Chapter 4

RESULTS AND DISCUSSION
EVALUATION OF SEDIMENT QUALITY

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11 Sediment Quality

Sediment quality is an important environmental concern because sediment may act as both sink and a source of water-quality constituents to the overlying water and to biota. Fine grained bottom sediments are formed out of suspended material and have composition that reflects the geochemical, biological and geological processes taking place in the aquatic environment. The rate of loading of these materials depends on the different chemical and physical properties of the sediment.

Bottom sediments regulate the fresh water ecosystem. Bottom sediments indicate the extent of biological activity and indirectly the fertility of the overlying water as well as the status of pollution of the waters. The organic matter from the water column gets transported to the surface sediments and becomes modified due to the activities of living organisms. In this study, the concentrations of important pollutants in the sediments of Vembanad Lake have been analyzed during Pre-monsoon, Monsoon and Post-monsoon seasons. The following is a brief narration of the results.

4.2 Textural Analysis

The texture of sediments plays a very important role in determining its composition. The terrigenous materials contributed by the rivers are the most predominant source of sediments in the Vembanad estuary. The surface sediments of the lake are mostly a mixture of clay, silt and sand. The sediment composition and texture are related to geology, bathymetry and physical factors of the estuary. Nearshore sediments are composed of silty clays and clays. The southern part of the lake is covered with silty sand and clayey silt. The prevailing anoxic condition in the lake was evident from the olive green colour of the sediment. Textural characteristics of Vembanad lake sediments are given in Table 4.1.

The seasonal values for sand, silt and clay did not exhibit significant variation during Pre-monsoon, Monsoon and Post-monsoon seasons. The compositions were
56.18%, 51.46% and 54.57%, 21.23% and 17.92% and 29.13%, 27.32% and 28.02% respectively during the three seasons. The average values during the period of study, were (54.07%), (17.95%) and (27.98%).

<table>
<thead>
<tr>
<th>Component</th>
<th>Pre-monsoon</th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Annual Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand (%)</td>
<td>56.18</td>
<td>51.46</td>
<td>54.57</td>
<td>54.07</td>
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<tr>
<td>Silt (%)</td>
<td>14.69</td>
<td>21.23</td>
<td>17.93</td>
<td>17.95</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>29.13</td>
<td>27.32</td>
<td>27.50</td>
<td>27.98</td>
</tr>
</tbody>
</table>

*Table 4.1* Seasonal and annual variation of composition of sediments

![Pie-diagrams showing seasonal and annual composition of sediments](image)

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

The sediment samples from the southern regions of the lake were richer in clay and silt fractions. This may be due to large quantities of silt deposited by the rivers Meenachil, Manimala, Pamba and Achenkovil which debouch into to the lake in this region. The percentage of sand was greater in stations located on the western and northern regions of
The percentage of sand, silt and clay fractions of sediments at each station along with the textural classification, during Pre-monsoon are presented in Table 4.2.

<table>
<thead>
<tr>
<th>Station</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Textural class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67.37</td>
<td>12.77</td>
<td>19.86</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>2</td>
<td>61.71</td>
<td>12.58</td>
<td>25.71</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>3</td>
<td>60.19</td>
<td>13.80</td>
<td>26.01</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>4</td>
<td>58.72</td>
<td>14.82</td>
<td>26.46</td>
<td>Sandy Clay Loam</td>
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<td>57.92</td>
<td>14.22</td>
<td>27.86</td>
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<tr>
<td>6</td>
<td>56.71</td>
<td>16.58</td>
<td>26.71</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>7</td>
<td>55.34</td>
<td>15.09</td>
<td>29.57</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>8</td>
<td>56.46</td>
<td>14.40</td>
<td>29.14</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>9</td>
<td>46.77</td>
<td>15.80</td>
<td>37.43</td>
<td>Sandy Clay</td>
</tr>
<tr>
<td>10</td>
<td>40.63</td>
<td>16.82</td>
<td>42.55</td>
<td>Clay</td>
</tr>
</tbody>
</table>

*Table 4.2 Textural characteristics of sediments (Pre-monsoon)*

![Ternary diagram showing sediment textural class (Pre-monsoon)](image)

*Fig. 4.2 Ternary diagram showing sediment textural class (Pre-monsoon)*

The annual mean values for sand, silt and clay were 56.18%, 14.69% and 29.13% during Pre-monsoon. The textural classes of sediments were sandy loam in station 1, sandy clay loam in stations 2, 3, 4, 5, 6, 7 and 8, sandy clay in station 9 and clay in station 10. The southernmost locations were having higher clay content.
The percentage of sand, silt and clay fractions of sediments and the textural classification, during Monsoon are given in Table 4.3. The annual mean values for sand, silt and clay were 51.46, 21.23%, and 27.32% during Monsoon. The textural classes of sediments were sandy loam in stations 1 and 2, sandy clay loam in stations 3, 4, 5, 6 and 8 and clay loam in stations 7, 9 and 10.

<table>
<thead>
<tr>
<th>Station</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Textural class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65.89</td>
<td>15.64</td>
<td>18.47</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>2</td>
<td>68.96</td>
<td>16.93</td>
<td>14.12</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>3</td>
<td>50.28</td>
<td>20.90</td>
<td>28.82</td>
<td>Sandy Clay Loam</td>
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<td>4</td>
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<td>19.70</td>
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</tr>
<tr>
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<td>53.82</td>
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<td>25.87</td>
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<td>49.67</td>
<td>22.09</td>
<td>28.24</td>
<td>Sandy Clay Loam</td>
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<tr>
<td>7</td>
<td>41.36</td>
<td>27.46</td>
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<td>Clay Loam</td>
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<td>53.85</td>
<td>17.91</td>
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</tr>
<tr>
<td>9</td>
<td>40.83</td>
<td>23.28</td>
<td>35.89</td>
<td>Clay Loam</td>
</tr>
<tr>
<td>10</td>
<td>33.71</td>
<td>28.06</td>
<td>38.24</td>
<td>Clay Loam</td>
</tr>
</tbody>
</table>

*Table 4.3 Textural characteristics of sediments (Monsoon)*

![Fig. 4.3 Ternary diagram showing sediment textural class (Monsoon)](image-url)
The sand, silt and clay percentage of sediments along with the textural classification during Post-monsoon period are presented in Table 4.4. The average values for sand, silt and clay were 54.57%, 17.93% and 27.50% during Post-monsoon. The textural classes of sediments were sandy clay loam in stations 1, 3, 4, 5, 6, 7 and 8, sandy loam in station 2, and clay loam in stations 9 and 10.

<table>
<thead>
<tr>
<th>Station</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Textural class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67.25</td>
<td>11.48</td>
<td>21.27</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>2</td>
<td>69.44</td>
<td>10.74</td>
<td>19.82</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>3</td>
<td>57.57</td>
<td>16.61</td>
<td>25.82</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>4</td>
<td>56.00</td>
<td>15.82</td>
<td>28.18</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>5</td>
<td>57.67</td>
<td>16.52</td>
<td>25.81</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>6</td>
<td>54.53</td>
<td>18.38</td>
<td>27.09</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>7</td>
<td>51.88</td>
<td>22.49</td>
<td>25.63</td>
<td>Sandy Clay Loam</td>
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<tr>
<td>8</td>
<td>50.57</td>
<td>20.16</td>
<td>29.27</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>9</td>
<td>40.95</td>
<td>24.69</td>
<td>34.36</td>
<td>Clay Loam</td>
</tr>
<tr>
<td>10</td>
<td>39.85</td>
<td>21.42</td>
<td>38.73</td>
<td>Clay Loam</td>
</tr>
</tbody>
</table>

*Table 4.4 Textural characteristics of Vembanad lake sediments (Post-monsoon)*

*Fig. 4.4 Ternary diagram showing sediment textural class (Post-monsoon)*
Unnithan et al.\textsuperscript{7} have reported that the sediments from Vembanad Lake were composed 44.7% of sand, 31.3% of clay and 18.7% silt. Harikumar et al.\textsuperscript{59} observed sand, silt and clay compositions of 71.71% and 11.64% and 10.65% respectively. Seralathan and Padmalal\textsuperscript{197} have reported sand, silt and clay compositions of 50% and 26% and 24% respectively for the central Vembanad estuary. Veerayya and Murthy\textsuperscript{198} showed a silty sand condition during the pre barrage period (1972) to a silty clay condition. Sediment characteristics showed spatial and temporal differences during the study period.

