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Ecology of Indian Estuaries: Part I—Physico-Chemical Features of Water & Sediment Nutrients of Ashtamudi Estuary

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Detailed analyses of physico-chemical characteristics and sediment nutrients of Ashtamudi estuary covering the entire biotope from the marine to the riverine zone are presented; this second biggest estuarine system in Kerala is found to be a zone of severe pollution caused by effluents from a paper mill situated upstream. Seasonal variations in temperature and *p*H and in the concentrations of dissolved oxygen, salinity, phosphate-P, nitrate-N, nitrite-N, and silicate-Si in estuarine waters have been observed at 4 selected stations. The study has indicated a distinct degree of change in relation to the water quality at Kadapuzha. The nature, degree, and extent of ecological transformation undergone by this vast estuarine system has been briefly discussed. Seasonal variations of organic carbon (OC), total P, total N and total K in the sediments are studied in relation to certain physico-chemical characteristics. Correlations between OC, total P, total N and total K and the grain size reveal that fine grained elements contain more OC and P. Existence of organic phosphate in the sediments of the Ashtamudi estuary is evidenced by the correlation between OC and P in all the 4 stations. Results of the present study indicate the imperative need to keep the effects of pollution within manageable limits.

Many studies have been undertaken to elucidate the hydrography of Indian estuaries and backwaters[1-7]. An outstanding phenomenon of the coastal belt of Kerala is its extensive system of estuaries and brackishwater lakes lying roughly parallel to the Arabian Sea. These water bodies, popularly known as 'kayals', which exist in different sizes and shapes have their bed levels at about 1.5 to 1.8 m below mean sea level. The waters of a majority of the 41 rivers in Kerala drain into the 'kayals' before they empty into the sea through a large number of perennial or temporary openings.

There are 30 'kayals' dotting the coast of Kerala. Many investigators working on the hydrography of these 'kayals' in Kerala[8-25] have provided a fairly good picture of the highly dynamic environmental conditions prevailing in the Cochin and Korapuzha estuaries, the Kayamkulam, Edava - Nadayara, Paravur and Veli 'kayals'. Of the many 'kayals' that remain relatively unexplored[26-27], Ashtamudi is the most important one, being the 2nd largest estuarine system in Kerala.

In this investigation seasonal changes in physico-chemical parameters of waters and in the nutrients of the sediments of Ashtamudi estuary have been studied.

Study Area

Ashtamudi estuarine system covering an area of 32 km^2 branches off into 8 creeks, known by different names (Fig. 1). The Kallada river originating from the Western Ghats enters the Ashtamudi estuary after traversing for about 120 km and this river carries an average annual run off of 75×10^9 m^3 of freshwater into the estuary[5]. The study area is polluted due to industrial and sewage effluents. Four representative stations were selected (Fig. 1) in the system for detailed investigations and they are described below:

Neendakara (st 1) is one of the biggest fish landing harbours of the west coast of India at the mouth of the estuary. Ashtamudi (st 2) is the central portion of the vast expanse of the backwater which is a very important fishing zone. Kanjirakode (st 3) represents the interior segment of the estuary and it has 3 arms and several creeks. Even though retting of coconut husks and industrial effluents have created some

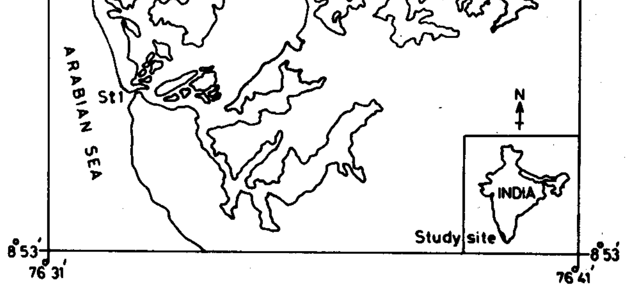


Fig. 1—Ashtamudi estuarine system in Kerala [st 1, Neendakara; st 2, Ashtamudi; st 3, Kanjirakode; and st 4, Kadapuzha]

pollution in the area it is an excellent fishing zone. Kadapuzha (st 4) is near the confluence of the Kallada river into the estuary and heavily polluted by the Punalur paper mill effluents.

