2. DISSOLVED NUTRIENTS

2. Dissolved Nutrients

2.1. Introduction

Nutrients are inorganic substances found in low quantities in aquatic ecosystems and are being constantly used by the phytoplankton community for organic production. Though aquatic plants need a number of nutrients for adequate growth and reproduction, nitrogen, phosphorus and silicon are the most critical ones. While nitrogen as nitrate and phosphorus as phosphate help in primary productivity, silicon is essential for the skeletal growth of diatoms, radiolarians and certain sponges.

The nutrients determine the potential fertility of the water masses. The biological wealth of an aquatic realm is largely dependent upon the dissolved nutrients. The estuary is the major nutrient source for the higher primary production.

Estuaries receive nutrient inputs from a variety of sources. River run-off contributes dissolved nutrients from chemical weathering of rocks. The influx of sea water provides a strong electrolyte solution of nearly constant composition with respect to major ions. Raymont (1980) stated that irrespective of man's influence, the concentrations of phosphate, nitrate and dissolved silicon are characteristically higher in river waters than in the surface sea water and this leads to a general enhancement of nutrients in estuaries and in coastal waters influenced by land drainage.

In order to understand the diversities exhibited in the distribution of marine population in space and time, the importance of the nutrients in the sea, especially of phosphates and silicates is well recognised. Observations on the distribution of micronutrients in the open ocean help in understanding ocean circulation and plankton ecology. In shallow water ecosystems like estuaries, the productivity of the water depends mainly on the dissolved nutrients. As dissolved nutrients are necessary for the growth of phytoplankton and as the consumers and decomposers depend on the phytoplankton, the nutrients are inextricably linked to almost all ecological processes.

2.2. Review of Literature

The significance of the total phosphorus concentration in the sea as an index of potential fertility of waters and for identifying different water masses as tracer has been emphasized by Rochford (1951). Johannes (1965, 1969) studied the influence of marine Protozoa on nutrient regeneration in lakes and oceans. Putnam (1966) observed phosphorus and silica as limiting factors of phytoplankton population in west coast Florida estuary. Ketchum (1967) discussed at length the phytoplankton nutrients in estuaries. Ryther and Dunstan (1971) analysed nitrogen, phosphorus and eutrophication in the coastal marine environment. Pomeroy *et al.* (1972) studied nutrient flux in estuaries. Banse(1974) discussed nitrogen phosphorus ratios in the photic zone of the sea. Hale (1975) studied the role of benthic communities in the nitrogen and phosphorus cycles of an estuary. Sinclair (1977) observed that low phytoplankton biomass was associated with low nutrient concentration. Eppley *et al* . (1978) made a study of plankton dynamics and nutrient cycling in the central gyre of the North Pacific Ocean. Boynton *et al.* (1980) studied the nutrient fluxes across the sediment water interface in the turbid zone of a coastal plain estuary. Rutgers (1981) studied the regeneration of nutrients in Dutch coastal sediments. Grantham (1981) studied chlorophyll 'a' and nutrients in the water column of Loch Eil. Nixon (1981) studied remineralization and nutrient cycling in coastal marine ecosystem. In a salt marsh estuary of North Umberland Strait, Howland *et al.* (1999) analysed the nutrients of the Chupa estuary, White sea, Russia. Shriadah and Saif (1999) surveyed nutrient salts of United Arab Emirates waters along the Arabian Gulf.

In India, along the east and west coasts several works have been carried out on nutrients especially in the last two decades.

Along the east coast of India observations pertaining to nutrients were made by Jayaraman (1951, 1954) in the waters of Bay of Bengal and Gulf of Mannar; Banerjee and Roy Choudhury (1966) in Chilka lake; Krishnamurthy (1967, 1970); Sreenivasan *et al.* (1969) in Adayar estuary; Ramasarma (1970) in Gaurami - Godavari estuary; Santhakumari (1970); Purushothaman and Venugopalan (1972); Rajendran (1974); Sundararaj and Krishnamurthy (1975); Ramanathan and Varadarajalu (1975) in Kistna estuary; Kaliyamurthy (1976) in Pulicat lake; Ramadhas (1977); Venugopalan *et al.* (1981); Chandran (1982); Sivakumar (1982); Thangaraj (1984) and Chandran and Ramamoorthi (1984 a) in Vellar estuary; Prabha Devi (1986) and Jegadeesan (1986) in Coleroon estuary; Balusamy *et al.* (1987) and Balusamy (1988) in Muthupet estuary; Upadhyay (1988) in Mahanadi estuarine system; Satpathy (1996) in the coastal waters of Kalpakkam; Jayaraju and Reddy (1997) in coastal and estuarine environments along south east coast; Padmavati and Satyanarayana (1999) in riverine, estuarine and adjoining coastal waters of Godavari and Padma and Periakali (1999) in Pulicat lake.

Along the west coast Rao and George (1959) reported nutrients of Korapuzha estuary in Kerala. The nutrients in relation to other hydrobiological features of Cochin backwater system have been thoroughly investigated by Sankaranarayanan and Qasim (1969); Devassy and Gopinathan (1970); Shynamma and Balakrishnan (1973); Wellershaus (1973); Anzari and Rajagopal (1974), and Sreedharan and Salih (1974).

Sarala Devi *et al.* (1983) studied the nutrients of four estuaries of Kerala coast viz Kallai, Beypore, Korapuzha and Mahe. The hydrological features including nutrients of Ashtamudi estuary, Akathumuri Anchuthengu and Kadinamkulam backwater systems of Kerala have been investigated by Nair *et al.* (1983a and 1984). Hydrobiological studies in relation to nutrients in Mandovi and Zuari estuarine system of Goa have been undertaken by Dehadrai (1970), Dehadrai and Bhargava (1972), Singbal (1973), Goswami and Singbal (1974), Dwivedi *et al.* (1974), De Souza (1977) and Qasim and Sengupta (1981). The relationship of nutrients and plankton in the Veli lake was carried out by Arunachalam *et al.* (1982) and Nair *et al.* (1987). Kahar (1988) made an extensive survey of the temporal and spatial variations of the nutrient concentrations in Poonthura backwater, Kerala. Bijoy Nandan (1991) analysed the nutrient concentration in relation to retting in Kadinamkulam Kayal. Shibu (1991) made a survey of nutrients in Paravur lake.

