# Chapter - IV

## RESULTS AND DISCUSSION

### SEDIMENTS

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The quality of sediment in a river system is an important environmental concern because it may act both as a sink and a source of water-quality constituents to the overlying water and to biota. Sediments act as the major sink for organic carbon, nitrogen, phosphorus, potassium etc. Both natural and anthropogenic materials accumulate in sediments and it is difficult to identify the proportion from each source. The rate of loading of these materials depends on the physicochemical properties of the sediment.

Highly polluted sediments adversely affect the ecological functioning of rivers due to heavy metal mobilization from urban areas into biosphere. The organic matter from the water column gets transported to the surface sediments and there it becomes modified due to the activities of living organisms. A number of investigations have been carried out on sediments of Indian rivers for physical and biogeochemical characteristics. A systematic study on the sediments of River Meenachil is meagre and hence the present study.

Superficial sediment samples were collected during pre-monsoon, monsoon and post-monsoon from 10 sampling stations and analysed for quality parameters. Samples were collected using a van Veen grab, stored deep frozen in polythene bags until analysis and dried in an oven at 55°C for 48 hours before analysis. Depth-profiling was not possible since the quantity of sediment available was meager due to sand-mining.

The texture, physicochemical parameters and organochlorine pesticide residues in the sediments of river Meenachil have been analyzed during the three seasons. The seasonal and annual distribution of sediment parameters are given in appendix Tables A5-A8, correlation matrices in A13-A16. results of Two-way ANOVA in A39-A48 and organochlorine pesticide levels in A81. The following is a brief narration of the results.

4.1 TEXTURAL ANALYSIS

The texture of the sediments plays a very important role in determining its composition. Textural characteristics of Meenachil river sediments during the study period
are given in appendix Table A8. The average values for sand, silt and clay during the study period were (90.10%), (6.85%) and (3.05%) respectively.

The samples from the downstream locations of the river were richer in clay and silt fractions. This may be due to the large quantities of silt carried in by the numerous rivulets and canals which carry sediments into the river. The percentage of sand was greater in stations located on the highland regions of the river.

The percentage of sand, silt and clay fractions of sediments along with the textural class, during pre-monsoon, is given in Table A5. The average values for sand, silt and clay were 90.56%, 6.36% and 3.08% during pre-monsoon period. The textural class of sediments is sandy in stations 1, 2, 3, 4, 5, 6, 7 and 8, loamy sand in station 9 and sandy loam in station 10.

Fig. 4.1 Pie-diagram showing seasonal and annual composition of sediments

The percentage of sand, silt and clay fractions of sediments along with the textural class, during pre-monsoon, is given in Table A5. The average values for sand, silt and clay were 90.56%, 6.36% and 3.08% during pre-monsoon period. The textural class of sediments is sandy in stations 1, 2, 3, 4, 5, 6, 7 and 8, loamy sand in station 9 and sandy loam in station 10.
The percentage of sand, silt and clay fractions of sediments and the textural classification during monsoon are given in Table A6. The values for sand, silt and clay were 89.57, 7.54%, and 2.89% during monsoon season. The textural class of sediments is sandy at stations 1 to 8, doamy sand at station 9 and sandy loam at station 10.

The sand, silt and clay percentage of sediments along with the textural classification during post-monsoon period is presented in Table A7. The average values for sand, silt and clay were 90.18%, 6.66% and 3.17% during post-monsoon. The textural class of sediments is sandy at stations 1 to 8, loamy sand in station 9 and sandy loam in station 10.

4.1.1 Sand

Tables A5-A8 gives the seasonal and annual percentage distributions of sand in the sediments of Meenachil River. The annual values for sand fluctuated between 77.5% at station 10 during monsoon and 95.8% at station 1 during pre-monsoon seasons. The seasonal values fluctuated between 79.7% at station 10 and 95.8% at station 1 during pre-monsoon season, 77.5% at station 10 and 94.1% at station 1 during Monsoon, and 79.5% at station 10 and 95.6% at station 1 during post-monsoon.

The median, sd and cv were respectively 91.63, 4.44 and 4.90 during Pre-monsoon, 91.13, 4.93 and 5.50 during Monsoon and 90.92, 4.45 and 4.94 during post-Monsoon seasons.