4.2.1 Sand

Tables A5-A8 gives the seasonal and annual percentage distributions of sand in the sediments of Vembanad estuary. The annual values for sand fluctuated between 33.71% at station 10 during Pre-monsoon and 69.44% at station 2 (ave. 54.07 %) during post-monsoon seasons. The seasonal values fluctuated between 40.63 % at station 10 and 67.37 % at station 1 (ave.56.18 %) during Pre-monsoon, 33.71 % at station 10 and 68.96 % at station 2 (ave.51.46%) during Monsoon, and 39.85% at station 10 and 69.44% at station 2 (ave.54.57%) during Post-monsoon. The median, sd and cv were 57.32, 7.55 and 13.44, 52.05, 10.97 and 21.32 and 55.27, 9.59 and 17.58 during Pre-monsoon, Monsoon and Post-monsoon respectively.

Stations 1 and 2 exhibited maximum distribution of sand during the study period. Stations 9 and 10 showed the minimum sand distribution as against the distribution of clay and silt. This may be due to the influx of sediment rich river waters into stations 9 and 10 which are situated in the southern region of the lake. High proportion of fine and medium sands in the immediate vicinity of Thanneermukkom bund may be due to the scouring action of the waterjet infiltration which winnows silt and clay resulting in the deposition of fine and medium sands.\textsuperscript{197}

Unnithan et al.\textsuperscript{7} reported a sand composition of 44.7% for Vembanad Lake. The eastern side of the Vembanad Lake was blanketed with sand dominated sediments.
Harikumar et al.\textsuperscript{39} observed sand composition ranging between 62.91% and 87.32% (av. 77.1%) during Pre-monsoon. Seralathan and Padmalal\textsuperscript{197} have reported sand content of 50.33% for the central Vembanad estuary. Geetha et al.\textsuperscript{199} reported 8.95-97.74% sand for Vembanad Lake sediments. The study revealed high values for sand.

![Graph showing seasonal and annual distribution of sand](image)

**Fig. 4.5 Seasonal and annual distribution of sand**

The percentage of sand in the sediments exhibited significant negative correlations with clay, silt, EC, LOI, OC, OM, TN, TP, sulphate, chromium, manganese, iron, nickel, copper, zinc and lead. Two-way ANOVA indicated significant temporal ($p=0.014$) and spatial ($p=3.94E-08$) variation in the distribution of sand in sediments.

### 4.2.2 Silt

The seasonal and annual distributions of silt in the sediments of Vembanad estuary are given in Tables A5-A8. There was significant seasonal variation in the silt content of lake sediments. The percentage of silt in the sediments of the Vembanad Lake fluctuated between 10.74% at station 2 during post-monsoon and 28.06% at station 10 during monsoon with an average of 17.95% during the study period. The percentage distribution of silt varied between 12.58% at station 2 and 16.82% at station 10 (ave.14.69%) during pre-monsoon, between 15.64% at station 1 and 28.06% at station 10(ave.21.8%) during
monsoon and between 10.74% at station 2 and 24.69% at station 9 (ave. 17.93%) during post-monsoon. The percentage of silt was more or less uniform during the pre-monsoon season. However, wide variations were observed during monsoon and post-monsoon seasons. Maximum percentage of silt was observed at stations 7, 9 and 10 while the minimum values were observed at stations 1 and 2. The median, sd and cv were respectively 14.61, 1.44 and 9.83 during Pre-monsoon, 20.61, 4.14 and 19.51 during Monsoon and 17.50, 4.39 and 24.48 during Post-monsoon.

![Graph showing seasonal and annual distribution of silt](image)

*Fig. 4.6* Seasonal and annual distribution of silt

Geetha *et al.*\(^{199}\) reported 1.41-65.55% silt for Vembanad Lake sediments. Seralathan and Padmalal\(^ {197}\) have reported silt content of 26.76% for the central Vembanad estuary. Stations showed marked difference in grain size. Harikumar *et al.*\(^ {59}\) observed silt composition ranging between 4.88% and 30.90% (av. 11.61%) during Pre-monsoon. Unnithan *et al.*\(^ {7}\) reported a silt content of 18.7%.

The percentage of silt has significant positive correlations with clay, EC, LOI, TSS, OC, OM, TN, TP, sulphate, chromium, manganese, iron, nickel, copper, zinc, and lead and negative correlation with sand. Two-way ANOVA indicated significant seasonal \((p=1.74E-05)\) and locational variations in the percentage of silt, \((p=0.00085)\).
4.2.3 Clay

The seasonal and annual distributions of clay in the sediments are given in Tables A5-A8. Figure 4.7 shows the seasonal, annual and average distributions of clay in the study area. The annual mean values for clay fluctuated between 14.12% at station 2 during Monsoon and 42.55% at station 10 during Pre-monsoon. The values were 42.55% at station 10 and 19.86% at station 1 during Pre-monsoon, 38.24% at station 10 and 14.12% at station 2 during monsoon and 38.73% at station 10 and 19.82% at station 2 during post-monsoon. The seasonal mean values for clay were 29.13%, 27.32% and 27.50% and the annual mean value was 27.98%. The median, sd and cv were 27.29, 6.42 and 22.04 during Pre-monsoon, 28.24, 7.28 and 26.63 during Monsoon and 26.46, 5.75 and 20.90 during Post-monsoon.

![Clay distribution graph](image)

*Fig. 4.7 Seasonal and annual distribution of clay*

The clayey character of sediments exhibited a gradual increase from north to south. Station 10 registered maximum clayey character (39.84%), while station 1 exhibited the minimum value (19.53%). The high clay content is attributed to land mining, sand mining and land filling activities taking place in the catchment areas of rivers which result in heavy influx of clayey sediments into the lake.
Harikumar et al.\textsuperscript{59} observed clay composition ranging between 6.18% and 23.42% (av. 10.65%) during Pre-monsoon. Unnithan et al.\textsuperscript{7} have reported a clay content of 31.3% and Geetha et al.\textsuperscript{199} have reported 0.0-32.60% clay for Vembanad Lake sediments. The study revealed low values for clay. Seralathan and Padmalal\textsuperscript{197} reported clay content of 24.55% for the central Vembanad estuary.

The percentage of clay in the sediments had significant positive correlations with silt, EC, LOI, TSS, OC, OM, TN, TP, sulphate, chromium, manganese, iron, nickel, copper, zinc and lead and significant negative correlation with sand. Two-way ANOVA indicated significant spatial ($p = 8.83\text{E-08}$) and on seasonal variation in the percentage of clay ($p = 0.19$).

4.3 PHYSICAL PARAMETERS

4.3.1 pH

pH is important in estimating the acidic or alkaline character of sediments. It determines the availability of nutrients, microbial activity and physical condition of the sediments. pH is influenced by the presence of metal ions in sediments. Table A5-A8 gives the seasonal and annual mean variation of pH of the sediments.

In the study area, pH varied from 3.8 to 5.4 with an average value of 4.9. During the study period, all the sediment samples were highly acidic. This may due to the high organic matter content of sediments in these areas undergoing putrefaction releasing CO$_2$. The mean pH values were 4.1, 4.9 and 4.4 during Pre-monsoon, Monsoon and Post-monsoon respectively. The min pH value, 3.8 was observed at stations 7 and 10 during Pre-monsoon and the max value, 5.4 was recorded at station 2 during Monsoon. The max and min values of pH were 3.8 and 4.8 during Pre-monsoon, 4.3 and 5.4 during Monsoon and 3.9 and 4.8 during post Monsoon respectively. The median, sd and cv were
respectively 4.00, 0.37 and 8.85 during Pre-monsoon, 4.90, 0.37 and 7.61 during Monsoon and 4.40, 0.28 and 6.44 during Post-monsoon.

