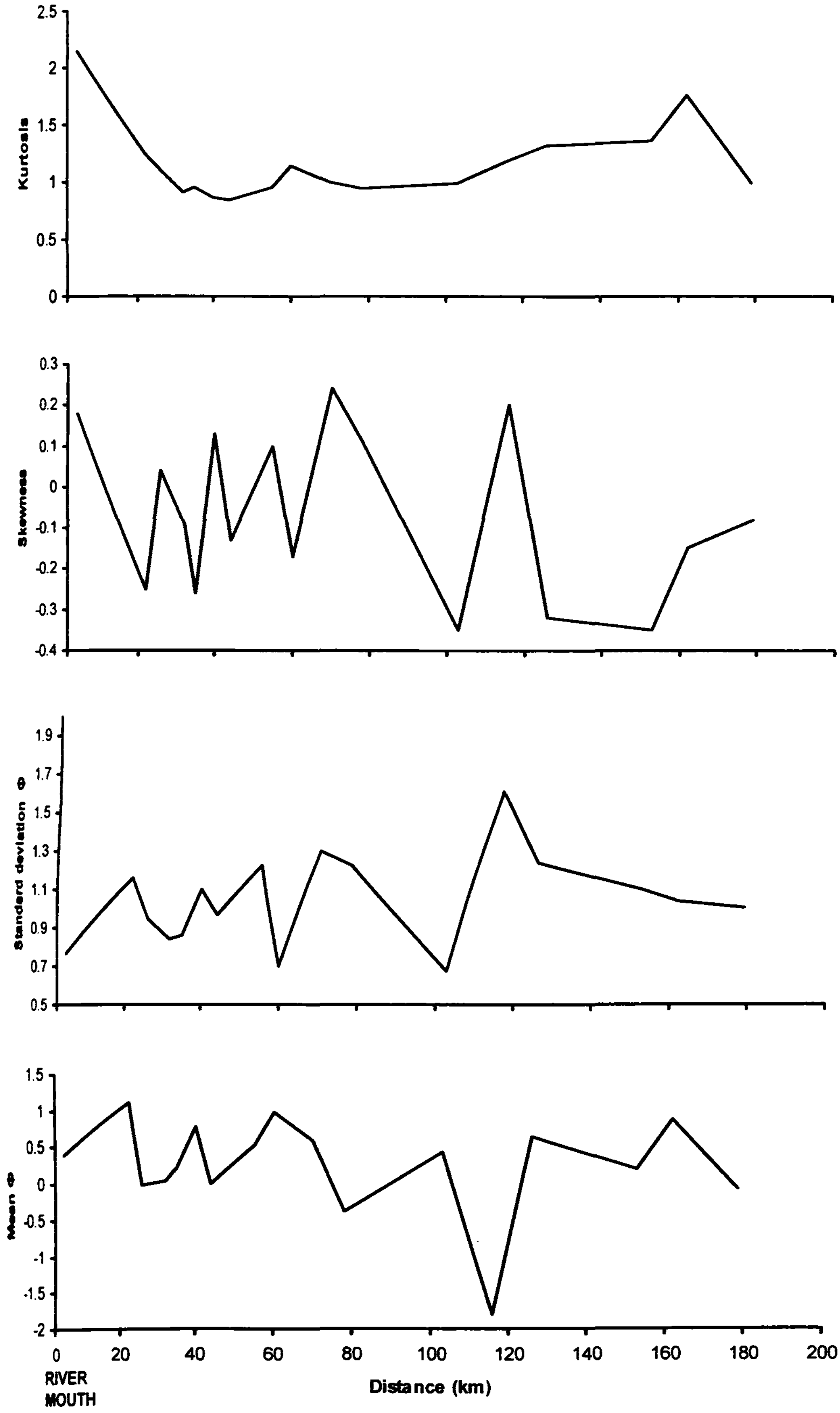


Fig. 3.4 Downstream variation of statistical parameters of the Periyar river

and lowland. The phi mean, in general, registers high negative values (range: -1.80Φ to -0.46; av. -1Φ) in the scarp zone. The respective ranges of phi mean values are -0.76Φ to 1.26Φ (av. 0.51Φ) in the plateau region, -0.46Φ to 0.97Φ (av. 0.25Φ) in the midland and -0.75Φ to 1.11Φ (av. 0.20Φ) in the lowland region.

In the Chalakudy river, the samples were collected only from the midland and lowland. The highland is generally covered with dense forest. The three uppermost samples (Stns. 33, 34 and 35), exhibit low phi mean values (or high mean size in mm) (range: -0.63Φ to 1.8Φ; av. -0.06 Φ). This is due to the high energy conditions prevailing in the area, controlled by the high gradient terrain characteristics. The maximum, minimum and average values of phi mean are – 0.56Φ to 1.8Φ (av. 0.59Φ) in the midlands and -0.03Φ to1.47Φ (av. 0.60Φ) in the lowlands.

Standard deviation

Standard deviation or sediment sorting is the particle spread on either side of average value. It is a measure of particle sorting in a sediment sample. Standard deviation is a useful statistical measure in textural analysis of clastic sediments and gives clues on the efficiency of depositional medium. The sediment sorting becomes good if the spread size is relatively narrow. Investigations show that mean size and sorting correlate well in sand and pebble grades and correlation worsens as grain size increases. It is also claimed that silt and clay show better sorting as grain size increases.

The standard deviation values of the Periyar river varies between 0.67Φ and 2.18ϕ (moderately well sorted to very poorly sorted) with an average of 1.23Φ. Fig. 3.4 shows the spatial variation of standard deviation along the profile of Periyar river. From this figure, it is clear that the sorting worsens in the scarp zone and the standard

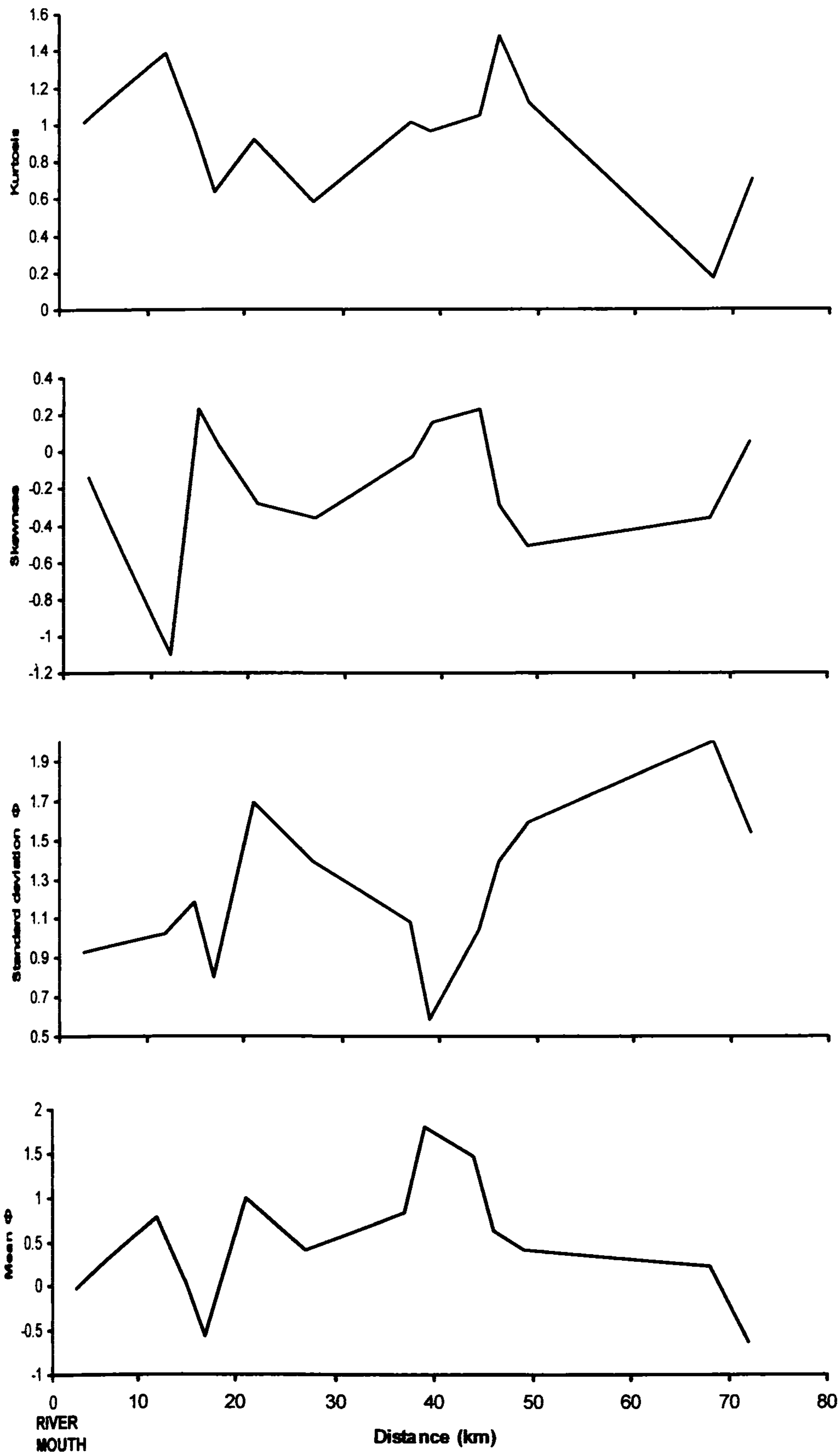


Fig. 3.5 **Downstream variation of statistical parameters of the Chalakudy river**

deviation ranges from 1.61Φ to 2.18Φ (av. 1.87Φ). The respective standard deviation values of plateau, midland and lowland are 0.78Φ to 1.40Φ (av.1.07Φ), 0.7Φ to 1.61Φ (av. 1.09Φ) and 0.77Φ to 4.17Φ (av.1.32Φ).

In the Chalakudy river, the standard deviation varies between 0.59Φ and 2ϕ (moderately well sorted to poorly sorted) with an average of 1.26Φ. Most of the sediment samples exhibit poorly sorted particle dispersal pattern (Fig. 3.5). The standard deviation in the midland and lowland is 0.59Φ to 1.69Φ (av. 1.17Φ) and 0.8Φ to 1.29Φ (av.1.04Φ), respectively.

Skewness

Skewness provides information on the energy level prevailed during the deposition of sediments (Damiani and Thomas, 1974; Sly, 1977; 1978). It is a measure of the asymmetry of the grain size population and gives clues on the type of environment. It is an important parameter in textural analysis and its extreme sensitivity in sub-population mixing is a noteworthy feature. Well-sorted unimodel sediments are usually symmetrical with zero skewness. In a fine skewed sediment population, the distribution of grains will be from coarser to finer and the frequency curve chops at the coarser end and tails at the finer. The reverse condition is the characteristic of coarse skewed sediments. Martin (1965) has suggested that coarse skewness in sediments could be due to two possible reasons: a) addition of materials to the coarser terminal or, b) selective removal of fine particles from a normal sediment population by winnowing action.

In the Periyar river, skewness varies between -0.36 and 0.29 (very coarse skewed to fine skewed). The skewness ranges from 0.36 to 0.17 (av. 0.16) in the plateau, -0.22 to

0.20 (av. -0.020) in the scarp, -0.26 to 0.249 (av. 0.013) in the midland and –0.30 to 0.29 (av. –0.044) in the lowland.

In the Chalakudy river, the skewness ranges from –1.1 to 0.23 (very coarse skewed to fine skewed) with an average of –0.07. The computed skewness values in the highland and midland are –0.51 to 0.23 (av. –0.12) and –1.10 to 0.23 (av. –0.39), respectively.

Kurtosis

Kurtosis is also a sensitive grain size parameter that provides the degree of sorting of the tails relative to the central portion of the size distribution curve. In other words, it is a measure of the contrast between sorting at the central part of the size distribution curve and that of the tails. Figs 3.4 and 3.5 show the spatial variation of the kurtosis in the Periyar and the Chalakudy rivers. In the former, kurtosis varies between 0.76 and 2.14 (platykurtic to very leptokurtic) with an average of 1.1. The kurtosis values in the plateau, scarp, midland and lowland are 0.85 to 1.76 (av. 1.26), 0.80 to 1.19 (av. 0.98), 0.82 to 1.15 (av. 0.94) and 0.76 to 2.14 (av. 1.18), respectively.

In Chalakudy river, the kurtosis ranges from 0.17 to 1.54 (platykurtic to very leptokurtic). The range of values in midland and lowland are 0.58 to 1.48 (av. 0.95) and 0.95 to 1.54 (av. 1.21), respectively.

3.3.3 Bivariate plots

Bivariate plots between various statistical parameters are one of the effective tools to assess the inter-relationships existing among these parameters. Pioneer researchers in sedimentology observed some significant trends when they plotted grain size parameters against each other (Folk and Ward, 1957; Friedman, 1967; Khan, 1984). Fig 3.6 depicts

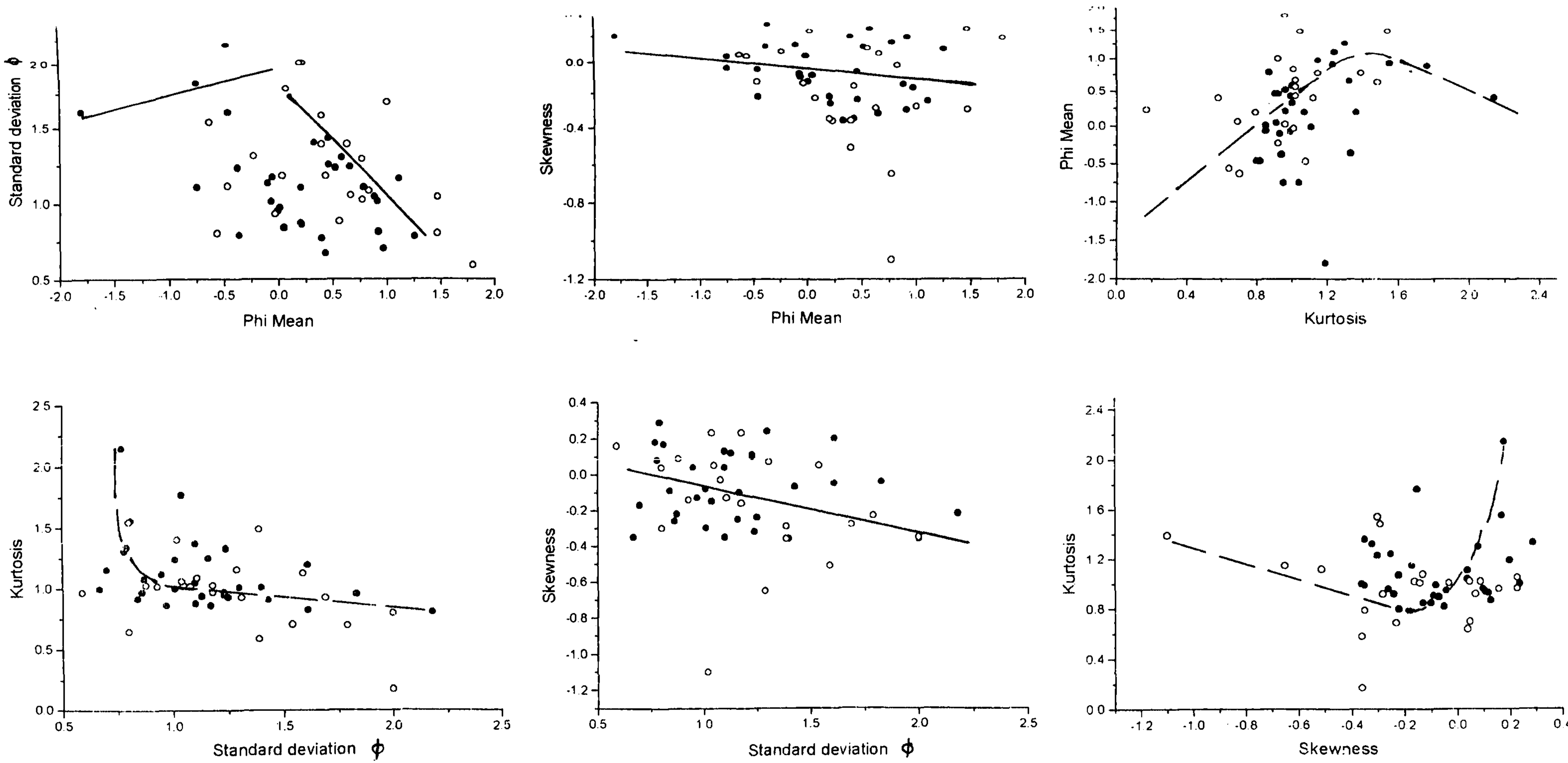


Fig. 3.6 Interrelationship between various statistical parameters in the sediments of Periyar (●) and Chalakudy (○) rivers

the scatter plots of various statistical parameters worked out for Periyar and Chalakudy rivers. The scatter plot of phi mean *vs* standard deviation exhibits a general trend that finer particles (i.e., particles with higher phi mean values) shows improved sorting. The scatter plots disclose wide scattering in the case of Chalakudy river than the Periyar river. The plot of phi mean *vs* skewness shows distinct scatter patterns in Periyar and Chalakudy rivers. In Periyar, the sample points generally fall in the phi mean of very coarse and coarse sand sector and the skewness vary widely between very coarse skewed to fine skewed. On the contrary, in Chalakudy river, the phi mean also vary considerably like the skewness. The bivariate plot between skewness and kurtosis shows wide scattering both in Periyar and the Chalakudy rivers. The difference observed in the scatter plots of the Periyar and Chalakudy rivers is attributed mainly to the difference in the physiographical set up of these rivers.

3.4 DISCUSSION

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

Detailed analyses of granulometry of the sediments of Periyar and Chalakudy rivers reveals that there is a progressive decrease in grain size downstream. Coarser particles like pebbles and granules register comparatively high values in river reaches with higher channel gradients and / or local turbulence. For example, the scarp zone, located between 104 km and 136 km upstream of the river mouth of Periyar records higher proportion of coarser particles like pebbles and granules (>52%) than the finer entities, compared to samples collected from the lowland. As velocity increases in these high gradient scarp zones, more and more grains in the finer entities in the particle spectrum are entrained and will be selectively removed downstream leaving the coarser particles in the scarp zones as lag concentrates. In addition to these major physiographic controls, rock exposures within river channel, meanders, man-made structures like bridges and check dams (Table 1.1) also have a profound effect on the overall dispersal pattern of sediments. Minor fluctuations in the size population if any, may be attributed to these factors, a process also observed elsewhere (Shideler and Flores, 1980). Compared to Periyar river, the Chalakudy river exhibits more fluctuations in the grain size population, presumably due to the effect of natural and man-made obstacles like meanders, check dams and bridges along the river course. The variation of mean size is also in consonance with the granulometric findings. The phimean increases (i.e. decrease in grain size) downstream, consequent to progressive decrease in the energy conditions downstream. The gradual decrease in grain size in the direction of transportation in a river channel is resulted from two important processes namely differential transport (Shideler, 1975; Allen, 1964; Seralathan, 1979) and abrasion (Thiel, 1940). Both these processes operate together and bring about a decrease in the mean size in the Periyar and

Chalakudy rivers. Though there are quite a number of opinions on the effect of transportation and the impact of grain size, the size *vs* distance relationship is not fully understood. However, it is well established that during transport the corners and surfaces of larger particles are rounded and smoothed and that the down current decline in size, is caused by abrasion (Pettijohn, 1984).

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

Standard deviation values significantly decrease downstream, or in other words, the sorting of the sediments improves significantly in the Periyar and Chalakudy rivers. The improvement of sorting is attributed to the differential transport of the sediments. There is a tendency for the sediments to assume normal distribution progressively downstream. Such a tendency arises from the successive lagging behind of the larger particles whose presence imparts comparatively ill-sorted character to the sediments upstream rather than downstream. Inman (1949) made a suggestion that once a sediment attained maximum sorting values any further fall in competency results in the increase of fine particles in the sediment which will then "round the turn" on the curve and sorting of it will worsen. Generally decrease in the standard deviation, without any abrupt change in the values, indicates the absence of considerable amount of very fine particles.

The skewness of sediments is a sensitive indicator of environment of deposition (Friedman, 1961; 1967; Martins, 1965; Hakanson and Janson, 1983; Sreejith et al., 1998). Perfectly sorted symmetrical and unimodal sediments have a skewness value of zero. The positive skewness indicates a relative increase of the coarse admixture in the sediments over the fine while in the case of negative skewness the converse is true. It has also been said by Cadigan (1961), "by convention poorer sorting in the coarser half is measured as negative skewness". Folk and Ward (1957) made a generalization that the pure modal fractions are in themselves nearly symmetrical, but the mixing of the modes produces negative skewness in the sediment due to two possible causes: (i) addition of material to the coarser terminal, or (ii) subtraction of fines from the normal population.