The observed maximum values for River Meenachil were in conformity with the values reported for the major rivers in Kerala. The sand content of sediment was between 62.6% and 98.5% with a mean value of 89.8% for river Pamba in Kerala (Mathew Koshy, 2001). Sand content ranged between 67.3% and 98.5% in the sediments of the Poovar estuary in Kerala (Helen et al., 2008).
The percentage of sand in the sediments of Meenachil river has significant correlation with clay (-0.995), silt (-0.971), EC (-0.948), LOI (-0.770), OC (-0.883), OM (-0.883), Nitrogen (-0.874), Phosphate-P (-0.771), Copper (-0.735) and chromium (-0.785).

![Fig. 4.2 Seasonal and annual distribution of sand in the sediments](image)

Two-way ANOVA was performed to test whether the average values for sand differ with (a) season and (b) location of stations. The seasonal averages have significant effect on percentage of sand since the F-value (7.34) is greater than the F-critical value (3.55) with $p=0.0047$. Location of stations also have effect on the percentage of sand since the F-value (186.9) is greater than the F-critical value (2.46) with $p=6.55E-16$.

4.1.2 Silt

The seasonal and annual distribution of silt in the sediments of Meenachil river is given in Tables A5-A8. The percentage of silt in the sediments of the Meenachil River fluctuated between 4.16% and 12.17% with an average of 6.85% during the study period. The percentage distribution of silt varied between 4.16% and 8.59% during pre-monsoon, 5.78% and 12.17% during monsoon and 4.27% and 9.22% during post-monsoon.

The median, standard deviation and coefficient of variation were respectively, 6.30, 1.18 and 18.57 during pre-monsoon, 6.81, 1.93 and 25.66 during Monsoon and, 6.78,
1.40 and 20.99 during post-Monsoon seasons. Maximum percentage of silt was observed at stations 9 and 10 while minimum values were observed at stations 1 and 2.

The seasonal distribution of silt in the sediments of Meenachil river is given in Fig. 4.3. The percentage of silt was more or less uniform during pre-monsoon. However, variations were observed during monsoon and post-monsoon seasons as expected.

The composition of silt ranged between 1.5% and 20.6% in the sediments of the Pazhayar river in Tamilnadu (Indirani and Natarajan, 2007). Silt content ranged between 1.5% and 20.6% in the pediments of the Poovar estuary (Helen et al, 2008) and between 1.5% and 22.7% with a mean value of 6.7% in river Pamba in Kerala (Mathew Koshy, 2001). The observed values for River Meenachil were less than the values reported for the major rivers in Kerala.

Fig. 4.3 Seasonal and annual distribution of silt in the sediments

The percentage of silt in the sediments of Meenachil river has significant correlation with clay (0.941), sand (-0.971), EC (0.955), LOI (0.873), OC (0.912), OM (0.912), nitrogen (0.907), PO₄-P (0.792), Cu (0.753), lead (0.733), manganese (0.712) and chromium (0.789).

There is significant seasonal variation in the silt content of the river sediments since the F-value (7.299) is greater than the F-critical value (3.55) with $p < 0.004771$. 
Location of stations also have significant effect on the percentage of silt, since the F-value (11.841) is greater than, the F-critical value (2.456) with $p=6.84\times10^{-6}$.

4.1.3 Clay

The annual values of clay fluctuated between 0.11% and 11.13% with an average of 3.05%. The values were 11.75% at station 10 and 0.07% at station 1 during pre-monsoon, 10.37 at station 10 and 0.11% at station 1 during Monsoon and 11.26% at station 10 and 0.14% at station 1 during post monsoon seasons. The seasonal mean values were 3.08%, 2.89% and 3.17%. The seasonal, and annual distribution of clay in the sediments of River Meenachil is given in Tables A5-A8.

The clayey character of sediments exhibited a gradual increase from station 1 to station 10. The high clay content is attributed to land mining, sand mining and land filling activities taking place in the lower part of the river. The median, sd and cv were respectively 2.18, 3.44 and 111.9 during Pre-monsoon, 2.25, 3.10 and 107.1 during Monsoon and 2.70, 3.19 and 100.7 during post-Monsoon. Fig. 4.4 shows the seasonal distribution of clay in the study area during the three seasons.

![Fig. 4.4 Seasonal and annual distribution of clay in the sediments](image)

The observed values for River Meenachil were less than those reported for the major rivers in Kerala. The percentage composition of clay ranged between 0.0-14.7 with a
mean value of 3.9 in the sediments of the river Pamba in Kerala (Mathew Koshy, 2001).
Clay content ranged between 7.18% and 39.7% in the sediments of the Poovar estuary in Kerala (Helen et al., 2008). The composition of clay was less than 7.2%-39.7% in the sediments of the Pazhayar river in Tamilnadu (Indirani and Natarajan, 2007).