In the present investigation, the dissolved nutrients such as silicate, inorganic phosphate, total phosphorus, nitrate and nitrite have been estimated monthly for a period of two years in Manakkudy estuary. The relationship of nutrients to salinity, productivity, plant pigments and plankton distribution has also been discussed.

2.3. Materials and Methods

The water samples for the estimation of nutrients were collected monthly using clean plastic buckets and were brought to the laboratory in polythene bottles. The water samples were filtered through a millipore filtering unit using Whatman GF/C filter paper. The dissolved nutrients were estimated by colorimetric method as described by Strickland and Parsons (1972) and were read out by the Unicam sp 500 Spectrophotometer at suitable wave lengths for different nutrients.

2.4. Results

2.4.1. Silicate

The results obtained for the seasonal variations of dissolved silicate at station I, II and III during 1990-'91 and 1991-'92 are presented in Fig. 2.1.

During 1990-'91 the silicate content fluctuated between 35.2 µgm at Si/ℓ (April) and 165.8 µgm at Si/ℓ (November) at station I, between 39.2 µgm at Si/ℓ(April) and 172.1 µgm at Si/ℓ(November) at station II and between 45.3 µgm at Si/ℓ(April) and 173.2 µgm at Si/ℓ (November) at station III.

During 1991-'92 the silicate content varied from 31.6 µgm at Si/ℓ(May) to 179.1 µgm at Si/ℓ (June) at station I, from 40.7 µgm at Si/ℓ (May) to 181.3 µgm at Si/ℓ(June) at station II and from 41.5 µgm at Si/ℓ (May) to 192.6 µgm at Si/ℓ(June) at station III.

2.4.2. Total Phosphorus

The results obtained for dissolved total phosphorus for the two years at station I, II and III are given in Fig. 2.2.

During 1990-'91 the total phosphorus varied from 0.41 µgm at P/ℓ (May) to 2.54 µgm at P/ℓ(November) at station I, from 0.70 µgm at P/ℓ(April) to 2.71 µgm at P/ℓ(November) at station II and from 0.86 µgm at P/ℓ(May) to 2.81 µgm at P/ℓ(November) at station III.

During 1991-'92 the total phosphorus fluctuated between 0.53 µgm at P/ℓ(May) and 2.41 µgm at P/ℓ(June) at station I, between 0.62

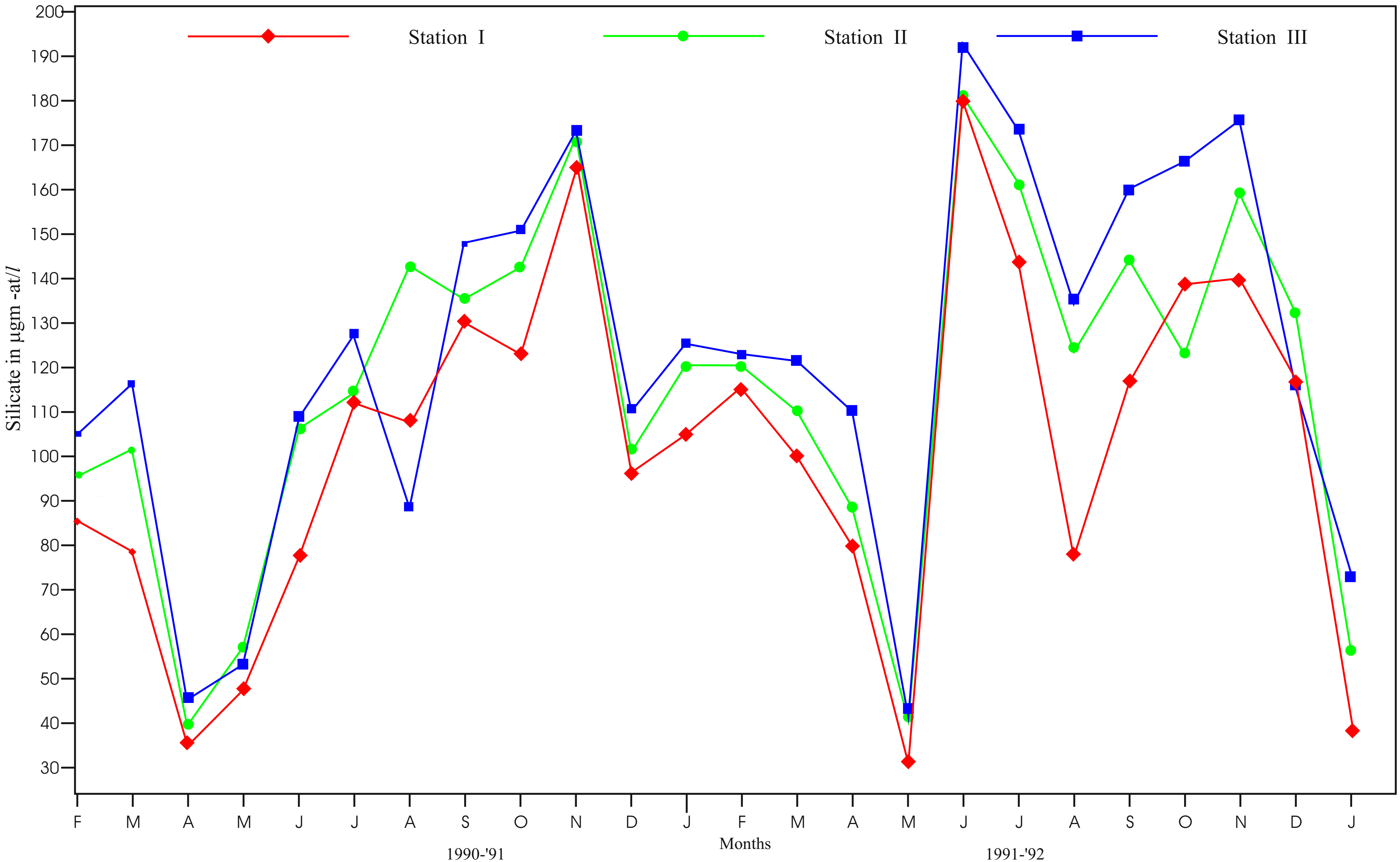

Fig. 2.1: The variations in dissolved silicate concentrations in Manakkudy estuary at station I, II and III during 1990-'91 and 1991-'92.

µgm at P/ℓ(May) and 2.52 µgm at P/ℓ(June) at station II and between 0.91 µgm at P/ℓ(May) and 2.61 µgm at P/ℓ(June) at station III.

