CHAPTER 3

MATERIALS AND METHODS

3.1. DESCRIPTION OF THE STUDY AREA

Cochin Estuary (Lat. 09° 30'-10°10' N and Lon. 76° 15'-76°25' E) is a bar-built estuary constituting a network of shallow canals situated on the southwest coast of India. Although the estuary has two openings at Cochin and Azhikode, the former inlet is wider (450 m) and forms the main entrance to the Arabian Sea. Six rivers and several tributaries discharging 20,000 Mm$^3$ of freshwater annually into this estuary, makes it the largest wetlands along west coast of India. Of these, River Periyar draining into the northern region of the estuary has a major influence on the salinity distribution of the estuary (Madhupratap, 1987). Salinity remains near zero over a large part of the estuary during monsoon period; but soon after as river discharge gradually diminishes, salinity gains momentum to play an important role in the ecology of the system (Madhupratap, 1987; Menon et al., 2000).

The sampling was conducted from the following six stations in the Cochin backwaters (Fig: 1).

<table>
<thead>
<tr>
<th>Stn No.</th>
<th>Name</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Thevara</td>
<td>Lat 9° 55' 35 N</td>
<td>76° 17' 53 E</td>
</tr>
<tr>
<td>2</td>
<td>Mattancherry</td>
<td>Lat 9° 56' 47 N</td>
<td>76° 15' 52 E</td>
</tr>
<tr>
<td>3</td>
<td>Barmouth</td>
<td>Lat 9° 58' 26 N</td>
<td>76° 14' 39 E</td>
</tr>
<tr>
<td>4</td>
<td>Marine Science Jetty</td>
<td>Lat 9° 57' 39 N</td>
<td>76° 16' 40 E</td>
</tr>
<tr>
<td>5</td>
<td>Bolghatty</td>
<td>Lat 9° 58' 52 N</td>
<td>76° 15' 50 E</td>
</tr>
<tr>
<td>6</td>
<td>Varapuza</td>
<td>Lat 10° 4' 30 N</td>
<td>76° 16' 48 E</td>
</tr>
</tbody>
</table>
3.2. PERIOD OF INVESTIGATION

The Research Vessel ‘King fisher’ was used as conveyance for the sample collection. The survey period consisted of two phases. During the first phase (July 2002-June 2003) monthly collection of samples was done. In the second phase (July 2003-May 2004) seasonal sampling was carried out. Altogether 15 collections were done.

For the sake of interpretation, the data collected were pooled together based on the seasons and subjected to further analyses. A calendar year was divided into 3 distinct seasons viz.,

i. Monsoon (June- September)

ii. Post-monsoon (October -January)

iii. Pre-monsoon (February -May)

3.3. ANALYSIS OF PHYSICOCHEMICAL PARAMETERS

Water samples for hydrographic data were collected at three intervals (surface, subsurface (0.5m depth) and bottom) along the water column. An ordinary clean plastic bucket was used to collect surface water. Subsurface and bottom samples were collected using Niskins Water Sampler. The analysis of following parameters was done in standardized way.

3.3.1. Depth (m)

The depth of the water column was measured by dead reckoning method using a lead weight connected to a graduated rope marked in centimeters.
FIG. 1 MAP OF COCHIN BACKWATER SYSTEM SHOWING STATIONS 1-6
3.3.2. Water transparency

A secchi disc of 30 cm diameter painted black and white in alternate sectors with ballast and connected to a graduated rope marked in centimeters was used for the measurement of transparency of water.

The attenuation coefficient was calculated using the formula $1.5/D$ (Quasim et al., 1968); D is the depth of visibility in meters as determined by Secchi disc.

3.3.3. Temperature ($^\circ$C)

Temperatures of surface and bottom water were recorded by means of an ordinary standard Celsius thermometer immediately after the collection of samples.

3.3.4. Salinity (ppt)

Salinity of both surface and bottom water was estimated using E-2 model salinometer.

3.3.5. Dissolved oxygen (ml/l)

Dissolved oxygen concentration of surface and bottom water was estimated by Winkler’s titration method (Grasshoff et al., 1983)

3.3.6. Chlorophyll- $a$ ($\mu$mol/l)

Sub surface water samples were collected in black colored plastic containers, kept in the dark and transported to laboratory in an icebox. Chlorophyll -$a$ concentration was estimated by passing a known volume of water sample through GF/F filter paper (Whatsman), then the pigments were extracted in 90% acetone at $4^\circ$C for 24 hr dark and followed by subsequent spectrophotometric analysis (Parsons et al., 1984).

3.3.7. Nutrients ($NO_2$-N, $NO_3$-N, $PO_4$-P & $SiO_3$-Si) ($\mu$mol/l)

The surface and bottom samples were collected in clean plastic bottles and transported to the laboratory in an icebox and analysis of Nitrite-Nitrogen ($NO_2$-N),
Nitrate - Nitrogen (NO$_3$-N), Phosphate -phosphorus (PO$_4$-P) and Silicate-Silicon (SiO$_3$-Si) were done in standardized methods (Grasshoff et al., 1983).