Materials and Methods

Fortnightly sampling was done both for water and sediments during Feb. 1980-Jan. 1981. Both surface and bottom water samples were collected invariably during the forenoon using a locally designed water sampler. Light penetration was measured using a Secchi disc. Dissolved oxygen, salinity, *p*H, phosphate, nitrate, nitrite and silicate were estimated following standard methods. Sediment samples were collected using a metal corer (6.6 cm internal diam. and 21 cm long). Each sample covered a surface area of approx. 34 cm^2 and a sediment volume of 718 cm^3 (ref.28). A portion of sediment was oven dried at 100-105°C overnight for chemical analysis. Dried samples were ground and sieved through 0.5 mm sieve and 0.5 g of the material was taken for the estimation of organic carbon[29]. Sample preparation for the estimation of total phosphorus, total nitrogen and total potassium was done by double acid fusion method using sulphuric acid and perchloric acid. Total phosphorus was determined by colorimetric method using aminonapthal sulfonic acid - reduced molybdophosphoric blue colour method, total nitrogen was determined by modified Kjeldahl method[30] and total potassium was determined by flame photometer[30]. Oven dried samples were used for the grain size analysis following the international pipette method[31]. Data on rainfall and river discharge were obtained from the Irrigation Department, Government of Kerala.

Results and Discussion

Rainfall and river discharge—Data on rainfall and river discharge show clear seasonal variations (Table 1). The SW monsoon over Kerala brings very heavy rains in this river basin during June-Aug. and the NE monsoon causes heavy precipitation during Oct.-Nov. This pattern of rainfall facilitates the division of the year into premonsoon, monsoon and postmonsoon periods with respect to monsoon. River discharge into the estuary was also maximum during June-Aug. synchronising with heavy rains. Earlier investigations on the Kerala estuaries[16,19,21,23,24] also show a seasonal pattern in the rainfall and the division of the year into 3 broad periods as observed during the present investigation. During periods of poor rainfall and river discharge salt water penetrates up to 'Uppukutu' in the Kallada river where further incursion is prevented by a water fall. It is this plentiful rainfall in the river basin and the consequent heavy flow of water in the Kallada river that has saved the entire Ashtamudi estuarine system from total pollution caused by the paper mill effluents.

Water characteristics

Temperature—There was variation in temperature following heavy rains during 2 monsoons and the consequent river discharge (Fig.2). The mean value during the premonsoon period was the highest both at surface and bottom waters at all stations. Monsoon

Table 1—Monthly Variations in Rainfall at Kallada River Basin and Monthly River Discharge into the Ashtamudi Estuary During 1980-81

Month		Rainfall (mm)	River discharge (Mm^3)
1980			
Feb.	Premonsoon	2.38	18.40
March		53.39	15.20
April		125.45	21.94
May		101.98	25.42
June	Monsoon	1025.18	138.87
July		446.37	291.95
Aug.		281.31	204.92
Sept.		168.34	90.95
Oct.	Postmonsoon	264.02	146.84
Nov.		203.20	114.91
Dec.		97.45	73.69
1981			
Jan.	Postmonsoon	—	—

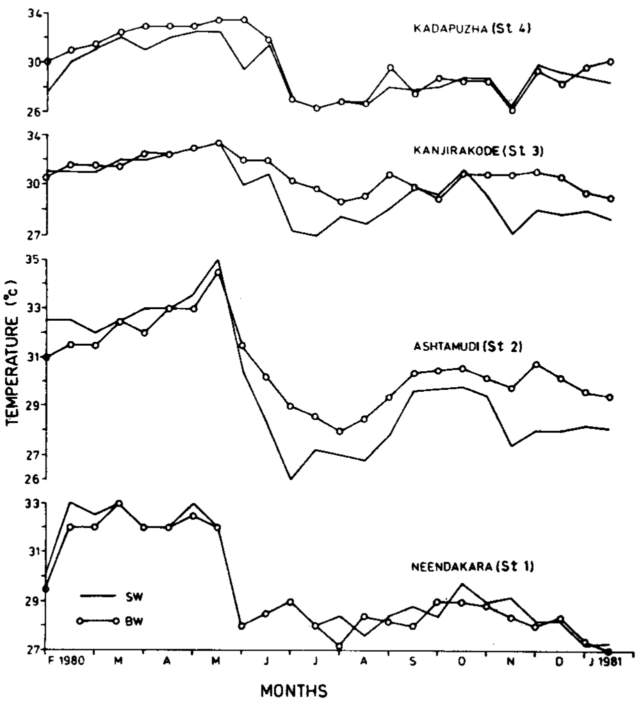


Fig. 2—Fortnightly variations of temperature in the Ashtamudi estuary during 1980-81 (SW = surface water; BW = bottom water)