2.4.3. Inorganic Phosphate

The data obtained for seasonal fluctuations of dissolved inorganic phosphate at station I, II and III during 1990-'91 and 1991-'92 are presented in Fig. 2.3.

The concentration of inorganic phosphate fluctuated between 0.48 µgm at P/ℓ(April) and 1.81 µgm at P/ℓ(November) at station I, between 0.62 µgm at P/ℓ(April) and 1.90 µgm at P/ℓ(November) at station II and between 0.79 µgm at P/ℓ(April) and 2.03 µgm at P/ℓ (November) at station III during 1990-'91.

During 1991-'92 the concentration varied from 0.16 µgm at P/ℓ (May) to 1.86 µgm at P/ℓ(June) at station I, from 0.23 µgm at P/ℓ(May) to 1.91 µgm at P/ℓ(June) at station II and from 0.49 µgm at P/ℓ(May) to 2.11 µgm at P/ℓ(June) at station III.

2.4.4. Nitrate

The results obtained for seasonal fluctuations of dissolved nitrate for 1990-'91 and 1991-'92 at station I, II and III are presented in Fig. 2.4.

During 1990-'91 the nitrate content ranged from 1.01 µgm at N/ℓ (April) to 12.36 µgm at N/ℓ (November) at station I, from 1.32 µgm at N/ℓ (April) to 13.96 µgm at N/ℓ (November) at station II and from 2.38 µgm at N/ℓ (April) to 16.47 µgm at N/ℓ (November) at station III.

During 1991-’92 the concentration of nitrate varied from 0.45 µgm at N/ℓ(May) to 13.09 µgm at N/ℓ(June) at station I, from 0.83 µgm at N/ℓ(May) to 13.98 µgm at N/ℓ(June) at station II and from 1.04 µgm at N/ℓ(May) to 17.24 µgm at N/ℓ(June) at station III.

2.4.5. Nitrite

The results obtained for the nitrite content at station I, II and III during 1990-’91 and 1991-’92 are presented in Fig. 2.5.

The concentration of nitrite fluctuated between 0.09 µgm at N/ℓ(April) and 0.61 µgm at N/ℓ(November) at station I, between 0.11 µgm at N/ℓ(April) and 0.93 µgm at N/ℓ(November) at station II and between 0.18 µgm at N/ℓ(April) and 1.03 µgm at N/ℓ(November) at station III during 1990-’91.

During 1991-’92 the nitrite content varied from 0.15 µgm at N/ℓ (January) to 0.99 µgm at N/ℓ (May) at station I, from 0.13 µgm at N/ℓ (May) to 0.95 µgm at N/ℓ(June) at station II, and from 0.20 µgm at N/ℓ (May) to 1.11 µgm at N/ℓ(June) at station III.

2.4.6. N : P Ratio

The nitrate : phosphate ratio was determined for station I, II and III during 1990-’91 and 1991-’92 and the results are presented in Fig. 2.6.

The N : P ratio at station I fluctuated from 2.11:1 in April to 11.68:1 in August during 1990-’91 and from 2.81:1 in May to 7.62:1 in October during 1991-’92.

At station II the N : P ratio varied from 2.13:1 in April to 10.72:1 in August during 1990-'91 and from 3.03:1 in January to 7.32:1 in June during 1991-'92.

At station III the N : P ratio ranged from 3.01:1 in April to 8.98:1 in March during 1990-'91 and from 2.12:1 in May to 8.17:1 in June during 1991-'92.

2.5. Statistical Treatment

Mean and standard error of nutrients are given in Table 2.1. Seasonal mean values are given in Table 2.2. Simple correlation of rainfall with nutrients is given in Table 2.3. Inter correlation of salinity and nutrients is given in Tables 2.4 to 2.9. Simple correlation of nutrients with physico-chemical parameters is given in Tables 2.10 to 2.15.

2.5.1. Silicate

The average silicate level did not exhibit any significant variation among the three stations in 1991-'92, whereas in 1990-'91 the average silicate level in station I was much higher than that in the other two stations, which were on par. The maximum silicate level was 192.60 µgm at Si/ℓ in station III in 1991-'92 and the minimum was 31.6 µgm at Si/ℓ in station I in 1991-'92. The annual mean value was higher during 1990-'91 and lower during 1991-'92.

The average silicate content was found higher in the monsoon season during both the years. Low values of silicate content were found in the premonsoon season throughout the period of study. The annual average silicate content was higher at station III and lower at station I during both the years.

The silicate content showed negative correlation with salinity and H_2S and positive correlation with oxygen.

2.5.2. Total Phosphorus

The phosphorus levels measured in both the years over the three stations indicated the fact that during 1990-'91, the average level did not show any significant variation among the three stations. During 1991-'92, the levels were on par in station I and II and also on par between station II and III, indicating the superiority of station III over station I alone. The maximum was 2.81 µgm at P/ℓ in station III during 1990-'91 and the minimum was 0.41 µgm at P/ℓ in station I during 1990-'91.

During 1990-'91 the average level of total phosphorus did not show any significant variation among the three stations. During 1991-'92 the annual average was high at station III followed by station II and I. The seasonal total phosphorus content was minimum in the premonsoon and maximum in the monsoon season at all stations during both years of study. Total phosphorus exhibited negative correlation with salinity and H_2S and positive correlation with oxygen.

In the present study, one peak of total phosphorus was noticed during 1990-'91 and two peaks during 1991-'92. The major peak was observed in the monsoon season and the minor peak was in the postmonsoon season, during 1991-'92.

2.5.3. Inorganic Phosphate

The mean level of inorganic phosphate did not show any significant variation among the 3 stations in both the years. The maximum was 2.11 μgm at P/ℓ in station III in 1991-'92 and the minimum was 0.16 μgm at P/ℓ in station I in 1991-'92.

In the present investigation, the mean values of inorganic phosphate were minimum in the premonsoon season during both years of study. The maximum values were recorded in the monsoon season.

In the present study, inorganic phosphate showed a single peak during 1990-'91 but two peaks during 1991-'92. The major peak was in the monsoon season and the minor peak was in the postmonsoon season during 1991-'92.

The seasonal mean values of inorganic phosphate were increasing from station I to station III through station II.

The concentration of inorganic phosphate showed a negative correlation with salinity and H_2S and positive correlation with oxygen.