The percentage of clay in the sediments of Meenachil river has significant correlation with silt (0.941), sand (-0.995), EC (0.927), LOI (0.711), OC (0.855), OM (0.855), nitrogen (0.844), phosphate-P (0.748), copper (0.713), and chromium (0.769).

Two-way ANOVA was performed to test whether the average values for clay differ with (a) season and (b) location of the station. From the results it is evident that location of stations have no significant effect on the percentage of clay since the $F$-value (1.02) is less than the $F$-critical value (3.55) with $\alpha=0.05$. The seasonal averages differ significantly ($p=2.41E-1$).

4.2 PHYSICAL PARAMETERS

4.2.1 pH

pH is important in estimating the acidic or alkaline character of sediments. pH determines the availability of nutrients, microbial activity and physical condition of the sediment. Tables A5-A8 gives the seasonal and annual distribution of pH of sediments of Meenachil river.

In the study area, pH varied from 5 to 6.4 with an average of value of 5.8. All the sediment samples during all the three seasons were acidic. This may be due to the high organic matter content of sediments in these areas undergoing putrefaction releasing CO$_2$ (Murty and Veerayya, 1971). The mean pH values were 5.5, 6.1 and 5.7 during pre-monsoon, monsoon and post-monsoon seasons respectively. The annual mean value was 5.8. The experimental data corresponding to the pH of the sediments along with mean, median, sd and cv are given in the appendix. The annual mean values of pH of the
Sediments at the selected ten locations are shown in Fig. 4.5. Station 4 (Erattupetta) recorded the lowest value indicating high organic load at this location in the river.

![Seasonal and annual variation of pH](image)

*Fig. 4.5 Seasonal and annual variation of pH*

The seasonal changes in pH are depicted in Fig.4.5. The lowest and highest values of pH were 5 and 5.8 during pre-monsoon, 5.8 and 6.4 during monsoon and 5.3 and 6.1 during post-monsoon respectively. The present study showed that the sediments were acidic during the pre-monsoon season. With the advancement of the post monsoon season, pH in all stations showed an increase indicating a reduction in acidity. This may be due to the high dissolved oxygen content and high temperatures of both surface and bottom waters which may aid the destruction of organic matter by oxidation rather than preservation of it in these sediments (Murty and Veerayya, 1971). pH is influenced by the presence of metal ions in sediment.

pH has significant negative correlation with silt (-0.654), LOI (-0.656), EC (-0.581), Nitrogen (-0.633), Nickel (-0.762) and Chromium (-0.592). The seasonal averages have significant effect oil pH since the $F$-value (37.09) is greater than the F-critical value (3.55) with $j7=0.000$. Location of stations also has significant effect on pH since the $F$-value (439) is greater than the F-critical value (2.46) with $p=0.004$. 
4.2.2 Electrical Conductivity

Sediments contain small amounts of various soluble salts. These salts may arise from different sources such as primary minerals found in soil and in the exposed rocks of the earth’s crust. Electrical conductivity is directly related to the soluble salt concentration of sediment. Electrical conductivity is influenced by industrial effluents, domestic and municipal sewage, salinity intrusion and fresh water influx from tributaries. The seasonal and annual values of electrical conductivity of the sediments of River Meenachil are given in Appendix Tables A5.-A8.

![Electrical Conductivity Chart](image)

**Fig. 4.6** Seasonal and annual variation in electrical conductivity of sediments.

The mean values for electrical conductivities were 207.2μS/cm, 138.9μS/cm and 161.4μS/cm during pre-monsoon, monsoon and post-monsoon seasons respectively. The mean EC of the sediments of the river during the study period was 169.2μS/cm. The minimum electrical conductivity of 98.5μS/cm was observed at station 1 during monsoon and the highest value of 381.0μS/cm was recorded at station 10 during pre-monsoon. The highest and lowest values of electrical conductivity were 381.0μS/cm and 115.0μS/cm during pre-monsoon, 195.6μS/cm and 98.5μS/cm during monsoon and 219.3μS/cm and 106.4μS/cm during post-monsoon respectively.
The seasonal and annual variation of electrical conductivity at the ten selected stations is given in Fig. 4.6. The EC values show a gradual increase from station 1 to station 10. High value is recorded at station 10 due to saline water intrusion from Vembanad lake into which the river debouches.