period registered lowest value at all stations followed by a period of recovery during postmonsoon period. At sts 3 and 4, seasonal average values of the bottom water was always higher than that of the surface water. This situation is presumed to be caused by the discharge of cold fresh water from the Kallada river and due to the absence of large scale mixing in the locality. The water column here is stratified on the basis of temperature. But at st 1, which is closest to the Arabian Sea, the surface water temperature was always higher than that of the bottom water. Variations of surface water values between different stations were not significant whereas those of bottom water were significant at 1% level. Seasonal variations were highly significant both at the surface and at the bottom. Variation between surface and bottom values were highly significant at st 3, significant at 5% level at st 1 and at 1% level at sts 2 and 4. The pattern of temperature variation at the Ashtamudi estuary was found similar to the distribution pattern observed in the Kayamkulam lake[19], in the Cochin estuary[32] and in the Paravur lake[24].

pH—Surface and bottom waters generally remained on the alkaline side at all stations (Fig.3) except for a brief acidic phase at sts 3 and 4 in July. Seasonal variations were highly significant. Variation between surface and bottom water *p*H was not significant at sts 2-4, but significant at 5% level at st 1. A clear decrease in *p*H from the marine to the freshwater zone was evident during all the seasons of the year.

Light—Light penetration was minimum at all stations during monsoon season with heavy rains and discharge of turbid waters from all drainage channels