2.5.4. Nitrate

The average level of the nitrate measured in 1991-'92 did not show any significant variations over the 3 stations, however in 1990-'91 in station I and II it was on par. Similarly station II and III were on par indicating the fact that station III recorded higher mean value than station I. The maximum was 17.24 μgm at N/ℓ in station III in 1991-'92 and the minimum was 0.45 μgm at N/ℓ in station I in 1991-'92.

In the present investigation, higher values of nitrate concentration were recorded in the monsoon and postmonsoon seasons and low values in the premonsoon season. In the present study, there was a single peak of nitrate concentration during 1990-'91 and during 1991-'92 there were two peaks. During 1990-'91 the peak was in the beginning of postmonsoon of north-east monsoon season. During 1991-'92 the major peak was in the southwest monsoon season and the minor peak was in the northeast monsoon season.

Station III recorded maximum values of nitrate followed by station II and I during both years. Nitrate showed negative correlation with salinity and H_2S and positive correlation with oxygen.

2.5.5. Nitrite

The average level of nitrite recorded in both years did not show any significant variations among the three stations. The variations were also very low here in both the years. The maximum recorded value was 1.11 µgm at N/ℓ in 1991-'92 in station III where as the minimum was 0.09 µgm at N/ℓ in station I in both the years.

In the present study, high values of nitrite concentration were recorded in the monsoon and postmonsoon seasons and low values in the premonsoon season during both the years. When the nitrite concentration of the three stations were compared, the values decreased from station III to I through II.

On comparing the values of salinity and nitrite, they showed a negative correlation. Higher values of nitrite coincided with the lower values of salinity and H_2S and higher values of oxygen.

A remarkable feature of nitrite was its low concentration compared to other nutrients of the estuarine water.

2.5.6. N:P Ratio

The average level of the N:P ratio recorded during 1991-'92 did not exhibit any significant variation among the three stations. However, in 1990-'91 station II had recorded a higher average value than that of station I and III, which were on par. The maximum recorded N:P ratio value was 0.78 in station II in 1991-'92 and the minimum of 0 was recorded in station I during 1990-'91 and in station II during 1991-'92.

The annual average of N : P ratio showed high values at station II and low values at station I. Seasonal N : P ratio showed maximum values during monsoon and postmonsoon seasons.

N : P ratio showed positive correlation with rainfall.

Table 2.1 : Mean and standard error of the nutrients. The mean values are written in the increasing order with the station numbers along with it in the paranthesis, S1 indicating station 1, S2 indicating station 2 and S3 indicating station 3. Bars above the means are used to indicate statistically on par values. The value in the paranthesis below each mean indicates the standard error.

S.No.	PARAMETERS	1990 – '91			1991 – '92		
1	Silicate	110.8333 (S2) (36.92)	112.5167 (S3) (35.56)	165.8 (S1) (35.72)	106.45 (S1) (43.78)	120.1375 (S2) (41.72)	127.8875 (S3) (59.25)
2	Phosphorous	1.5558 (S1) (.6095)	1.7458 (S2) (.6222)	2.0719 (S3) (.5937)	1.43 (S1) (.5397)	1.6092 (S2) (.5198)	1.9022 (S3) (.5295)
3	Inorganic phosphate	1.2050 (S1) (.3891)	1.3067 (S2) (.3853)	1.4892 (S3) (.3810)	1.3525 (S1) (.5262)	1.3792 (S2) (.5435)	1.4983 (S3) (.5377)
4	Nitrate	7.7933 (S1) (3.6341)	8.7642 (S2) (3.6389)	11.1742 (S3) (3.6668)	6.9108 (S1) (4.2559)	7.7667 (S2) (4.2667)	9.1750 (S3) (4.8043)
5	Nitrite	.3358 (S1) (.1504)	.3858 (S2) (.2073)	.4583 (S3) (.2273)	.3583 (S1) (.1955)	.430 (S2) (.2596)	.530 (S3) (.3236)
6	N:P ratio	.4525 (S3) (.0507)	.4633 (S1) (.1847)	.5542 (S2) (.1066)	.4792 (S1) (.0846)	.5275 (S3) (.0844)	.5283 (S2) (.1871)

Table 2.2 : Mean values of the nutrients in the premonsoon, monsoon and postmonsoon seasons in all the stations during 1990-'91 and 1991-'92.

I	Premonsoon						Monsoon						Postmonsoon					
	1990-'91			1991-'92			1990-'91			1991-'92			1990-'91			1991-'92		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
Silicate	62.0750	73.3125	80.1000	81.0750	89.6625	76.4625	106.6375	124.9000	117.7750	128.9125	152.5625	164.7250	122.8625	134.2875	139.6750	109.3625	118.1875	142.4750
Total phosphorus	1.0875	1.2800	1.5683	.9275	1.1975	1.3865	1.2700	1.4350	1.5925	1.4825	1.7600	1.9375	1.4225	1.5200	1.7800	1.3650	1.6425	1.6425
Inorganic phosphate	.9225	.9650	1.0950	.5500	.7350	.9150	1.6625	1.8400	2.2725	1.7250	1.9000	2.3050	1.9175	2.1175	2.3750	1.6375	1.7300	2.0150
Nitrate	3.5675	4.9775	7.7425	2.5025	3.1275	4.5600	10.1600	11.0350	12.7500	9.8050	10.9500	13.7350	9.6525	10.2800	13.0300	8.4250	9.2225	10.2300
Nitrite	.2350	.2650	.3175	.1850	.2175	.2600	.3250	.3550	.4025	.4700	.5725	.6650	.4475	.5375	.6550	.4200	.5000	.6650
N : P ratio	3.60	4.6925	6.7550	4.03	3.9550	4.2950	8.3650	7.6950	8.0325	6.5450	5.9458	6.5375	6.8475	6.7013	7.3350	5.8800	5.5400	6.0950

Table 2.3 : Simple correlation of rainfall with nutrients at station I, II and III during 1990-'91 and 1991-'92.

YEAR	1990-'91			1991-'92		
Station	**S1**	**S2**	**S3**	**S1**	**S2**	**S3**
Silicate	0.308	0.251	0.257	0.310	0.442	0.361
Phosphorus	0.420	0.398	0.375	0.160	0.132	0.393
Phosphate	0.330	0.274	0.190	0.421	0.342	0.375
Nitrate	0.364	0.309	0.331	0.415	0.407	0.355
Nitrite	0.318	0.414	0.616	0.349	0.316	0.345
N:P ratio	0.615*	0.652*	0.512	0.601*	0.611	0.352

Table 2.4: Inter correlation of salinity and nutrients in station I during 1990-'91.