3.4. ANALYSIS OF SEDIMENT CHARACTERISTICS

After the collection of water samples, Sediment samples (quadruplicate) were collected with a 0.05m$^2$ van Veen Grab. To estimate the interstitial water content, soil texture and total organic carbon about 100gms of well-mixed sediment samples were sub sampled from each station from respective grab haul. The samples were transferred into cleaned labeled polythene bags and transported to laboratory in an icebox.

3.4.1. Sediment temperature ($^0$C)

Temperature of the sediment was recorded by means of a standard Celsius thermometer, immediately after the collection of sediment samples.

3.4.2. Interstitial water content

Interstitial water content was measured by first taking wet weight of a known quantity of sediment, and then dried it to a constant weight at 110$^0$C and reweighed. Wet weight minus dry weight was interpreted as a rough estimate of the weight of the interstitial water content, from which the percentage of interstitial water was calculated.

3.4.3. Texture analysis

The sediment samples were subjected to Pipette Analysis by standard method (Krumbein and Pettijohn, 1938). The percentage composition of each grade (Sand, Silt and Clay) was calculated and plotted on triangular graphs based on the nomenclature suggested by Shepard (1954).
3.4.4. Organic carbon and Organic matter

The organic carbon content in sediment samples was analyzed using the standard method (Walkley and Black, 1934). The amount of organic matter in the sediment is obtained by multiplying the organic carbon values by a factor of 1.724 (Trask, 1939).

3.5. ANALYSIS OF BIOLOGICAL SAMPLES

3.5.1. MEIOFAUNA

3.5.1.1. Collection, extraction, enumeration and identification of meiofauna

15 cm long graduated glass corer with an inner diameter of 2.5 cm was used to sub sample meiofauna from 0.05 m² van Veen Grab grab hauls. Duplicate core samples were taken at each station from separate grab hauls. The corer was inserted into the undisturbed sediment, to a depth of 8 cm. All sediment cores were vertically subdivided at site into the following depth horizons: 0-2, 2-4, 4-6 and 6-8. Each slice was transferred into separately labeled plastic containers containing 4% neutral formalin and transported to the laboratory.

The sediment containing the meiofauna was stained with Rose Bengal biological stain (0.1 g in 100 ml of distilled water). Later the sediment were seived through a set of two sieves, the top one with a mesh size of 0.500 mm and the bottom one with 0.063 mm mesh size. The filtrate retained by the fine screen was transferred into petridishes containing water. The organisms were separated and enumerated using a binocular microscope and preserved in 4 % neutral formalin. The numerical abundance of organisms was extrapolated in to no/10 cm². The nematodes were identified upto genus level; however a few were attempted up to species level. The rest of the organisms were examined upto major taxa. The organisms appearing in small numbers were pooled and categorized as 'others'.
3.5.1.2. Biomass estimation of meiofauna

The wet weight of 50-100 representative of each group of organisms was estimated using high sensitive Sartorius electronic balance. From this the average wet weight of single organism and the biomass of entire community can be calculated. The biomass was expressed in mg/10 cm$^2$.

3.5.1.3. Permanent slide preparation and Identification of nematodes

From each station hundred nematodes were randomly selected for identification during each collection. In the case of samples with low densities all specimen were taken.

Nematodes were transferred into a cavity block containing Seinhorst solution 1 (95% ethanol, glycerin and distilled water in the ratio 20:1:79) and kept the vial in a desiccator and left overnight in an incubator at 35-40$^\circ$C. This will allow all the water in suspension with the nematodes replaced with ethanol. In the next day the vial was refilled with seinhorst II solution (95% ethanol and glycerin in the ratio 95:5). By the next day the organisms were impregnated in pure glycerin and ready for mounting in slides.

Bee’s wax was melted at about 60$^\circ$C. A 10 cm long cross cut metal tube with smooth, thin ring and slightly smaller diameter than the cover slips was heated at one end. Then the heated end was pushed down vertically into the melted bees wax so that it get covered by melting wax, and then pressed the end down vertically on the middle of the glass slide. A small drop of pure glycerin should be added to the center of this wax ring. The specimens were transferred to the glycerin drop. Five to ten nematodes were mounted per slide. Glass rods of an appropriate diameter were kept at four corners of the glycerin drop, under a stereo microscope then the specimen were pushed into the bottom of the glycerin drop with fine needle, made sure none overlapped with one another. Dropped another cover slip over the wax ring and the glycerin drop and put the slide above a small flame, allowed the wax to melt around
the glycerin drop. Once the wax was set, it acted both as seal and a separating layer between the cover slips. It was then used for the preparation of Cobb’s aluminum slide, which consists of an aluminum carrier supporting two cover slips between which the specimens were sandwiched and sealed; so that they can be turned over and observed from both sides at high power. The detailed examination of the prepared slides was done using a high power microscope, equipped with a 100X oil immersion lens.

The nematodes were mostly identified up to genus level with very few up to species level. Taxonomic fixing of the free-living nematodes were carried out by using Lunds Chile expedition reports (Wieser, 1953, 1954 and 1956) and synopsis of free living marine nematodes 1,11 and 111 (Platt and Warwick, 1983, 1988 and 1998). The illustrated keys by different authors and CDs (Darwin nematode identification project-electronic nematode identification key) were also used. The identifications were confirmed by expertise at University of Gent, Belgium.