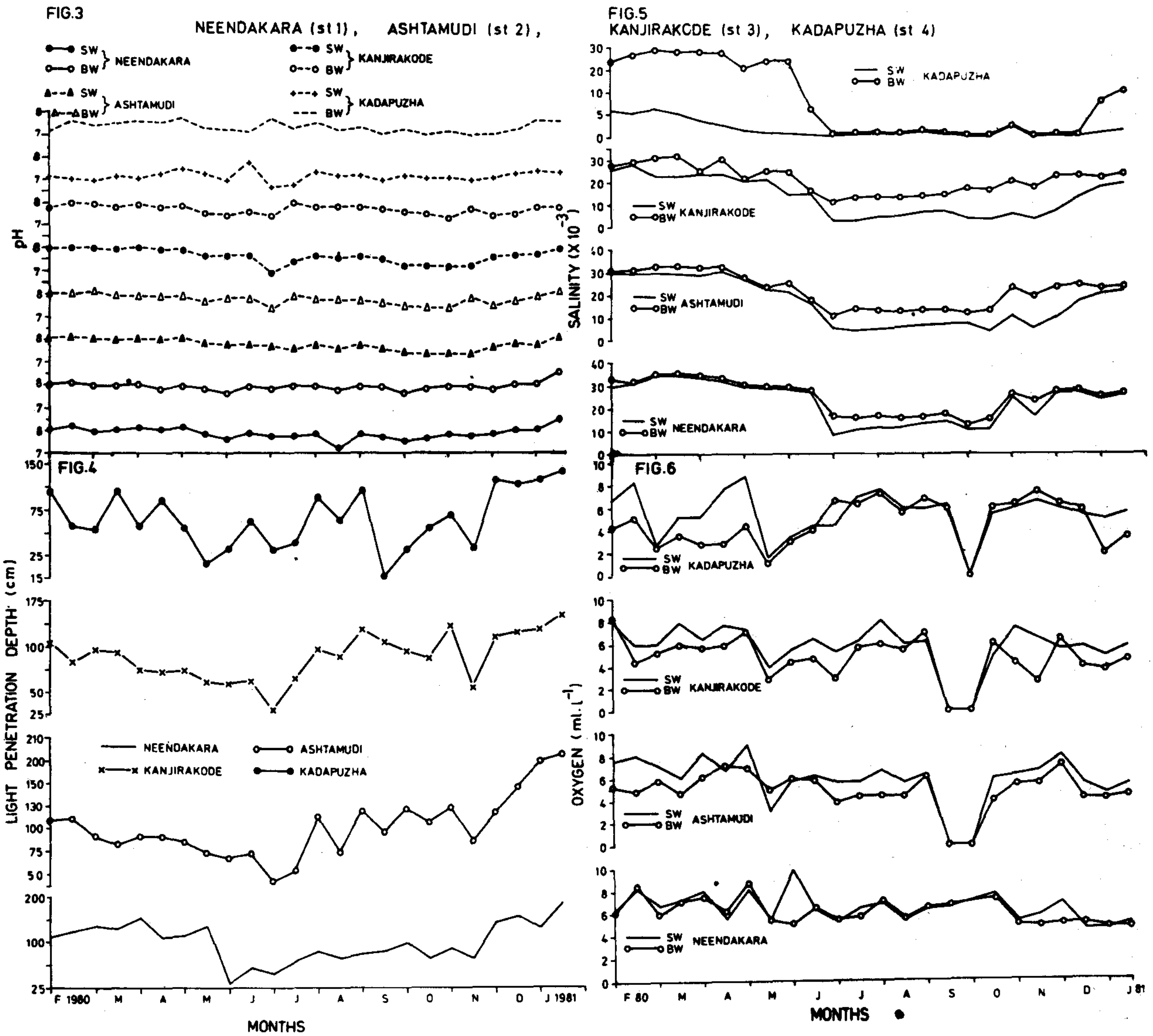


Fig 3 to 6—Fortnightly variations in *p*H (3), light penetration (4), salinity (5), and dissolved oxygen (6) during 1980-81 at different stations [SW = surface water; BW = bottom water] around and from the Kallada river (Fig.4). During premonsoon period light penetration was modest at these stations but with the advent of the monsoon rain, water became turbid and light penetration depth naturally decreased. The present data reveal that the water at st 4 is extremely turbid throughout the year. Continuous sand collection, heavy discharge of paper mill effluents and river discharge from the upper reaches are reasons for highly turbid conditions noticed at st 4. Variations in light penetration between the 4 stations were highly significant.

Salinity—Based on the trend of salinity variations 3 broad patterns of distribution can be elicited, (i) a period of high salinity with very little fluctuations during Feb. to May—pre SW monsoon period, (ii) a fairly long spell of comparatively low salinity with greater fluctuations from June to Nov.—period of the 2 monsoons, and (iii) a period of recovery during Dec. and Jan.—post-NE monsoon period. Thus a period of great fluctuations is flanked by periods of lesser fluctuations (Fig.5). The surface salinity progressively diminished from the estuary mouth at st 1 to sts 2 and 3 and attains the lowest value at st 4 on the riverine zone. Salinity of the bottom water, exhibited the same trend from the marine to the freshwater zone but maintained higher values throughout. Thus the entire water body is virtually stratified on the basis of this parameter alone. Seasonal variations in salinity was highly significant. The salinity distribution in the Ashtamudi estuary and the division of the year into 3 periods closely agree with the pattern observed by earlier workers[8-10,16,19,23,24,32]. In all these studies salinity in the estuaries of Kerala varied from limnetic to mixohaline conditions during the course of an year.