	Salinity surface	Salinity bottom	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Salinity surface	1	0.986**	-0.902**	-0.772**	-0.838**	-0.912**	-0.774**	-0.592*
Salinity bottom		1	-0.905**	-0.822**	-0.845**	-0.921**	-0.829**	-0.591*
Silicate			1	0.877**	0.739**	0.869**	0.911**	0.561*
Phosphorus				1	0.566*	0.754**	0.852**	0.524
Phosphate					1	0.732**	0.691*	0.254
Nitrate						1	0.743**	0.821**
Nitrite							1	0.443
N:P ratio								1

Table 2.5: Inter correlation of salinity and nutrients in station I during 1991-'92.

	Salinity surface	Salinity bottom	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Salinity surface	1	0.988**	-0.882**	-0.848**	-0.946**	-0.979**	-0.913**	-0.938**
Salinity bottom		1	-	-0.862**	-0.960**	-0.974**	-0.936**	-0.905**
Silicate			1	0.839**	0.830**	0.853**	0.805**	0.808**
Phosphorus				1	0.903**	0.860**	0.820**	0.732**
Phosphate					1	0.972**	0.917**	0.876**
Nitrate						1	0.913**	0.943**
Nitrite							1	0.801**
N:P ratio								1

Table 2.6: Inter correlation of salinity and nutrients in station II during 1990-'91.

	Salinity surface	Salinity bottom	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Salinity surface	1	0.974**	-0.887**	-0.799**	-0.777**	-0.832**	-0.866**	-0.604*
Salinity bottom		1	-0.822**	-0.873**	-0.795**	-0.830**	-0.740**	-0.578*
Silicate			1	0.853**	0.759**	0.872**	0.801**	0.703*
Phosphorus				1	0.712**	0.729**	0.851**	0.505
Phosphate					1	0.881**	0.780**	0.467
Nitrate						1	0.720**	0.817**
Nitrite							1	0.362
N:P ratio								1

Table 2.7: Inter correlation of salinity and nutrients in station II during 1991-'92.

	Salinity surface	Salinity bottom	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Salinity surface	1	0.974**	-0.887**	-0.799**	-0.777**	-0.832**	-0.866**	-0.604*
Salinity bottom		1	-0.822**	-0.873**	-0.795**	-0.830**	-0.740**	-0.578*
Silicate			1	0.853**	0.759**	0.872**	0.801**	0.703*
Phosphorus				1	0.712**	0.729**	0.851**	0.505
Phosphate					1	0.881**	0.780**	0.467
Nitrate						1	0.720**	0.817**
Nitrite							1	0.362
N:P ratio								1

Table 2.8: Inter correlation of salinity and nutrients in station III during 1990-'91.

	Salinity surface	Salinity bottom	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Salinity surface	1	0.971**	-0.745**	-0.742**	-0.719**	-0.756**	-0.686*	-0.459
Salinity bottom		1	-0.847**	-0.812**	-0.823**	-0.845**	-0.771**	-0.474
Silicate			1	0.698**	0.805**	0.827**	0.753**	0.676
Phosphorus				1	0.644**	0.714**	0.747**	0.377
Phosphate					1	0.889**	0.675*	0.338
Nitrate						1	0.734**	0.707**
Nitrite							1	0.420
N:P ratio								1

Table 2.9: Inter correlation of salinity and nutrients in station III during 1991-'92.

	Salinity surface	Salinity bottom	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Salinity surface	1	0.993**	-0.855**	-0.892**	-0.901**	-0.882**	-0.805**	-0.780**
Salinity bottom		1	-0.858**	-0.898**	-0.881**	-0.884**	-0.801**	-0.800**
Silicate			1	0.830**	0.836**	0.852**	0.751**	0.750**
Phosphorus				1	0.960**	0.973**	0.798**	0.908**
Phosphate					1	0.946**	0.786**	0.827**
Nitrate						1	0.834**	0.936**
Nitrite							1	0.689*
N:P ratio								1

Table 2.10 : Simple correlation of nutrients with physico – chemical parameters in station I during 1990-'91.

	Silicate	Phosphor-us	Phosphate	Nitrate	Nitrite	N:P ratio
Depth	0.170	0.356	- 0.18	0.251	0.249	0.561
Light penetration	-0.619*	-0.502	-0.594	-0.340	-0.535	0.443
Atmospheric temperature	-0.490	-0.594	-0.242	-0.288	-0.657*	0.821**
Surface temperature	-0.369	-0.342	-0.179	-0.471	-0.435	-0.231
Bottom temperature	-0.479	-0.386	-0.165	-0.605*	-0.456	-0.132
Surface salinity	-0.902**	-0.772**	-0.838**	-0.912**	-0.774**	-0.592*
Bottom salinity	-0.905**	-0.822**	-0.845**	-0.921**	-0.829**	-0.591*
Surface oxygen	0.584*	0.431	0.519	0.740**	0.390	0.601*
Bottom oxygen	0.633**	0.441	-0.654	0.767**	0.443	0.401
Surface pH	-0.472	-0.473	-0.386	-0.248	-0.341	-0.061
Bottom pH	-0.670*	-0.601	-0.519	-0.464	-0.522	-0.236
Surface H_2S	0.239	0.308	0.092	-0.013	0.369	0.107
Bottom H_2S	0.506	0.237	-0.722**	0.710**	0.239	0.113

Table 2.11: Simple correlation of nutrients with physico – chemical parameters in station I during 1991-'92.