Figs. 3.4 and 3.5 indicates that there is an overall decrease in the skewness values in the river channel and a sharp rise in skewness values starting from the head of the estuary to the river confluence. Eventhough, there are much fluctuations of skewness upstream mainly ranging from very positive to nearly symmetrical values, they are not significant in the lower reaches of the fresh water river channel. The high positive skewness values upstream (Figs. 3.4 and 3.5) indicate that the sediments are predominantly of coarse mode. The relationship between phimean size and skewness in the sediments of Periyar and Chalakudy rivers (Fig. 3.6) further substantiates the above discussion. It is evident that as the phi mean size increases, the skewness value decreases from very positive to near symmetry and further changes to negative skewness.

Folk and Ward (1957) and Cadigan (1961) while classifying kurtosis, have stated that if the central part of the grain size distribution is relatively better sorted than that on the average in the tails, the distribution is called leptokurtic, while the converse is true in the case of platykurtic. When the sorting of sediments in the central part of the size distribution curve is nearly same as that of the average in the tails, it is mesokurtic. In the light of the above definitions, it can be stated that the lack of significant variation in the kurtosis over a distance of 100 km of the Periyar and 40 km of the Chalakudy river is due to the uniformly good interval sorting in majority of the sands analysed. Figs. 3.4 and 3.5 shows that moderately sorted river channel sands are predominantly mesokurtic in nature. The predominant mesokurtosis of the river channel sediments indicates that there is no significant variation in sort of the central part relative to the tails of the size distribution curves. Though there are significant variations in the values of skewness (-0.36 to 0.29 in Periyar and -0.65 to 0.23 in Chalakudy), variations in kurtosis values are comparatively less (0.76 to 2.14 in Periyar and 0.17 to 1.54 in Chalakudy). This signifies that, although, slight addition of fine mode to the predominant coarse sand mode influences the variations in skew of the river sands, it does not alter the internal sorting or kurtosis of the sediments to any great extent.

3.5 CLASSIFICATION OF SEDIMENTS

The sediment samples of the present study are composed essentially of gravel, sand and mud. Hence the textural classification put forth by Folk et al. (1970) for gravel bearing sediments has been applied for deciphering the sediments (Tables 3.5 and 3.6).

Table 3.5 Gravel, sand and mud contents in the sediments of Periyar river

Sample No.	Gravel %	Sand %	Mud %	Sediment type (Folk et.al.1970)
1	17.56	81.65	0.79	Gravelley sand
2	6.17	88.82	5.01	Gravelley sand
2	13.06	83.62	3.32	Gravelley sand
4	22.54	76.99	0.47	Gravelley sand
5	18.33	78.75	2.92	Gravelley sand
6	3.31	94.18	2.51	Slightly gravelley sand
7	11.12	80.80	8.08	Gravelley sand
8	73.66	25.53	0.81	Sandy gravel
9	3.67	96.19	0.14	Slightly gravelley sand
10	17.55	78.41	4.04	Gravelley sand
11	1.14	88.15	10.71	Slightly gravelley sand
12	41.63	56.90	1.47	Sandy gravel
13	39.05	59.94	1.01	Sandy gravel
14	24.29	75.39	0.32	Gravelley sand
15	8.70	90.94	0.36	Gravelley sand
16	1.31	98.40	0.29	Slightly gravelley sand
17	12.07	87.19	0.74	Gravelley sand
18	9.28	90.34	0.38	Gravelley sand
19	16.96	82.87	0.17	Gravelley sand
20	3.77	94.62	1.47	Slightly gravelley sand
21	11.25	88.38	0.37	Gravelley sand
22	12.00	86.76	1.19	Gravelley sand
23	12.30	85.29	2.39	Gravelley sand
24	31.03	68.84	0.11	Sandy gravel
25	6.35	92.34	1.25	Gravelley sand
26	2.80	97.10	0.11	Gravelley sand
27	6.37	93.22	0.38	Gravelley sand
28	0.33	76.37	23.3	Slightly gravelley sand
29	21.79	76.95	1.26	Gravelley sand
30	16.66	83.11	0.23	Gravelley sand
31	41.09	58.13	0.78	Sandy gravel
32	0.00	25.06	74.94	Sandy mud

Table 3.6 Gravel, sand and mud contents in the sediments of Chalakudy river

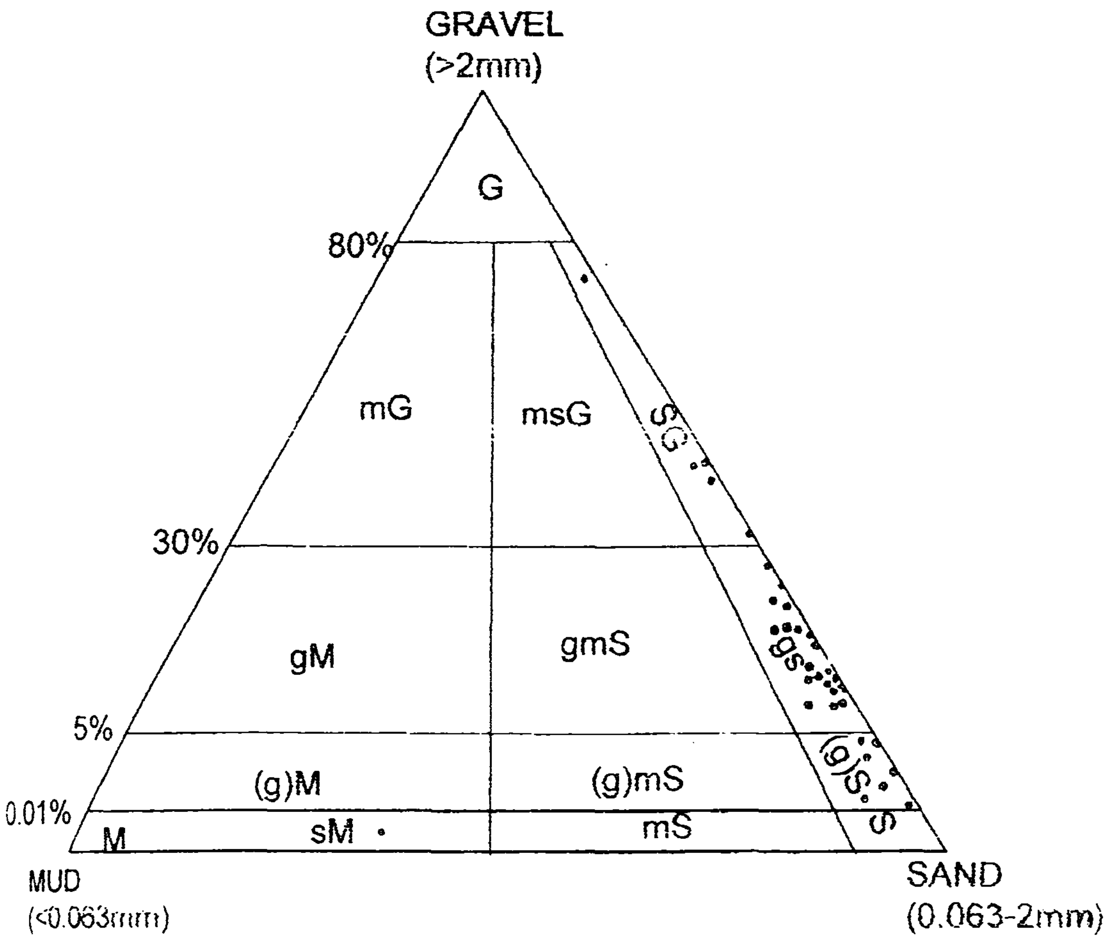
Sample No.	Gravel %	Sand %	Mud %	Sediment type (Folk et.al.1970)
33	40.39	58.71	0.90	Sandy gravel
34	30.62	67.14	2.24	Sandy gravel
35	31.32	68.17	1.54	Sandy gravel
36	28.52	70.23	1.23	Gravelley sand
37	1.68	97.53	0.79	Slightly gravelley sand
38	24.77	74.34	0.90	Gravelley sand
39	5.35	93.74	0.73	Gravelley sand
40	15.14	79.80	5.06	Gravelley sand
41	10.12	88.67	1.11	Gravelley sand
42	0.59	96.48	2.87	Slightly gravelley sand
43	1.27	96.12	2.54	Slightly gravelley sand
44	2.48	95.33	2.16	Slightly gravelley sand
45	9.76	88.63	1.68	Gravelley sand
46	17.83	79.19	2.92	Gravelley sand
47	12.90	83.56	3.48	Gravelley sand
48	11.57	86.04	2.40	Gravelley sand
49	5.23	94.51	0.53	Gravelley sand
50	14.95	84.45	0.61	Gravelley sand
51	5.88	93.01	1.15	Gravelley sand
52	13.13	86.01	0.88	Gravelley sand
53	1.91	97.10	0.99	Slightly gravelley sand
54	13.11	85.94	0.90	Gravelley sand

Figs. 3.7 and 3.8 depict the distribution of ternary plots representing the sediment samples of the Periyar and Chalakudy rivers.

In Periyar river, about 65% of the samples fall in the gravelly sand, 19% in the slightly gravelly sand and 16% in the sandy gravel sediment categories. The former two categories are the samples either representing the plateau region or the midland region. The similarity in the textural classes of these two physiographic zones is one of the most striking features of the Periyar river that distinguishes it from the other rivers of Kerala. On the other hand, the sandy gravel sediments are confined to the high gradient (scarp) zones of the Periyar river. Like the case of Periyar, the Chalakudy river also recorded similar types of sediment suites such as sandy gravel (14%), gravelly sand (64%) and slightly gravelly sand (22%). Of these textural types, the former is confined to upstream of the Athirappally water falls (Stns. 33 and 34). The latter two categories represent the remaining part of the midland and lowland areas.

3.6 CM PATTERN

The CM pattern of the Periyar and Chalakudy rivers are depicted in Figs. 3.9 and 3.10 and values of C and M (in microns) are presented in Table 3.7. Most of the sediments of the Periyar and Chalakudy rivers are having above 5000 microns of C, indicating the coarsest material which are transported by rolling and are deposited upstream reaches. The rolling mode of transportation is the major process of sediment movement in the pebble rich tributary channels. The high gradient terrain with high perennial flows is capable of enhancing the competency of the river. Particles with 3500 and 5000 microns of C are transported mainly by rolling and suspension modes. The particles ranging from 1400 to 4000 microns of C will be moved predominantly by suspension and partly by rolling.



G- Gravel
msG- Muddy sandy gravel
gS- Gravelly sand
gM- Gravelly mud
(g)M- Slightly gravelly mud
M- Mud,

sG- Sandy gravel
mG- Muddy gravel
gmS- Gravelly muddy sand
(g)mS- Slightly gravelley muddy sand
S- Sand
G- Gravel

Fig. 3.7 Ternary diagram illustrating the nature of sediments in Periyar river

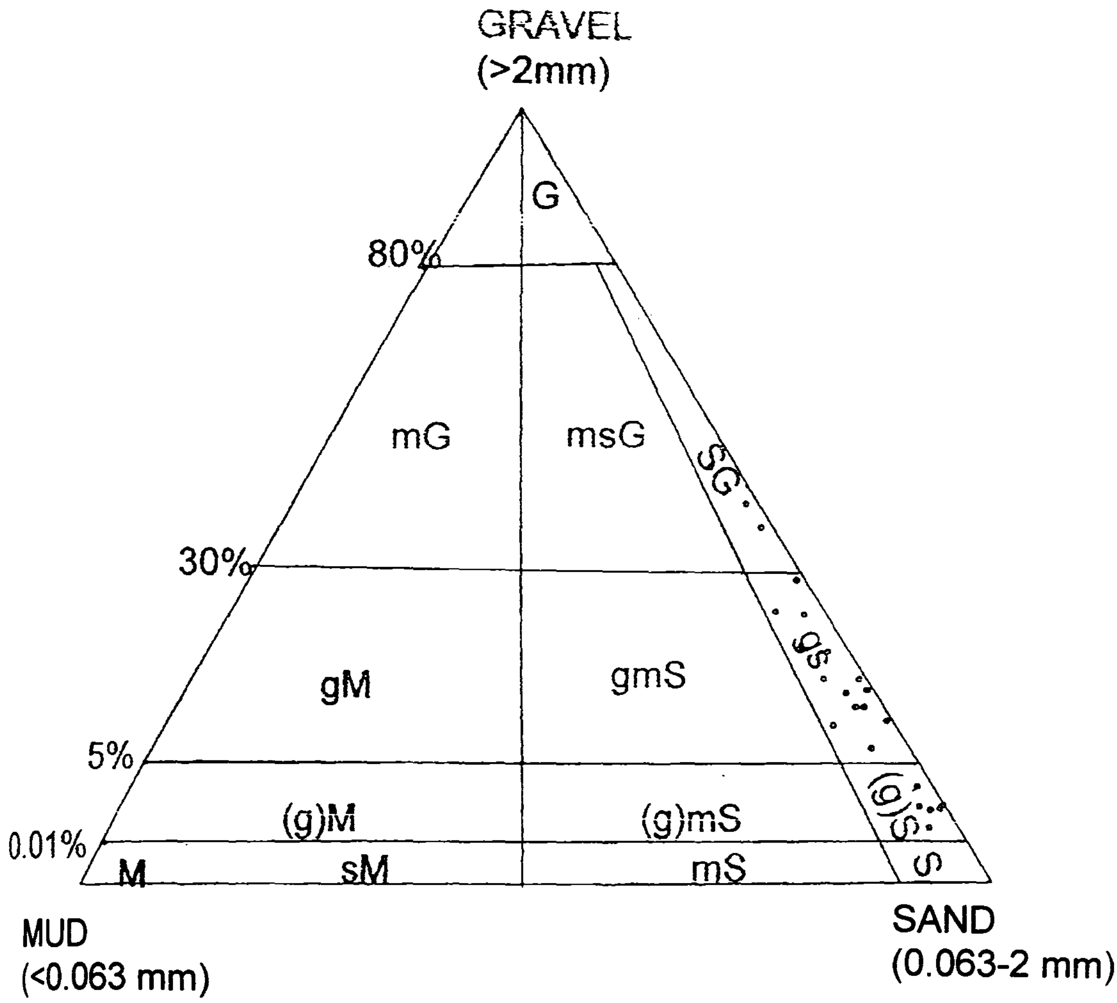


Fig. 3.8 Ternary diagram illustrating the nature of sediments in Chalakudy river (Refer Fig. 3.7 for facies terminologies)

Table 3.7 C and M values of Periyar and Chalakudy river sediments

Periyar sediments			Chalakudy sediments		
Sample No.	C	M	Sample No.	C	M
1	7460	1040	33	10500	1650
2	8600	520	34	14900	570
3	16500	770	35	26000	4600
4	6300	980	36	13000	610
5	11310	620	37	2850	660
6	3360	500	38	8000	3100
7	9800	540	39	7000	6620
8	32000	4000	40	9200	500
9	3030	660	41	9200	580
10	4760	660	42	1900	430
11	2140	440	43	3500	310
12	25990	1570	44	2850	540
13	42250	1070	45	5600	620
14	8880	1410	46	21500	540
15	3610	780	47	15000	430
16	2000	480	48	5700	660
17	4920	650	49	4600	620
18	20390	1320	50	9800	1500
19	4150	940	51	7500	520
20	4590	500	52	7500	470
21	4600	790	53	3050	330
22	3630	930	54	8000	1500
23	6730	1070			
24	3250	410			
25	6500	620			
26	2800	760			
27	6960	470			
28	4300	800			
29	4600	1100			
30	200	1520			
31	9850	1740			
32	2850	1350			

C (one percentile) and M (median) are expressed in microns.

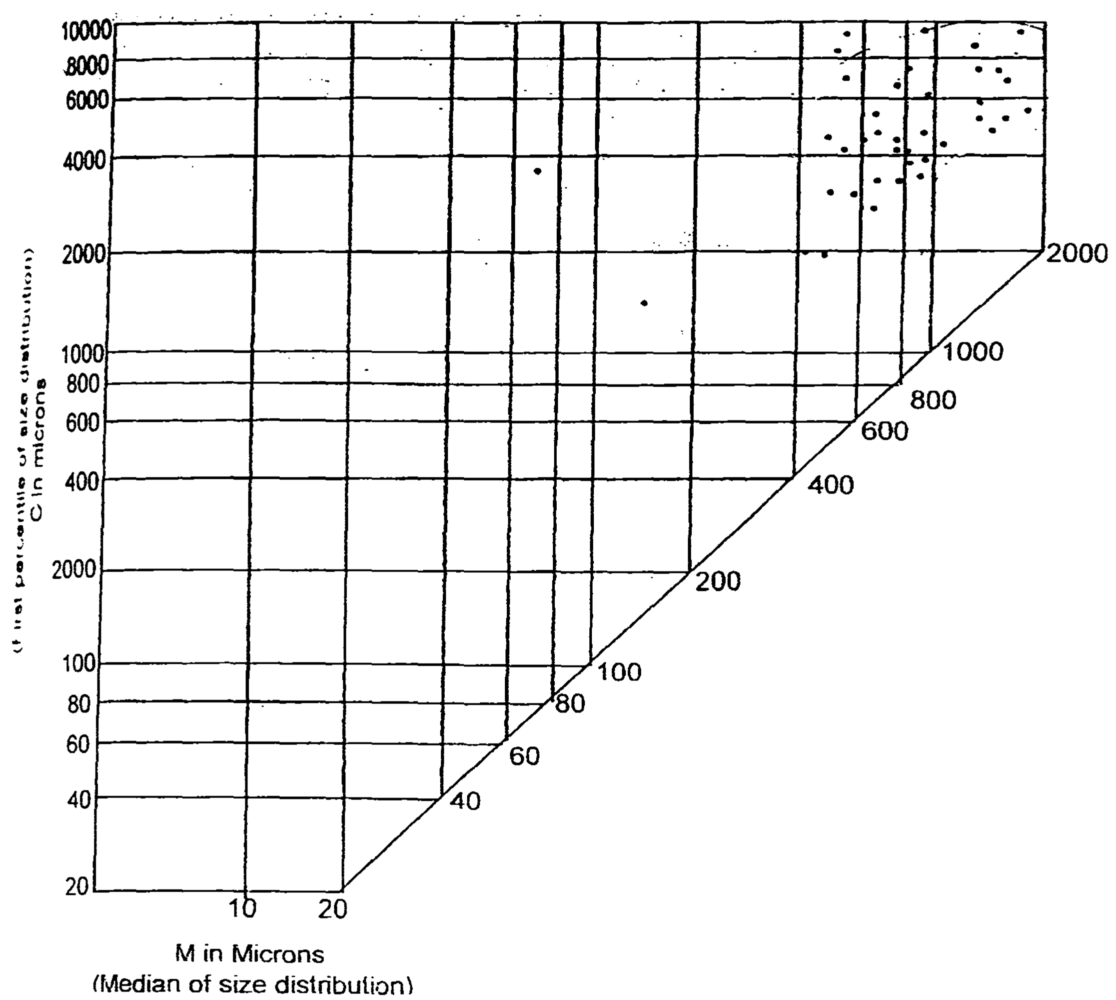


Fig. 3.9 CM pattern of sediments of Periyar river

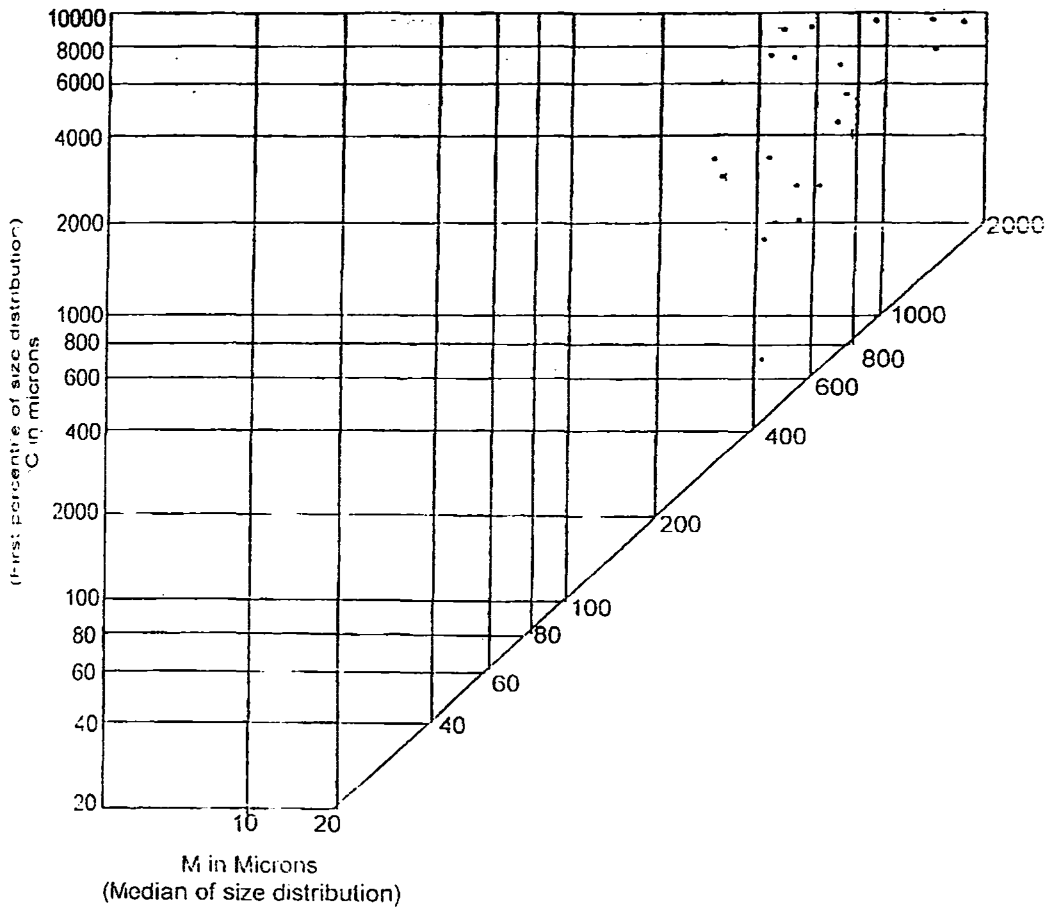


Fig. 3.10 CM pattern of sediments of Chalakudy river

CHAPTER 4

MINERALOGY

4.1 INTRODUCTION

Minerals, the naturally occurring inorganic substances with a definite chemical composition and regular internal structure, form an integral part of rocks and sediments. The study of minerals in sediments and sedimentary rocks assumes much importance in the understanding of the pathways of sediment movement. Additionally, information on the nature of contribution and energy condition of the depositing medium can also be deduced from the relative proportions of heavy and light mineral fractions. In short, minerals serve as a source of information about the nature of initial size distribution resulting in the mechanical disintegration at the source, the effect of dynamic process on the original size distribution and assertion in nature of the phenomenon of hydraulic equivalence of size. In some cases, the mineralogical constitution of samples that belong to one association can also vary considerably especially in the case of fluvial sediments often, but not always, rapid changes in composition occur due to various reasons, such as addition of new minerals by tributaries, erosion of bottom materials and by the varied hydrodynamic condition during transportation and deposition. The mineralogic make of detrital constituents of sediments is of profound importance in bringing out the depositional history of sedimentary basins. Studies on the mechanism of fluvial and alluvial placer evolution have facilitated a better appreciation of process operating in the entrainment and concentration of minerals (Singerland, 1977; Komar and Wang, 1984; Peterson et al., 1986; Komar, 1987; Komar et al., 1989).