3.5.2. MACROFAUNA

3.5.2.1. Collection, extraction, enumeration and identification of macrofauna

Concurrent macrofauna samples were also collected. Four grab hauls were taken from each station. The collected samples were emptied into a plastic tray and well mixed with water. The larger organisms were picked out immediately from the sediment. Macrobenthos was extracted by washing the samples through a 0.5 mm mesh sieve until all fine sediment was washed away; and the material retained in the sieve was stored in a labeled plastic container and fixed with 5% neutral formalin.

In the laboratory the sediment was stained with Rose Bengal biological stain (0.1g in 100 ml of distilled water) and re-sieved using 0.5mm sieve to remove the residual sediment and formalin. The residue in the sieve was then transferred into
Petri dishes. The organisms were extracted and preserved in 5% neutral formalin for further analysis.

Specimens were identified to the lowest possible taxonomic level. The number of each organism was enumerated. The numerical abundance was expressed in no/0.1m². Only organisms that were determined to be alive at the time of collection were counted. Many of the bivalves and gastropods had to be opened to confirm staining of biological tissue. Numerous taxonomic references were used for identification. The most often used were Fauvel (1953), Day (1967) and Boggemann (2005).

3.5.2.2. Biomass estimation of macrofauna

Wet weight of each sample was determined using a monopan electronic balance. Biomass values were based on blotted wet weight, excluding hard parts. Biomass of polychaetes, mollusc and crustaceans were taken separately and that of minor groups were pooled and represented as ‘others’. The biomass was expressed in gm/m². The individual organisms having wet weight more than 0.5g/0.05m² were not extrapolated into 1.00 m² instead, taken as such in order to avoid a biased picture. Wet weights of major taxonomic groups were converted into dry weight with the conversion factors developed by Parulekar et al. (1980). For polychaetes, crustaceans, molluscs and miscellaneous faunal groups the conversion factors were 0.119, 0.141, 0.062 and 0.09 respectively.

3.6. STATISTICAL ANALYSIS

The computer programme PRIMER v.5 (Plymouth Routines in Multivariate Ecological Research) software package developed at the Plymouth Marine Laboratory (Clarke and Warwick, 1994; Clarke and Gorley, 2001) was used for statistical analysis. Statistical methods for analyzing the benthic community fall under
the following three techniques namely, univariate analyses, distributional techniques and multivariate analyses.

3.6.1. Univariate Methods

This analysis collapses the full set of species counts for a sample into a single coefficient. The following diversity indices were computed for the estimation of community structure of nematodes and macro fauna.

3.6.1.1. Margalef’s index (d) is the measure of total number of species present in a given number of individuals.

\[ d = \frac{(S-1)}{\log N} \]

Where \( N \) = total number of individuals. \( S \) = total number of species

3.6.1.2. Shannon – Wiener index (H’) is a measure of species diversity

\[ H' = -\sum P_i \log (P_i) \]

\( P_i \) = proportion of the individuals belonging to the ith species.

3.6.1.3. Pielou’s evenness index (J’) is the relative abundance or proportion of individuals among the species.

\[ J' = \frac{H'}{\log (S)} \]

Where \( H' \) = Shannon – Wiener diversity \( S \) = total number of species

3.6.1.4. Simpson’s index (I-\( \lambda' \)) is a measure of Species dominance

\[ 1-\lambda' = 1 - \frac{\sum N_i (N_i-1)}{N \cdot (N-1)} \]

Where, \( N_i \) is the number of individuals of species \( i \).
3.6.2. Multivariate techniques

Multivariate methods of classification and ordination compare communities on the basis of the identity of the component species as well as their relative importance in terms of abundance or biomass. For multivariate analysis, the data were subjected to a square root transformation and similarity matrices were obtained using the Bray–Curtis similarity coefficient.

3.6.2.1. Cluster analysis

In multivariate analysis the commonly used classification method is cluster analysis. Classification analyses assign entities to groups. The most commonly used clustering technique is the hierarchical agglomerative method. The results of this are represented by a tree diagram or dendrogram with the x-axis representing the full set of samples and the y-axis defining the similarity level at which the samples or groups were fused.

3.6.2.2. MDS (non-metric Multi Dimensional Scaling)

Ordination techniques used in the present study was multidimensional Scaling (MDS). This method assigns entities spatially so that similar entities are close and dissimilar ones are distant.

3.6.3. Draftsman plot

This technique was used to check the interrelation between different environmental variables in the present study. The correlation matrix provides the co-linearity between variables indicated by a straight-line relationship with little scatter.
3.6.4. BIO – ENV procedure

In the present study, to ascertain the relationship between biological and environmental variables, the BIO-ENV procedure was employed. The basic principle behind this is to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Normalized Euclidean distance) matrices. A Spearman rank correlation coefficient ($\rho_s$) was used to determine the harmonic rank correlation between the biological matrix and all possible combinations of the environmental variables.

$$\rho_s = 1 - \frac{6}{N (N^2 - 1)} \sum_{i=1}^{N} \frac{(r_i - s_i)^2}{r_i + s_i}$$

The influence of water qualities like depth (m), turbidity, water temperature (${}^\circ$C), salinity (ppt), pH, DO (ml/l), NO$_2$-N ($\mu$mol/l), NO$_3$-N ($\mu$mol/l), PO$_4$P($\mu$mol/l), SiO$_3$-Si($\mu$mol/l) and chlorophyll-a ($\mu$mol/l); and the sediment properties like sand (%), silt (%), clay(%), organic carbon C(%), sediment temperature (${}^\circ$C) and interstitial water content (%) on biota were also analysed using BIOENV technique.