The present study showed that the sediments were highly acidic during Pre-monsoon. With the advancement of the post Monsoon season, pH of all stations showed an increasing trend, indicating a reduction in acidity. This may be due to the high dissolved oxygen content and high temperatures waters which may aid the destruction of organic matter by oxidation rather than preservation of it in the sediments. Harikumar et al.\textsuperscript{59} reported pH values between 3.5 and 4.9 (av. 4.1) during Pre-monsoon. Unnithan et al.\textsuperscript{7} reported pH values ranging between 3.9 and 7.0 (av. 5.3).

\textbf{Fig. 4.8} Seasonal and annual variation of pH of sediments

pH had significant negative correlation with clay, EC, TSS and sulphate. Two-way ANOVA showed that pH exhibited significant temporal ($p=0.0004$) and spatial ($p=0.005$) variation.

\textbf{4.3.2. Electrical Conductivity}

Electrical conductivity is directly related to the soluble salt concentration of sediment. It is influenced by industrial effluents, domestic and municipal sewage, salinity
intrusion and fresh water influx from rivers. The seasonal and annual variations of EC of the sediments of Vembanad Lake are given in Tables A5-A8.

The mean values for electrical conductivity were 2.01mS/cm, 1.33 mS/cm and 1.58mS/cm during Pre-monsoon, Monsoon and Post-monsoon seasons respectively. The mean EC of the lake during the study period was 1.64mS/cm. The min electrical conductivity of 0.98mS/cm was observed at station 3 during Monsoon and the max value of 2.34 mS/cm was recorded at station 10 during Pre-monsoon.

\[ \text{EC (mS/cm)} \]

\[ S1 \quad S2 \quad S3 \quad S4 \quad S5 \quad S6 \quad S7 \quad S8 \quad S9 \quad S10 \quad Av \]

\[ \Delta \text{PRM} \]
\[ \triangleleft \text{MON} \]
\[ \text{POM} \]
\[ \text{ANL} \]

**Fig. 4.9** Seasonal and annual variation of electrical conductivity of sediments

The max and min values of electrical conductivity were 2.34mS/cm and 1.85mS/cm during Pre-monsoon, 1.61mS/cm and 0.98mS/cm during Monsoon and 1.91mS/cm and 1.17mS/cm during Post-monsoon respectively. The mean, median, sd and cv were 2.01, 1.98, 0.158 and 7.87 during Pre-monsoon, 1.33, 1.37, 0.216 and 16.20 during Monsoon and 1.58, 1.63, 0.265 and 16.77 during Post-monsoon.

Hrikumar *et al.*\(^5\) reported EC values ranging between 0.323mS/cm and 1.473mS/cm (av. 0.683mS/cm) during Pre-monsoon. Unnithan *et al.*\(^7\) reported EC values between 1.0mS/cm and 5.0 mS/cm (av. 3.0mS/cm). Increase in electrical conductivity with increase in organic content was observed in the present study.
EC showed significant positive correlations with clay, silt, TSS, OC, OM, TN, TP, chromium, nickel, copper and zinc and negative correlation with sand. Two-way ANOVA indicated significant seasonal \( (p=6.79E-10) \) and locational variation in electrical conductivity \( (p=8.75E-05) \).

4.3.3. Loss on Ignition

Loss on ignition of sediments 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 organic matter content of lagoonal sediments, which depends on sources like land run off and overlying waters, plays a major role in the LOI values of sediments. With several rivers joining the lake at different points, the source from land is evident. The seasonal and annual distribution of LOI values are given in Tables A5-A8.

![Graph showing seasonal and annual variation of Loss on Ignition](image)

**Fig. 4.10** Seasonal and annual variation of Loss on ignition

The annual mean value for LOI was 12.83%. The max and min values recorded during the present study were 8.35% at station 5 during Monsoon and 17.47% at station 10 during Monsoon. The min and max seasonal values of LOI were 8.45 % at station 5 and 16.69% at station 10 during Pre-monsoon, 8.35% at station 5 and 15.73% at station 10.
during Monsoon and 8.42% at station 1 and 17.47% at station 10 during Post-monsoon.
The mean LOI during the three seasons were 12.88%, 12.73% and 12.87% respectively.
The median, sd and cv were 13.71%, 3.03 and 23.55 during Pre-monsoon, 12.92%, 2.42
and 19.05 during Monsoon and 13.38%, 3.20 and 24.88 during Post-monsoon respectively
and the annual values were 13.02%, 2.51 and 19.59.

The annual mean values of LOI exhibited significant positive correlations with
clay, silt, OC, OM, Total nitrogen, total phosphorus, sulphate, chromium, manganese,
iron, nickel, copper, zinc, and cadmium and significant negative correlation with sand.
Two-way ANOVA indicated no significant seasonal variation in LOI ($p=0.739$). However,
location of stations had significant effect on Loss on Ignition ($p=0.0001$).

4.3.4. Total Soluble Salts

Soluble salts which may be present in solid samples consists of ions like calcium,
magnesium, sodium, potassium, chlorides, nitrate, carbonates, bicarbonates, heavy metals
etc. Excessive salts in sediment cause high osmotic pressure, which prevent the absorption
of moisture and nutrients by plants in adequate amounts. The seasonal and annual mean
distributions of TSS are given in Tables A5-A8.

![Graph](image)

**Fig. 4.11** Seasonal and annual variation of Total soluble salts
Total soluble salts content was 1.76% during Pre-monsoon, 1.12% during Monsoon and 1.35% during Post-monsoon. The min and max values of TSS were 1.45% at station 3 and 1.97% at station 8 during Pre-monsoon, 0.78% at station 3, and 1.38% at station 10 during Monsoon, and 0.99% at station 3 and 1.64% at station 9 during Post-monsoon respectively. The lowest and the highest values were 0.78% and 1.97% respectively and the mean TSS of the lake during the study period was 1.41%. The median, sd and cv were 1.77, 0.18 and 10.04 during Pre-monsoon, 1.16, 0.21 and 18.34 during Monsoon and 1.39, 0.23 and 16.94 during Post-monsoon respectively.

The annual mean values of TSS exhibited significant positive correlation with clay, silt, EC, OC, OM, TN, sulphate, chromium, manganese, iron, nickel, copper, zinc and lead and significant negative correlation with sand and pH. Two-way ANOVA indicated significant seasonal ($p=2.69E-10$) and spatial variation in TSS ($p=3.05E-05$).

4.4 CHEMICAL PARAMETERS

4.4.1 Organic Carbon

The organic carbon content of lagoonal sediments depends upon sources like land run off and from the overlying waters through organic productivity. With the presence of several rivers joining the lake at different points, the source from land is evident. Presence of patches of mangrove forest on lake banks, high rate of primary production, prevailing anoxic condition and fine particle size of sediments also contribute organic matter. The seasonal and annual distribution of sedimentary organic carbon is given in Tables A5-A8.

The annual mean values of OC fluctuated between 25.83mg/g at station 2 during Monsoon and 67.72mg/g at station 10 during post-monsoon seasons. The seasonal values fluctuated between 29.06mg/g at station 5 and 63.74mg/g at station 6 during pre-monsoon, 25.83 mg/g at station 2 and 56.95mg/g at station 7 during monsoon, between 27.43mg/g at station 4 and 67.72mg/g at station 10. The median, sd and cv were 49.51, 13.45 and 28.57
during Pre-monsoon, 41.18, 11.57 and 27.91 during Monsoon and 48.13, 12.96 and 27.09 during Post-monsoon seasons. The seasonal means were 47.08, 41.44 and 47.83 respectively.

Generally, organic carbon increases with percentage of silt and clay. The concentration varies temporally 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. It is found that total OC content increased with precipitation and clay content and decreased with temperature.\(^\text{201}\) In the Vembanad estuary, high organic content has been reported by earlier authors\(^\text{133, 136, 202}\). The high OC content may be due to the cumulative effects of fine grain sizes.

![Graph showing seasonal and annual variation of Organic carbon in sediments](image)

**Fig. 4.12** Seasonal and annual variation of Organic carbon in the sediments

The organic carbon content of sediments was higher at all stations during Pre-monsoon and Post-monsoon seasons. This may be due to the increased pollution load. Increased concentration in stations 6, 8, 9 and 10 could be due to increased terrigenous addition. Decomposition and decay of plant and animal materials, agricultural runoff from the paddy fields of Kuttanad, coconut-husk retting, and tourism activities are the major
reasons for the high organic carbon content of sediments. The seasonal variations observed at the various stations may be due to anthropogenic activities.