Heavy mineral (specific gravity >2.89) fraction in sediments is often composed of diverse mineral species in which each mineral grain conveys its own history. It is the sedimentary petrologist's task to decipher the message encoded in the mineral assemblages and apply them for the purposes of a) determining provenance, b) tracing sediment transport paths, c) mapping sediment dispersal patterns, d) outlining and, in suitable cases, correlating various sand bodies, e) indicating the action of particular hydraulic regimes and concentrating process, f) locating potential economic deposits and g) elucidating diagenetic processes. Heavy minerals are often the only means of re-constructing provenance in sedimentary sequences. Pettijohn et al. (1972) has suggested that the diversities in heavy mineral assemblages are more in the youngest sediments than that of ancient ones. And, further, the number of heavy mineral species may gradually decrease as the age of the sediment increases. It is commonly believed that heavy minerals have a limited value of time. Each lithostratigraphic unit is often associated with a specific suite of heavy mineral assemblage. Depositional breaks or unconformities are typified by marked changes in heavy mineral suites. This emphasizes the stratigraphic significance of heavy minerals. Heavy mineral studies have been proved to be an important contributor to the analysis of sedimentation associated with tectonically active hinterlands. Heavy minerals are sensitive indicators of sedimentary processes and are useful in signaturing even the minute change of the depositional environments of facies (Mange and Maurer, 1992).

4.2 REVIEW OF LITERATURE

Ever since the introduction of hydraulic equivalent concept by Rubey (1933), it has been widely recognized that the hydraulic behaviour of heavy minerals is jointly influenced by their physical properties (size, shape and density), availability of minerals and dynamics of transporting medium. The complex interrelationship between the source rock characteristics and the transportational processes was stressed by Rittenhouse (1943). Interrelationship between various heavy minerals and the influence of size, shape and density on hydraulic sorting has been further investigated in detail by Briggs (1965). Bradley (1952), Van Andel and Poole (1960), Lowright et al. (1972), Stapor (1973), Singerland (1977), Flores and Shideler (1975), Morton (1985) and Statteger (1987) have used the heavy mineral assembles in unraveling the transportational and depositional histories of sediments. Pettijohn (1984) has opined that the reduction of number of heavy mineral species with time is related to the prolonged action of intrastratal solutions. The effect of physical and chemical weathering on minerals is often difficult to distinguish (Dryden and Dryden, 1946; Raeside, 1959). Several investigators have made systematic approach to the study of mineralogic diversities observed along the course of rivers. Pollack (1961) has summarized that selective sorting based on shape factor is not an important factor for downstream variation of heavy minerals. However, Briggs et al. (1962) have pointed out that both density and shape of minerals are important in imparting sorting of minerals downstream. The role of progressive sorting based on size and density differences has also been investigated by researchers like Allen (1970), Carver (1971), Blatt et al. (1972), Komar and Wang (1984) and Komar et al. (1989).

In India, many renowned scientists have studied in detail about the heavy mineral constituents of recently deposited sediments. Tipper (1914) was the pioneer scientist to study the heavy mineral deposits between Quilon and Cape Camorin in the Southwest coast of India. Jacob (1956) made a detailed study on the heavy mineral concentrate of the beach sands of Tirunelveli, Ramnad and Tanjore districts of Tamil Nadu. Studies are also available for the major river systems like Godavari (Naidu, 1968), Krishna (Seetharamaswamy, 1970), Mahanadi (Sathyanarayana, 1973) Vasishta-Godavari (Dora, 1978) and Cauvery (Seralathan, 1979) as well. Chatterjee et al. (1968) and Siddique et al. (1972; 1979) have made detailed studies on the heavy mineral assemblage in the sediments of Mangalore coast. In addition, considerable amount of information exists on the heavy mineral occurrences of the beach environments of the Indian coast. Investigators like Aswathanarayana (1964), Rao (1968), Mallik (1986), Purandara et al. (1987), Mallik et al. (1986), Unnikrishnan (1987), Sasidharan and Damodaran (1988) and Purandara (1990) have studied the heavy mineral suite of the beach sands of Kerala. Samsuddin (1990) has evaluated the heavy mineral assemblages of the beach, strand plain and inner shelf sediments of the Northern Kerala coast. Padmalal (1992) have discussed mineralogical composition of Muvattupuzha river and Central Vembanad estuarine sediments. The heavy mineral deposits of the shelf region of the west coast of India have also been studied by several investigators (Mallik, 1974; Siddique et al., 1979; Siddique and Rajamanickam, 1979; Rajamanickam, 1983). Mallik (1981) has investigated the distribution of heavy minerals of the continental shelf of Kakinada. Kidwai et al. (1981) have investigated the distribution of heavy minerals in the outer continental shelf sediments between Vengurla and Mangalore. They have suggested that heavy mineral assemblages of sediments indicate mixed igneous and metamorphic provenance. Detailed geological and geophysical surveys conducted along the Konkan coast by Gujar et al. (1989) reveals the occurrence of several promising isolated placer mineral deposits in that area. Rajendran et al. (1996) have studied the heavy mineral constituents of the lower Bharathapuzha sediments.

The composition of light minerals (bromoform floats) of clastic sediments is also used extensively for sedimentological analysis. It is a fact that the compositional variability of light minerals is related closely to the mineralogical maturity and fluvial processes. Pettijohn (1984) has pointed out that the mineralogical maturity of sediments can be expressed by the quartz / feldspars ratio. Though there is no much difference in the specific gravities between quartz (2.65) and feldspars (2.70), there exists considerable differences in the stability index between the two, because feldspars are comparatively less stable than quartz. Many researchers opined that an increase of quartz / feldspars ratio downstream is the result of selective abrasion of the easily weatherable feldspars (Russel, 1937; Pollack, 1961; Seibold, 1963; Seetharamaswamy, 1970; Seralathan, 1979; Pettijohn, 1984). The relative proportions of these minerals in sediments have also been extensively used for reconstructing climatic as well as tectonic history of ancient sedimentary deposits (Blatt et al., 1972; Hashmi and Nair, 1986).

Like heavy and light minerals, knowledge on clay minerals is also very useful for all sediment related studies. The clay mineral composition of sediments can provide clues in unraveling the conditions under which the sediment deposited (Grim, 1953). Many such studies are available in literature. Shaw (1973) has studied the mineralogy of the clay deposit of the recent sediments of the Alicia basin, North Eastern Mediterranean. Piper and Slatt (1977) have evaluated the Southeast Indian Ocean sediments. Rao and Rao (1977) brought out the regional distribution of clay minerals for the sediments of the Eastern part of Bay of Bengal. In his classic study on the bottom sediments of the

Amazon shelf and Tropical Atlantic, Gibbs (1977b) revealed the mechanisms of clay mineral segregation in the marine environment.

4.3 RESULTS AND DISCUSSION

4.3.1 Mineralogy of sand

The coarser and finer fractions of the sediments of Periyar and Chalakudy rivers have been analysed for various heavy and light minerals. Clay fraction from selected sediment samples were studied using X-ray diffractogram. The results obtained from these analyses are discussed in the following sections.

Total Heavy Minerals (THM)

The total heavy mineral residue in the coarser (1mm - 0.25mm) and finer (0.25mm - 0.063mm) fractions of Periyar and Chalakudy rivers are shown in Table 4.1 and their downstream variations are depicted in Figs. 4.1 to 4.10. In the Periyar river, the THM vary between 3.53% and 25.26% (av. 11.69%) in the coarser fraction and between, 9.14% and 57.74% (av. 24.07%) in the finer fraction. Spatial analysis of heavy mineral residue reveals distinct features. The highland exhibits comparatively higher concentration of THM than that of the midland and lowland. However, the fluctuations in the THM content downstream are more in the case of Chalakudy river and which is attributed to natural and man-made obstacles. The ranges of THM in the Chalakudy river are 4.2% - 59.73% (av. 17.95%) in the coarser fraction and 13.2% – 79.02% (av. 37.93%) in the finer fraction.

Table 4.1 Heavy mineral contents in coarser and finer fractions of Periyar (Sample No. 1-31) and Chalakudy (33-54) river sediments.

Sample No.	Sand Fraction	LM[a]	HM[a]	MF[a] (Magnetite)	NMF[a]	Heavy minerals in NMF[b] (100%)							
		(100 %)		(100 %)		Ilmenite	Inosilicates	Garnet	Monazite	Zircon	Sillimanite	Biotite	Others
1	CF	81.44	18.56	23.49	76.51	59.10	27.10	5.94	0.99	0.99	-	1.97	3.81
	FF	63.18	36.82	35.24	64.76	57.86	23.27	7.55	-	5.03	1.26	3.77	1.26
2	CF	89.65	10.35	2.94	97.03	61.79	25.95	6.67	-	1.54	-	1.98	2.07
	FF	68.22	31.78	4.71	95.29	51.10	34.64	7.62	0.75	2.15	-	2.16	1.58
3	CF	81.17	18.83	10.30	89.70	66.67	20.16	7.75	0.78	2.33	-	1.55	0.78
	FF	80.55	19.45	9.03	90.97	41.77	44.30	5.06	1.27	2.53	-	3.80	1.27
4	CF	77.77	22.23	10.59	89.41	57.72	31.71	5.69	-	2.44	-	1.63	0.81
	FF	55.12	44.88	13.67	86.33	52.5	33.75	8.75	-	1.25	-	2.50	1.25
5	CF	94.19	5.81	12.21	87.71	69.93	21.68	1.40	1.40	2.10	-	2.10	1.40
	FF	76.07	23.93	10.84	89.16	81.85	13.71	-	0.81	-	0.81	2.02	0.81
7	CF	94.56	5.44	23.15	76.85	72.37	22.76	0.81	-	-	-	3.25	0.81
	FF	89.99	10.01	22.08	77.92	55.29	39.13	1.24	-	1.24	-	1.86	1.24
8	CF	83.69	16.31	28.60	71.40	61.91	29.58	2.66	1.06	1.60	-	2.13	1.06
	FF	67.29	32.71	15.33	84.67	58.39	26.09	0.62	2.48	8.70	0.62	1.86	1.24
9	CF	74.44	25.56	24.78	75.22	52.71	40.54	2.70	-	-	-	2.70	1.35
	FF	42.26	57.74	40.50	59.50	53.13	34.38	4.17	1.04	4.17	-	2.08	1.04

CF- Coarser Fraction; FF – Finer Fraction; LM - Light Minerals; HM - Heavy Minerals; MF - Magnetic Fraction (Magnetite); NMF - Non Magnetic Fraction:
a - expressed in weight percentage; b - expressed in number percentage.

Table 4.1 (Contd.)

Sample No.	Sand Fraction	LM[a]	HM[a]	MF[a] (Magnetite)	NMF[a]	Heavy minerals in NMF[b] (100%)							
		(100 %)		(100 %)		Ilmenite	Inosilicates	Garnet	Monazite	Zircon	Sillimanite	Biotite	Others
10	CF	89.99	10.01	11.11	88.89	64.96	21.90	0.73	-	1.46	-	9.49	1.46
	FF	86.21	13.79	36.47	63.53	35.30	27.45	-	-	3.92	-	31.37	1.96
11	CF	87.43	12.57	24.72	75.28	67.94	23.24	1.47	-	-	-	5.88	1.47
	FF	74.49	25.51	38.63	61.37	43.38	40.44	1.47	0.74	7.35	-	5.15	1.47
12	CF	80.06	19.94	37.25	62.75	62.31	33.85	2.31	-	-	-	0.77	0.77
	FF	83.78	16.22	33.85	66.15	38.95	46.02	2.65	-	2.65	-	7.96	1.77
13	CF	83.82	16.18	13.39	86.61	42.62	26.23	8.20	-	3.28	1.64	14.75	3.28
	FF	58.02	41.98	8.31	91.69	41.13	42.99	2.80	-	1.87	0.93	8.41	1.87
14	CF	90.02	9.98	16.57	83.43	46.36	43.64	6.36	-	-	-	1.82	1.82
	FF	73.96	26.04	20.16	79.84	36.08	45.57	3.80	0.63	3.80	-	8.86	1.27
15	CF	92.29	7.71	7.02	92.98	46.04	36.51	3.17	1.59	-	-	9.52	3.17
	FF	85.85	14.15	58.67	41.33	46.77	37.10	3.23	-	-	-	9.68	3.23
16	CF	94.85	5.15	2.37	97.63	55.79	36.84	3.16	-	1.05	-	2.11	1.05
	FF	87.95	12.05	1.64	98.36	23.53	51.76	5.88	-	-	-	17.65	1.18
17	CF	92.53	7.47	3.91	96.09	18.67	64.00	-	-	1.33	1.33	12.00	2.67
	FF	81.31	18.69	10.27	89.73	29.25	57.83	3.40	0.68	2.04	0.68	4.76	1.36

CF- Coarser Fraction; FF - FinerFraction; LM - Light Minerals; HM - Heavy Minerals; MF - Magnetic Fraction (Magnetite); NMF - Non Magnetic Fraction: a - expressed in weight percentage; b - expressed in number percentage.

Table 4.1 (Contd.)

Sample No.	Sand Fraction	LM[a]	HM[a]	MF[a] (Magnetite)	NMF[a]	Heavy minerals in NMF[b] (100%)							
		(100 %)		(100 %)		Ilmenite	Inosilicates	Garnet	Monazite	Zircon	Sillimanite	Biotite	Others
19	CF	88.68	11.32	14.37	85.63	16.95	67.80	3.39	-	-	-	8.47	3.39
	FF	78.75	21.25	30.03	69.97	22.95	65.57	4.92	-	-	-	3.28	3.28
20	CF	96.47	3.53	0.24	99.76	16.25	75.00	2.50	-	-	-	1.25	5.00
	FF	80.90	19.10	8.17	91.83	20.75	68.89	0.74	0.74	2.96	-	4.44	1.48
21	CF	92.87	7.13	0.74	99.26	14.75	75.41	4.92	-	-	-	3.28	1.64
	FF	75.87	24.13	2.19	97.81	19.41	71.18	1.18	0.59	2.35	1.18	2.94	1.18
22	CF	82.85	17.15	2.05	97.95	15.15	72.73	6.06	-	-	-	3.03	3.03
	FF	75.78	24.22	5.17	94.83	23.03	57.52	2.65	2.65	5.31	0.88	6.19	1.77
23	CF	79.41	20.59	4.09	95.91	25.50	54.90	5.88	1.96	1.96	-	7.84	1.96
	FF	82.23	17.77	9.48	90.52	26.09	64.60	1.24	1.86	1.86	0.62	3.11	0.62
24	CF	93.70	6.30	1.88	98.12	49.21	34.92	7.94	-	-	-	6.35	1.59
	FF	79.77	20.23	6.62	93.38	35.44	55.12	-	0.79	2.36	-	4.72	1.57
26	CF	96.48	3.52	0.70	99.30	27.42	61.29	3.23	-	-	-	4.84	3.23
	FF	90.86	9.14	0.94	99.06	2.33	84.88	3.49	-	3.49	1.16	3.49	1.16
27	CF	86.95	13.05	2.24	97.76	51.70	37.66	-	-	4.26	-	4.26	2.13
	FF	68.73	31.27	9.29	90.71	46.77	39.78	0.54	-	4.84	1.08	5.91	1.08

CF- Coarser Fraction; FF – Finer Fraction; LM - Light Minerals; HM - Heavy Minerals; MF - Magnetic Fraction (Magnetite); NMF - Non Magnetic Fraction: a - expressed in weight percentage; b - expressed in number percentage.

Table 4.1 (Contd.)

Sample No.	Sand Fraction	LM[a]	HM[a]	MF[a] (Magnetite)	NMF[a]	Heavy minerals in NMF[b] (100%)							
		(100 %)		(100 %)		Ilmenite	Inosilicates	Garnet	Monazite	Zircon	Sillimanite	Biotite	Others
29	CF	95.66	4.34	11.15	88.85	12.33	67.12	8.22	1.37	-	2.74	6.85	1.37
	FF	86.50	13.50	23.12	76.88	14.95	68.24	0.93	1.87	8.41	0.93	2.80	1.87
30	CF	87.59	12.41	14.73	85.27	35.29	43.53	11.76	-	-	-	8.24	1.18
	FF	77.18	22.82	31.68	68.32	22.98	62.22	3.70	2.22	3.70	0.74	2.96	1.48
31	CF	95.81	4.19	6.80	93.20	52.27	25.00	9.09	-	-	-	9.09	4.55
	FF	79.21	20.79	14.95	85.05	42.24	36.02	1.24	3.11	11.18	-	4.97	1.24
33	CF	48.98	51.02	28.49	71.51	52.16	37.61	1.20	-	2.12	-	3.85	3.06
	FF	26.74	73.26	68.71	31.29	62.75	27.45	-	1.31	4.58	-	2.61	1.31
34	CF	69.29	30.71	13.39	86.61	60.82	32.33	-	-	1.37	-	2.74	2.74
	FF	35.45	64.55	8.31	91.69	69.58	15.94	-	1.45	6.52	0.72	5.07	0.72
40	CF	40.27	59.73	45.30	54.70	62.73	32.35	1.23	-	1.23	-	1.23	1.23
	FF	20.98	79.02	73.16	26.84	57.82	22.64	1.15	1.15	14.94	-	1.15	1.15
41	CF	85.84	14.16	15.22	84.78	20.15	15.21	-	-	-	-	61.42	3.22
	FF	67.95	32.05	22.45	77.55	52.50	34.17	0.83	1.67	2.50	-	6.67	1.67
42	CF	91.23	8.77	32.70	67.30	41.38	27.59	3.45	-	3.45	-	22.41	1.72
	FF	84.81	15.19	26.92	73.08	35.00	39.44	-	1.11	5.56	-	17.78	1.11

CF- Coarser Fraction; FF – Finer Fraction; LM - Light Minerals; HM - Heavy Minerals; MF - Magnetic Fraction (Magnetite); NMF - Non Magnetic Fraction: a - expressed in weight percentage; b - expressed in number percentage.