	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Depth	0.465	0.732**	0.686*	0.569	0.495	0.601*
Light penetration	0.048	0.119	0.055	-0.009	0.113	0.175
Atmospheric temperature	0.105	-0.041	-0.254	-0.249	-0.082	-0.582
Surface temperature	-0.049	-0.253	-0.400	-0.387	-0.215	-0.412
Bottom temperature	-0.062	-0.182	-0.294	-0.224	-0.099	-0.118
Surface salinity	-0.882**	-0.848**	-0.946**	-0.979**	-0.913**	-0.938**
Bottom salinity	-0.893**	-0.862**	-0.960**	-0.974**	-0.936**	-0.905**
Surface oxygen	0.585*	0.711**	0.857**	0.785**	0.676*	0.612*
Bottom oxygen	0.583*	0.669	0.831**	0.767**	0.660*	0.602*
Surface pH	-0.192	-0.159	0.165	-0.291	-0.317	0.216
Bottom pH	-0.212	-0.136	-0.204	-0.316	-0.388	0.311
Surface H_2S	-0.587	-0.938**	-0.949**	-0.836*	-0.763*	0.631*
Bottom H_2S	0.049	-0.253	-0.400	-0.387	-0.215	-0.051

Table 2.12: Simple correlation of nutrients with physico – chemical parameters in station II during 1990-'91.

	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Depth	0.302	0.340	0.242	0.150	0.089	0.165
Light penetration	-0.456	-0.339	-0.812**	-0.613*	-0.570	0.620*
Atmospheric temperature	-0.301	-0.210	-0.049	-0.173	-0.180	0.213
Surface temperature	-0.237	-0.245	-0.225	-0.312	-0.158	0.056
Bottom temperature	0.320	0.260	-0.039	-0.058	0.167	0.115
Surface salinity	-0.887**	-0.799**	-0.777**	-0.832**	-0.766**	-0.604*
Bottom salinity	-0.822**	-0.783**	-0.795**	-0.830**	-0.740**	-0.578*
Surface oxygen	0.554	0.458	0.626*	0.749**	0.551	0.671*
Bottom oxygen	0.564	0.459	0.581	0.735**	0.560	0.600*
Surface pH	-0.783**	-0.645*	-0.506	-0.531	-0.620*	0.426
Bottom pH	-0.694*	-0.609*	-0.468	-0.503	-0.588	0.551
Surface H_2S	-	-	-	-	-	-
Bottom H_2S	-	-	-	-	-	-

Table 2.13: Simple correlation of nutrients with physico - chemical parameters in station II during 1991-'92.

	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Depth	0.325	-0.437	0.550	0.388	0.154	0.178
Light penetration	-0.026	-0.081	0.050	-0.017	0.007	0.162
Atmospheric Temperature	-0.225	-0.176	-0.232	-0.122	0.113	0.115
Surface Temperature	-0.371	-0.232	-0.309	-0.197	-0.036	-0.025
Bottom Temperature	-0.445	-0.297	-0.415	-0.268	-0.104	-0.112
Surface Salinity	-0.855**	-0.892**	-0.901**	-0.882**	-0.805**	-0.759**
Bottom Salinity	-0.858**	-0.898**	-0.881**	-0.884**	-0.801**	-0.897**
Surface Oxygen	0.634*	0.737**	0.771**	0.702*	0.524	0.672*
Bottom Oxygen	0.595*	0.700*	0.736**	0.665*	0.590*	0.631*
Surface pH	-0.507	-0.553	-0.617*	-0.465	-0.404	0.501
Bottom pH	-0.687*	-0.774**	-0.807**	-0.752**	-0.733**	0.621*
Surface H_2S	-	-	-	-	-	-
Bottom H_2S	-	-	-	-	-	-

Table 2.14 : Simple correlation of nutrients with physico – chemical parameters in station III during 1990-'91.

	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N : P ratio
Depth	0.087	0.503	0.051	0.086	0.084	0.011
Light penetration	-0.891**	-0.493	-0.725**	-0.620*	-0.522	0.375
Atmospheric temperature	0.061	-0.369	-0.137	-0.048	-0.283	0.251
Surface temperature	-0.094	-0.150	-0.293	-0.172	-0.299	0.263
Bottom temperature	-0.039	-0.016	-0.244	-0.147	-0.172	0.165
Surface salinity	-0.745**	-0.742**	-0.719**	-0.759**	-0.686*	0.707**
Bottom salinity	-0.847**	-0.812	-0.823**	-0.845**	-0.771**	-0.812*
Surface oxygen	0.464	0.599*	0.786**	0.760**	0.609*	0.652*
Bottom oxygen	0.509	0.710*	0.822**	0.791**	0.643*	0.631*
Surface pH	-0.773**	-0.531	-0.569	-0.608*	-0.600*	0.589
Bottom pH	-0.695*	-0.437	-0.563*	-0.668*	-0.623*	0.523
Surface H_2S	-	-	-	-	-	-
Bottom H_2S	-	-	-	-	-	-

Table 2.15: Simple correlation of nutrients with physico – chemical parameters in station III during 1991-'92.

	Silicate	Phosphorus	Phosphate	Nitrate	Nitrite	N:P ratio
Depth	0.378	-0.445	0.710**	0.425	0.162	0.134
Light penetration	-0.069	0.003	0.136	-0.003	0.050	0.078
Atmospheric temperature	-0.044	-0.144	-0.443	-0.302	-0.003	0.101
Surface temperature	-0.021	-0.167	-0.427	-0.268	0.023	0.056
Bottom temperature	0.132	0.039	-0.361	-0.164	0.073	0.079
Surface salinity	-0.734**	-0.866**	-0.947**	-0.910**	-0.764**	-0.780**
Bottom salinity	0.881**	-0.856**	-0.786**	-0.924**	-0.843**	-0.800**
Surface oxygen	0.807**	0.677*	0.784**	0.773**	0.588*	0.603*
Bottom oxygen	0.819	0.694*	-0.692*	0.751**	0.591*	0.615*
Surface pH	-0.714**	-0.714**	-0.811**	-0.888**	-0.773**	0.732**
Bottom pH	0.854**	-0.757**	-0.834**	-0.864**	-0.760**	0.715**
Surface H_2S	-	-	-	-	-	-
Bottom H_2S	-	-	-	-	-	-

2.6. Discussion

Silica occurs in natural waters as soluble and colloidal forms. Diatoms among the phytoplankton are the main consumers of silica as silicates. Silica is irrecoverably removed by the diatoms, the latter being insoluble except in very high alkaline solutions. So the major portion of the shell sinks to the bottom as sediment. Thus the cycle of silica is not complete and a large amount leaks out of the cycle as sediment.