3.6.5. Distributional/ graphical techniques

The ABC method involves plotting of separate $k$-dominance curves for species abundances and species biomasses on the same graph and making a comparison of the forms of these curves. The species are ranked in the order of importance in terms of abundance or biomass on the X-axis (logarithmic scale) with percentage dominance on the Y-axis (cumulative scale). Cumulative plot is often referred to as a $k$-dominance curve. In undisturbed communities the $k$-dominance curve for biomass lies above the curve for abundance for its entire length. As pollution becomes more severe, benthic communities become increasingly dominated by one or a few very small species and the abundance curve lies above
the biomass curve throughout its length. This is the basis of the ABC method of determining levels of disturbance on benthic macrofaunal communities.
CHAPTER 4

HYDROGRAPHY

4.1. INTRODUCTION

Aquatic ecosystem is a complex one comprising of interacting physicochemical and biological component whose dynamics are often integrated. Organisms are totally dependent upon the environment for their sustenance. The highly variable physicochemical environment caused by the mixing of marine and fresh water stresses most animals in the estuary. Estuarine organisms have different tolerance and response to different physicochemical parameters. A comprehensive knowledge of various physicochemical parameters is imperative to document the community structure of benthos. This chapter describes the important physicochemical features that shape the character of the study area. The estuary is subjected to distinct seasonality in the physicochemical parameters due to strong southwest monsoon. The monthly data were pooled together for seasons to the analysis. Spatial and temporal fluctuations of various physicochemical parameters are documented in respective tables and figures.

4.2. RESULTS
4.2.1. Depth

At station 1, the depth varied between 1.84 (monsoon) and 2.43 m (post-monsoon). With respect to station 2, it varied from 3.03 (pre-monsoon) to 3.2 m (monsoon). At station 3, it ranged from 4.24 (monsoon) to 5.33 m (post-monsoon). In station 4, the depth values fluctuated from 2.4 (monsoon) to 2.91 m (post-monsoon). With respect to station 5, it varied between 3.53 (monsoon) and 3.8 m (post-monsoon). As far as station 6 is concerned the depth fluctuated from 4.02 (monsoon)
to 4.22 m (post-monsoon). The average values of depth at stations 1 to 6 were 2.1 m, 3.1 m, 4.9 m, 2.6 m, 3.7 m and 4.1 m respectively (Table: 4.1 and Figure: 4.1). As sampling was not possible at uniform tidal condition, the depth recorded will have the impact of tide.

4.2.2. Turbidity

At station 1, the turbidity varied between 2.19 (post-monsoon) and 3.52 (monsoon). In station 2, it varied from 1.76 (post-monsoon) to 2.58 (monsoon). At station 3, it ranged from 1.45 (pre-monsoon) to 2.29 (monsoon). In station 4, the turbidity values fluctuated from 1.73 (post-monsoon) to 2.74 (monsoon). With respect to station 5, it varied between 1.36 (post-monsoon) and 2.5 (monsoon). As far as station 6 is concerned the turbidity values fluctuated from 1.67 (post-monsoon) to 2.07 (pre-monsoon). The average values of turbidity at stations 1 to 6 were 3.02, 2.08, 1.82, 2.18, 1.83 and 1.82 respectively (Table: 4.2 and Figure: 4.2).

4.2.3. Water temperature

At stations 1, 2 and 3 the surface water temperature varied from 29°C (monsoon) to 31°C (pre-monsoon). In station 4, it ranged between 29°C (monsoon) and 30°C (post-monsoon). At station 5, the surface water temperature varied from 29°C (monsoon) to 31°C (post-monsoon). In station 6, it fluctuated from 29°C (monsoon) to 32°C (pre-monsoon) (Table: 4.3 and Figure: 4.3).

At stations 1, 2 and 3 the bottom water temperature varied from 29°C (monsoon) to 31°C (pre-monsoon). In station 4, it ranged between 28°C (monsoon) and 30°C (pre-monsoon). At station 5, it fluctuated from 28°C (monsoon) to 31°C (pre-monsoon). In station 6, it ranged between 28°C (monsoon) and 32°C (pre-monsoon) (Table 4.4 and Figure 4.4).

The average values of surface water temperature at stations 1 to 6 were 29.9°C, 29.8°C, 29.4°C, 29.5°C, 29.8°C and 30°C respectively; and that of bottom water temperature is 30°C, 29.4°C, 29.4°C, 29.4°C, 29.8°C and 29.9°C correspondingly.
4.2.4. Salinity

At station 1, the surface salinity varied between 7 (monsoon) and 20 ppt (pre-monsoon). In station 2, it varied from 9 (monsoon) to 27 ppt (pre-monsoon). At station 3, it ranged from 10 (monsoon) to 28 ppt (pre-monsoon). In station 4, the salinity values fluctuated from 10 (monsoon) to 29 ppt (pre-monsoon). With respect to station 5, it varied between 7 (monsoon) and 20 ppt (pre-monsoon). As far as station 6 is concerned the surface salinity values fluctuated from 0.6 (monsoon) to 1 (pre-monsoon) (Table: 4.5 and Figure: 4.5).