The seasonal variation of electrical conductivity at the selected stations is given in Fig. 4.6. High values of electrical conductivity were observed during pre-monsoon period, and low values during monsoon period due to larger amount of water present. The experimental data, mean, sd and cv values are given in the appendix. The median, sd and cv were, 196.5, 85.2 and 41.1 during pre-monsoon, 132.1, 28.3, and 20.41 during monsoon and 164.8, 35.7 and 22.1 during post-monsoon.

EC shows significant positive correlation with clay (0.927), silt (0.955), sand (-0.948), LOI (0.796), OC (0.956), OM (0.956), nitrogen (0.919), phosphate-P (0.879), iron (0.672), zinc (0.607), copper (0.757), nickel (0.757) lead (0.811), manganese (0.783) and chromium (0.900).

There is significant seasonal variation of electrical conductivity since the F-value (37.09) is greater than the F-critical value (3.55) with $\beta$=4.2E-07. Location of stations also has a significant effect on electrical conductivity since the $F$-value (4.39) is greater than the F-critical value (2.46) with $\beta$=0.003692.

4.2.3 Loss on Ignition

Loss on ignition (LOI) indicates the presence of organic matter, which is primarily detritus in nature. It is influenced by organic pollutants from industries, agriculture, domestic and municipal sewage etc. The seasonal and annual values of Loss on Ignition of the sediments of River Meenachil are given in Appendix Tables A5-A8.

The lowest LOI values recorded were 0.67% at station 1 during post-monsoon and 0.74% at station 1 during pre-monsoon and the annual mean; for the river during the study
period was 1.05%. The minimum and maximum values of LOI were 0.74 % at station 1 and 1.28% at station 10 during pre-monsoon, 0.84% at station 1 and 1.29% at station 10 during monsoon and 0.67% at station 1 and 1.35% at station 10 during post-monsoon seasons. The mean LOI during Monsoon was 1.09%, post-monsoon was 0.98% and pre-monsoon was 1.09% respectively.

![Fig. 4.7 Seasonal and annual variation of Loss on Ignition of sediments](image)

Fig. 4.7 Seasonal and annual variation of Loss on Ignition of sediments

High LOI value recorded at station 10 may be due to greater silt content of sediment arising from agricultural and municipal wastes and various other anthropogenic activities around this location (Fig.4.7). The median, standard deviation and coefficient of variation during the three seasons were 1.14 0.18 and 16.4 during pre-monsoon, 1.11, 0.14 and 12.84 during monsoon and 1.03, 0.23 and 23.63 during post-monsoon respectively.

The annual mean values of LOI exhibited significant correlation with clay (0.711), silt (0.873), sand (- 0.770), EC (0.796), OC (0.857), OM (0.857), nitrogen (0.781), phosphate-P (0.755), Cu (0.695), Pb (0.684), Mn (0.763), and Cr (0.617).

There is no significant seasonal variation in Loss-on-ignition since the F-value (3.68) is comparable to F-critical value (3.55) with \( p=0.04 \). Location of stations have significant effect on Loss on Ignition since the F-value (8.03) is greater than the F-critical value (2.46) with \( p=0.0001 \).
4.3 CHEMICAL PARAMETERS

4.3.1 Organic Carbon

The organic matter content of river sediments depends upon sources like land run off and from the overlying waters through organic productivity. With the presence of several water channels joining the river at different points, the source from land is evident. Presence of patches of mangrove forest on river banks, high rate of primary production in tropical rivers, prevailing anoxic condition and fine particle size of sediments also contribute to organic matter.

The seasonal distribution of the sedimentary organic carbon (SOC) is given in Tables A5-A8. The annual values of SOC fluctuated between 0.08 mg/g at station 1 during Monsoon and 0.94 mg/g at station 10 during pre-Monsoon seasons. The seasonal values fluctuated between 0.13 mg/g at station 1 and 0.94 mg/g at station 10 during pre-Monsoon, 0.08 mg/g at station 1 and 0.74 mg/g at station 10 during Monsoon, between 0.12 mg/g at station 1 and 0.85 mg/g at station 10.

Fig. 4.8 Seasonal and annual variation in Organic carbon of sediments.

It is found that total SOC content increased with precipitation and clay content and decreased with temperature (Jobbagy and Jackson, 2000). Fig. 4.8 denotes the annual
variation of SOC at the selected locations. Increased concentration of organic carbon in stations 4, 8, 9 and 10 could be due to increased terrigenous addition of organic matter.