The biogeochemical cycle of organic carbon and its distribution and seasonal variations have been studied extensively and reported by several authors; 0.10 - 3.0 mg/g by Alagarsamy\textsuperscript{203} for the Mandovi estuary, Goa, 0.24 – 6.15 mg/g by Seralathan et al.\textsuperscript{136} for Cochin harbor, 6.08 – 54.44 mg/g for Veli-akkulam lake by Retnamani\textsuperscript{204} and 0.63 - 60.34 for Cochin estuary by Nayar\textsuperscript{205}. Leena grace\textsuperscript{182} reported OC values of 1.61mg/g-8.68mg/g for Veli Lake. Harikumar et al.\textsuperscript{59} observed OC compositions ranging between 1.90% and 6.98% (av. 4.05%) for Vembanad lake during Pre-monsoon. Unnithan et al.\textsuperscript{7} reported 2.20% to 3.10% (av. 2.71%) and Abdulla Bava reported 2.84 - 5.8% for Vembanad Lake. Murty and Veerayya\textsuperscript{202} have shown that Vembanad lake sediments were rich in OM, with an average value of 2.55%. Geetha et al.\textsuperscript{199} reported 00.09-4.32% clay for Vembanad Lake sediments.

Organic carbon showed significant positive correlations with clay, silt, EC, LOI, TSS, OM, TN, TP, sulphate, chromium, manganese, iron, nickel, copper, zinc and lead and significant negative correlation with sand. Two-way ANOVA indicated significant seasonal ($p=0.0004$) and locational ($p=6.71E-11$) variation in organic carbon content of sediments.

4.4.2 Organic Matter

Sediment organic matter can 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.

Organic matter has a high affinity for fine-grained sediment that accumulates and gets adsorbed onto mineral surfaces. OM concentrations increase with decreasing grain size. Sandy sediments are relatively poor in organic matter preservation.\textsuperscript{206} 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.\textsuperscript{193} 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 sedimentary organic carbon is given in Tables A5-A8.

The annual values of OM fluctuated between 45.51 mg/g at station 2 during Monsoon and 116.6mg/g at station 10 during post-monsoon. The seasonal values fluctuated between 50.08 at station 5 and 109.83 mg/g at station 10 during Pre-monsoon, 44.51mg/g at station 2 and 98.13 mg/g at station 7 during Monsoon, between 47.25 mg/g at station 4 and 116.68mg/g at station 10. The annual mean value was 106.00mg/g. The median, sd and cv were 85.31, 23.17 and 28.57 during Pre-monsoon, 70.95, 19.93 and 27.90 during Monsoon and 82.93, 22.32 and 27.09 during Post-monsoon.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{Fig_4.13.png}
\caption{Seasonal and annual variation of Organic matter in sediments}
\end{figure}

The finer clay particles may provide increased surface area per unit weight for adsorption of organic matter and therefore organic matter concentrations increase with decreasing grain size.\textsuperscript{207-209} Monsoon season is marked by heavy rain and flood, river
discharge etc and it is therefore not favourable for the accumulation of organic matter. Pre-
monsoon season is most favourable for organic matter accumulation. Purandara and
Dora found that the percentages varied between 1.699 and 11.732%. Harikumar et al. observed OC composition ranging between 3.28% and 12.04% (av. 7.53%) during Pre-
monsoon. Mallick and Suchindran found OC content varying between 0.5% and 13.9% (av.9.11%). Organic matter exhibited clear positive correlation with clay. Temporal and
spatial variations were observed, since they were regulated by factors like forest type, climate, sediment texture, sedimentation rates, tidal effects, oxygen availability, rate of
primary production and biological activity.

Organic Matter showed significant positive correlations with clay, silt, EC, LOI, TSS, OM, TN, TP, sulphate, chromium, manganese, iron nickel, copper, zinc and lead and
significant negative correlation with sand. Two-way ANOVA indicated that organic
matter content of sediments exhibited significant seasonal (p=0.0004) and locational
(p=6.71E-11) variation.

4.4.3 Total Nitrogen

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.

Total nitrogen concentrations in the sediments were in the range 1.41 mg/g - 5.30
mg/g with a mean value of 3.38 mg/g. The seasonal values were 1.41mg/g - 4.83 mg/g with
a mean of 3.34 mg/g during Pre-monsoon, 1.46 mg/g - 4.58 mg/g with a mean of 2.85 mg/g
during Monsoon and 1.87 mg/g - 5.30 mg/g with a mean of 3.94 mg/g during Post-
monsoon respectively. The maximum concentration of nitrogen was observed during the
Post-monsoon season at station 10. The high nitrogen concentration may be the result of
high terrestrial input due to heavy rainfall and land run-off during this season. The median,
sd and cv were 3.44, 1.29 and 38.70 during Pre-monsoon, 2.74, 1.08 and 37.85 during Monsoon and 4.07, 1.16 and 29.38 during Post-monsoon.

A general trend observed during the three seasons was the greater concentrations of nitrogen in the eastern and southern locations. A decrease in nitrogen content observed during the Monsoon may be attributed to the erosion of sediments. Generally, a positive correlation exists between total nitrogen and percentage of clay.211 Agricultural runoff, discharge of domestic and municipal sewage, retting of coconut husk and other anthropogenic activities facilitate an increase in the concentration of nitrogenous material in the sediment.

![Graph showing seasonal and annual variation in Total nitrogen in sediments](image)

*Fig. 4.14* Seasonal and annual variation in Total nitrogen in sediments

Leena grace182 reported TN values of 0.30mg/g-0.72mg/g for Veli Lake. Abdulla Bava1 has reported 1.8-5.8mg/g of sediment nitrogen for Vembanad Lake. Similar results were reported earlier by Sankaranarayanan and Panampunnayil212 and Remani et. al.213. Nayar205 reported 0.02-2.38 TN for Cochin estuary and Njemi214 reported 0.11-0.98 for Poovar.

Total nitrogen showed significant positive correlations to clay, silt, EC, LOI, TSS, OC, OM, TP, sulphate, chromium, manganese, iron, nickel, copper, zinc, cadmium and
lead and negative correlation to sand. Two-way ANOVA indicated significant temporal 
\( p=0.0098 \) and spatial \( p=3.1E-08 \) variation in Total nitrogen content of sediments.

4.4.4 Total Phosphorus

Sediment phosphorus is an important parameter, since it acts as a reservoir for 
phosphorus by retaining it through adsorption and releasing it to the overlying water under 
favourable conditions. The increased load of phosphorus in lakes derived from 
agricultural land, sewage and industrial effluents has a crucial role in eutrophication 
processes. The continuous adsorption and desorption of phosphates by sediments 
serve both as a source and a sink for phosphate in phosphorus cycle. In an estuarine 
system, total phosphates will be high both in fresh water and marine zones.

![Image of graph]

**Fig. 4.15** Seasonal and annual variation of Total phosphorus in the sediments

The seasonal and annual distribution of phosphorus in sediments is depicted in Fig. 
4.15 and the values are given in Tables A4-A8. The concentrations of Total phosphorus, 
during the study period, fluctuated between 0.29mg/g and 1.07mg/g with an average value 
of 0.595mg/g. The TP level in the study area exhibited large variation. The concentrations 
of TP in sediments were 0.364mg/g to 1.070mg/g during Pre-monsoon, 0.293mg/g to 
0.744mg/g during Monsoon and 0.305mg/g to 0.934mg/g during Post-monsoon. The
mean, median, sd and cv were 0.653, 0.7, 0.23 and 35.43 during Pre-monsoon, 0.499, 0.5, 0.15 and 29.46 during Monsoon and 0.632, 0.7, 0.22 and 35.48 during Post-monsoon.

Phosphorus levels in sediments from stations located on the eastern side were higher than stations on the western side during Post-monsoon. This may be due to the influx of river water with phosphate load from paddy fields and other agricultural lands. In the study area, TP increased almost steadily from north to south with stations 9 and 10 exhibiting maximum values. This may be due to the pollution load carried in by the Pamba, Achenkovil and Manimala rivers.