At station 1, the bottom salinity varied between 7 (monsoon) and 24 ppt (pre-monsoon). In station 2, it varied from 12 (monsoon) to 33 ppt (post-monsoon). At station 3, it ranged from 12 (monsoon) to 34 ppt (post-monsoon). In station 4, the salinity values fluctuated from 16 (monsoon) to 34 ppt (post-monsoon). With respect to station 5, it varied between 13 (monsoon) and 27 ppt (post-monsoon). As far as station 6 is concerned the bottom salinity values fluctuated from 2 (monsoon) to 8 ppt (pre-monsoon) (Table: 4.6 and Figure: 4.6).

The average values of surface water salinity at stations 1 to 6 were 15 ppt, 21 ppt, 22 ppt, 22 ppt, 14 ppt and 1 ppt respectively and that of bottom water were, 18 ppt at station 1, 24 ppt at station 2, 26 ppt at stations 3 and 4 and 22 ppt at station 5 and 5 ppt at station 6.

4.2.5. pH

At station 1, the surface water pH varied between 7.27 (monsoon) and 7.74 (pre-monsoon). At station 2, it ranged from 7.38 (monsoon) to 7.98 (pre-monsoon). In station 3, the pH fluctuated from 7.36 (monsoon) to 7.98 (pre-monsoon). As far as station 4 is concerned, it fluctuated from 7.22 (monsoon) to 7.95 (pre-monsoon). The station 5 registered the minimum value of 7.32 (monsoon) and the maximum value of 7.63 (pre-monsoon). Coming to station 6 pH ranged from 5.46 (pre-monsoon) to 6.46 (monsoon) (Table: 4.7 and Figure: 4.7).
At station 1, the bottom water pH varied between 7.31 (monsoon) and 7.81 (pre-monsoon). In station 2, it ranged from 7.34 (monsoon) to 7.92 (post-monsoon). At station 3 the pH fluctuated from 7.49 (monsoon) to 8.14 (pre-monsoon). In station 4, it fluctuated from 7.6 to 8.04 (post-monsoon). The station 5 registered the minimum value of 7.36 (monsoon) and the maximum value of 8 (pre-monsoon). Coming to station 6 it ranged from 6.48 (monsoon) to 7.12 (pre-monsoon) (Table: 4.8 and Figure: 4.8).

The average values of surface water pH were 7.6 at station 1, 7.7 at stations 2, 3 and 4, 7.5 at station 5 and 5.84 at station 6; and that of bottom water at stations 1 to 6 were 7.57, 7.7, 7.85, 7.85, 7.73 and 6.79 respectively.

4.2.6. Dissolved Oxygen (DO)

At station 1, the dissolved oxygen of surface water varied from 2.59 (pre-monsoon) to 4.22 ml/l (post-monsoon). At station 2, it fluctuated from 2.6 (pre-monsoon) to 3.89 ml/l (monsoon). At station 3, it ranged between 2.97 (pre-monsoon) and 3.7 ml/l (monsoon). In station 4, it varied from 2.91 (pre-monsoon) to 3.89 ml/l (monsoon). With respect to station 5, it ranged from 3.48 (pre-monsoon) to 3.92 ml/l (post-monsoon). Coming to station 6, the dissolved oxygen of surface water varied from 3.48 (pre-monsoon) to 4.2 ml/l (monsoon) (Table: 4.9 and Figure: 4.9).

At station 1, the dissolved oxygen of bottom water varied from 3.17 (pre-monsoon) to 4.07 ml/l (monsoon). In station 2, it fluctuated from 3.26 (pre-monsoon) to 3.81 ml/l (monsoon). At station 3, it ranged between 3.84 (pre-monsoon) and 3.89 ml/l (monsoon). In station 4, it varied from 3.08 (pre-monsoon) to 3.85 ml/l (post-monsoon). With respect to station 5, it ranged from 3.22 (pre-monsoon) to 3.68 ml/l (monsoon). Coming to station 6, the dissolved oxygen of surface water varied from 3.59 (pre-monsoon) to 4.71 ml/l (monsoon) (Table: 4.10 and Figure: 4.10).

The average values of dissolved oxygen of surface water at different stations were 3.66 ml/l at station 1, 3.39 ml/l at station 2, 3.26 ml/l at station 3, 3.5 ml/l at
station 4, 3.71 ml/l at station 5 and 3.9 ml/l at station 6. The average value of DO of bottom water at stations 1 to 6 were 3.7 ml/l, 3.6 ml/l, 3.86 ml/l, 3.48 ml/l, 3.49 ml/l and 4.27 ml/l respectively.