The values were in conformity with those obtained for other rivers in Kerala. Nayar (1992) reported sediment organic carbon content that varied between 0.63 and 60.34 mg/g for Muvattupuzha River. Sediment organic carbon fluctuated between 2.71 and 62.90 mg/g for Parvathyputhenar river (Prasanthan and Nayar, 2000), between 1.96 and 4.09 mg/g for Poovar river (Njemi, 2000), and 0.6 and 1.39 mg/g for River Pamba (Mathew Koshy, 2001). Prasad et al. (2008) reported OC values that varied from 37 mg/g to 80 mg/g for River Pamba and 20 mg/g to 75 mg/g for River Achenkovil in Kerala. The composition of OC ranged between 0.517% and 1.523% in the sediments of the Pazhayar river in Tamilnadu (Indirani and Natarajan, 2007). OC content ranged between 0.517% and 1.523% in the sediments of the Poovar estuary in Kerala (Helen et al, 2008).

The organic carbon values were higher at all stations during pre-monsoon season. This may be due to the increased pollution load. Decomposition and decay of plant and animal materials, agricultural runoff, and tourism activities are the major reasons for the high organic carbon content of sediments. The seasonal variations at the various stations may be due to anthropogenic activities. The median, standard deviation and coefficient of variation were 0.63, 0.25 and 42.04 during pre-monsoon, 0.47, 0.21 and 46.74 during monsoon and 0.39, 0.24 and 58.61 during post-monsoon seasons. The seasonal means were 0.59, 0.44 and 0.42 respectively.

Organic carbon shows significant positive correlation with clay (0.855), silt (0.912), EC (0.956), LOI (0.857), OM (1.00), Nitrogen (0.888), phosphate (0.948), Fe (0.805), zinc (0.745), copper (0.828), nickel (0.729), lead (0.844) manganese (0.897), chromium (0.870), and significant negative correlation with sand (-0.883). There is significant seasonal variation in organic carbon content of sediments since the F-value
(9.64) is much greater than the F-critical value (3.55) with \( p = 0.0014 \). Location of stations have significant effect on organic carbon content since the F-value (15.93) is greater than the F-critical value (2.46) with \( p = 7.48 \times 10^{-7} \).

### 4.3.2 Organic Matter

Sediment OM has to be regarded as the residue of organic life. Investigation on organic matter in the sediments can give evidence to the extent of biological activity and indirectly the fertility of overlying water as well as the status of pollution of the overlying water. The identification of sources of organic matter helps to study their effects on the carbon and nitrogen dynamics of these ecosystems.

The seasonal distribution of the sedimentary organic matter is given in Table A5-A8. The annual values of OM fluctuated between 0.14 mg/g at station 1 during Monsoon and 1.62 mg/g at station 10 during pre-Monsoon seasons. The seasonal values fluctuated between 0.22 at station 1 and 1.62 mg/g at station 10 during pre-Monsoon, 0.14 mg/g at station 1 and 1.28 mg/g at station 10 during Monsoon, between 0.21 mg/g at station 1 and 1.46 mg/g at station 10. The annual mean value for organic matter was 0.83 mg/g.

The annual variation of organic matter of sediments at the selected stations is given in Fig.4.9. Stations 4, 9 and 10 show high values due to greater pollution load. The seasonal variation is also given in Fig.4.9. High values were observed during pre-monsoon period due to low disturbance in the river bed. The experimental data, mean, sd and cv are given in the appendix Tables A5-A7. The median, standard deviation and coefficient of variation were 1.08, 0.43 and 42.04 during pre-monsoon, 0.81, 0.35 and 46.74 during monsoon and 0.67, 0.42 and 58.61 during post-monsoon seasons.

The physical and chemical properties of sediments such as water retention capacity, porosity and compressibility are to a great extent controlled by the amount of organic material within the sediments. The texture of the sediment plays a very important
role in binding the organic matter. Organic matter has a high affinity for fine-grained sediment that accumulates and gets adsorbed onto mineral surfaces. The finer particles may provide increased surface area per unit weight for adsorption of organic matter (Sunil Kumar, 1996). Therefore, organic matter concentrations increase with decreasing grain size. Sandy sediments are relatively poor in organic matter preservation (Suthhof et al, 2000). The different types of organic matter found in sediments are humic acids, fulvic acid, amino acids, fatty acids, carbohydrates, proteins, lipids, purines, pyrimidines, lignins, hydrocarbons, steroids, chlorophyll etc.