Leena grace\textsuperscript{182} reported TP values of 1.8mg/g-5.13mg/g for Veli Lake. The distribution of sediment phosphate in the Cochin estuary was studied by Reddy and Sankaranarayanan\textsuperscript{218}, and Remani \textit{et al.}\textsuperscript{213}. The highest concentration of phosphorus, 622.7µg/g was observed at station 10 during Pre-monsoon and the lowest concentration, 205.3µg/g at station 4 during Monsoon. Murty and Veerayya\textsuperscript{198} reported that the average phosphorus content of sediment samples collected from Vembanad Lake was 416µg/g. It was observed that the concentration of phosphate remained higher at certain stations where agricultural and related anthropogenic activities were intense. Abdulla Bava\textsuperscript{1} reported 1.2-2.5mg/g of phosphorus. Harikumar \textit{et al.}\textsuperscript{59} observed PO\textsubscript{4}-P content ranging between 11.62 µg/g and 231.9µg/g (av. 343.7µg/g) during Pre-monsoon. Unnithan \textit{et al.}\textsuperscript{7} have reported available phosphorus content of 342µg/g for Vembanad Lake. Similar results were reported by Mallick and Suchindan\textsuperscript{195}, Quasim and Sankaranarayanan\textsuperscript{219} Sankaranarayanan and Panampunyanayil\textsuperscript{212}. Padmalal and Seralathan observed a slight lowering of values during monsoon.

TP exhibited significant positive correlations between clay, silt, EC, LOI, OC, OM, TN, sulphate, chromium, manganese, iron, nickel, copper, zinc, cadmium, and lead and negative correlation with sand. Results of two-way ANOVA indicated significant seasonal \((p=0.00037)\) and locational \((p=3.62E-07)\) variation in Total phosphorus.
4.4.5 Sulphate

Sulphate in sediments has an important role in the eutrophication and hence the future of lakes. Under anoxic condition, sulphate reduction takes place and promotes the release of phosphorus from sediment because some iron oxyhydroxides that bind phosphate are converted to iron sulphides that cannot bind phosphorus. This results in an increase in concentration of phosphorus in the water column and subsequent eutrophication. The seasonal and annual distribution of sulphate in lake sediments are given in Tables A5-A8.

![Graph showing sulphate content variation](image)

**Fig. 4.16 Variation in sulphate content in the sediments**

The seasonal variations of sulphate were 8.862 mg/g to 19.92 mg/g during Pre-monsoon, 6.68 mg/g to 14.01 mg/g during Monsoon and 6.83 and 18.26 mg/g during Post-monsoon. The max and min values obtained during the study period were 6.68 at station 2 during Monsoon 19.92 mg/g at station during Pre-monsoon. The mean, median, sd and cv were respectively 14.09, 13.65, 3.52 and 24.98 during Pre-monsoon, 10.77, 11.37, 2.66 and 24.72 during Monsoon and 12.55, 12.07, 3.84 and 30.61 during Post-monsoon. The annual values were 12.47, 12.31, 3.29 and 26.35.
Abdulla Bava\textsuperscript{1} reported 5.0–29.0mg/g of sulphate for sediments of Vembanad Estuary. Harikumar \textit{et al.}\textsuperscript{59} observed SO\textsubscript{4} content ranging between 4.91mg/g and 13.76mg/g (av. 8.32mg/g) during Pre-monsoon. Mallick and Suchindan\textsuperscript{195} reported sulphate content ranging between 1.2 and 18 ppm (av.12.69ppm) for Vembanad Lake south of Thanneermukkom.

Sulphate showed significant positive correlations with clay, silt, EC, LOI, TSS, OC, OM, TN, TP, chromium, manganese, iron, nickel, copper, zinc, and lead and significant negative correlation with sand and pH. Two-way ANOVA showed that there was significant seasonal ($p=0.010$) and spatial variation in sulphate content of sediment samples ($p=1.86E-05$).

4.5 Carbon: Nitrogen ratio

The C/N ratio helps to determine the availability of different sources of carbon and nitrogen in a system. It also helps to distinguish between algal and land-plant origins of sedimentary organic matter. The seasonal and annual distribution of C/N ratio of Vembanad lake sediments are given in Tables A5-A8.

The mean value for the study period was 14.38. The values showed marked spatial and temporal variations during the different seasons. The C/N ratio ranged between 8.63 at station 8 and 26.57 at station 4 during the study period. The values were between 11.57 and 20.55 during Pre-monsoon, 8.63 and 26.57 during Monsoon and 8.66 and 16.96 during Post-monsoon seasons respectively. The min C/N value of 11.57 was observed at stations 2 and the max 20.55 at station 5 during Pre-monsoon season. The highest value, 26.57 was recorded at station 4 and the lowest, 8.63 at station 8 during Monsoon. The highest and lowest values of C/N were 16.96 at station 5 and 8.66 at station 4 during Pre-monsoon. The mean values during the three seasons were 14.94, 15.70 and 12.49. The median, sd and cv were 13.99, 3.06 and 20.50 during Pre-monsoon, 14.38, 5.25 and 33.44 during Monsoon and 12.24, 2.59 and 20.75 during Post-monsoon.
Generally a low C/N ratio indicated of aquatic and a high value indicated terrestrial origin of OM. The results indicate significant lateral origin of organic matter in the lake from the surroundings. The change in the C/N ratio can also be due to the difference in grain size distribution of the sediment. Shanmugappa\textsuperscript{221} observed values between 3.91 and 30.5 for Porto Novo. Normally, the C/N ratio of marine organic material is in the range 6-7 and that of terrigenous organic matter is greater than 20.\textsuperscript{222} Zeena P Ravi\textsuperscript{140} reported C/N ratio between 11.44 and 14.36 in the sediments of the Mangrove sediments of Cochin backwaters. Verma and Subramonian\textsuperscript{223} reported C/N ratios between 1.0-21.8 for Vembanad lake sediments. Quasim and Sankaranarayanan\textsuperscript{219} reported C/N ratio between 5.0 and 10.5 and Sankaranarayanan and Panampunnayil\textsuperscript{212} reported between 2.5 and 16.9 in the sediments of the Cochin backwaters. The factors contributing to high C/N ratios are especially forest humus, terrestrial plants and wood debris containing lignin.

![C-N ratio graph](image)

**Fig. 4.17 Seasonal and annual mean C/N values of sediments**

The higher ratio registered at stations during Monsoon and Post Monsoon may be due to forest humus and the terrestrial organic matter formed by the death and decay of plants and wood debris. The source of organic carbon in the sediment is of terrestrial origin. The high C/N ratio observed at station 4 during Monsoon period may be due to the
combined effect of allochthonous and autochthonous matter. Rasheed et al.\textsuperscript{224} reported that since clay can hold more organic matter due to greater surface area the difference in grain size can alter the C/N ratio.

4.6 Carbon: Phosphorus ratio

C/P ratio can be used as an index of pollution which may be due to domestic sewage in any aquatic environment. C/P ratio is widely used to estimate the extent of degradation in sinking particulate material. The seasonal and annual distribution of C/P ratio of Vembanad Lake sediments are given in Tables A5-A8.

![Graph showing C/P ratio over different stations and months]

\textit{Fig. 4.18} Seasonal and annual mean C/P ratio of sediments

Seasonal variation of C/P ratios were 83.18 during Pre-monsoon, 131.9 during Monsoon and 90.85 during Post-monsoon. The C/P ratio ranged between 54.27 at station 7 during Post-monsoon and 131.9 at station 4 during Monsoon. The values were between 59.09 and 83.18 during Pre-monsoon, 68.03 and 106.33 during Monsoon and 67.52 and 90.85 during Post-monsoon seasons respectively. The min C/P value during Pre-monsoon was observed at station 10 and the max at station 2 during Pre-monsoon. The highest value was recorded at station 4 and the lowest at station 2 during Monsoon. The highest and lowest values of C/P were recorded at station 2 and at station 7 during Pre-monsoon. The
median, sd and cv were 75.99, 6.92 and 9.37 during Pre-monsoon, 79.99, 19.45 and 22.88 during Monsoon and 79.66, 18.27 and 22.90 during Post-monsoon.