4.2.7. Nitrite-Nitrogen (NO$_2$-N)

At station 1, the nitrite content of surface water varied from 0.68 (post-monsoon) to 2.59 μmol/l (pre-monsoon). With respect to station 2, it ranged between 0.5 (post-monsoon) and 0.61 μmol/l (pre-monsoon). In station 3, it fluctuated from 0.53 (post-monsoon) to 0.92 μmol/l (pre-monsoon). At station 4, the NO$_2$-N content varied from 0.41 (post-monsoon) to 1 μmol/l (monsoon). In station 5, the level varied between 1.04 μmol/l (pre-monsoon) and 1.83 (monsoon). At station 6, it fluctuated from 0.43 (post-monsoon) to 2.11 μmol/l (monsoon) (Table: 4.11 and Figure: 4.11).

At station 1, the nitrite content of bottom water varied from 0.43 (post-monsoon) to 1.27 μmol/l (pre-monsoon). In station 2, it ranged between 0.51 (post-monsoon) and 0.81 μmol/l (pre-monsoon). At station 3, it fluctuated from 0.44 (post-monsoon) to 0.81 μmol/l (pre-monsoon). At station 4, the NO$_2$-N content varied from 0.57 (post-monsoon) to 1.19 μmol/l (monsoon). In station 5, the level varied between 0.69 μmol/l (post-monsoon) and 0.75 (monsoon). At station 6, it fluctuated from 0.57 (pre-monsoon) to 2.06 μmol/l (monsoon) (Table: 4.12 and Figure: 4.12).

The average values of nitrite concentration in surface water observed for stations 1 to 6 were 1.43 μmol/l, 0.58 μmol/l, 0.73 μmol/l, 0.75 μmol/l, 1.2 μmol/l, and 1.01 μmol/l respectively and that of bottom water were 0.94 μmol/l at station 1, 0.67 μmol/l at station 2, 0.65 μmol/l at station 3, 0.91 μmol/l at station 4, 0.72 μmol/l at station 5 and 1.12 μmol/l at station 6.

4.2.8. Nitrate - Nitrogen (NO$_3$-N)

At station 1, the surface water NO$_3$-N level ranged from 4.37 (post-monsoon) to 10.68 μmol/l (monsoon). With respect to station 2, it varied between 2.87 (pre-
monsoon) and 7.87 $\mu$mol/l (monsoon). In station 3, the NO$_3^-$ N content ranged between 5.33 (pre-monsoon) and 10.32 $\mu$mol/l (monsoon). In station 4, it ranged from 3.11 (pre-monsoon) to 7.71 $\mu$mol/l (monsoon). The station 5 registered a minimum value of 3.24 (pre-monsoon) and a maximum value of 11.64 $\mu$mol/l ((monsoon). At station 6, it fluctuated from 9.37 (pre-monsoon) to 22.17 $\mu$mol/l (monsoon) (Table: 4.13 and Figure: 4.13).

At station 1, the bottom water NO$_3^-$ N level ranged from 2.88 (pre-monsoon) to 9.37 $\mu$mol/l (monsoon). In station 2, it varied between 2.29 (post-monsoon) and 7.26 $\mu$mol/l (monsoon). At station 3, the NO$_3^-$ N content ranged between 2.5 (pre-monsoon) and 10.79 $\mu$mol/l (monsoon). In station 4, it ranged from 3.57 (pre-monsoon) to 9.14 $\mu$mol/l (monsoon). The station 5 registered a minimum value of 2.35 (post-monsoon) and a maximum value of 9.6 $\mu$mol/l (monsoon). At station 6, it fluctuated from 6.11 (pre-monsoon) to 18.01 (monsoon) $\mu$mol/l (Table: 4.14 and Figure: 4.14).

The average values of NO$_3^-$ N concentration in surface water were 6.91 $\mu$mol/l at station 1, 5.15 $\mu$mol/l at station 2, 7.38 $\mu$mol/l at station 3, 5.7 $\mu$mol/l at station 4, 6.68 $\mu$mol/l at station 5 and 15.9 $\mu$mol/l at station 6 and that of bottom water were 5.4 $\mu$mol/l, 4.26 $\mu$mol/l, 5.02 $\mu$mol/l, 5.56 $\mu$mol/l, 5.18 $\mu$mol/l and 12.7 $\mu$mol/l respectively at stations 1 to 6.

### 4.2.9. Phosphate - phosphorus (PO$_4^-$P)

At station 1, the PO$_4^-$P level of surface water ranged between 1.91 (monsoon) and 3.59 $\mu$mol/l (pre-monsoon). With respect station 2, it fluctuated from 0.82 (pre-monsoon) to 1.53 $\mu$mol/l (monsoon). In station 3, the level varied from 0.97 (post-monsoon) to 1.33 $\mu$mol/l (monsoon). In station 4, it ranged between 0.86 (post-monsoon) and 1.47 $\mu$mol/l (pre-monsoon). With respect to station 5, the level of PO$_4^-$P ranged from 1.07 (pre-monsoon) to 2.13 $\mu$mol/l (monsoon). At station 6, it
fluctuated from 0.61 (pre-monsoon) to 4.38 \( \mu \text{mol/l} \) (post-monsoon) (Table: 4.15 and Figure: 4.15).