![Fig. 4.9 Seasonal and annual distribution of organic matter in sediments](image)

The preservation of organic matter is almost exclusively restricted to sediments. The amount of organic matter found in sediment is a function of the amount of various sources reaching the sediment surface and the rates at which different types of organic matter are degraded by microbial processes during burial. The major sources of organic matter are decayed matter from plants, zooplankton, phytoplankton and higher plants and organic wastes and runoff from towns and cities. Particles from the euphotic zone sink to the sediment water interface, where benthic organisms rapidly degrade the labile organic compounds present in the settled materials. The survival of these compounds in sediments depends mainly on their chemical stability (Premuzic et al, 1982).
The finer clay particles may provide increased surface area per unit weight for adsorption of organic matter and therefore the concentrations increase with decreasing grain size (Hedges and Keil, 1995; Nair et al. 1993; Sunilkumar, 1996). Generally organic rich sediments are deposited in areas where organic productivity is high and oxygen supply is low. Monsoon season is marked by heavy rain and flood, river discharge etc and is therefore not favourable for the accumulation of organic matter. Pre-monsoon season is most favourable for organic matter accumulation (Nandan and Aziz, 1996).

Organic matter shows a clear positive correlation with the clay content of the sediments. Generally, OM increases with silt percentage and clay percentage. The concentration of organic matter varies temporarily and spatially since they are regulated by so many factors like forest type, climate, sediment texture, sedimentation rates, tidal effects, oxygen availability, rate of primary production and biological activity. The seasonal distribution of the sedimentary organic carbon (SOC) is given in Tables A5-A8.

Organic Matter shows significant positive correlation with clay (0.855), silt (0.912), EC (0.956), LOI (0.857), OC (1.0), Nitrogen (0.888), phosphate (0.948), Fe (0.805), zinc (0.745), Cu (0.828), nickel (0.729), lead (0.844), manganese (0.897) and chromium (0.870), and significant negative correlation with sand (-0.883). Significant seasonal variation in organic matter content of sediments since the F-value (9.65) is greater than the F-critical value (3.55) with $p=0.00142$. Location of stations also has significant effect on organic matter content since the F-value (15.93) is greater than the F-critical value (2.45) with $p=2.54E-5$.

### 4.3.3 Total Nitrogen (TN)

Nitrogen is an essential nutrient for plants and animals. Nitrates in sediments are the result of natural biological processes associated with the decomposition of plant and
animal matter. Organic Nitrogen forms a significant fraction of sedimentary organic matter and is closely related to biological productivity.

The annual nitrogen concentration in the sediments was in the range 0.080 mg/g to 0.22 mg/g with a mean value of 0.12 mg/g. The seasonal values were 0.08 to 0.16 with a mean of 0.12 mg/g during pre-monsoon, 0.08 mg/g to 0.19 mg/g with a mean of 0.13 mg/g during monsoon, 0.08 mg/g to 0.22 mg/g with a mean of 0.12 mg/g during post-monsoon respectively. From the values of seasonal mean for sedimentary organic nitrogen, the maximum concentration was observed during post-monsoon season at station 10. This high nitrogen concentration may be the result of high terrestrial input due to heavy rainfall and land run-off during this season.

![Fig. 4.10 Seasonal and annual variation in Nitrogen content of sediments](image)

The annual variation of organic nitrogen in the sediments at the selected stations is given in Fig. 4.10. Stations 4 and 10 recorded higher values due to greater discharge of organic wastes at these locations.

The seasonal variations at the various stations may be due to anthropogenic activities. The sewage and waste materials reaching the river water may be the reason for the increased nitrogen content. The decreased nitrogen content observed during monsoon season could be due to the turbulent flow of water which may lead to the erosion of
sediments. Mathew Koshy (2001) reported a maximum nitrogen concentration of 0.573 mg/g for River Pamba. TN of sediments of the Poovar estuary ranged between 0.002% and 0.06% (Helen et al, 2008).

The median, standard deviation and coefficient of variation were 0.12, 0.03 and 21.84 during pre-monsoon, 0.13, 0.03 and 20.92 during monsoon and 0.11, 0.04 and 35.18 during post-monsoon seasons.

Generally, a positive correlation exists between total nitrogen and percentage of clay (Knicker et al, 1996). Agricultural runoff, discharge of domestic and municipal sewage and other anthropogenic activities facilitate an increase in the concentration of nitrogenous material in the sediment.