The higher C/P ratio at station 4 may be due to the decay of plant debris. Lower C/P values indicate that the major portion of the phosphorus in the sediment was of abiogenic origin, from domestic sewage and other anthropogenic sources. Shanmugappa\(^{221}\) attributed the high C/P values between 21.1 and 105.4 for Porto Novo to domestic sewage. Sankaranarayanan and Panampunnayil\(^{212}\) reported C/P ratio between 2.78 and 27.41 in the sediments of the Cochin backwaters. The factors contributing to low C/P ratios may be the increased phosphorus content of domestic sewage reaching the lake. Quasim and Sankaranarayanan\(^{219}\) reported a C/P ratio between 22.61 and 60.4 for sediments collected from Cochin estuary. In general higher C/P values are observed at estuarine stations than riverine stations. Seasonally, C/P ratio varied from 13.17 to 37.02 at the Cochin estuarine region.\(^{225}\)

4.7 Nitrogen: Phosphorus ratio

N/P ratio can be used as an index of pollution which is due to domestic sewage. The distribution of N/P ratio of Vembanad Lake sediments is shown in Tables A5-A8.

The mean N/P value during the study period was 5.75. Seasonal values of N/P were 5.10 during Pre-monsoon, 5.71 during Monsoon and 6.43 during Post-monsoon. The N/P ratio ranged between 3.85 at station 5 during Pre-monsoon and 8.77 at station 2 during Post-monsoon. The values were between 3.88 and 7.19 during Pre-monsoon, 4.12 and 8.75 during Monsoon and 5.39 and 8.77 during Post-monsoon seasons respectively.

The factors contributing to low N/P ratios may be the increased nitrogen content of sewage and fertilizer runoff reaching the lake. High N.P ratio may be due to the thick vegetation which undergoes decay and adsorption into sediments. Sankaranarayanan and Panampunnayil\(^{212}\) have reported N/P ratio between 1.2 and 4.07 in the sediments of the Cochin backwaters. They found that the major portion of the phosphorus in the sediments
is of abiogenic origin. Shanmugappa\textsuperscript{221} reported N/P ratio between 2.3 and 13.2 for the sediments of Porto Novo. Rattenberg \textit{et al.}\textsuperscript{226} reported low N/P values for the sediments of Catalina, Santa Barbara and Santa Monica basins as 5.8:1, 3.3:1 and 1.4:1 respectively. Nayar\textsuperscript{205} reported N/P values between 0.72 and 1.61 at Cochin estuary. The median, sd and cv were 4.95, 1.02 and 19.99 during Pre-monsoon, 5.07, 1.42 and 24.80 during Monsoon and 6.24, 1.05 and 16.38 during Post-monsoon.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure}
\caption{Seasonal and annual mean N/P ratios of sediments}
\end{figure}

The study of carbon, nitrogen and phosphorus showed that the main source of organic carbon was allochthonous material brought in by the rivers and canals that debouch into the lake. The C/P ratio suggests that the major portion of sedimentary phosphorus was abiogenic in origin. The study of the source and flux of total nitrogen and total phosphorus revealed that they were abiogenic in origin.

\section*{4.8 HEAVY AND TRACE METALS}

Heavy and trace-metals are considered to be an important class and cause of environmental pollution.\textsuperscript{16} The mechanisms by which trace elements are taken up by the sediments include adsorption to clays, metal oxides/hydroxides and organic matter, biological uptake and physical accumulation of metal enriched particulate material by
sedimentation and entrainment. Pekey demonstrated that heavy metals tend to be trapped in the aquatic environment and accumulate in sediments. Certain trace metals are preferentially incorporated from sea water into near shore and estuarine anoxic sediments. Trace metals are potentially hazardous particularly in estuaries and near shore waters. Discussion on the metal concentrations with respect to sediment-quality guidelines is limited to eight metals.

4.8.1 Chromium

Chromium is distributed in the earth’s crust at about 100 ppm levels. Trivalent chromium is essential for maintaining the normal glucose metabolism and glucose tolerance in human beings. Hexavalent chromium is far more toxic than trivalent chromium. Chromium pollution usually occurs from stainless steel and other alloy industries, chrome plating, photography, textile manufacture, leather tanning, varnishes, paints, inks, pigments, explosives, dyeing, and wood preservation. The seasonal and annual distributions of chromium are presented in Tables A5-A8.

Chromium concentration fluctuated between 41.58 mg/kg at station 2 during Monsoon and 143.73 mg/kg at station 10 during Post-monsoon. The seasonal variations were 57.80 mg/kg to 143.73 mg/kg during Pre-monsoon, 41.58 mg/kg to 90.40 mg/kg during Monsoon and 53.40 mg/kg and 128.40 mg/kg during Post-monsoon. The mean, median, sd and cv were respectively 94.28, 98.40, 27.38 and 29.04 Pre-monsoon, 61.73, 60.53, 17.41 and 28.19 during Monsoon and 93.7, 94.7, 25.85 and 27.58 during Post-monsoon.

Mallick and Suchindan reported Cr content of 44.82 mg/kg for sediments from Vembanad Lake. Padmalal et al. reported Cr concentration of 125 ppm for nearshore surfical sediments of Cochin estuary. Jayashree and Nair have reported Cr concentration of 1.0 ppm during Pre-monsoon period. Chromium contamination above TEL (52.3 mg/kg) was noticed in most of the stations. Acute contamination, above PEL (160 mg/kg),
was not noticed in any of the stations. The average concentration of chromium for the lake was 83.3 mg/kg.

![Graph showing chromium levels at different stations](image)

**Fig. 4.20** Seasonal and annual of chromium in the sediments

Chromium exhibited significant positive correlations with clay, silt, EC, LOI, TSS, OC, OM, TN, TP, sulphate, Fe, Zn, Cu, Ni, Pb and Mn and significant negative correlations with sand during the study period. Two-way ANOVA indicated significant temporal ($p=0.002$) and no spatial variation in concentration of Cr ($p=0.06$).

### 4.8.2 Manganese

Manganese is an essential trace nutrient in all forms of life. Combustion of fossil fuels and the use of this metal as fertilizers are the main sources of manganese in the environment. Mn content of sediment is mainly derived from rocks through which the river flows. The geochemistry of Mn and Ce are similar, both responding to oxidative precipitation and reductive dissolution.\(^{229}\) It can occur in sediments as discrete oxide particles, coatings on particles and as manganese (II) adsorbed on organic materials.\(^{230}\) Excess particulate manganese concentrations in the sediments were due to the oxidation of dissolved manganese.\(^{28}\) The organic matter status of sediments had a profound influence
on the distribution of manganese.\textsuperscript{225} The seasonal and annual distributions of manganese are presented in Tables A5-A8.

Concentration of manganese fluctuated between 114.20mg/kg at station 1 during Monsoon and 817.00mg/kg at station 9 during Pre-monsoon. The seasonal variations of manganese were 135.80mg/kg to 817.00mg/kg during Pre-monsoon, 114.20mg/kg to 443.20 mg/kg during Monsoon and 211.60 mg/kg and 568.00mg/kg during Post-monsoon. Mn concentration recorded the max value (817mg/kg) at station 10 and the min value (114.2mg/kg) at station 1 during post-monsoon. The average concentration of manganese was 367.12mg/kg. The mean, median, sd and cv were respectively 412.24, 479.70, 236.12 and 57.28 Pre-monsoon, 273.52, 261.70,118.12 and 43.18 during Monsoon and 403.44, 403.80, 128.81 and 31.93 during Post-monsoon.

![Graph showing seasonal and annual manganese concentrations](image)

\textit{Fig. 4.21} Seasonal and annual of manganese in the sediments

Manganese concentrations of 0.0044-0.0318% have been reported along the Kerala coast and 0.0123-0.028% in the Cochin backwaters by Rajamami Amma.\textsuperscript{231} Mallick and Suchindan\textsuperscript{195} reported Mn content of 469.8 mg/kg for sediments from Vembanad Lake. Leena Grace\textsuperscript{127} reported Mn content of 54.24mg/kg for Kadinamkulam estuary, 61.24mg/kg for Veli Lake and 64.28mg/kg for Poonthura backwater. Murty and
Veerayya have reported Mn concentration ranging between 30 mg/kg and 898 mg/kg in the sediments of Vembanad Lake. In the present study, Mn concentrations were found to be higher in samples from the southern and eastern locations.