In the present study the dissolved silicate content was higher during monsoon and postmonsoon seasons and lower during premonsoon season. Higher values of silicate during monsoon and postmonsoon seasons may be due to the heavy influx of monsoonal flood which carries silicon deposits from the upper reaches of the river. This finding was in conformity with the observations in other Indian estuaries by Krishnamurthy (1970), Jegatheesan (1974), Anzari and Rajagopal (1974), Sundararaj and Krishnamurthy (1975), Ramadhas (1977), Thangaraj *et al.* (1979), Qasim and Sengupta (1981), Sivakumar (1982), Sarala Devi *et al.* (1983), Nair *et al.* (1983 a, b, 1984), Thangaraj (1984), Jegadeesan (1986) and Balusamy (1988).

The annual average silicate content of station III was higher than that of station I. This was because station III was situated in the riverine zone where addition of more and more freshwater enhanced silicate content. Similar type of spatial distribution of silicon was observed in the Ashtamudi estuary by Nair *et al.* (1983 a), in the Kadinamkulam backwater by Nair *et al.* (1984), in the Veli lake by Gopinathan (1985), in Muthupet estuary by Balusamy (1988), in the Poonthura backwater by Kahar (1988), in the Mahanadi estuarine system by Sen Gupta and Upadhyay (1987) and Upadhyay (1988) and in Paravur lake by Shibu (1991).

In the present study the silicate content showed a negative correlation with salinity. This may be attributed to the fact that freshwater flow was the main source of silicate. Station III had higher silicate content but lower salinity. This is because station III was situated towards the mouth of the river. Station I had lower silicate content but higher salinity. This was because station I was situated nearer to the sea. Burton *et al.* (1970) observed a significant inverse relationship between chlorinity and silicate in Southampton waters. Similarly, the negative correlation between silicate and salinity in the estuarine waters was observed by Purushothaman and Venugopalan (1972) and Sivakumar (1982) from Vellar estuary, Qasim and Sengupta (1981) from Mandovi and Zuari estuaries, Sarala Devi *et al.* (1983) from four estuaries of Kerala *viz.* Kallai, Beypore, Korapuzha and Mahe, Nair *et al.* (1984) from Kadinamkulam estuary, Jegadeesan (1986) from Coleroon estuary, Balusamy (1988) from Muthupet estuary and Shibu (1991) from Paravur lake.

Ketchum (1967) reported that inorganic phosphate is a useful index of the state of eutrophication of water bodies. Redfield (1934) reported that the total phosphorus present in an estuary can be taken as an index of potential fertility of the ecosystem as a whole. In the estuarine waters the phosphorus (Putnam, 1966, Thayer 1969) appears to be the second limiting nutrient, the first being nitrogen (Ryther and Dunstan, 1971). In the present investigation, the annual average inorganic phosphate and total phosphorus were high at station III followed by station II and I. As station III was situated near the river mouth, higher values of inorganic phosphate and total phosphorus were associated with the influx of fresh water. A similar type of observation was made in Zuari and Mandovi river system where the concentration of phosphate decreased from the river towards the sea indicating that the river water was the source of phosphate (De Souza *et al.*, 1981). In Kadinamkulam backwater Nair *et al.* (1984) also observed that phosphate was extremely high at the station which was farthest from the bar mouth. A similar observation was made in Ashtamudi estuary by Nair *et al.* (1984) and in Cochin backwater by Qasim *et al.* (1969). In Mandovi estuary Dehadrai (1972) noted an increase in inorganic phosphate and he predicted that the high inorganic phosphate was probably brought in by the land drainage.

In the present study, the concentration of inorganic phosphate and total phosphorus were found to be low during the premonsoon season, picked up with the advent of the monsoon and recorded the highest values during the monsoon and postmonsoon seasons in all the stations. The monsoon maximum was due to the impact of rainfall and river discharge. This observation was in conformity with the similar type of observations made in Korapuzha estuary by Rao and George (1959), in Cochin backwaters by Sankaranarayanan and Qasim (1969) and Haridas *et al.* (1973), in Mandovi and Zuari estuaries by Dehadrai (1970), Dwivedi *et al.* (1974) and Goswami and Singbal (1974), in the Vellar estuary by Santhakumari (1968), Krishnamurthy (1970), Rajendran (1974), Ramadhas (1977), Venugopalan *et al.* (1981), Sivakumar (1982), Chandran and Ramamoorthi (1984 b) and Thangaraj (1984), in Ashtamudi estuary and Kadinamkulam backwaters by Nair *et al.* (1983 a, 1984), in Coleroon estuary by Jegadeesan (1986) and Prabha Devi (1986) and in Muthupet estuary by Balusamy (1988). However, low phosphate values were recorded during monsoon in Mahanadi estuarine ecosystem by Upadhyay (1988) and in Paravur lake by Shibu (1991).

The monsoon maximum was caused by the cumulative effect of rainfall and local phenomena. The interchange of phosphorus between sediment and water is known to be one of the major factors governing phosphate concentration of overlying water. Sediments of estuaries are several times richer in phosphate compared to overlying waters. Estuarine sediments act as trap for phosphate. Estuarine sediments can trap 80 to 90% of phosphate when present in high levels during periods of excessive run off. Resuspension of sediments by disturbances like tide, wind, etc., adds phosphate to the estuarine water. Nair *et al.* (1983a) reported that 80 to 90% of the phosphorus content in the estuarine waters might be released from the sediments. In addition bubbles rising to the surface, decomposition of particulate organic matter and excretion by plankton enrich the water with phosphorus.

In the present investigation all the stations recorded minimum values of inorganic phosphate and dissolved phosphorus in the premonsoon season. This was attributed to the absence of influx of freshwater and the utilization by phytoplankton. De Souza *et al.* (1981) explained that loss of phosphate during premonsoon could be attributed to utilization of nutrients by phytoplankton and removal by absorption on to sediment and suspended particles. The relation between minimal total phosphorus and phytoplankton utilization was observed by Santhakumari (1970), Ramadhas (1977), Thangaraj *et al.* (1979), Sivakumar (1982), Prabha Devi (1986), Jegadeesan (1986) and Balusamy (1988).

Nitrate is the most oxidised form of nitrogen and is an important nutrient of plants. De Souza *et al.* (1981) stated that in the estuary nitrate was added due to river run-off, land drainage and precipitation, while it was removed through biological productivity and denitrification. In the present study, the concentration of nitrate exhibited a clear upward trend from the bar mouth to the head of the estuary. This showed that freshwater was the main source of nitrate in an estuary. Sankaranarayanan and Qasim (1969) observed that in Cochin backwaters nitrate was very low during premonsoon when the conditions were predominantly marine and explained that the contribution from sea was very little. Brooks *et al.* (1971) reported that the sources of nitrogen in the estuary were from the river run off, upwelling and also from *in situ* fixation. In Kadinamkulam backwater Nair *et al.* (1984) observed that nitrate values (like phosphate) were likely to be influenced by the influx of freshwater. Balusamy (1988) reported that the annual average nitrate content increased from the mouth to the head in Muthupet estuary.