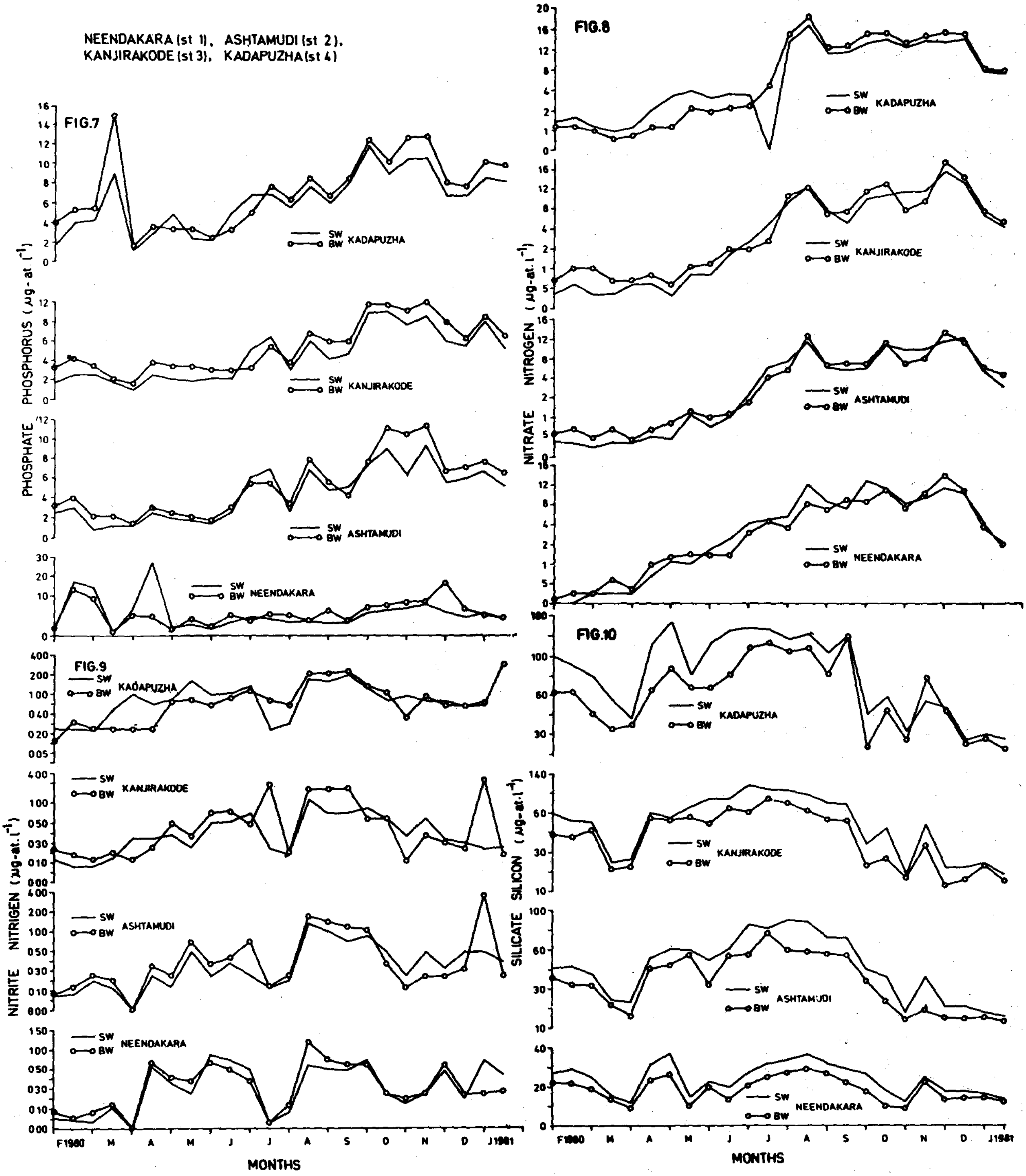
Dissolved oxygen—The impact of paper mill effluents, retting, eutrophication, rain fall, etc. are reflected in the oxygen regime at the 4 stations in the estuary. There were rapid and wide fluctuations in the dissolved oxygen concentration from fortnight to fortnight and there was even total oxygen depletion resulting in the occurrence of brief anoxic periods ranging from a fortnight to a month at all the stations except at st 1 (Fig.6). At st 4 premonsoon was particularly a period of intense pollution resulting in very low oxygen values. The values in the surface water ranged from 1.7 to 8.81 $ml.l^{-1}$ and that at the bottom from 1.24 to 5.2 $ml.l^{-1}$. The paper mill effluents may be cited as the reason for the significant level of oxygen depletion at st 4. At st 3 also there is depletion of oxygen presumably due to the effluents that pass into this zone through the rivulets from the Kallada river. Similarly, oxygen depletion was noticed at all stations toward the close of the monsoon season and in early postmonsoon which is believed to have been caused by eutrophication. Abdul Azis and Nair[23] observed total oxygen depletion in the Edava-Nadayara backwater lying south of the Ashtamudi estuary.