Manganese showed significant positive correlations with clay, silt, LOI, OC, TN, TP, sulphate, Fe, Zn, Cu, Ni, Pb and Cr and significant negative correlation with sand. Two-way ANOVA indicated that there was no temporal ($p=0.07$) or spatial ($p=0.06$) variation of concentration of manganese.

4.8.3 Iron

Iron has received more attention than any other transition metal in estuarine studies. Oxidation of dissolved iron particles changes the iron to white, then yellow and finally to red brown solid particles that settle out. Iron will cause reddish brown staining of laundry, porcelain dishes, utensils and even glassware. Iron toxicity may be suspected when a reddish brown scum of Fe(OH)$_3$ is visible on the soil surface along cracks or when a thin oily looking layer of Fe(OH)$_3$ floats on the inundation water. The seasonal and annual mean values of iron are given in Tables A5-A8.

The iron content ranged between 18.43mg/g at station 2 and 79.80mg/g at station 6 during pre-monsoon. The average iron content for the lake was 48.43mg/g. The seasonal variations were 18.43mg/g to 79.80mg/g during Pre-monsoon, 21.31 mg/g to 70.80mg/g during Monsoon and 25.60mg/g and 70.80mg/g during Post-monsoon. The mean, median, sd and cv were respectively 54.62mg/g, 62.81mg/g, 22.94 and 42.00 during Pre-monsoon, 41.68mg/g, 36.89mg/g, 16.22 and 38.91 during Monsoon and 48.99mg/g, 47.60mg/g, 16.80 and 34.30 during Post-monsoon.

The influence of organic matter buried into the sediments might account for the high iron content. In general, the maximum concentration of iron was recorded in silty clay sediments and minimum in coarse sandy sediments. Several previous studies have
shown high concentration of iron in Vembanad Lake and its adjacent shelf by Balachandran et al.\textsuperscript{118}, Mallik and Suchindran\textsuperscript{195}, and Shajan Kuttickat Paul\textsuperscript{233}. Murty and Veerayya\textsuperscript{13} have reported iron content of sands, silty sands, clayey silts and silty clays as 1.16\%, 4.03\%, 5.94\% and 5.44\% respectively. The iron content varied between 0.22 mg/g and 8.26 mg/g. Mallik and Suchindran\textsuperscript{195} have reported iron content of 4.41\% for sediments.

Fig. 4.22 Seasonal and annual of iron in the sediments

Iron exhibited significant positive correlations with silt, EC, LOI, OC, TN, TP, Zn, Cu, Ni, and Pb, Mn and Cr and negative correlations with sand. Two-way ANOVA indicated significant temporal ($p=0.16$) and no spatial variation of iron ($p=0.02$).

4.8.4 Nickel

Nickel constitutes about 0.008\% of the earth’s crust. Soil contains about 40 ppm nickel. Nickel is essential in human nutrition but it is found to be toxic for most plants and fungi. Acidic condition renders Ni more mobile in sediment and may lead to its dissolution in the overlying water column. The seasonal and annual mean values of nickel are given in Tables A5-A8.
The concentration of nickel varied between 9.40 mg/kg at station 5 and 67.20 mg/kg at station 9 during pre-monsoon, with a lake average of 30.20 mg/kg. The seasonal variations were 9.40 mg/kg and 67.20 mg/kg during Pre-monsoon, 9.47 mg/kg to 43.25 mg/kg during Monsoon and 17.82 mg/kg and 52.48 mg/kg during Post-monsoon. The mean, median, sd and cv were respectively 34.10 mg/kg, 29.00 mg/kg, 20.17 and 59.15 during Pre-monsoon, 21.44 mg/kg, 19.13 mg/kg, 9.14 and 42.64 during Monsoon and 35.06 mg/kg, 32.32 mg/kg, 11.18 and 31.91 during Post-monsoon.

![Seasonal and annual nickel]  

**Fig. 4.23** Seasonal and annual of nickel in the sediments

Nickel contamination above TEL (15.9 µg/g) was noticed in almost all stations except station 2 during Post-monsoon season. Acute nickel contamination above PEL (42.8 µg/g) was noticed at stations 6, 7, 8 and 10 during Pre-monsoon, stations 4, 6, 8, and 10 during Monsoon and stations 6 and 10 during Post-monsoon. The average concentration of Ni in the sediment was 31.96 µg/g.

Padmalal\(^{133}\) reported Ni concentration of 109 ppm for nearshore surficial sediments of Cochin estuary. Jayashree and Nair\(^{129}\) reported a Ni concentration of and 3 ppm. Leena Grace\(^{128}\) reported Ni content of 61.77 mg/kg for Kadinamkulam estuary, 60.03 mg/kg for Veli Lake and 64.58 mg/kg for Poonthura backwater. Mallik and Suchindran\(^{195}\) have
reported nickel content of 44.97mg/kg for sediments from Vembanad Lake. Murty and Veerayya\textsuperscript{13} have reported nickel concentration ranging between 7.0ppm and 60.0ppm for sediments from Vembanad Lake.

Nickel showed significant positive correlations with silt, EC, LOI, TSS, OC, TN, TP, sulphate, Fe, Zn, Cu, Pb, Mn and Cr and significant negative correlation with sand. Two-way ANOVA showed significant seasonal and but no spatial variation in the concentration of nickel ($p=0.058$).

4.8.5 Copper

Copper is a necessary trace element in human diet and a factor in plant metabolism. Copper compounds are used extensively in agriculture for the preparation of fungicides and insecticides. Pollution due to copper results from disposal of municipal and industrial wastes. Most copper compounds found in sediments are embedded in minerals. The seasonal and annual mean values of copper are given in Tables A5-A8.

Copper showed a max concentration of 52.60mg/kg at station 10 during pre-monsoon and a min concentration of 8.15mg/kg at station 1 in Monsoon. The average value of copper for the lake was 21.87mg/kg. The seasonal variations were 9.60 mg/kg and 52.60mg/kg during Pre-monsoon, 8.15mg/kg to 26.41mg/kg during Monsoon and 11.25mg/kg and 41.27mg/kg during Post-monsoon. The mean, median, sd and cv were respectively 27.32mg/kg, 22.70mg/kg, 16.10 and 58.94 during Pre-monsoon, 17.15mg/kg, 14.60mg/kg, 6.71 and 39.11 during Monsoon and 21.13mg/kg, 16.42mg/kg, 10.76 and 50.93during Post-monsoon.

Murty and Veerayya\textsuperscript{13} have reported copper concentrations ranging between 3.0 ppm and 100.0 ppm for sediments from Vembanad Lake. Mallik and Suchindran\textsuperscript{195} have reported copper content of 25.69 mg/kg for the lake. Padmalal\textsuperscript{133} reported Cu concentration of 31ppm for nearshore surficial sediments of Cochin estuary. Jayashree and Nair\textsuperscript{129}
reported a Cu concentration of 0.35 ppm. Leena Grace\textsuperscript{127} reported Cu content of 12.54 mg/kg for Kadinamkulam estuary, 12.18 mg/kg for Veli Lake and 13.02 mg/kg for Poonthura Backwater. The average concentration of copper for the Lake was 21.9 µg/g. Copper contamination above TEL (18.79 µg/g) was observed in many stations. Acute copper contamination, above PEL (108 µg/g) was not observed.

![Graph](image)

**Fig. 4.24** Seasonal and annual of copper in the sediments

Copper showed significant positive correlation with clay, silt, EC, LOI, TSS, OC, TN, TP, sulphate, Fe, Zn, Ni, Pb, Mn and Cr and negative correlation with sand. Two-way ANOVA indicated no significant temporal variation ($p=0.056$), but significant spatial variation was observed ($p=0.012$).

### 4.8.6 Zinc

Zinc forms about 0.004% of the earth’s crust. Soils contain about 50 ppm of zinc. Smelting, municipal refuse, automobiles, pesticides and fungicides are sources of environmental pollution due to zinc. The seasonal and annual mean values of zinc are given in Tables A5-A8.