The annual mean concentration of nitrogen is correlated with clay (0.844), silt (0.907), sand (-0.874), EC (0.919), LOI (0.781), OC (0.888), OM (0.888), P04-P (0.742), Fe (0.670), Cu (0.831), Ni (0.732), Pb (0.933), Mn (0.817) and Cr (0.905). There is no significant seasonal variation in total nitrogen content of sediments since the F-value (0.53) is less than the F-critical value (3.55) with $p=0.596$. Location of stations have significant effect on total nitrogen content since the F-value (9.849) is greater than the F-critical value (2.46) with $p=2.54E-05$.

4.3.4 Total Phosphorus

The seasonal and annual distribution of phosphorus of Meenachil River sediments are depicted in Fig. 4.11. The concentration of phosphate during the study period fluctuated between 0.01 mg/g and 0.90 mg/g with an average value of 0.39 mg/g.

The phosphate level in the study area exhibited variations. The concentrations of phosphate in sediments were 0.08 mg/g to 0.90 mg/g during pre-monsoon, 0.01 mg/g to 0.42 mg/g during monsoon and 0.02 mg/g to 0.74 mg/g during post-monsoon seasons. Phosphate level of sediments of stations in the upstream locations was found lower than in
sediments in the downstream locations in the post-monsoon season. This may be due to the influx river water with phosphate load from paddy fields and other agricultural lands.

The highest concentration of phosphate (0.90 mg/g) was observed at station 10 during the pre-monsoon season and the lowest concentration (0.01 mg/g) at station 1 during monsoon season.

Phosphorus content is an important sediment quality parameter since it acts as a reservoir for phosphate by retaining it through adsorption and releasing it to the overlying water under favourable conditions (Murthy and Veeryya, 1971). The increased load of phosphorus in rivers is derived from agricultural land, sewage and industrial effluents has a crucial role in eutrophication processes (Rohlich, 1969; Golterman, 1996; Wetzel, 1975). The continuous adsorption and desorption of phosphates by sediments serve both as a source and a sink for phosphate in phosphorus cycle (Nair and Balchand, 1993). Mathew Koshy (2001) reported' a maximum phosphate concentration of 1.314mg/g for River Pamba. TP of sediments of the Poovar estuary ranged between 0.025% and 0.057% (Helen et al, 2008).

Fig. 4.11 Seasonal and annual distribution of phosphorus in sediments

The seasonal and annual distribution of phosphorus of Meenachil River sediments is given in Tables A5-A8. The concentration of phosphate during the study period
fluctuated between 0.01mg/g and 0.90mg/g with an average value of 0.39mg/g. The median, standard deviation and coefficient of variation were 0.64, 0.27 and 46.9 during pre-monsoon, 0.22, 0.15 and 71.14 during monsoon and 0.37, 0.22 and 59.33 during post-monsoon seasons. It was observed that the concentration of phosphate remained higher at certain stations where agricultural and related activities were higher than the other stations.

Phosphate exhibited significant correlation with clay (0.748), silt (0.792), sand (-0.771), EC (0.879), LOI (0.755), OC (0.948), OM (0.948), nitrogen (0.742), iron (0.847), zinc (0.827), copper (0.727), lead (0.735), manganese (0.887), and chromium (0.792).

There was significant seasonal variation in Total phosphorus content of sediments, since the $F$-value (43.11) is much greater than the $F$-critical value (3.55) with $p=1.37E-07$. Location of stations have significant effect on phosphate-P content since the $F$-value (15.67) is greater than the $F$-critical value (2.46) with $p=8.49E-07$.

4.4 PESTICIDES

Sediment samples from River Meenachil were free from serious contamination by organochlorine pesticides. Different BHC isomers were present in stations 3 to 10 in low concentrations. α-Endosulphan was found in samples from stations 2, 6 and 10 and traces of DDT were present in samples 3, 4, 6, 8 and 10. Aldrin, Dieldrin, and β-Endosulphan were completely absent in all samples. The variations in concentration of organochlorine pesticides in the sediments of River Meenachil are shown in Appendix Table A81.

The level of pesticide residue in the river sediments was bdI to 9.92μg/kg with a mean of 2.66μg/kg. The values were bdI-9.85μg/kg for BHC, bdI–0.11μg/kg for Endosulphan and bdI–0.06μg/kg for DDT. There was significant spatial variation in the distribution of pesticide residues. Station 10 was found to be the most polluted with BHC (9.85μg/kg), Endosulphan (0.01μg/kg) and DDT (0.06μg/kg). This may be due to
pesticide runoff from the extensive paddy fields of Kuttanad and the proximity of the sampling station to the Vembanad Lake.