Generally, concentration of dissolved oxygen was higher in the present area of investigation. Average values at all stations were highest during premonsoon period followed by lower values during monsoon and postmonsoon. Seasonal variations in the surface water were significant at a very high order whereas in the bottom water they were not significant. A clear stratification on the basis of oxygen values also could be observed in the estuary in that the surface and bottom water differences were highly significant at all stations.

Phosphate-phosphorus—At st 1 mean seasonal surface and bottom water phosphate was maximum during premonsoon season and minimum during the monsoon (Fig.7). At sts 2 to 4 phosphate was maximum during postmonsoon and minimum in premonsoon period both in surface and bottom waters. As the seasonal variations have been found to be significant it can be stated that the impact of rainfall and river discharge on phosphate-P changes is indeed prominent. Rainfall resulting in heavy river discharge leads to transportation of sediments in a big way. Thus an increase in the value of phosphate was noticed with the onset of the monsoon rains. This ascending trend lasted for several months recording the peak value in the postmonsoon period. Sediments in estuaries are reported to trap 80-90% of phosphorus[33,34,35], releasing the same to the overlying water[36,37]. Thus, presence of total phosphorus in an estuary can be taken as an index of potential fertility of the ecosystem as a whole[38,39].

Nitrate-nitrogen—Mean seasonal value in the surface and bottom waters was maximum at st 4 and minimum at st 1 (Fig.8). The concentration exhibited a clear upward trend from the marine to the riverine zone. During the monsoon and postmonsoon periods, lowest value was observed at st 2 and the highest at st 4. When the seasonal average was observed it was generally low during the premonsoon period at all stations, slightly higher during monsoon and highest during postmonsoon period (Fig.8). The postmonsoon peak might be due to the cumulative impact of rainfall and river discharge experienced in the area. The variation between seasons at all stations was highly significant. The concentration of nitrate was always high at the polluted st 4. The river water probably enriched the nitrate content of the water as observed in the Korapuzha estuary[21] and in the Cochin backwater[17]. Apart from the river water enrichment most of the nitrate may be derived from decomposition of organic wastes. Total depletion of nitrate at st 4 in July might have been caused by the abundant growth of macrophytes[40,41]. This nitrate depletion, however, was not accompanied with oxygen depletion as noticed at the Edava-Nadayara backwaters[24]. A distinct stratification was also absent in its spatial distribution in the estuary.

Nitrite-nitrogen—Nitrite-N distribution in surface and bottom waters exhibited a similar trend in that the average concentration was maximum at st 4 throughout the year and minimum at st 1 during monsoon and postmonsoon periods (Fig.9). The bottom water, in general, contained more nitrite than the surface water. The seasonal variation was significant at all stations. At all the zones in the estuary, concentration of nitrite-N was low during premonsoon period. In the monsoon period a sharp



Figs 7 to 10—Fortnightly variations in phosphate - phosphorus (7), nitrate-nitrogen (8), nitrite-nitrogen (9), and silicate-silicon (10) during 1980-81 at different stations [SW = surface water; BW = bottom water] rise in concentration was evident, presumably due to heavy rainfall and river discharge. Although the values declined slightly during the postmonsoon it was higher than that observed during the premonsoon. Generally, the trend of variation followed that of the nitrate-nitrogen in the estuary. The pattern of distribution noticed in this estuary broadly agrees with the one observed in the Cochin estuary[17]. Higher nitrite value observed at st 4 indicates the influence of land drainage, and industrial waste discharge.

Silicate-silicon—Silicate-Si showed high values throughout the estuary (Fig.10). Average values in surface and bottom waters were maximum at st 4 and minimum at st 1. Values showed an increasing trend from st 1 to st 4 both in surface and in bottom waters. Surface water was always higher in silicate-Si concentration, maintaining a stratification similar to the one observed in the case of other parameters. Variations were highly significant. The low concentration of silicate-Si in the surface and bottom waters during premonsoon period attains highest values during monsoon at all stations presumably due to the river water that brings in additional quantities of this nutrient. Concentration declines during postmonsoon period. While the silicate concentration ranged from 9-172 μg-at.l^{-1} in this estuary, it ranged from 17.48 to 134.30, 12.43 to 89.98 and 20 to 140 μg-at.l^{-1} respectively at Mandovi, Zuari and Vellar-Coleron estuaries.