The zinc content spans between 20.80 mg/kg at station 1 during Monsoon and 117.94 mg/kg at station 9 during pre-monsoon with 62.70 mg/kg as an average. The
seasonal variations were 28.58 mg/kg and 117.94 mg/kg during Pre-monsoon, 20.80 mg/kg to 80.80 mg/kg during Monsoon and 35.90 mg/kg and 92.90 mg/kg during Post-monsoon. The average concentration of nickel for the Lake was 62.66 mg/g. The mean, median, sd and cv were respectively 72.98 mg/kg, 68.80 mg/kg, 32.27 and 44.22 during Pre-monsoon, 53.39 mg/kg, 57.90 mg/kg, 18.96 and 35.52 during Monsoon and 61.60 mg/kg, 58.0 mg/kg, 19.79 and 32.12 during Post-monsoon.

![Graph showing seasonal and annual values of zinc in sediments](image)

**Fig. 4.25** Seasonal and annual of zinc in the sediments

Padmalal\textsuperscript{134} reported Zn concentration of 90 ppm for nearshore surficial sediments of Cochin estuary. Jayashree and Nair\textsuperscript{129} reported a Ni concentration of and 14 ppm. Leena Grace\textsuperscript{127} reported Ni content of 59.72 mg/kg for Kadinamkulam estuary, 62.84 mg/kg for Veli Lake and 67.80 mg/kg for Poonthura backwater. Mallik and Suchindran\textsuperscript{195} have reported zinc content of 85.40 mg/kg for sediments from Vembanad Lake. High concentrations of zinc may be due to the influx of discharges from agriculture fields, where zinc containing pesticides were used. Similar results were observed in earlier studies conducted by Murty and Verayya.\textsuperscript{13} Contamination due to zinc above TEL (124 μg/g) or PEL (271 μg/g) was not observed in any of the stations of Vembanad Lake.
Zinc exhibited significant positive correlation with silt, EC, LOI, TSS, OC, TN, TP, sulphate, Fe, Cu, Ni, Pb, Mn and Cr. Two-way ANOVA indicated no significant temporal \( (p=0.076) \) but significant spatial variation in concentration of zinc in the sediments \( (p=0.011) \).

4.8.7 Cadmium

Cadmium is present in fertilizers and sewage sludge applied to crop fields. Cd along with Pb and Hg are the three major trace elements having the greatest potential environmental hazard. Soils contain about 4.5ppm of cadmium. Cadmium level ranging from 0.01ppb to 0.4ppb has been reported from unpolluted natural fresh waters. The seasonal and annual mean values of cadmium are given in Tables A5-A8.

![Cadmium Concentration](image)

**Fig. 4.26** Seasonal and annual of Cadmium in the sediments

The cadmium concentration varied between below detectable level (bdl) and 0.83mg/kg at station 4 during Monsoon with 0.16 mg/kg as an average. The seasonal variations were bdl to 0.24 mg/kg during Pre-monsoon, bdl to 0.83mg/kg during Monsoon and bdl and 0.11mg/kg during Post-monsoon. The mean, median, sd and cv were respectively 0.24mg/kg, 0.00 mg/kg, 0.34 and 140.30 during Pre-monsoon, 0.12 mg/kg, 0.00, 0.27 and 230.46 during Monsoon, and 0.11, 0.00mg/kg, 0.19mg/kg and 168.89mg/kg
during Post-monsoon. The sediment from station 6 recorded a concentration of 0.74 mg/kg of cadmium with a lake average of 0.16mg/kg. The presence of cadmium in this station is attributed to local pollution. No upstream-to-downstream diversity was discernible for cadmium because of a large number of non-detections in samples from the lake.

Mallik and Suchindran have reported cadmium content of 4.69 mg/kg for sediments from Vembanad Lake. Padmala reported Cd concentration of 4 ppm for nearshore surficial sediments of Cochin estuary. Jayashree and Nair reported a Cd concentration of and 5 ppm in the sediments of Cochin estuary.

Cadmium contamination above TEL (0.676μg/g) was noticed at station 4 during Monsoon and stations 3, 6 and 10 during Pre-monsoon seasons. Cadmium contamination above PEL (4.21μg/g) was not observed in any of the stations. ANOVA indicated that concentration of cadmium exhibited no significant seasonal (p=0.53) or spatial variation (p=0.60).

4.8.8 Lead

Lead is a poisonous heavy metal that comes into water bodies from industrial, mine and smelter discharges. Lead is widely distributed in the rocks and soils of the earth’s crust. Lead is a cumulative, slow-acting general protoplasmic poison. The WHO has suggested a provisional tolerance of 7μg/kg body weight per day for adults. The seasonal and annual mean values of lead are given in Tables 5-8.

Lead recorded a high concentration of 41.13mg/kg at station 10, during Post-monsoon and a low concentration of 13.71mg/kg at station 2, during Post-monsoon. The average concentration of lead for the lake was 29.5mg/kg. The concentration of lead varied between 22.86mg/kg and 40.05mg/kg during Pre-monsoon, 13.71mg/kg to 38.11mg/kg during Monsoon and 13.71mg/kg and 41.13mg/kg during Post-monsoon. The average concentration of lead was 29.50mg/kg. The mean, median, sd and cv were
respectively 32.31mg/kg, 33.15mg/kg, 5.79 and 17.91 during Pre-monsoon, 25.73mg/kg, 28.00, 7.84 and 30.43 during Monsoon and 30.47mg/kg, 33.47mg/kg, 7.84 and 25.73 during Post-monsoon.

Mallick and Suchindan\textsuperscript{195} reported Pb content of 24.58mg/kg for sediments from Vembananad Lake. Padmalal\textsuperscript{133} reported Pb concentration of 14ppm for surfical sediments of Cochin estuary. Jayashree and Nair\textsuperscript{129} reported a Pb concentration of and 2.7 ppm. Leena Grace\textsuperscript{126, 127} reported Pb content of 52.55mg/kg for Kadinankulam estuary, 57.26mg/kg for Veli Lake and 60.26 mg/kg for Poonthura backwater. Lead contamination above TEL (30.2μg/g) was noticed in most of the stations of Vembananad Lake. Contamination, above PEL (112μg/g) was not noticed at any station.

![Graph](image)

*Fig. 4.27 Seasonal and annual of lead in the sediments*

The mean, median, sd and cv were respectively 29.50mg/kg, 31.28mg/kg, 5.27, 17.87. Lead showed significant positive correlations with clay, silt, EC, LOI, TSS, C, TN, TP, sulphate, Fe, Zn, Cu, Ni, Mn and Cr and significant negative correlation with sand. Two-way ANOVA showed that the concentration of lead exhibited no temporal ($p=0.06$) or spatial ($p=0.06$) variation in the sediments of Vembananad Lake.
4.9 Conclusion

Textural studies indicated that the southern part of the lake was blanketed by sediments rich in clay and silt. Sediments were sandy-clay-loam in most of the stations and clay loam in the southern locations. The locations on the western side were rich in sand and coarser fractions. Sand content generally increased towards the northern region. Low pH values indicated that the sediments were highly acidic. EC and TSS were high and exhibited spatial and temporal variations with maximum values during pre-monsoon. The acidic pH and high LOI indicated richness of organic matter in the sediments.

High values for OC, OM, TN and TP indicated contamination of the sediments by organic matter which increased with the silt and clay percentage. The concentration of phosphate was high at stations where agricultural and related activities were intense. Significant seasonal and temporal variations were seen in the sulphate content. High C/N ratios were registered during monsoon and post monsoon indicated that the sources of organic carbon in the sediments were of terrestrial origin. Low C/P and N/P ratios could be due to domestic sewage and increased nitrogen content due to fertilizer runoff.

The sediments were contaminated with heavy metals such as iron, manganese, zinc, copper, nickel, lead and chromium. Cadmium was present in a few samples. Trace-metal levels were related the textural composition. Metal concentrations exhibited spatial diversity, except for cadmium because of a large number of non-detections. The average concentration of manganese and iron were high. Zinc contamination was below TEL at all stations. Exceedances of TELs were observed for copper, chromium, nickel, lead and cadmium in many stations but no exceedance of PELs was noticed for any metal except nickel in any station. Temporal variations were observed for Cr and Ni and spatial variations for Fe, Cu and Zn. The spatial distribution of heavy metals indicated contamination due to anthropogenic activity.