Table 4.1 (Contd.)

Sample No.	Sand Fraction	LM[a]	HM[a]	MF[a] (Magnetite)	NMF[a]	Heavy minerals in NMF[b] (100%)							
		(100 %)		(100 %)		Ilmenite	Inosilicates	Garnet	Monazite	Zircon	Sillimanite	Biotite	Others
43	CF	95.80	4.20	2.43	97.57	54.22	27.71	-	-	-	-	15.66	2.41
	FF	86.80	13.20	2.03	97.97	43.33	46.68	1.11	-	2.22	-	4.44	2.22
44	CF	93.00	7.00	42.10	57.90	61.55	25.64	1.28	-	2.56	-	6.41	2.56
	FF	78.00	22.00	39.13	60.88	23.57	64.29	3.57	1.43	2.14	-	3.57	1.43
46	CF	90.60	9.40	30.77	69.23	70.42	19.72	1.41	-	1.41	-	4.23	2.82
	FF	78.40	21.60	40.15	59.85	42.86	47.06	-	-	4.20	-	5.04	0.84
47	CF	88.90	11.10	2.66	97.34	70.13	20.78	1.30	-	-	-	5.19	2.60
	FF	84.50	15.50	2.61	97.39	50.35	42.95	-	-	2.68	1.34	1.34	1.34
49	CF	89.60	10.40	1.59	98.41	65.85	28.05	1.22	-	2.44	-	1.22	1.22
	FF	40.80	59.20	3.07	96.93	64.49	24.64	1.45	-	5.80	-	2.17	1.45
50	CF	89.50	10.50	12.38	87.62	74.68	16.46	1.27	-	2.53	-	3.80	1.27
	FF	64.60	35.40	18.82	81.18	53.52	38.73	1.41	-	1.41		3.52	1.41
51	CF	91.10	8.90	34.65	65.35	55.57	33.33	2.22	-	0.00	2.22	4.44	2.22
	FF	60.80	39.20	63.48	36.52	45.22	40.00	-	0.87	8.70	-	2.61	2.61
54	CF	92.60	7.40	42.45	57.55	53.45	31.03	5.17	-	-	-	6.90	3.45
	FF	77.05	22.95	45.14	54.86	37.18	54.87	0.88	0.88	3.54	-	1.77	0.88

CF- Coarser Fraction; FF – Finer Fraction; LM - Light Minerals; HM - Heavy Minerals; MF - Magnetic Fraction (Magnetite); NMF - Non Magnetic Fraction:
a - expressed in weight percentage; b - expressed in number percentage.

Heavy Mineral Assemblage

Magnetic Fraction (MF) -Magnetite

The fractions of heavy mineral residue separated using a hand magnet is referred here as the Magnetic Fraction (MF). This fraction is composed mostly of magnetite with an Fe_2O_3 content of over 68.97 %. Magnetite is concentrated substantially in the finer fraction than coarser fraction. In the Periyar river, the content of magnetite varies from 0.24% to 37.25% (av. 11.53%) in the coarser fraction and 0.94% to 58.67% (av. 19.67%) in the finer fraction. The respective concentrations of magnetite in the Chalakudy river are 2.43% to 45.30% (av. 23.39%) in the coarser fraction 3.07% to 73.16% (av. 31.84%) in the finer fraction. Spatial distribution of magnetite reveals that they are concentrated in highland compared to midland and lowland. The scarp zone of the Periyar river accounts for the highest content of magnetite both in coarser and finer fractions. However, a fluctuating trend in the content of magnetite is noticed in the case of Chalakudy river.

Non-Magnetic Fraction (NMF)

The heavy mineral residue left after the separation of the magnetic fraction (i.e., magnetite) is referred here as Non-Magnetic Fraction (NMF). In the Periyar river, the NMF varies between 62.75% and 99.76% (av. 88.46%) in the coarser fraction and 41.33% and 99.06% (av. 80.33%) in the finer fraction. The contents of NMF in the Chalakudy river ranges between 54.70 % and 98.41% (av. 76.61%) in the coarser fraction and 26.84% and 96.93% (av. 68.16%) in the finer fraction. The NMF comprises a spectrum of minerals (Plate 6), viz: ilmenite, inosilicates, zircon, garnets, boitite, monazite and sillimanite. In addition to these, a small portion of weathered / unidentified

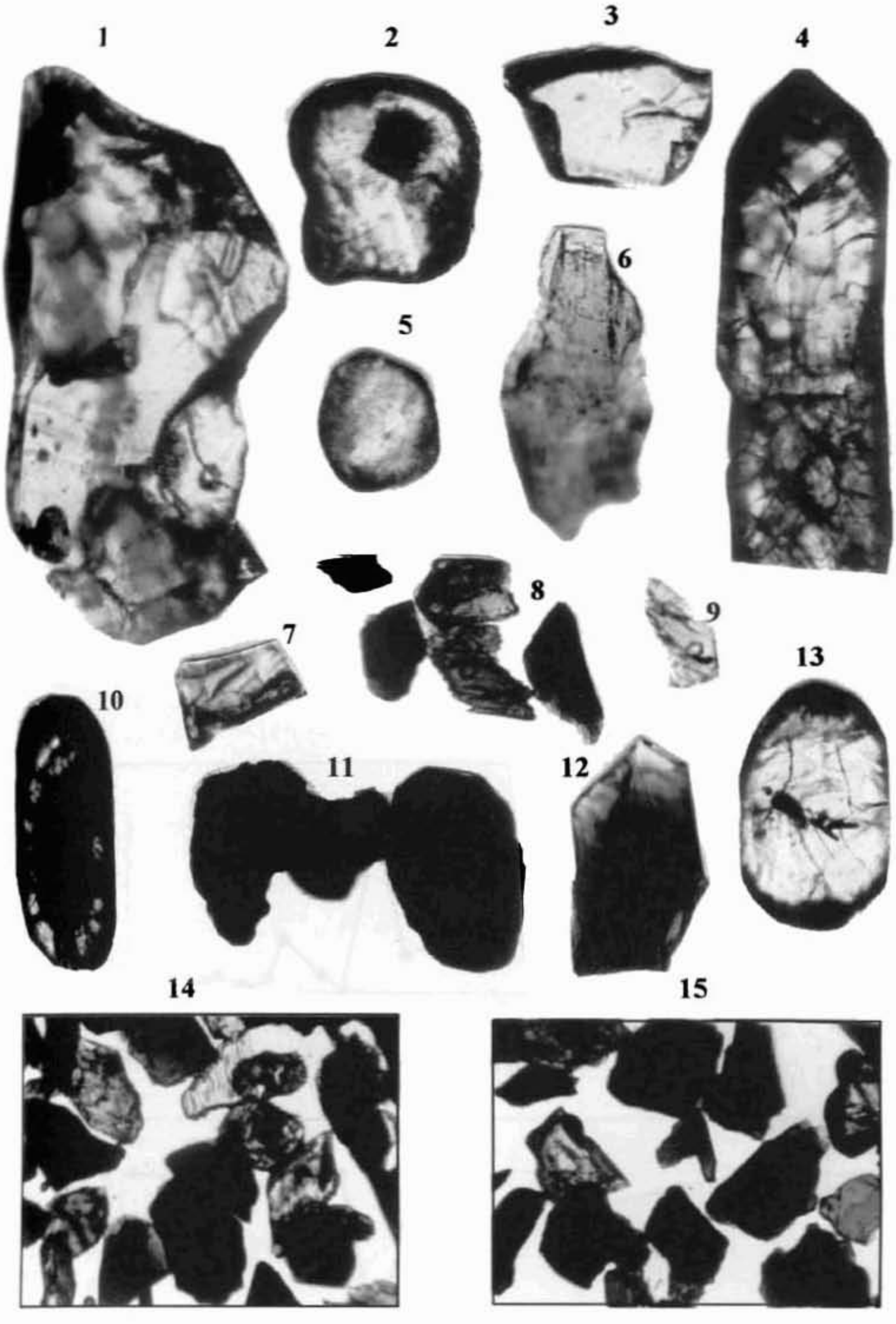


Plate 6: Heavy minerals (non magnetic) in the sand fraction of the study area. 1:Pink garnet; 2&5:Monazite; 3:Colourless garnet; 4,10&13:Zircon; 6,7,8,9&12:Inosilicates; 11:Ilmenite; 14:Heavy mineral residue in the finer sand fraction of Periyar river; 15:Heavy mineral residue in the fine sand fraction of Chalakudy river.

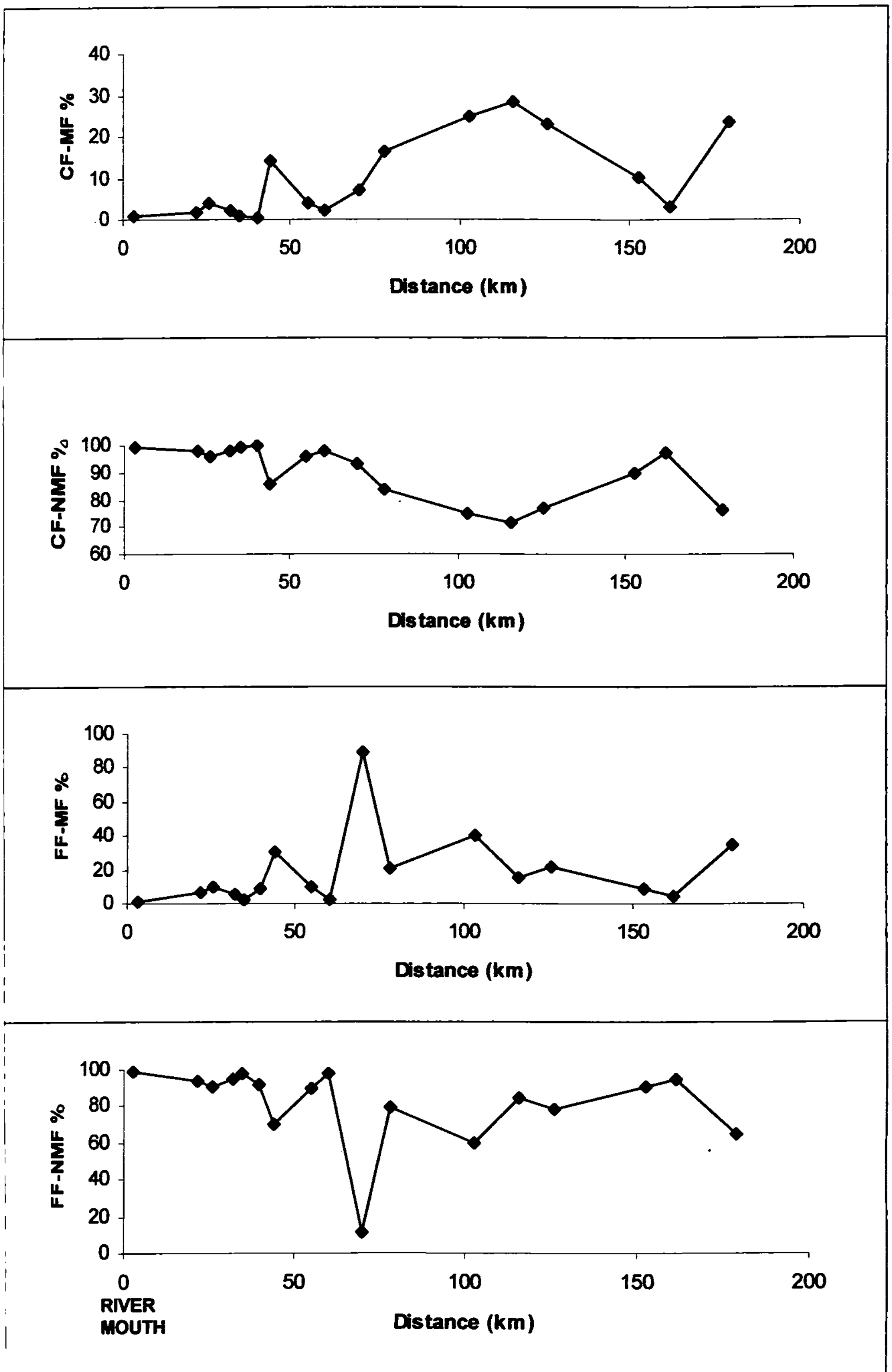


Fig. 4.1 Downstream variations of magnetic and non-magnetic minerals in coarser and finer fractions of Periyar river (CF- Coarser fraction; FF- Finer fraction; MF – Magnetic fraction; NMF – Non-magnetic fraction)

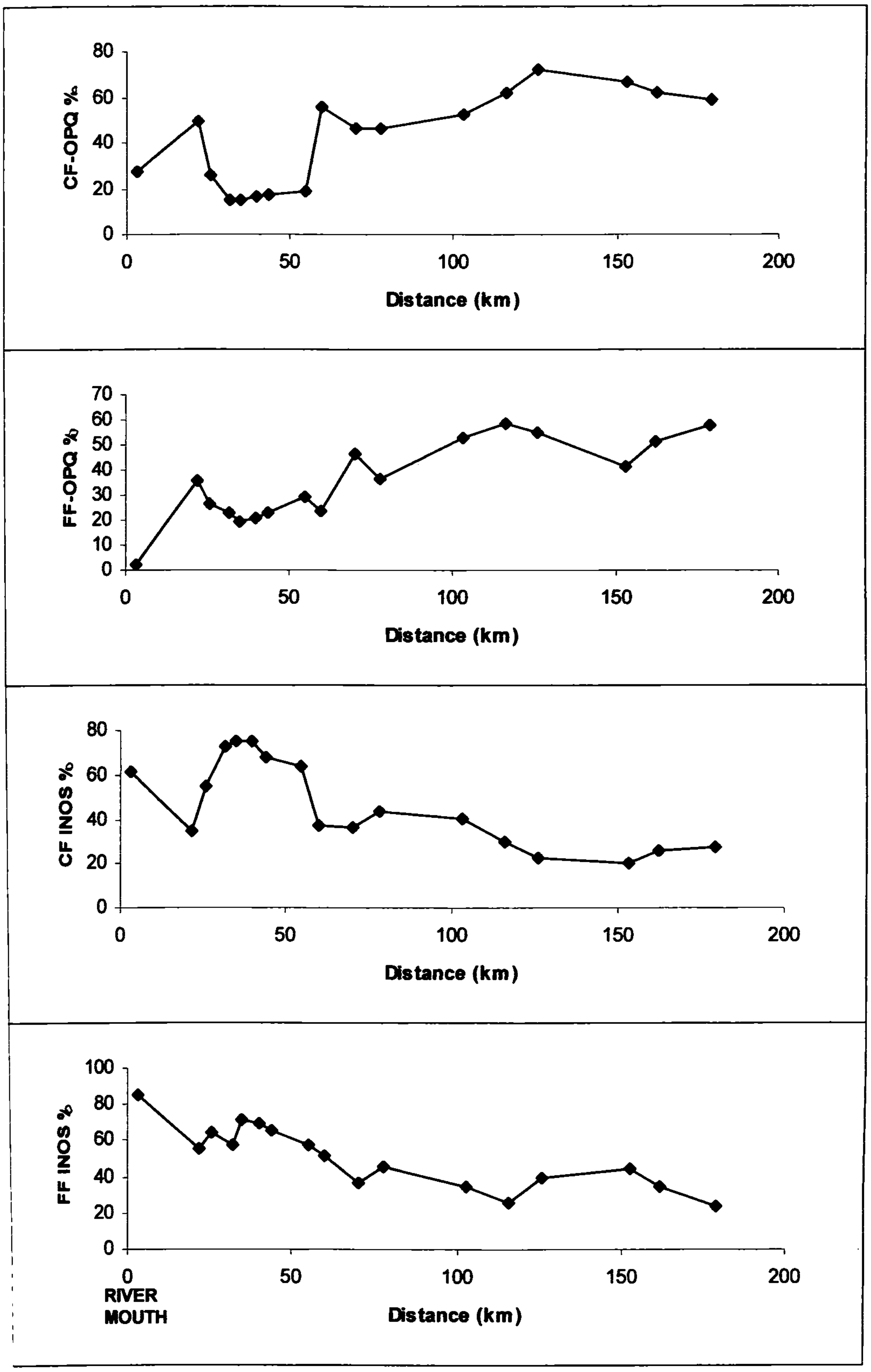


Fig. 4.2 Downstream variations of inosilicates and opaques in coarser and finer fractions of Periyar river (CF- Coarser fraction; FF- Finer fraction; OPQ - Opaques; INOS - Inosilicates)

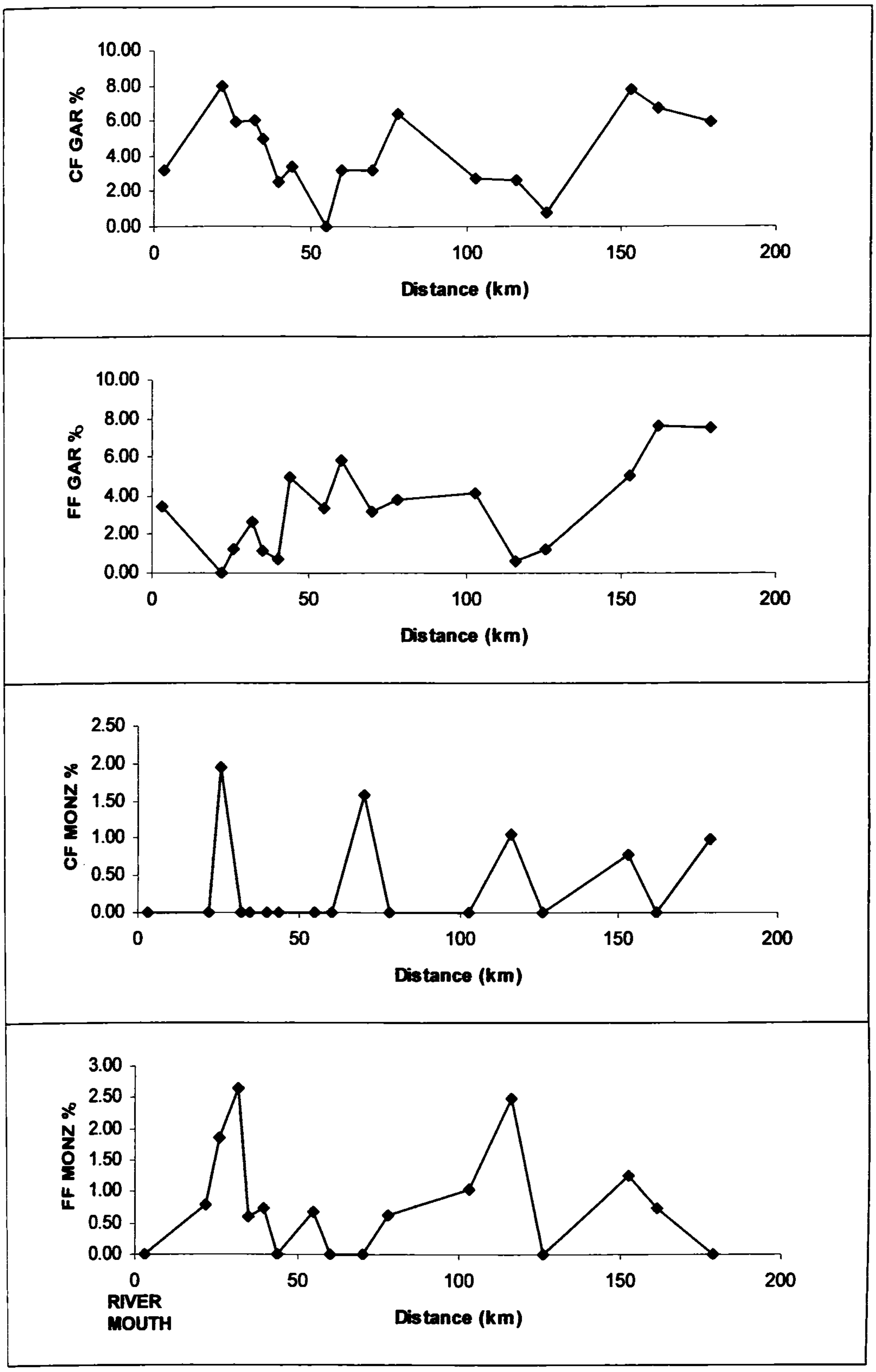


Fig. 4.3 Downstream variations of monazite and garnets in coarser and finer fractions of Periyar river (CF- Coarser fraction; FF- Finer fraction; GAR- Garnets; MONZ- Monazite)