Sediment characteristics

Textural—In the sediment at st 1 coarse sand ranged from 6.05% in July to 15.29% in Feb., fine sand from 22.94% in Feb. to 73.44% in July, clay from 1.04% in May to 11.98% in Jan. and silt from 0% in July to 4.02% in April. The grain size was of same magnitude at st 2 sediments also. Though sandy material (coarse sand, 60.47-85.88%) dominated all through the year, other fractions showed some fluctuations. Percentage of clay varied between 2.6 in April and 12.49% in Nov. and silt between 0% in June and 6.67% in Oct. At st 3 coarse sand ranged between 33.28% in March and 92.56% in June dominating the textural characteristics due to a fall in the fine sized material during monsoon (June-Sept.). Premonsoon season (Feb.-May) showed the peak percentage of clay (26.04%) and silt (11.46%). At st 4 coarse sand ranged between 33.34-76.45% in Aug. and Feb. Pereentage of clay and silt varied between 4.17% in Nov. and 18.29% in March and 0% in March and 10.2% in April respectively.

Nutrients—Seasonal variations in organic carbon, total phosphorus, total nitrogen and total potassium are shown in Fig.11.

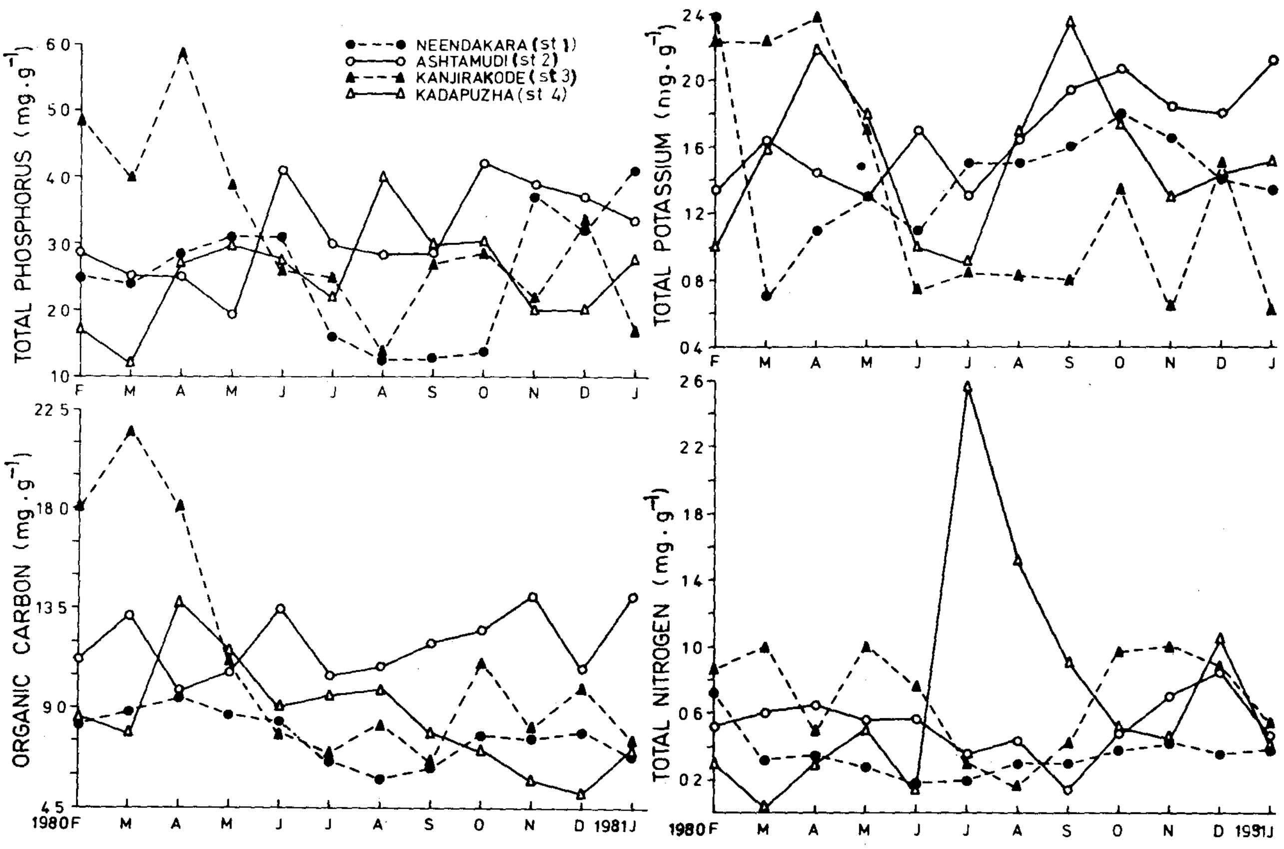


Fig. 11—Seasonal fluctuations of organic carbon, total phosphorus, total nitrogen and total potassium

Organic matter in lake sediments is derived from primary production within the aquatic ecosystem (autochthonous sources) and also from terrestrial biota (allochthonous sources) by transport of leached and eroded material into the lake[42]. Higher organic carbon (OC) during premonsoon at sts 1, 3 and 4 and during postmonsoon at st 2 as compared with that during monsoon revealed that the allochthonous input of organic matter into the system is less when compared to that of Cochin backwaters[15,18,43-46]. Increase of OC during premonsoon may be due to the retting of coconut husk; the practice of dumping the pith into the adjacent water after processing is prevalent. Direct correlation between OC and clay fraction in the sediments of sts 2 and 3 (significant at 5% level) is in accordance with earlier reports[47,48] that fine grained sediments always have higher content of organic matter. The amount of organic matter in sediments is usually inversely related to the medium grain size[48] and this is applicable to the inverse correlation (significant at 1% level) of OC and coarse sand at st 3. This may be due to the increased surface area per unit weight for adsorption of organic matter as particle size decreases. In a normal estuarine system total P will be at the maximum in both freshwater and marine zones although their