The concentration of nitrate was higher in the monsoon and postmonsoon seasons. The highest value was recorded when the estuary was flooded with freshwater. The higher nitrate content was mainly due to the contribution of river run off. This observation was in conformity with the similar type of observations made by Qasim *et al.* (1969) in Cochin backwaters, Sundararaj and Krishnamurthy (1975) in Kille backwater, De Souza (1977) in Mandovi and Zuari estuaries, Sivakumar (1982) and Chandran and Ramamoorthi (1984a) in Vellar estuary, Sarala Devi *et al.* (1983) in Beypore, Korapuzha and Mahe estuaries, Nair *et al.* (1983a, 1984) in Ashtamudi estuary and Kadinamkulam backwater, Prabha Devi (1986) and Jegadeesan (1986) in Coleroon estuary and Balusamy (1988) in Muthupet estuary. However, Shibu (1991) recorded higher values during premonsoon and lower values during monsoon seasons.

In the present study a minor peak was noticed in the postmonsoon season during 1991-'92. This was caused by northeast monsoon rain and the corresponding flooding of the estuary. Nair *et al.* (1983a) stated that most of the nitrate may be derived from the decomposition of organic wastes apart from the river water enrichment.

The minimum values of nitrate during premonsoon were due to the ceasation of freshwater influx and also probably be due to its utilization by biological activity. Bolter *et al.* (1981) reported that the nutrient depletion was also caused by bacteria and phytoplankton. De Souza *et al.* (1981) stated that nitrate was removed from the estuary by denitrification in addition to productivity.

Nitrite, a partially oxidised form of nitrogen, has received considerable interest due to its role as an intermediate in the interconversion of nitrate and ammonia. Nitrite production in backwater and mangrove environment is due to biological causes like excretion of nitrogenous compounds by plankton and decay of vegetation; perhaps nitrite is recycled here more number of times than other compounds; it is an intermediate product in the regeneration of nitrogen compounds by bacterial action (Sundararaj and Krishnamurthy, 1975). In the present study the concentration of nitrite was maximum in the monsoon and postmonsoon seasons and minimum in the premonsoon season. The higher concentration of nitrite during monsoon and postmonsoon seasons was mainly caused by the rainfall and the resulting river run off. The river discharge carried large amount of detritus which caused the rise in nitrite concentration during the monsoon season. The monsoonal increase of nitrite in the present study was in accordance with the observation of Sreedharan and Salih (1974) from Cochin estuary, Sundararaj and Krishnamurthy (1975) from the mangrove and backwater environment of Kille, Ramadhas (1977) and Chandran and Ramamoorthi (1984a) from Vellar estuary, Nair *et al.* (1983a) from Ashtamudi estuary, Sarala Devi *et al.* (1983) from Kallai and Mahe estuaries, Nair *et al.* (1984) from the

Kadinamkulam backwater, Kahar (1988) from Poonthura backwater and Balusamy (1988) from Muthupet estuary.

Nitrite recorded minimum values at all the stations in the premonsoon season. This was in agreement with the observations made in Vellar estuary (Purushothaman and Venugopalan, 1972), in Coleroon estuary (Prabha Devi, 1986) and in Muthupet estuary (Balusamy, 1988) where low values were recorded in the summer season. The depletion of nitrite in the premonsoon season was due to its oxidation to nitrate and / or biological oxidation (Nair *et al.* 1984). However, the observation of premonsoon minimum was in contrast to that of Shibu (1991) in the Paravur lake, where maximum values were recorded in the premonsoon season.

The concentration of nitrite was always higher at station III and lower at station I. This was because the station III was situated farthest from the sea and was most likely to be influenced by freshwater.

In the present study, the higher values of nitrite, somehow, coincided with the higher values of nitrate. This was in conformity with the observations of Sreedharan and Salih (1974), Nair *et al.* (1983, 1984) and Sarala Devi *et al.* (1983).

A remarkable feature of nitrite was its low concentration compared to other nutrients of the estuarine water. Comparatively low values were also recorded in other estuaries such as Vellar estuary (Vijayalakshmi, 1973, Ramadhas, 1977, Chandran and Ramamoorthi, 1984a), Cochin estuary (Sreedharan and Salih, 1974), Kille backwater

(Sundararaj and Krishnamurthy 1975), Akathumuri-Anchuthengu-Kadinamkulam backwater systems and Ashtamudi estuary (Nair *et al.* 1983b), Kallai, Beypore, Korapuzha and Mahe estuaries (Sarala Devi *et al.* 1983), Coleroon estuary (Jegadeesan, 1986 and Prabha Devi, 1986), Muthupet estuary (Balusamy 1988) and Paravur lake (Shibu, 1991).

The N : P ratio showed high values in the monsoon and postmonsoon seasons and low values in the premonsoon season. The high values during monsoon and postmonsoon seasons were attributed to the influence of terrestrial run off into the river. In addition, the fertilizers applied in the irrigation fields were ultimately discharged into the river, resulting in the enhancement of nitrate content in the water in lower reaches. Sivakumar (1982) reported that the enrichment of nutrients during monsoon was primarily in the form of nitrate and therefore the high values of nitrate and phosphate largely depended in the strength and intensive flow of rain water. Similar type of observations were made by Sankaranarayanan and Qasim (1969) in Cochin backwaters, Santhakumari (1970), Rajendran (1974), Ramadhas (1977), Venugopalan *et al.* (1981), Sivakumar (1982), Chandran and Ramamoorthi (1984 b) in Vellar estuary, Butler and Tibbitts (1972) in Tamar estuary, Balusamy (1988) in Muthupet estuary and Shibu (1991) in Paravur lake.

The low values of N : P ratio in premonsoon season coincided with the ceasation of freshwater flow and rich density of phytoplankton. Similar observations were also made by Ramadhas (1977) in Vellar estuary, Jegadeesan (1986) in Coleroon estuary, Balusamy (1988) in Muthupet estuary and Shibu (1991) in Paravur lake.