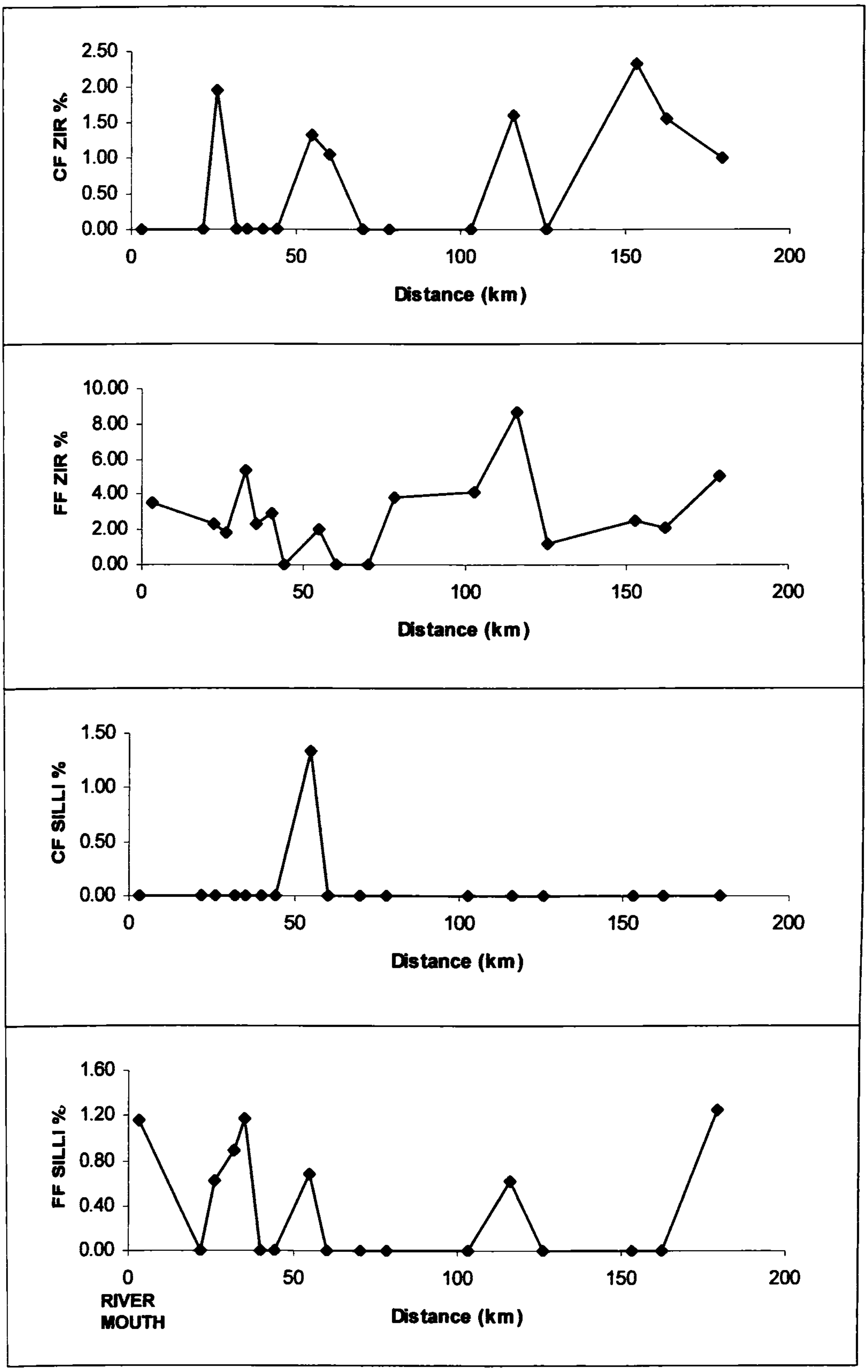


Fig. 4.4 Downstream variations of zircon and sillimanite in coarser and finer fractions of Periyar river (CF- Coarser fraction; FF- Finer fraction; SILLI- Sillimanite; ZIR-Zircon)

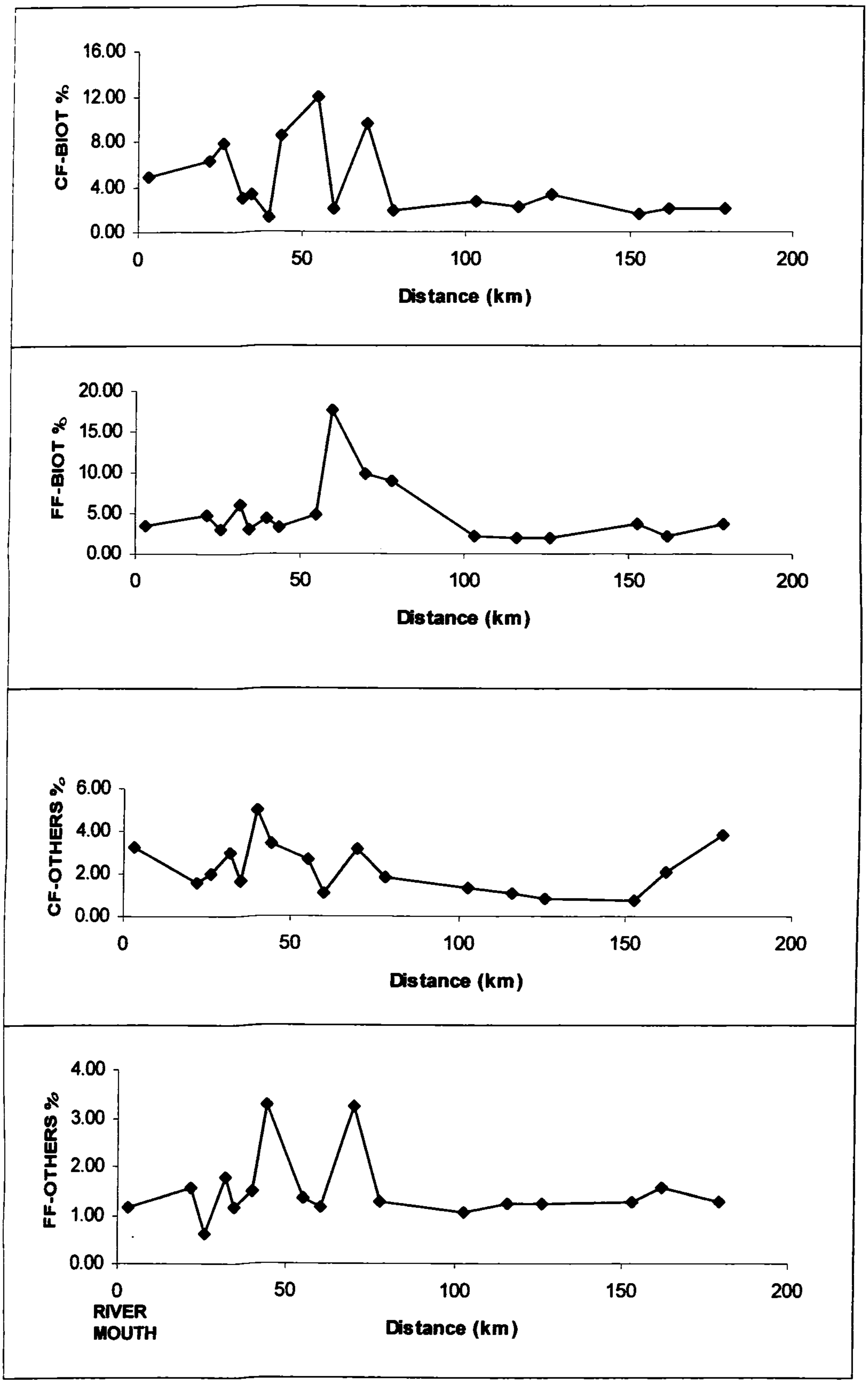


Fig. 4.5 Downstream variations of biotite and others in coarser and finer fractions of Periyar river (CF- Coarser fraction; FF- Finer fraction; BIOT- Biotite)

minerals are also present in many of the samples. They are categorised here as 'other minerals'.

Ilmenite

Ilmenite constitutes one of the most dominant opaque minerals in the coarser and finer fractions of Periyar and Chalakudy rivers. These grains are generally sub-angular to sub-rounded in shape. The average number percentage of ilmenite in the coarser and finer fractions of the Periyar river are 45.32% (range: 12.33 to 72.37) and 37.90% (range: 2.33 to 81.85), respectively. The Chalakudy river accounts for comparatively higher content of ilmenite in the coarser fraction (av. 57.16%; range: 20.15 to 74.68) and the finer fraction (av. 49.09%; range: 23.57 to 69.58). Like magnetite, the highest concentration of ilmenite is observed in the high gradient upstream reaches (plateau: 59.95%; scarp: 50.88%) of the Periyar river than the low gradient midland (32.42%) and lowland (32.74%). A similar trend is observed in the case of Chalakudy river as well (highland: 61.33%; midland: 51.02% and lowland: 53.27%).

Inosilicates

Inosilicates are the common rock forming minerals of many igneous and metamorphic rocks. The inosilicate group, referred to here, includes hornblende (amphibole) and hypersthene (pyroxene) as the major minerals. The former accounts over 60%. As these two minerals fall in the lighter heavy mineral category (specific gravity of hornblende = 3.5; hypersthene = 3) and with almost similar hydraulic properties, they are treated in this investigation as a single group - the 'inosilicates'.

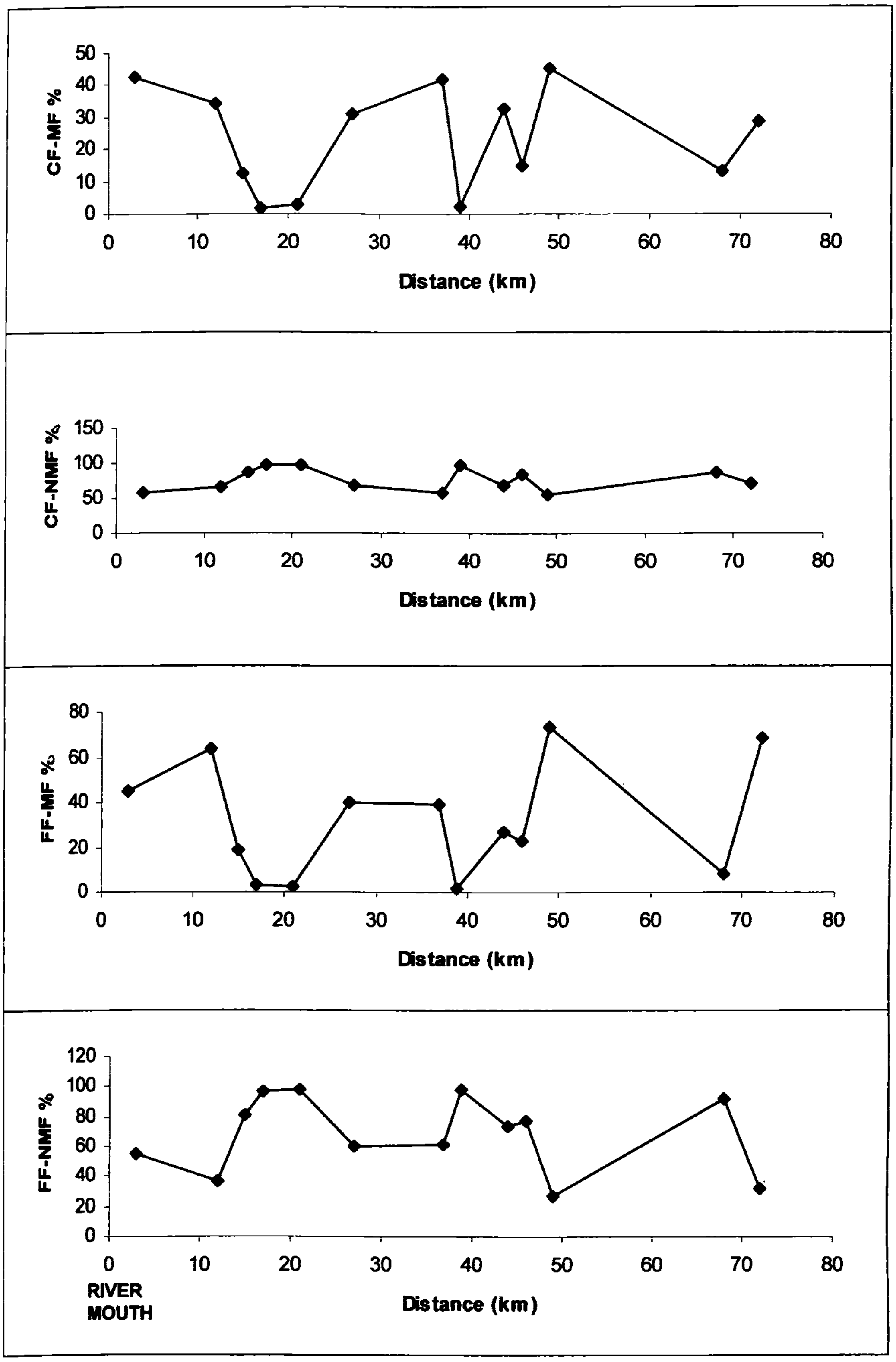


Fig. 4.6 Downstream variations of magnetic and non-magnetic minerals in coarser and finer fractions of Chalakudy river (CF- Coarser fraction; FF- Finer fraction; MF – Magnetic fraction; NMF – Non-magnetic fraction)

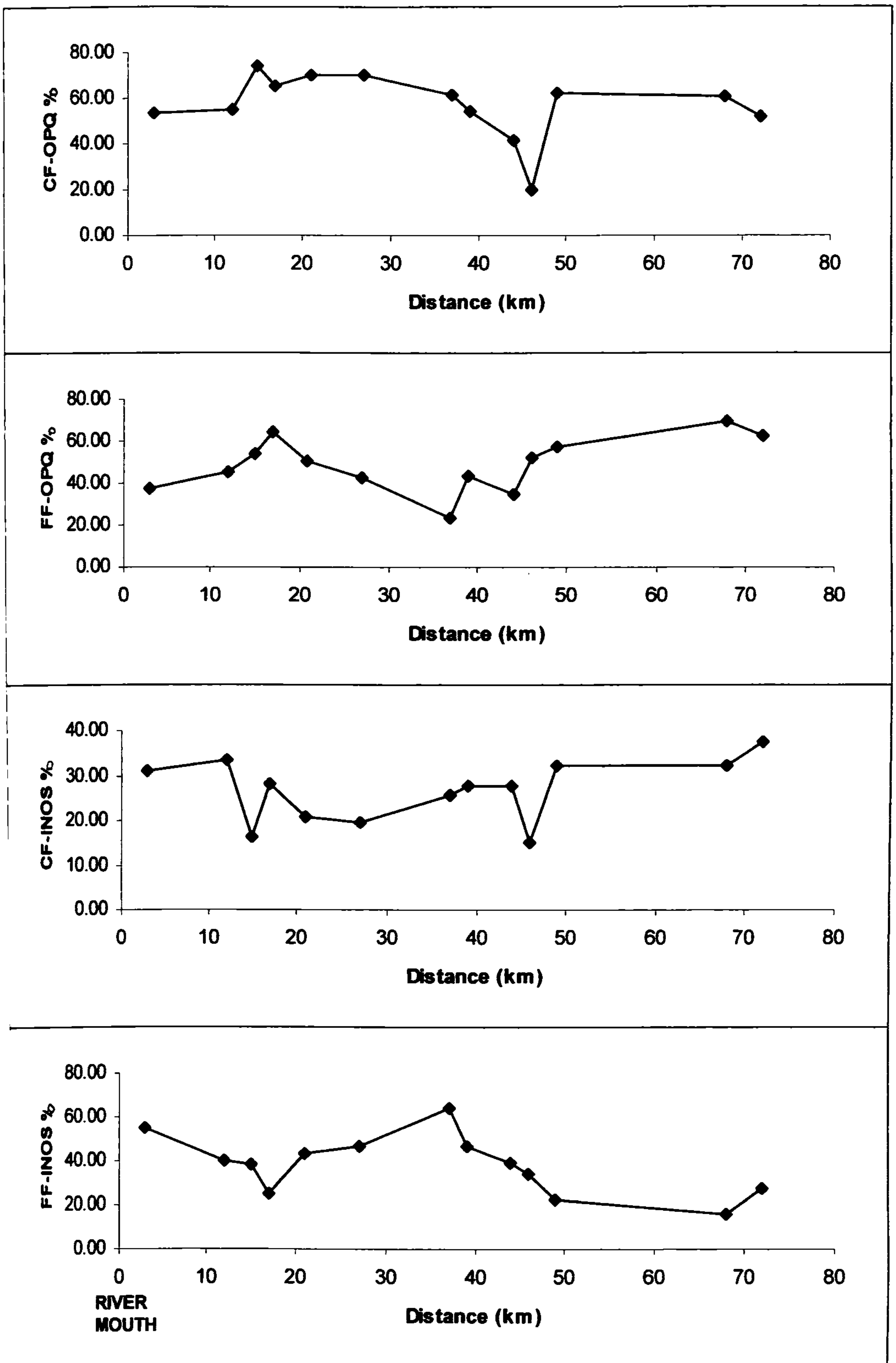


Fig. 4.7 Downstream variations of inosilicates and opaques in coarser and finer fractions of Chalakudy river (CF- Coarser fraction; FF- Finer fraction; OPQ - Opaques; INOS - Inosilicates)

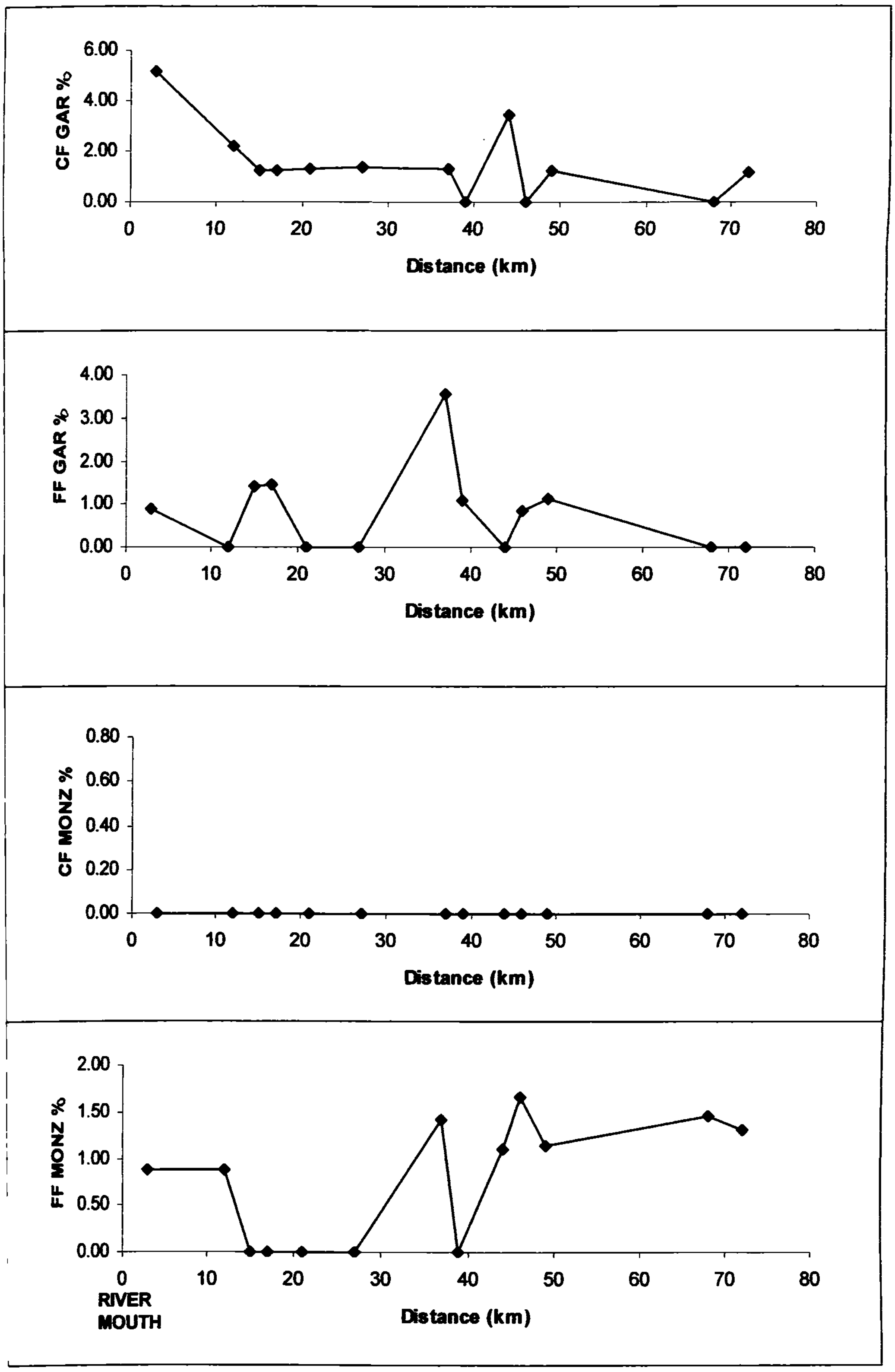


Fig. 4.8 Downstream variations of monazite and garnets in coarser and finer fractions of Chalakudy river (CF- Coarser fraction; FF- Finer fraction; GAR- Garnets; MONZ- Monazite)