derivatives in these zones are quite different[49] and accordingly as a marine zone at st 1 sediments show higher values during premonsoon. Relationship of silicate concentration of the overlying water at st 1 to the total P content showed that most of the P released from the sediments may precipitate with colloidal silicates. Less turbulent mixing at Kanjirakode during the premonsoon with higher percentage of silt (6.8 and 11.5) and clay (18.3, 14.3 and 26) may be attributed to the retention of autochthonous P. The positive correlation (significant at 1% level) with clay and negative correlation (significant at 1% level) with coarser, sand fraction of the sediments with total P support this fact. Besides, macroalgae and seagrass beds are abundant at st 3 and they are capable of using and precipitating as much of P available to them[33-35] leading to higher productivity and hence the large fraction of P in the sediment[38,39]. At st 2 though the pre and postmonsoonal conditions are similar to those of st 3 the incidence of algal species is relatively poor. Higher content of total P during monsoon in st 4 sediments can be explained by the deposition of alluvium brought into the area by the Kallada river and this is supported by the maximum river discharge during this period and also the texture of the sediments shows that the fine grained elements always dominated particularly during the monsoon and they can bind P.

Lower levels in total N content at sts 1 to 3 during monsoon was mainly due to the river discharge into the system which alters the textural characteristics thoroughly. The destruction of algal, clam and oyster beds by the intrusion of the turbid freshets into the estuarine system supports the fact that N-release from the sediments is controlled to a large extent by biological processes[50]. Though the minimum and maximum values of N from st 4 sediments occurred during June and July respectively the seasonal values showed a peak during the monsoon and this is mainly due to the heavy disposal of effluents from the Punalur paper mills.

The correlation between OC and K in the Ashtamudi estuary except at st 1 suggests that the organic detritus associated with K entered the system mainly by leaching and Serruya[51] states that K is generally associated with detritic silicates and their paucity in lake sediments may indicate the predominance of leaching over erosion.

The correlation noticeable between total P and OC at all stations of the estuary suggests that detrital P is another fraction of the total P in the sediments.

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