At station 1, the \( \text{PO}_4^2- \text{P} \) level of bottom water ranged between 1.99 (pre-monsoon) and 2.13 \( \mu \text{mol/l} \) (monsoon). At station 2, it fluctuated from 1.05 (pre-monsoon) to 1.87 \( \mu \text{mol/l} \) (monsoon). At station 3, the level varied from 0.81 (pre-monsoon) to 1.83 \( \mu \text{mol/l} \) (monsoon). In station 4, it ranged between 0.90 (post-monsoon) and 2.00 \( \mu \text{mol/l} \) (monsoon). With respect to station 5, the level of \( \text{PO}_4^2- \text{P} \) ranged from 1.16 (pre-monsoon) to 2.19 \( \mu \text{mol/l} \) (post-monsoon). At station 6, it fluctuated from 0.58 (pre-monsoon) to 6.17 \( \mu \text{mol/l} \) (post-monsoon) (Table: 4.16 and Figure: 4.16).

The average values of phosphate concentration in surface water at stations 1 to 6 were 2.5 \( \mu \text{mol/l} \), 1.18 \( \mu \text{mol/l} \), 1.1 \( \mu \text{mol/l} \), 1.23 \( \mu \text{mol/l} \), 1.6 \( \mu \text{mol/l} \) and 2.1 \( \mu \text{mol/l} \) respectively and that in bottom water were 2.06 \( \mu \text{mol/l} \) at station 1, 1.35 \( \mu \text{mol/l} \) at station 2, 1.2 \( \mu \text{mol/l} \) at station 3, 1.46 \( \mu \text{mol/l} \) at station 4, 1.73 \( \mu \text{mol/l} \) at station 5 and 2.67 \( \mu \text{mol/l} \) at station 6.

4.2.10. Silicate-Silicon (\( \text{SiO}_3^2- \text{Si} \))

At station 1, the silicate content of the surface water fluctuated from 20.55 (pre-monsoon) to 69.91 \( \mu \text{mol/l} \) (monsoon). With respect to station 2, it varied from 11.51 (pre-monsoon) to 59.02 \( \mu \text{mol/l} \) (monsoon). At station 3, it fluctuated between 14.71 (pre-monsoon) and 77.06 \( \mu \text{mol/l} \) (monsoon). At station 4, it varied from 13.34 (post-monsoon) to 43.97 \( \mu \text{mol/l} \) (monsoon). With respect to station 5, the \( \text{SiO}_3^2- \text{Si} \) concentration ranged between 20.54 (pre-monsoon) and 57.96 \( \mu \text{mol/l} \) (monsoon). At station 6, it fluctuated from 22.73 (pre-monsoon) to 54.01 \( \mu \text{mol/l} \) (monsoon) (Table: 4.17 and Figure: 4.17).

At station 1, the silicate content of the surface water fluctuated from 14.99 (pre-monsoon) to 73.29 \( \mu \text{mol/l} \) (monsoon). With respect to station 2, it varied from 8.72
(pre-monsoon) to 60.57 μmol/l (monsoon). In station 3, it fluctuated between 11.12 (pre-monsoon) and 65.13 μmol/l (monsoon). At station 4, it varied from 13.99 (post-monsoon) to 49.4 μmol/l (monsoon). With respect to station 5, the silicate content ranged between 14.06 (pre-monsoon) and 49.36 μmol/l (monsoon). At station 6, it fluctuated from 22.43 (pre-monsoon) to 57.48 μmol/l (monsoon) (Table: 4.18 and Figure: 4.18).

The averages of silicate concentration in surface water at stations 1 to 6 were 42.69, 34.45, 38.26, 24.37, 37.64 and 33.7 μmol/l respectively and that of bottom water were 40.69 μmol/l at station 1, 27.5 μmol/l at station 2, 32.24 μmol/l at station 3, 26.08 μmol/l at station 4, 31.87 μmol/l at station 5 and 37.87 μmol/l at station 6.

4.2.11. Chlorophyll- a

In station 1, the Chlorophyll- a content of the sub surface water ranged between 10.05 (pre-monsoon) and 14.53 μmol/l (post-monsoon). At station 2, it fluctuated from 4.11 (pre-monsoon)) to 8.19 μmol/l (post-monsoon). With respect to station 3, the Chlorophyll content varied between 4.3 (post-monsoon) and 8.82 μmol/l (monsoon). At station 4, the levels fluctuated from 4.14 (pre-monsoon) to 6.57 μmol/l (monsoon). In station 5, it ranged between 4.87 (post-monsoon) and 7.3 μmol/l (pre-monsoon). At station 6, it fluctuated from 4.3 (monsoon) to 5.23 (pre-monsoon) μmol/l. The average values of chlorophyll a concentration at stations 1 to 6 were 12.08, 6.76, 6.08, 5.49, 6.77 and 4.71 μmol/l respectively (Table: 4.19 and Figure: 4.19).

4.2.12. Draftsman plot

In order to determine the correlation between different environmental parameters Draftsman plot was drawn (Figure: 4.20). Strong positive correlations were obtained for attenuation coefficient and chlorophyll content(0.849), water temperature and PO4-P(0.879), temperature and SiO3-Si (0.872), water temperature and sediment
temperature (0.889), salinity and pH (0.996), DO and NO₂-N (0.822), NO₂-N and NO₃-N (0.807), NO₂-N and PO₄-P (0.855), PO₄-P and sediment temperature (0.957).