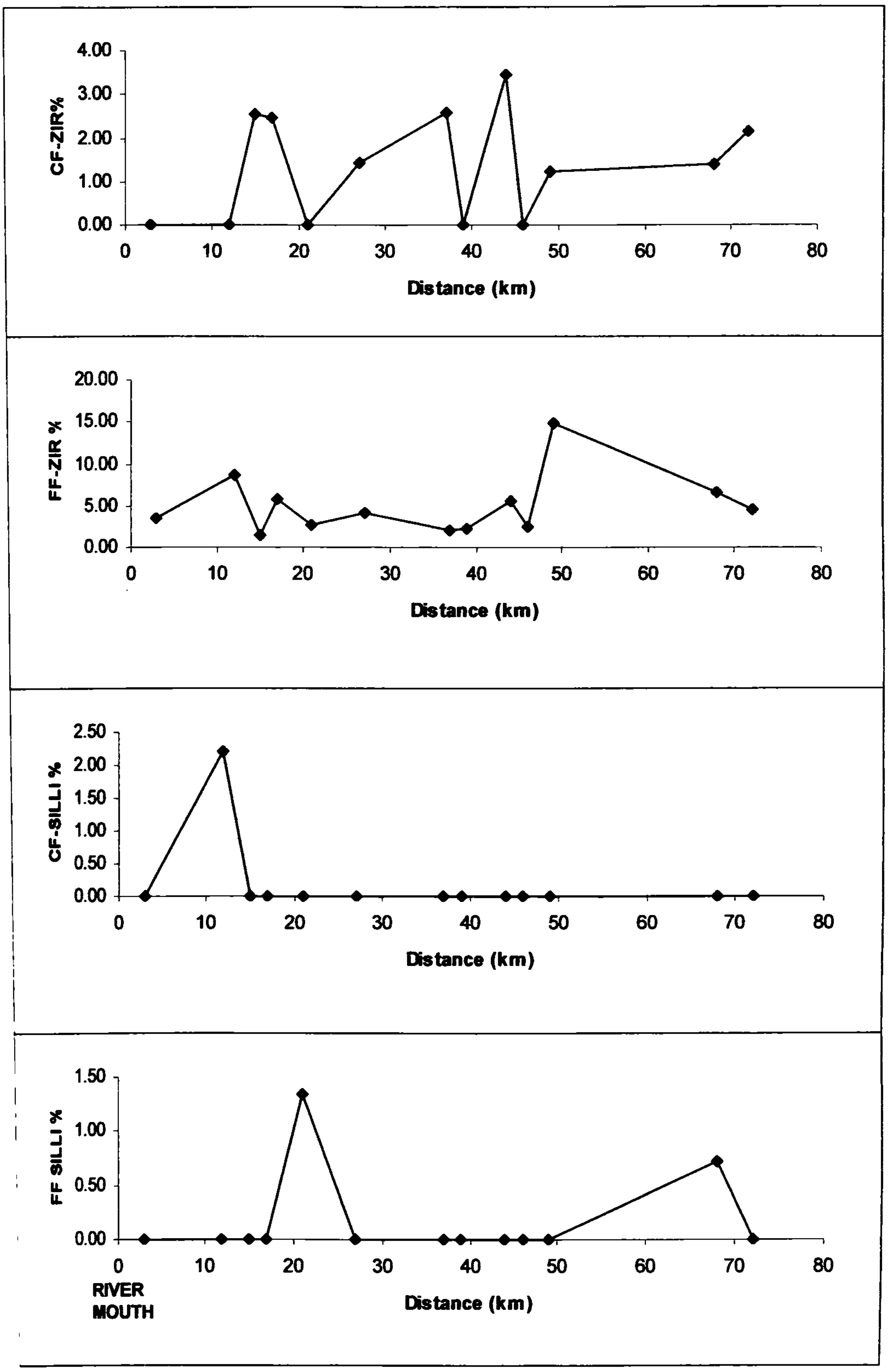


Fig. 4.9 Downstream variations of sillimanite and zircon in coarser and finer fractions of Chalakudy river (CF- Coarser fraction; FF- Finer fraction; SILLI- Sillimanite; ZIR-Zircon)

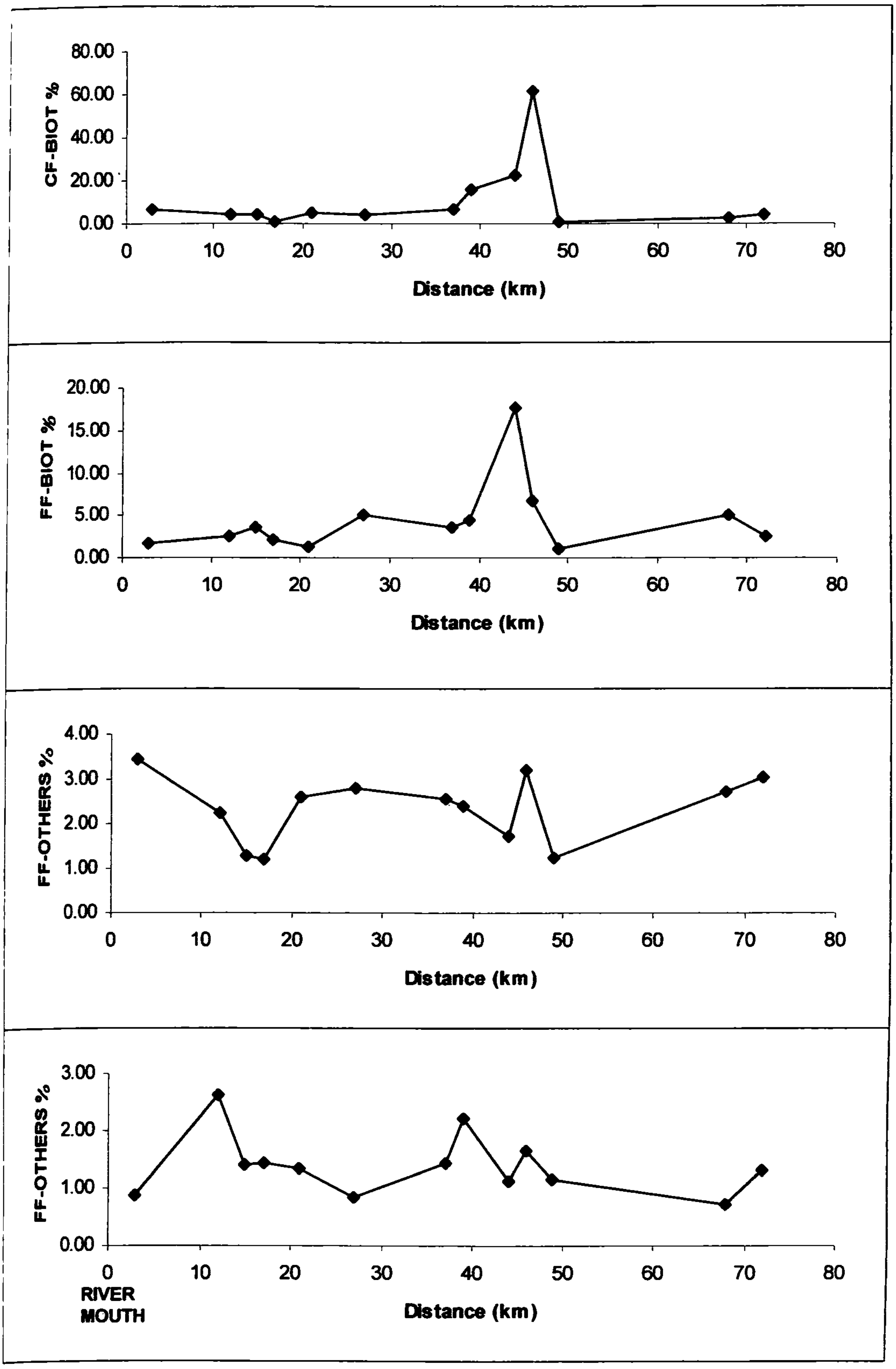


Fig. 4.10 Downstream variations of biotite and others in coarser and finer fractions of Periyar river (CF- Coarser fraction; FF- Finer fraction; BIOT- Biotite)

In the Periyar river inosilicates averages 41.52% in the coarser fraction and 47.13% in the finer fraction, while in the Chalakudy river, inosilicate averages 26.75% in the coarser fraction and 38.37% in the finer fraction. The plateau region of the Periyar river accounts for an average inosilicate content of 24.66% in the coarser fraction. The respective inosilicate concentration in the scarp, midland and lowland are 29.85%, 53.57% and 44.92%. Finer fraction account for an average inosilicate concentration of 32.75% in the plateau region, 38.37% in scarp, 52.89% in midland and 57.71% in lowland. Highland, midland and lowland of Chalakudy river account for an average of 34.97%, 24.63% and 26.94%, respectively in the coarser fraction and 21.70%, 46.24% and 45.31%, in the finer fraction.

Garnets

Detrital garnets occur either as euhedral crystals or sharp irregular fragments often with conchoidal fracture. Most of the garnets are pink under plane polarized light. Minor amount of colourless garnets are also seen in some samples, especially in the downstream reaches. The average content of garnets in the coarser and finer fractions of the Periyar river are 4.52% and 2.92%, respectively. In the Chalakudy river, the garnets averages about 1.52% and 0.8%, respectively, in the coarser and finer fractions. Except an initial decrease from upstream, in general, the concentration of garnets does not exhibit any specific trend along the longitudinal profile of either Periyar or Chalakudy rivers.

Zircon

Zircon is considered as a valuable index mineral in petrographic studies. The mineralogical characteristic of zircon is indicative of the physical and chemical conditions of the depositional environments. Zircon grains are characterized by high relief and surrounded by a black halo. Average zircon contents in the coarser and finer fractions of the Periyar river are 0.9% and 3.45% and that of Chalakudy river are 1.32% and 4.98%, respectively. The number percentage of zircon in coarser and finer fractions reveals interesting results. In the coarser fraction zircon generally exhibits a decreasing content downstream, whereas in finer fraction, the number percentage of zircon exhibits an opposite trend, a feature also observed earlier by Padmalal et al. (1997a) in Muvattupuzha river. Zircon in the coarser fraction of plateau, scarp, midland and lowland region of Periyar river are 1.34%, 1.62%, 0.53% and 0.71% and in the finer fraction the respective content are 2.79%, 4.41%, 2.40% and 5.67%. For the Chalakudy river, coarser fraction contains 1.74%, 1.39% and 0.89% in the highland, midland and lowland respectively, while in the finer fraction the concentrations are 5.55%, 5.01% and 4.55%.

Biotite

Biotite exhibits brown colour under plane polarized light. It is usually flaky in nature. The average biotite content in the coarser and finer fractions of the Periyar river are 5.08% and 5.88%, respectively. In Chalakudy river, biotite accounts for an average concentration of 10.73% in the coarser fraction and 4.44% in the finer fraction.

Monazite and Sillimanite

Monazite and sillimanite are present only in lesser numbers (about 2% of the total NMF). Monazite grains are rounded to sub-rounded with honey yellow colour under plane polarized light. They also show high relief and distinct borders. Sillimanite is slender, prismatic and colourless under plane polarized light. They show high relief, straight extinction, moderate birefringence and biaxial positive optical characteristics. Monazite and sillimanite are concentrated in the finer fraction.

Other minerals

In this category, minerals which could not be confirmed because of their highly altered appearance are generally included. Majority of the altered minerals appear to be hypersthene, hornblende and biotite based on their shape and colour.

Correlation matrix of heavy minerals

Correlation matrix analysis of heavy mineral species (magnetic and non-magnetic) in different samples is attempted to delineate the relationship existing among different minerals of similar hydraulic properties. Tables 4.2 to 4.5 show the Pearson correlation matrix for the heavy mineral suites of Periyar and Chalakudy rivers. In coarser fraction, ilmenite exhibits a significant positive correlation with magnetite ($r = 0.5$) and zircon ($r = 0.29$). In general, the heavier heavies such as ilmenite, magnetite, zircon and monazite give positive loading among each other. At the same time, these minerals exhibit marked negative relationship with lighter heavies like biotite and inosilicates. This is very much so in the case of Periyar. But slight deviations are observed in the case of Chalakudy river, which can be explained in the light of the differential settling of minerals due to natural and man-made obstacles encountered at many locations in the river course. The cluster pattern of heavy mineral assemblage in coarser and finer fractions is depicted in Figs. 4.11 to 4.14.

Table 4.2 Pearson correlation matrix for the coarser fraction of Periyar river

	Biotite	Garnets	Inosilicates	Magnetic fraction	Monazite	Non magnetic fraction	Opaques	Others	Sillimanite	Zircon
Biotite	1.00									
Garnets	0.15	1.00								
Inosilicates	0.06	0.01	1.00							
Magnetic fraction	-0.20	-0.15	-0.44	1.00						
Monazite	0.03	0.06	-0.06	0.05	1.00					
Non magnetic fraction	0.20	0.15	0.44	-1.00	-0.05	1.00				
Opaques	-0.31	-0.20	-0.95	0.50	0.00	-0.50	1.00			
Others	0.31	0.08	0.35	-0.37	-0.05	0.37	-0.45	1.00		
Sillimanite	0.48	0.20	0.24	-0.05	0.18	0.05	-0.39	0.03	1.00	
Zircon	0.09	-0.12	-0.37	-0.15	0.16	0.15	0.29	-0.15	0.10	1.00

Number of observations = 27

Table 4.3 Pearson correlation matrix for the finer fraction of Periyar river

	Biotite	Garnets	Inosilicates	Magnetic fraction	Monazite	Non magnetic fraction	Opaques	Others	Sillimanite	Zircon
Biotite	1.00									
Garnets	-0.09	1.00								
Inosilicates	-0.19	-0.05	1.00							
Magnetic fraction	0.18	0.11	-0.34	1.00						
Monazite	-0.30	-0.29	0.07	-0.18	1.00					
Non magnetic fraction	-0.18	-0.11	0.34	-1.00	0.18	1.00				
Opaques	-0.12	0.01	-0.93	0.26	-0.08	-0.26	1.00			
Others	0.24	0.09	0.11	0.61	-0.23	-0.61	-0.19	1.00		
Sillimanite	-0.28	-0.08	0.21	-0.33	0.11	0.33	-0.15	-0.27	1.00	
Zircon	-0.11	-0.29	-0.10	-0.04	0.65	0.04	-0.02	-0.20	0.15	1.00

Number of observations = 27

Table 4.4 Pearson correlation matrix for the coarser fraction of Chalakudy river

	Biotite	Garnets	Inosilicates	Magnetic fraction	Non magnetic fraction	Opaques	Others	Sillimanite	Zircon
Biotite	1.00								
Garnets	-0.20	1.00							
Inosilicates	-0.49	0.24	1.00						
Magnetic fraction	-0.14	0.56	0.37	1.00					
Non magnetic fraction	0.14	-0.56	-0.37	-1.00	1.00				
Opaques	-0.88	-0.01	0.03	-0.10	0.10	1.00			
Others	0.33	0.10	0.03	0.13	-0.13	-0.40	1.00		
Sillimanite	-0.12	0.15	0.29	0.21	-0.21	-0.03	-0.05	1.00	
Zircon	-0.24	0.07	0.05	0.14	-0.14	0.20	-0.51	-0.32	1.00

Number of observations = 13

Table 4.5 Pearson correlation matrix for the finer fraction of Chalakudy river

	Biotite	Garnets	Inosilicates	Magnetic fraction	Monazite	Non magnetic fraction	Opaques	Others	Sillimanite	Zircon
Biotite	1.00									
Garnets	-0.23	1.00								
Inosilicates	0.02	0.46	1.00							
Magnetic fraction	-0.18	-0.05	0.01	1.00						
Monazite	0.24	0.09	-0.17	0.45	1.00					
Non magnetic fraction	0.18	0.05	-0.01	-1.00	-0.45	1.00				
Opaques	-0.31	-0.42	-0.92	-0.12	-0.03	0.12	1.00			
Others	-0.14	0.10	0.16	0.02	-0.14	-0.02	-0.15	1.00		
Sillimanite	-0.18	-0.33	-0.15	-0.45	-0.16	0.45	0.26	-0.21	1.00	
Zircon	-0.11	-0.20	-0.54	0.56	0.26	-0.56	0.33	-0.04	-0.11	1.00