The downstream regions of River Meenachil flow through the extensive paddy fields of Kuttanad. According to a study conducted under Indo-Dutch programme (1989), about 25,000 tonnes of fertilizers and 500 tonnes of highly toxic pesticides were used in the 55,000 hectares of paddy fields in Kuttanad, annually. A major portion of these agrochemicals reached the water bodies as runoff. The report indicated the presence of DDT in the Vembanad Lake and Endosulphan in River Meenachil and River Manimala. At present, the quantity-and periodicity of pesticide application has reduced considerably. Nearly one fourth of the farmers in the region has adopted organic farming and stopped using pesticides or insecticides in their paddy fields (Thomas, 2002).

Fig. 4.12 Distribution of organochlorine pesticides in the sediments

Pesticide residue concentrations recorded in the present study are in conformity with the values reported elsewhere. The concentrations of various pesticides in Yangtse River was in the range of 1.42-8.06ng/g (HCH), and <0.01-4.12ng/g (DDT), while the concentrations of PCBs were below detection limit (Yongrui et al., 2000). The total PAHs, PCBs and organochlorine pesticides in surficial sediments of Tonghui River were 127-928 ng/g, 0.78-8.47ng/g and 1.79-13.98ng/g dry weight, respectively (Zhang et al, 2004).
The pesticide content of sediments from Haihe River were in the range of 3.30-75.96ng/g dw (HCH) and 1.57-211.57ng/g dw (DDT) and Dagu Drainage River ranged from 2.30 to 124.61 ng/g dw (HCH) and from 11.28 to 237.30 ng/g dw, (DDT) (Ding et al., 2005). Concentration of OCPs in the sediments of Haihe River ranged from 1.88 to 18.76 ng g\(^{-1}\) (mean 7.33 ng g\(^{-1}\)) for HCH, 0.32–80.18 ng g\(^{-1}\) (mean 15.94 ng g\(^{-1}\)) for DDT and the Dagu Drainage River ranged from 33.24 to 141.03 ng g\(^{-1}\) (mean 87.74 ng g\(^{-1}\)) and DDT ranged from 3.60 to 83.49 ng g\(^{-1}\) with a mean value of 35.52 ng g\(^{-1}\) (Yang et al., 2005). Doong et al. (2002) reported pesticide concentrations in the range of 0.57–14.1 ng/g for HCH, 0.05–0.15 ng/g for aldrin, 0.12–5.8 ng/g for dieldrin, 0.22–0.64 for endrin, 0.24–6.37 ng/g for endosulfan and 0.21–8.81 ng/g for DDT (\(p,p'\)-DDD, \(p,p'\)-DDE, \(p,p'\)-DDT) in sediments of Da-han River and Erhjen River in Taiwan.

The concentration of HCH in surface sediments from the river Kaveri ranged between 4.35 to 158.4ng/g (Rajendran and Subramanian, 1999). The levels of DDT varied from 0.69 to 4.85ng/g. The mean values of the mass fraction of HCHs, HCB, and DDTs in the sediments were 0.05–12, 0.05–1.4, and 0.05–11.5ng/g dry weight in the Sunderban wetland (Sarkar et al., 2008).

The spatial distribution of pesticide residues indicate that most of the sampling locations in the study area are more or less contaminated due to anthropogenic activity. BHC, Endosulphan and DDT were the major organochlorine pesticide residues found in the sediments of River Meenachil. This may be due to extensive use of pesticides in agriculture, increased population pressure and fast urbanization.

4.5 CONCLUSION

The sediment samples from the downstream locations of the river were richer in clay and silt fractions and the percentage of sand was greater in stations located on the highland regions of the river. The sediments, during all the three seasons were acidic due
to organic matter content. The EC values showed a gradual increase from station 1 to station 10. The organic carbon values were high at all stations during pre-monsoon due to increased pollution load. High values for organic matter were observed in the downstream regions of the river. Loss-on-ignition, total nitrogen and total phosphorus levels were higher in the downstream locations.

The maximum concentration of sedimentary organic nitrogen was observed during post-monsoon. Phosphate level of sediments in the upstream locations was found to be lower than in the downstream locations in the post-monsoon season due to the influx river water with Phosphate load from paddy fields and other agricultural lands. Organochlorine pesticide residues such as those of BHC, Endosulphan and DDT were found in the sediments of River Meenachil. Being nonbiodegradable, aquatic organisms bioaccumulate these pollutants and could become a serious threat to humans.

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