4.3. DISCUSSION

Water quality is a vital aspect for the survival and well being of estuarine organisms. Hydrographical conditions in the estuarine system mainly depend on the interaction of the seawater, freshwater, wind, rainfall, water current and tidal forces. Since the seawater is dominating during the summer and the fresh water during the monsoon months there is a seasonal pattern in the variations of different parameters.

Water clarity is a major determinant of the condition and productivity of an aquatic system. Turbidity is an important parameter for estuarine monitoring since this will give an idea about sedimentation in the estuary. Greater the amount of suspended solids in the water higher the measured turbidity. Suspended sediment can smother the benthic organisms and its habitats when it settles. The minimum value for turbidity was found during post monsoon and maximum during monsoon season. The alluvial coastal belt of Kerala is packed up with laterite mass of fine material. During the monsoon period, when the freshets from rivers containing large amounts of finer clay particles, flowed into the estuary, the turbidity generally increases to a high level and the low intensity of solar radiation makes the water less transparent. During the post monsoon period the land runoff decreases and intensity of solar radiation increases which makes the water more transparent. These observations are synchronized well with Sarala (1986).

Temperature is one of the most common ecological factors influencing all the activities of an organism. It acts as the limiting factor for growth and distribution of animals. It interacts with many other ecological factors and results in many climatic changes. The temperature in estuarine environment is largely influenced by changes in air temperature, intensity of solar radiation, evaporation, and freshwater ingression. In the present study, the water temperature showed monsoonal minimum and pre-
monsoonal maximum. The higher temperature during the pre-monsoon period is due to intense solar radiation. The fall in water temperature noticed during the monsoon season is due to the cold weather and rainfall. The water was nearly vertically isothermal with in the estuary. The northern limb of estuary registered a slight increase in the temperature when compared to the southern limb; this may be due to its proximity to industrial discharge.

Salinity was noticed as the major environmental variable in the present study. It varied from place to place, season-to-season and surface to bottom. It was highest near the mouth of the estuary and at upstream where fresh water flows in it was lowest. The distribution of salinity was seasonal. During monsoon, the entire estuary attains near freshwater conditions. The strong flow of fresh water in to the estuary declines the salinity during monsoon period. The post-monsoon was presenting a trend of recovery. An appreciable vertical gradient in salinity was observed at all stations. The observed changes in salinity were primarily due to various causes like annual variation in precipitation, temperature, evaporation, wind, increase of fresh water and tidal action. The present findings are in affirmative with Chandramohan (1990) and Saravanan (1999).

pH remained slightly alkaline throughout the study period at stations 1 to 5. However, Station 6 was slightly acidic nature. The fluctuation in pH may be due to localized influence of effluents from different sources. In general pH in the estuary was minimum during monsoon season and maximum during pre-monsoon. Vertical gradient of pH remained less conspicuous during the most part of the year. The chemical components of seawater resist large changes in the pH.

It is well known that the solubility of oxygen in the estuary is a function of its partial pressure on one hand and its salinity and temperature on the other. Normally highest dissolved oxygen concentration was observed during monsoon season both in surface and bottom water owing to the low salinity and temperature prevailing
during this period. Comparatively low DO values recorded during Pre-monsoon were
due to higher water temperature and high salinity, which reduce the solubility of
oxygen in water. The trend noticed in the present study is in conformity with the
findings of Saraladevi (1986) and Mitra et al. (1990). Generally during Pre-monsoon
and post-monsoon DO of bottom water was found to be higher than that of surface
water; this may be due to the high photosynthetic activity of benthic algae during
these seasons.

The nutrient rhythm in backwater followed marked seasonal pattern. Among
various nutrients studied, silicate showed more pronounced spatial and temporal
variability. The increase in silicate concentration on the onset of monsoon is mainly
due to the intrusion of fresh water containing relatively more silicate in to the system.
There exhibited an inverse relationship between silicate concentration and salinity.
Other nutrients generally established high concentration during monsoon season.
Still, occasionally higher values were also obtained during pre monsoon and post
monsoon season also. The surface-bottom differences arising out of either surface
excess over bottom or vice versa were inconsistent. These fluctuations that were
seen in the present study may be due to local effect. It was understood that the large
input from industrial units, sewage works and agricultural runoffs determine the
nutrient concentration in the water column. The regional differences of the stations to
a limited extend was also observed in the estuary. The river Periyar after flowing
through the industrial complex area empties near station 6, which resulted higher
nutrient concentration at this station. Draft man plot demonstrated a strong
correlation between concentration of $PO_4$ - P and $SiO_3$-Si with temperature of water
column and sediment.

Information on primary production is essential for assessing the fertility of the
aquatic systems and predicting the potential of living resources. Measurement of the
amount of the Chlorophyll in water column gives a useful index of phytoplankton
density and this also reflects the level of primary productivity of the estuary. The distribution and availability of nutrients in estuaries determines the productivity of phytoplankton. The occasional algal bloom and the subsequent decay of planktons are due to the nutrient enrichment in the system. Draft man plot displays a strong correlation between turbidity and Chlorophyll - a (0.849). The continuous, irregular as well as unpredictable pattern of the estuarine environment may influence the spatial and temporal distribution of benthic community. A regular and systematic monitoring of different physicochemical parameters is imperative to understand the response of organism to various ecosystem changes.