Number of observations = 13

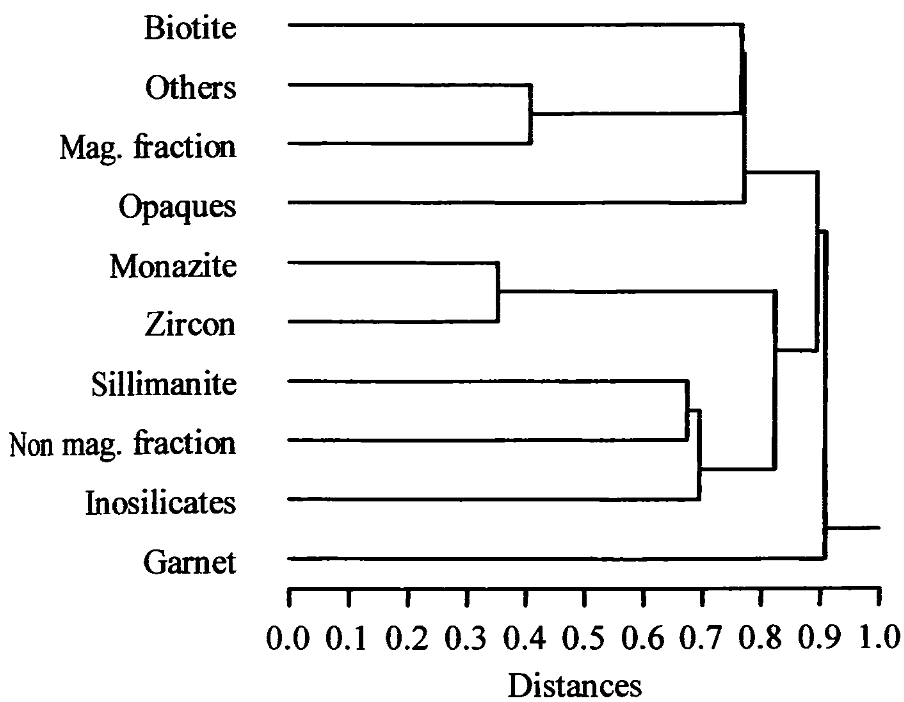


Fig. 4.11 Dendrogram for the finer fraction of Periyar river

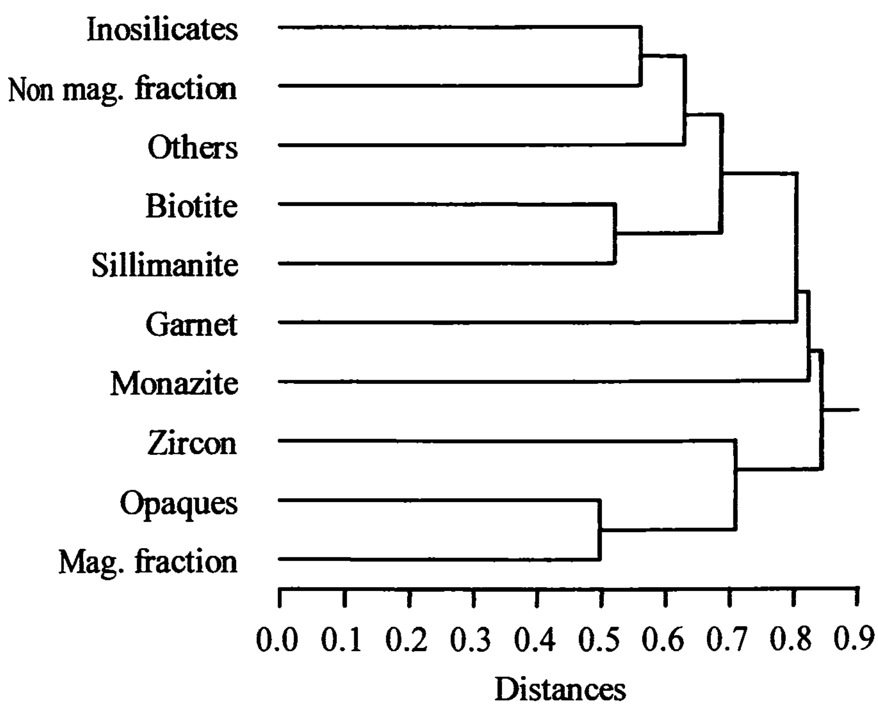


Fig. 4.12 Dendrogram for the coarser fraction of Periyar river

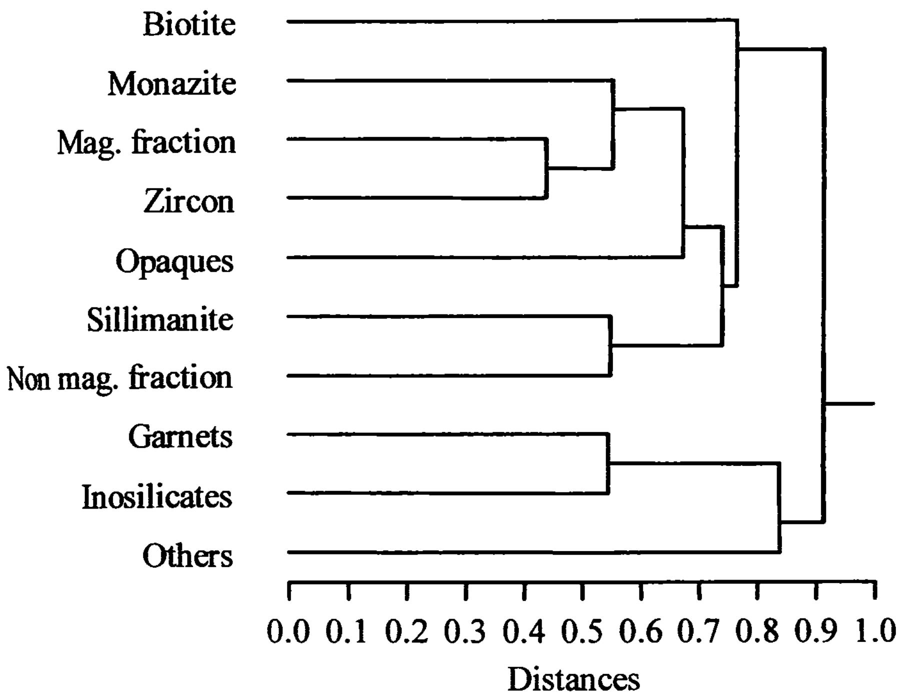


Fig. 4.13 Dendrogram for the finer fraction of Chalakudy river

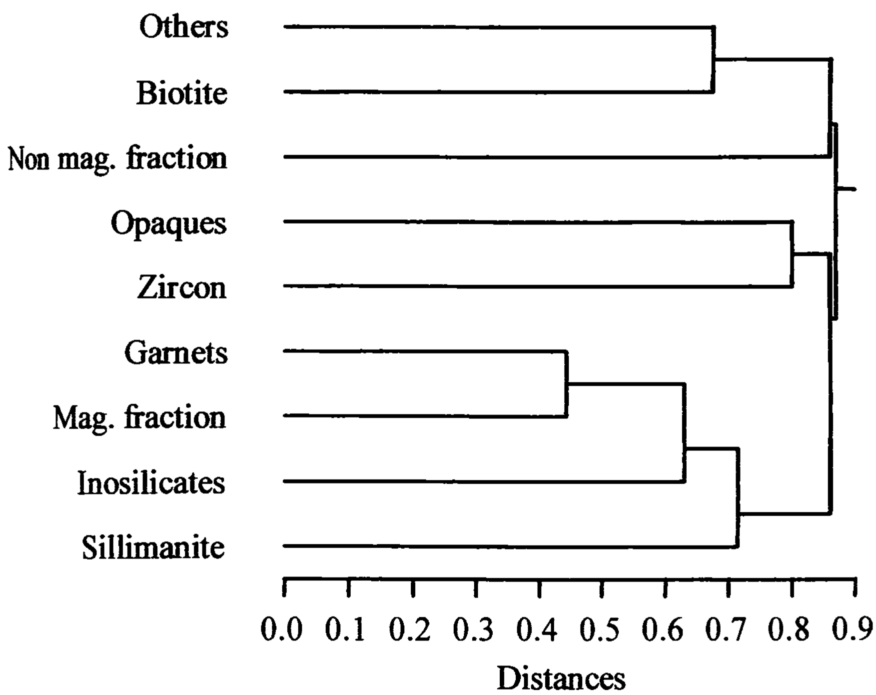


Fig. 4.14 Dendrogram for the coarser fraction of Chalakudy river

Causes of total heavy mineral variation

The total heavy mineral content in the riverbed of the Periyar and Chalakudy rivers reveals distinct segregation patterns. The highland physiographic provinces like plateau and scarp in the case of Periyar river exhibit higher concentration of THM. Further the content of THM is substantially higher in the finer fraction than coarser fraction. These observations corroborates well with the earlier studies of Rubey (1933), who stated that the grains of different densities if deposited together should have the same settling velocities or that the denser mineral should be smaller by an amount predictable, on the basis of settling velocity equation. Based on the theoretical observations, he emphasized that the grain size distribution of heavy minerals would be displaced towards the finer size grades with respect to quartz. However, subsequent investigations by a number of other researcher's show that the heavy and light minerals in natural sands and sandstones are seldom in hydraulic equilibrium (Briggs, 1965; Lowright et al., 1972; Singerland, 1977). Thus, the working hypothesis proposed by Rubey is considered to be somewhat imperfect. Hand (1964) has also observed the non-hydraulic equilibrium conditions in modern sands and explained the heavy light mineral variations primarily on the basis of selective sorting. White and Williams (1967) have found that heavy minerals once deposited are less easily entrained and transported by currents than grains of light minerals of the same size and shape. Therefore, heavies moving by saltation along with lighter minerals would tend to be smaller than the predicted size by settling velocity equation. The heavies are further shielded from currents by larger quartz grains and thus remain behind, while larger quartz grains are moved. The upstream of the Periyar river is characterized by high gradient physiographic features with high flow velocity during monsoon season. This high energy hydrodynamic regime is favourable for the concentration of the heavier / denser heavy minerals in the sediment population along with coarser lighter particles like pebbles and granules. The observed enrichment of total heavies in this section is in consonance with the high energy condition characterized by the simultaneous deposition of the coarser (lighter) and heavier grains in the upstream side consequent upon the drop in the gradient of the river profile as it enters in the midland and lowland.

Selective sorting of the heavies based on their size, shape and density plays a pivotal role in their entrainment and transportation resulting in their progressive enrichment with finer size. Studies made by Komar et al. (1989) also re-affirmed the general impression that selective sorting process significantly effects the heavy mineral composition in sediments. Apart from this, certain amount of variation can brought about by the inability of the low energy currents to entrain the heavies after its deposition and also by the shielding action of coarser light minerals, which prevents further movement of heavies (White and Williams, 1967).

The Chalakudy river also exhibit a similar type of enrichment of THM in the coarser and finer fractions - higher values in the upstream channels and lower concentration in the downstream side. The respective content of average total heavy mineral content in the coarser and finer fractions are 8.93% and 32.52% in the lowland region, in the midland an average of 15.60% in the coarser fraction and 32.22 % in the finer fraction are observed while in the highland region, an average of 40.87% in the coarser fraction and 68.91% in the finer fraction are observed. The minor fluctuations observed in the heavy mineral contents in the downstream might be due to the local turbulences resulted from natural and man made obstacles – a feature also reported earlier from the Rio Grande river of South Western Texas by Shideler and Flores (1980). The locally increased heavy mineral content can be explained by the presence of engineering structures across the river. The flow pattern undergoes considerable changes due to the presence of these structures. The jetting of water through the gaps creates local turbulences, which in turn cause the flushing away of lighter grains and favour concentration of the heavies and coarser lighter grains.

Causes of mineralogical diversities

The heavy mineral assemblage of Periyar and Chalakudy river sands consists predominantly of ilmenite, ionosilicates, garnets and biotite. Monazite, zircon and sillmanite are present only in minor quantities. In the Periyar river, opaques exhibit decreasing trend downstream in both coarser and finer fractions. While the inosilicates exhibit an opposite trend. Garnets in general, exhibits higher contents in upstream side, but in the downstream, the mineral exhibit a fluctuating trend. Biotite in both the fractions shows an increasing trend downstream. In the Chalakudy river, the concentration of opaques in the coarser and finer fractions are almost similar and there are some fluctuations in some locations.

The overall mineralogical diversities observed along the longitudinal profile of Periyar and Chalakudy river sands could be explained in terms of progressive sorting based on density differences of these minerals. During deposition, the denser minerals such as magnetite (sp. gr. 5.2) opaques (4.7) garnet (4.3) and zircon (4.6) settle quickly at the point of current impingements owing to their greater settling velocities, while the less denser minerals like inosilicates (hornblende = 3.5 ; hypersthene = 3; biotite = 2.9;

sillimanite = 3.2 etc) are transported still further downstream. Moreover, the high competency of the river water does not allow free settling of low gravity minerals in the upstream and as a result these minerals will be flushed further downstream and get deposited. Therefore, opaques, garnets and zircon remain upstream owing to their higher specific gravity. (Seralathan, 1979; Lewis, 1984; Kundras, 1987).

In the spatial variation diagrams (Fig 4.1 to 4.10) the positive anomalies of denser heavy minerals in each size fractions coincide with negative anomalies of lighter heavy minerals. All these clearly indicate the role of progressive sorting based on density in differentiating the heavy minerals downstream. High content of denser heavy minerals at some stations is attributed to local hydraulic conditions owing to the differences in the morphologic character of the terrain and / or the presence of engineering structures. While working on the lower Rio Grande river of Southwestern Texas, Shideler and Flores (1980) also observed a similar type of enrichment of denser heavy minerals immediately downstream of engineering structures. The anomalous increase of denser minerals downstream of Chalakudy town, is due to the natural turbulence resulted from the presence of rock exposures in the stream channel.

Many investigators (Pollack, 1961; Briggs et al., 1962; Shideler; 1975; Flores and Shideler, 1978) opined that progressive sorting based on shape of heavy minerals in accordance with the density of minerals plays a significant role in the observed mineralogical diversity. Since most of the coarser and finer fraction particles are being transported in suspension upstream and they do not settle at the same place. When particles of the same volume and densities but having different shapes are allowed to settle simultaneously through a column of liquid, particles with greatest sphericity will have the highest settling velocity (Blatt et al., 1972; Pettijohn, 1984). This may also attribute some role in the observed diversity of heavy mineral assemblage in the Periyar and Chalakudy river sediments.

Total light minerals

The sand fraction of the Periyar and Chalakudy rivers contains very high content of light minerals. The finer fraction accounts for an average of 71.42% (range: 20.98% to 90.86%) light minerals. The coarser fraction records slightly higher content (av. 86.28%; range: 40.27% to 96.48%) of light minerals than the finer counterparts. Spatial analysis of light minerals along the profile of these rivers reveals that these mineral suite exhibit a reverse trend compared to the heavy residue (Fig. 4.15). This clearly indicates the role of density based sorting prevailed in the Periyar and Chalakudy river and observed elsewhere (Padmalal, 1992).

Mineralogically, the light minerals are composed mainly of quartz and feldspars - the former dominates over the latter. Counting of light minerals of samples under microscope reveals that the number percentages of feldspars are found to be decreasing downstream indicating the intensity of abrasion taking place in these fluvial regimes when the grains are moved through the high gradient physiography.

4.3.2. Clay Mineralogy

Clay minerals constitute a major part of the finer fraction of the aquatic sediments and are reactive geological materials or particulates that regulate the overall physico-chemical milieu of aquatic environments (Whitehouse et al., 1960; Prithviraj and Prakash, 1990). The clay mineral compositions of sediments depend on the climatic

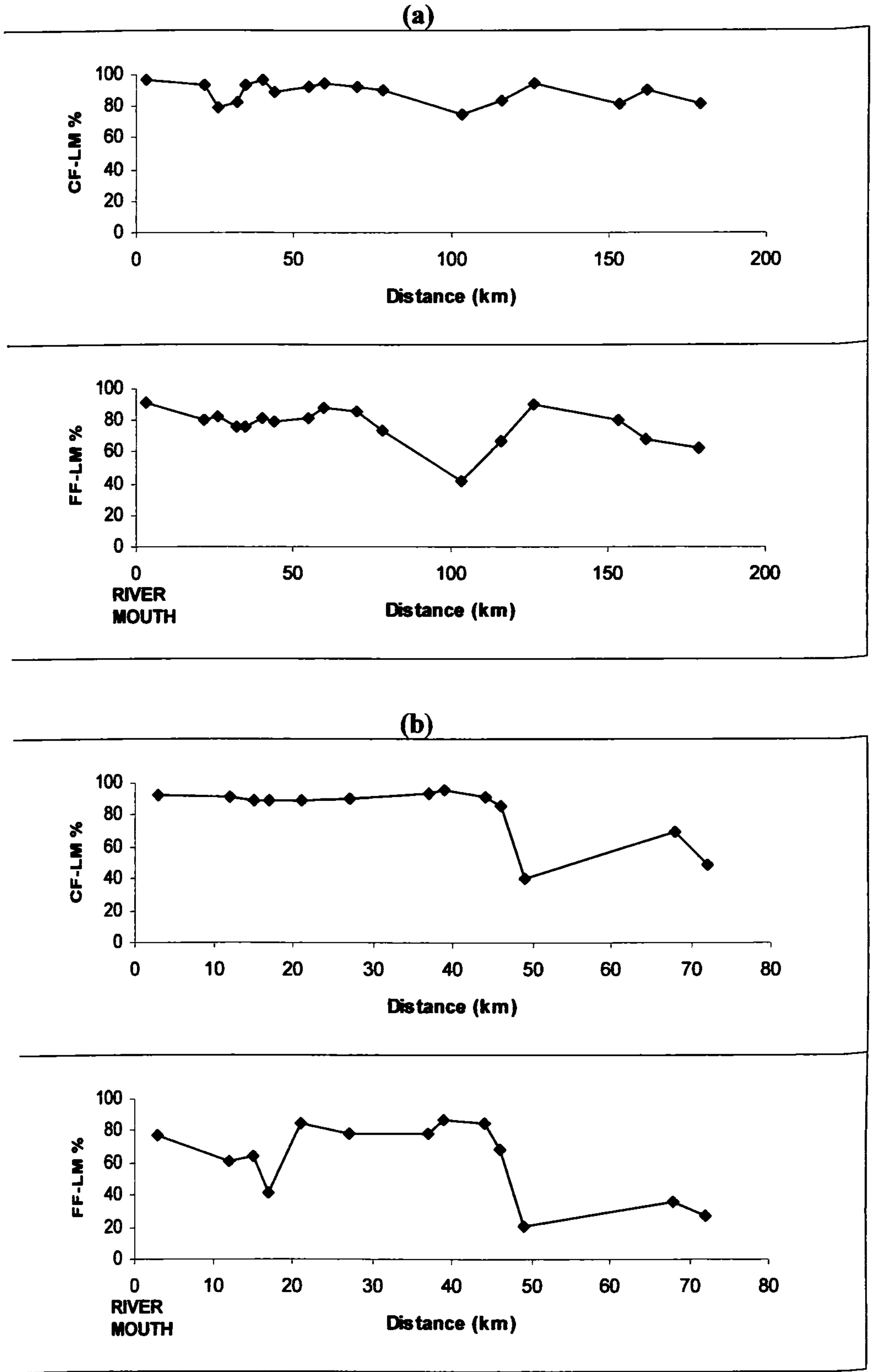


Fig. 4.15 Downstream variations of total light minerals (LM) in coarser and finer fractions of Periyar (a) and Chalakudy (b) rivers (CF- Coarser fraction; FF- Finer fraction)

conditions, provenance, rock types etc., of the region. The composition and distribution of clay minerals have been used as indicators of sediment dispersal in various environments (Biscaye, 1964; Grim, 1968). Information on clay minerals is essential for a better understanding of the origin, early diagenesis and environment of deposition of the sediments.

Fig 4.16 shows the X-ray diffractogram of clay fraction of the sediments of Periyar and Chalakudy rivers. The diffractogram exhibits prominent peaks of kaolinite [Al_2 $(OH)_4$ Si_2O_5] montmorillonite [$(Mg,Ca)O.Al_2O_3.5SiO_2.nH_2O$] and gibbsite ($Al_2O_3.3H_2O$). Among these three, kaolinite is the most dominant clay mineral identified from the area. Montmorillonite is confined mainly to the downstream of these river systems.

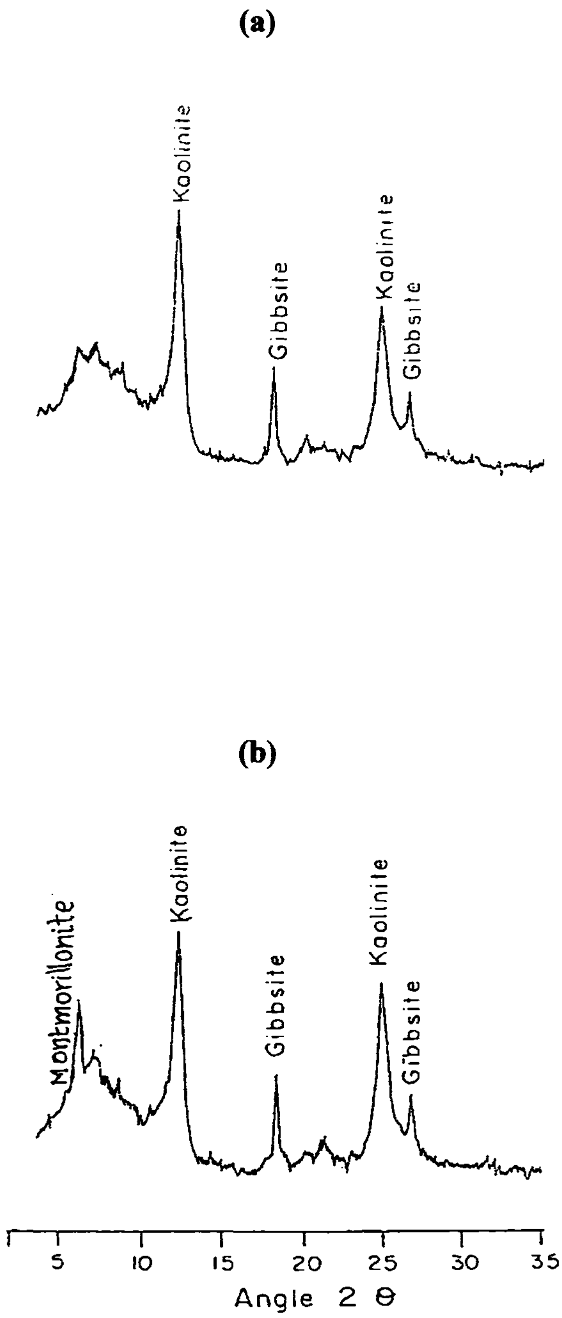


Fig 4.16 X-ray diffractogram of the clay fractions of Chalakudy (a) and Periyar (b) river basins

CHAPTER 5

GEOCHEMISTRY

INTRODUCTION

Over the past 3 - 4 decades, studies on aquatic sediments have increasingly being carried out for assessing the geochemical transport of elements, especially nutrients and heavy metals from land to oceans. It is now established that considerable changes in the global budget of geochemical signals, particularly of toxic contaminants, have occurred following the beginning of industrialization. In any aqueous environment, the transport phases of elements are generally controlled by size characteristics of clastic sediments (De Groot et al., 1982 ; Forstner, 1990). A large part of fluvial transport of matter occurs in the form of suspended sediments. During periods of low flows, these geochemical carriers sink to bottom as bed sediments. In an earlier study, Gibbs (1977a) formulated calculations of heavy metal concentrations in relation to grain size spectrum and revealed that the heaviest enrichment of metals occur in the finer grades ranging from 0.2 µm to 20 µm diameters. The variations of major and trace elements in the sediments are the reflections of the various factors, which govern their distribution. Such elements are introduced in aquatic environments either in solid / colloidal or in soluble forms by water and wind. Elements, which have their source in solid materials, include those located within the lattice structure of lithogenous minerals and those incorporated into surface by adsorption and ion exchange processes. Geochemical data of sediments may reflect the influence of several factors including the source characteristics. Chemical elements in estuarine sediments may be found as constituents of primary rock forming minerals, minerals formed during weathering, minerals typical of mineralisation, ions adsorbed onto colloidal particles and clays and in combination with organic matter. The annual riverine input of a trace element to the oceans must be equal to the output of that element associated with marine sediments. Bed load sediment discharge is deemed to represent not more than 10% of the suspended load (Meade, 1985) but the data substantiating this estimate are still fragmentary, (Milliman and Meade, 1983; Albarede and Semhi, 1995). Geochemists have extensively studied the major rivers of the world in order to estimate the fluxes of continental material supplied to the oceans (Potter, 1978; Seralathan, 1979; Meybeck, 1988; Padmalal, 1992; Milliman, 1995; Ittekkot and Lanne, 1991; Badarudeen, 1997; Sajan, 1998; Goolsby, et al., 2000; Krishnakumar, 2002; Reji, 2002; Turner and Millward, 2002; Somayajulu et al., 2002; Helland et al., 2003; Jennerjahn et al., 2004).

Considering the importance of sediments in the study of geochemical signals of aquatic environments, an attempt has been made in this chapter to evaluate the status of a few major (Fe, Na, K and Mg), minor (Mn) and trace elements (Ni, Zn, Pb and Cr) in the bulk sediments and mud fraction of the Periyar and Chalakudy rivers.

5.2 REVIEW OF LITERATURE

Many studies have been carried out in the world to understand the geochemical behaviours of elements moving from land to sea through various fluvial systems. Geochemical processes have been studied in great detail in river basins by several investigators (Gibbs, 1967; Seetharamaswamy, 1970; Satyanarayana, 1973; Seralathan, 1979; Stallard and Edmond, 1983; Subramanian et al., 1985a; Padmalal et al., 1997b). *The overall balance between dissolved and sedimented load carried out to the* oceans has been computed on the basis of the world's major river input studies by Holeman (1968), Meybeck (1976), Martin and Meybeck (1979) and Milliman and Meade (1983). Gibbs (1970) discussed the mechanisms that control the world river water chemistry. A number of geological agents are actively involved in the transfer of heavy metals from the terrestrial environment to the ocean realm. Rivers and estuaries are the major pathways in tropical and subtropical regions (Gibbs, 1967; Lal, 1977; Babu et al., 2000). Subramanian et al. (1985b) have computed that about 20% of global supply of sediments to ocean is from the Indian subcontinent. In recent years, there have been lot many studies to identify the sources and sinks of heavy metals in rivers, estuaries and nearshore environments. The fate of heavy metals in these environments is of extreme importance due to their impact on ecosystem (Vale, 1986; Mance, 1987; Klomp, 1990; Windom, 1990). Recent interest in anthropogenic contamination of the hydrosphere by heavy metals has magnified the urgency of elucidating the cyclicity of toxic metals in rivers and estuaries. Chemical analysis of river waters and the sediments is being carried out for exploration as well as environmental monitoring and management. The mechanism of trace metal concentration is believed to be adsorption on various geochemical phases such as hydrous metal oxide, clays and organic matter. Metal concentrations in sediments varied widely reflecting differences in sediment grain size, with higher metal concentrations located in the fine grained and have high spatial variability (Breslin et al., 1999; Zhang et al., 2002). Extensive work has been done in the world's major rivers by several investigators (Reeder et al., 1972, in Mackenzie river; Trefrey and Presley, 1976, in Mississippi river; Duinker and Nolting, 1976, in Rhine river; Gibbs, 1977a, in Amazon and Yukon rivers; Meybeck, 1978, in Zaire river; Yeast and Bewer, 1982, in St. Lawrence river; Sarin and Krishnaswami, 1984, in Ganges - Brahmaputra rivers and Qu and Yan, 1990, in Chang Jiang and Don Jiang rivers; Jeffrey et al., 1991, in Amazon Zaire and Orionoco rivers; Goolsby et al., 2000, in Missisippi river; Philip et al., 2003, in Yorkshire river; Turner and Rabalais, 2004 in Missisippi river).

The elemental concentration of sediments not only depends on anthropogenic and lithogenic sources, but also on the textural characteristics, organic matter content, mineralogical composition and depositional environment of sediments (Presley and Trefrey, 1980). It is an established fact that metals are associated with smaller grain size particles (Whitney 1975; Gibbs 1977a; Biksham et al., 1991). In addition, the grain size distribution of sediments may show spatial heterogeneity, so that a wide range in heavy metal concentration may be found. Several studies have indicated that in environments, where grain size distribution varies considerably, valid comparisons of metal concentrations cannot be made without a correction for grain size effect (De Groot et al., 1982; Forstner and Wittmann, 1983).

Albarede and Semhi (1995) have carried out geochemical investigation on three sand size fractions from the Meurthe river and its tributaries and brought to light the control of bedrock geology on the geochemistry of the fluvial sediments. Trefrey and Presley (1976) estimated the total flux of particulate and dissolved heavy metals from Mississippi river to the Gulf of Mexico. They have computed that over the past 25 - 30 years, the Pb and Cd fluxes in the Mississippi river sediments have increased about 60% and 100% respectively. The relationship between solid concentration and river water chemistry has been studied on the western Australian rivers by Imerson and Verstraten

1981). Several researchers opined that the metal pollution assessment can effectively be carried out from sediment analysis (Forstner and Wittmann, 1983 ; Allen, 1990).

From economical point of view, it must be realized that, sediments are also a medium in which certain substances can be concentrated from solution and thereby represent profitable sources of raw materials (Turekian, 1972). The size has a strong bearing on metal enrichment in sediments. Later, this view was supported by investigations made by Williams et al. (1978), Forstner (1982), Forstner and Wittmann (1983) and Lee (1985).

Much geochemical work has not been carried out in the rivers and estuaries of Kerala particularly in relation to the granulometry of the sediments. Murty and Veerayya (1972 a, b and 1981) made a preliminary survey on organic carbon, phosphorus and trace element contents in the bulk sediments on the Vembanad lake. They established the existence of a close relationship between organic carbon and phosphorus in this sedimentary environment. The trace metal concentration and its association in various chemical phases in the sediments of Periyar river and Varapuzha estuary have been investigated by Paul and Pillai (1983).

The geochemistry of sediments of the Indian rivers have received wide attention in the recent past to understand the elemental composition of the sediments, the influence of anthropogenic activities on riverine chemistry and the transport of metals from rivers to the coastal oceans (Borole et al., 1982; Subramanian et al., 1985a; Seralathan, 1987; Jha et al., 1990; Ramesh et al., 1990; Biksham et al., 1991; Konhauser et al., 1997; Singh, 1999). A comprehensive review of environmental geochemistry of Indian river basins is that of Subramanian (1987). Mass transfer studies of geochemical constituents in Indian rivers have been carried out by researchers like Subramanian (1980), Sarin and Krishnaswami (1984), Sitasawad (1984), Seralathan and Seetharamaswamy (1987), Chakrapani and Subramanian (1990). The geochemical transfer of metals through Cauvery river has been investigated by Subramanian et al. (1985b) and Seralathan (1987). The mineralogical and geochemical association of metals in the Krishna river sediments has been studied by Ramesh et al. (1989; 1990). Mallik and Suchindan (1984) and Padmalal (1992) analysed a few major and trace metals in the sediments of Vembanad estuary and Muvattupuzha river and Central Vembanad estuary respectively to ascertain their relation with granulometry. Desorption from fresh water clay minerals and control of Fe and Mn oxides over the trace elements in the estuarine region has documented by Seralathan (1987).

The distribution of Si, Al, Fe, Mn, Cu, Ni, and Cr in different grain size fractions and geochemical association of Fe, Mn, Cu, and Zn with less than 63μm size fraction of bed sediments of Damodar river shows that concentrations of trace metals tend to increase as the size fractions become finer. The exchangeable fraction of the Damodar river sediments contains very low amount of trace metals suggesting poor bioavailability of metals (Singh, 1999). The main processes that determine the behaviour of heavy metals in the Scheldt estuary are tidal hydrodynamics, sediment transport and sorption of heavy metals on suspended matter (Babi et al., 1998). The studies on calculated profiles of dissolved and sorbed concentrations of heavy metals in the water column indicated an accumulation of heavy metals in the zone of the turbidity maximum, while closer to the sea, the concentrations diminish due to mixing of the polluted fluvial sediments with unpolluted marine sediments and came out with a conclusion that only a small part of the heavy metals reaches the sea. It was not possible to predict sediment areas with the highest levels of metal contamination using visual criteria or knowledge of the erosion and sedimentation pattern of the river (Bervoets et al., 1999). Mallik and Suchindan (1984) have analysed a few major and minor elements in the bulk sediments of the Vembanad estuary. Later, Ouseph (1987) and Purandara (1990) have also studied the geochemical characteristics of a few sediment samples of Vembanad estuary. The speciation studies on the trace metals were carried out by Shibu et al. (1990) and Nair et al. (1991).

The speciation of heavy metals in the aquatic environment has received considerable attention recently (Chen et al, 1976; Hong and Forstner, 1984; Rapin, 1984). These studies throw light on two aspects: 1) their levels in the environment and 2) their fractionation in different phases. The investigations provide information on the mobility of the metal and bioavailability factors, and also highlight the role of processes such as sorption, diffusion and mobilization in controlling the concentration of metals in sediments. Calmano and Forstner (1983) are of the opinion that sequential extraction procedures would provide information on the history of metal inputs, diagenetic transformation within the sediments and the reactivity of heavy metal species of both natural and anthropogenic origin. Earlier studies on heavy metals are confined to the partitioning of metals in the detrital and non detrital fractions (Gad and Le Rich, 1966).

5.3 RESULTS AND DISCUSSION

5.3.1 Organic carbon (C-org)

Organic carbon constitutes a significant fraction of aquatic sediments. Organic material that survives in the water column is incorporated in sediments, where it can be more or less preserved or subjected to further biological degradation. Organic carbon compounds, reaching the aquatic environments mainly in the form of organic matter, originate from allochthonous or autochthonous sources. The relative proportions of organic matter derived from these sources are a function of the characteristics of the catchment area in relation to the productivity of the aquatic environment (Hakanson and Jansson, 1983). Further, the intensity of weathering, type of sediments, flow pattern of the medium that transport sediments also determine the C-org distribution in the sediments (Padmalal and Seralathan, 1995 ; Ittekkot and Lanne, 1991).

In the Periyar river, C-org content ranges between 0.4% and 4.71% (av. 1.70%) in bulk sediments and between 1.62% and 6.21% (av. 2.94%) in the mud fraction. The ranges of C-org in the Chalakudy river are 0.2% - 1.58% (av. 0.7%) in the bulk sediments and 2.11% - 3.96% (av. 2.95%) in the mud fraction. Tables 5.1 – 5.4 summarise the concentration of C-org in the sediments of the Periyar and Chalakudy river. Table 5.5 depicts a comparative evaluation of C-org in the bulk sediments and mud fraction of Periyar and Chalakudy rivers with some aquatic systems of Kerala and neighbouring States. In both the rivers C-org, generally, exhibits an increasing trend downstream. However, elevated concentrations are observed in some locations close to the urban centres. It may be due to the addition of significant amount of organic sewages to these river segments. Low values, if noticed, are attributed to the abundance of quartz rich

Table 5.1 Chemical parameters of bulk sediments of the Periyar river

Sample No.	C-org	Na	K	Fe	Mg	P	Mn	Ni	Zn	Pb	Cr
	(%)						(ppm)				
1	1.39	0.28	0.82	1.92	0.05	0.01	181	93	40	56	69
2	1.51	0.50	1.20	3.46	0.10	0.01	535	87	73	79	100
3	1.33	1.02	1.68	2.19	0.10	0.03	282	109	57	89	71
4	3.16	0.48	1.22	4.61	0.10	0.02	462	71	91	37	121
5	3.31	0.58	1.02	2.85	0.05	0.03	301	118	95	42	89
6	3.36	0.40	0.96	3.05	0.19	0.04	450	128	87	75	84
7	1.45	0.32	0.40	2.91	0.19	0.05	300	104	68	11	144
8	1.27	0.20	0.48	1.72	0.10	0.01	434	84	44	51	57
9	1.09	1.00	1.22	2.39	0.10	0.01	366	96	84	42	84
10	3.62	0.82	1.72	2.57	0.10	0.03	369	127	75	88	49
11	3.57	0.96	2.24	4.40	0.19	0.04	461	102	100	77	100
12	1.21	0.02	0.06	3.88	0.10	0.02	540	116	84	26	109
13	2.95	1.52	2.10	3.86	0.05	0.03	402	74	65	63	94
14	0.31	0.40	0.76	1.67	0.05	0.02	307	104	60	53	66
15	0.16	0.38	0.42	2.19	0.15	0.01	397	99	52	70	79
16	3.00	1.26	2.16	1.25	0.10	0.01	199	71	50	117	48
17	3.73	0.24	0.48	5.56	0.15	0.12	636	141	107	82	148
18	2.79	1.00	1.70	1.29	0.10	0.02	254	89	46	63	76
19	0.30	0.54	1.04	0.50	0.15	0.01	224	59	42	33	45
20	0.40	0.82	1.56	0.95	0.05	0.01	175	46	43	58	47
21	0.70	0.76	1.64	1.05	0.19	0.01	221	94	44	116	36
22	0.40	0.90	1.70	1.52	0.15	0.01	217	85	56	84	40
23	0.40	0.74	1.58	2.57	0.10	0.02	448	78	66	51	86
24	0.40	1.14	1.96	2.22	0.15	0.02	396	87	77	47	79
25	0.90	0.88	1.06	1.07	0.10	0.01	199	85	37	30	58
26	0.37	0.94	1.44	0.57	0.10	0.03	188	66	38	35	17
27	0.40	0.48	1.04	2.41	0.15	0.02	451	91	39	68	58
28	3.00	0.88	1.50	1.71	0.10	0.01	209	103	71	86	89
28a	0.40	0.91	1.12	1.14	0.10	0.01	185	101	66	54	67
29	0.44	1.02	1.60	1.29	0.10	0.02	115	66	81	54	55
29a	2.48	1.22	1.51	4.09	0.10	0.50	301	137	63	84	107
30	0.16	0.30	0.96	0.46	0.05	0.01	86	100	43	103	42
31	3.10	0.36	0.76	0.43	0.15	0.01	91	101	39	40	43
32	4.71	0.82	1.30	6.01	0.09	0.01	246	113	95	40	105
Average	1.70	1.38	1.25	2.35	0.11	0.04	313	95	64	62	75

[illegible]

Sample No.	C-org	Na	K	Fe	Mg	P	Mn	Ni	Zn	Pb	[illegible]
	(%)						(ppm)				
1	2.90	0.44	1.32	4.78	0.12	0.13	561	98	225	112	204
2	2.87	0.44	1.34	6.38	0.37	0.13	603	40	181	98	212
3	4.16	0.42	0.86	6.69	0.12	0.13	556	68	140	102	188
4	2.82	0.38	0.98	5.96	0.14	0.13	690	37	196	92	142
5	3.70	0.34	0.96	7.66	0.30	0.12	692	69	145	88	198
6	2.70	0.48	0.98	9.14	0.18	0.17	504	62	204	98	282
7	3.20	0.22	0.70	10.04	0.06	0.17	629	73	85	92	312
8	3.61	0.26	0.42	6.12	0.12	0.16	750	59	72	90	282
9	3.70	0.18	0.16	4.19	0.20	0.06	633	68	70	98	196
10	2.66	0.60	1.36	4.50	0.24	0.09	618	70	99	102	212
11	5.12	0.62	1.56	8.86	0.37	0.10	467	71	156	152	121
12	2.54	0.56	0.96	5.62	0.19	0.10	1352	101	165	98	151
13	2.35	1.18	2.20	7.18	0.15	0.11	1238	110	132	101	195
14	2.38	0.46	1.06	7.51	0.15	0.12	2993	128	217	152	182
15	1.94	0.24	0.48	4.89	0.10	0.06	1339	93	152	128	171
16	2.24	0.50	1.49	6.70	0.21	0.12	1711	155	280	107	216
17	3.47	0.50	0.94	5.82	0.10	0.11	934	122	273	84	204
18	3.23	0.56	1.23	6.28	0.05	0.16	625	110	291	103	210
19	1.62	1.36	1.79	4.37	0.38	0.10	998	157	269	90	268
20	2.08	0.72	1.30	4.45	0.15	0.13	516	136	169	88	265
21	4.19	1.16	1.48	4.14	0.19	0.14	528	113	271	70	226
22	2.46	0.46	0.96	4.57	0.10	0.17	796	148	184	123	194
23	2.25	0.72	1.28	5.61	0.05	0.13	826	140	195	79	233
25	3.46	2.60	1.04	4.36	0.05	0.09	304	94	152	54	166
26	1.95	0.43	0.92	4.62	0.10	0.31	213	116	136	95	279
28	2.51	0.32	1.00	5.65	0.15	0.11	361	109	674	91	226
28a	2.81	0.41	0.99	8.91	0.05	0.34	861	128	1008	824	741
29	3.10	0.40	2.80	4.19	0.24	0.06	402	68	237	35	257
29a	2.00	0.42	1.15	7.10	0.10	0.31	213	117	840	300	579
30	1.97	0.36	1.10	6.60	0.12	0.11	338	180	176	90	278
31	1.83	0.74	1.30	4.89	0.05	0.07	200	113	128	88	165
32	6.21	0.91	2.01	9.13	0.10	0.09	451	165	142	60	150
Average	2.94	0.61	1.19	6.15	0.16	0.13	747	104	239	124	241

Table 5.3 Chemical parameters of bulk sediments of Chalakudy river

Sample No.	C-org	Na	K	Fe	Mg	P	Mn	Ni	Zn	Pb	Cr
	(%)						(ppm)				
33	0.20	0.68	1.96	5.61	0.05	0.15	1536	124	154	63	145
34	1.07	0.64	1.24	6.67	0.05	0.15	2554	87	152	39	145
35	0.50	0.70	1.34	6.10	0.10	0.18	1231	119	95	75	105
36	0.40	0.96	1.60	7.70	0.24	0.14	1456	80	116	116	106
37	0.47	0.64	1.44	5.09	0.19	0.18	627	88	84	51	107
38	1.58	1.10	1.72	5.63	0.19	0.17	727	126	102	67	128
39	0.67	0.24	0.74	4.23	0.10	0.13	681	83	78	46	101
40	0.67	0.58	1.08	8.60	0.10	0.18	1078	94	168	96	149
41	0.67	1.06	1.62	3.69	0.15	0.18	619	113	74	89	92
42	0.64	0.90	1.70	2.14	0.10	0.03	461	82	56	60	68
43	0.80	1.60	2.22	2.22	0.10	0.07	432	75	65	67	82
44	1.27	0.78	1.56	1.32	0.10	0.03	314	106	51	37	55
45	1.41	1.48	2.16	6.46	0.15	0.03	429	83	73	67	78
46	1.17	1.20	1.82	1.90	0.19	0.03	402	74	59	79	48
47	0.64	1.08	1.74	2.73	0.10	0.04	452	88	77	95	74
48	0.80	0.70	1.42	1.83	0.10	0.09	351	78	47	72	47
49	0.20	0.48	1.12	1.94	0.05	0.02	307	58	44	23	65
50	0.20	1.12	2.04	3.35	0.05	0.02	441	71	64	63	69
51	0.47	0.74	0.54	2.84	0.05	0.04	484	93	60	46	45
52	0.50	0.02	0.10	3.23	0.05	0.02	565	94	75	65	68
53	0.54	0.34	0.84	4.39	0.05	0.01	785	103	88	40	74
54	0.60	0.10	0.44	0.73	0.05	0.03	292	67	33	74	31
Average	0.70	0.78	1.38	4.02	0.10	0.09	737	90	82	65	86

Table 5.4 Chemical parameters of mud fraction of Chalakudy river

Sample. No	C-org	Na	K	Fe	Mg	P	Mn	Ni	Zn	Pb	Cr
	(%)						(ppm)				
33	2.16	0.36	0.74	5.82	0.24	0.10	1825	132	168	55	212
36	3.45	0.56	1.20	6.56	0.10	0.05	2012	143	173	68	152
39	2.98	0.28	1.09	7.90	0.19	0.01	1575	216	172	56	218
40	3.15	0.52	1.26	10.41	0.10	0.02	1303	125	310	93	213
41	3.32	0.50	1.38	5.72	0.10	0.02	782	137	173	98	197
43	2.83	0.54	1.38	6.43	0.37	0.18	937	146	233	108	209
46	2.62	0.92	1.38	6.71	0.30	0.19	752	128	234	115	196
48	3.10	0.30	0.90	7.13	0.10	0.03	672	158	318	109	203
50	2.98	0.41	2.70	6.36	0.18	0.03	529	205	381	93	228
52	3.96	0.48	1.22	7.77	0.05	0.03	602	130	229	70	192
53	2.79	0.42	1.16	6.30	0.10	0.02	646	125	192	84	183
54	2.11	0.61	1.36	7.42	0.16	0.02	722	229	231	105	236
Average	2.95	0.49	1.31	7.04	0.16	0.06	1030	156	235	88	203