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The Ratios of Carbon, Nitrogen, and Phosphorus in a Wetland Coastal Ecosystem of Southern India

key words: organic carbon, phosphorus, nitrogen, sediments, seasonal variations, monsoon

Abstract

The fertility of the coastal and estuarine waters is of great concern because of its influence on the productivity of these waters. Seasonal variations in the distribution of organic carbon, total nitrogen and total phosphorus in the sediments of Kuttanad Waters, a part of the tropical Cochin Estuary on the south west coast of India, are examined to identify the contribution of sediments to the fertility of the aquatic systems. The adjoining region has considerable agricultural activity. The fresh water zones had higher quantities of silt and clay whereas the estuarine zone was more sandy. Organic carbon, total phosphorus and total nitrogen were higher in the fresh water zones and lower in the estuarine zones. Total phosphorus and organic carbon showed the lowest values during monsoon periods. No significant trends were observed in the seasonal distributions of total nitrogen.

Ratios of C/N, C/P and N/P, and the phosphorus and nitrogen content indicate significant modification in the character of the organic matter. Substantial amounts of the organic matter can contribute to reducing conditions and modify diagenetic processes.

1. Introduction

The aquatic system adjacent to land is always subject to considerable influences from human activities. The biogeochemical processes in the system may re-mineralize the organic load discharged from the land. Significantly high organic carbon can be observed in most of the sediments. Owing to the increased reactivity and anthropogenic inputs, there is a gradual increase in the flux of organic material in the sediment (WALSH *et al.*, 1985).

The source of nitrogen and phosphorus in most aquatic environments is from discharges off the land, where synthetic fertilizers and detergents are major contributors. Although concentrations of nutrients in aquatic systems are governed by the biological uptake and regeneration, sedimentary processes are important also. The relationship between nitrogen, phosphorus and carbon, observed in the living systems and the diagenetic processes, are generally not observed in aquatic sediments near landmasses. The absence of normal diagenesis of organic carbon, due to the reducing conditions present in these systems, may complicate an interpretation.

The study of nutrients in the dissolved and sedimented forms would help in understanding the potential availability of life supporting elements in any particular aquatic region (KLUMP and MARTENS, 1981). In our study, we address the distribution of carbon, nitrogen and phosphorus in the sediments of Kuttanad Waters. Kuttanad Waters is a part of Cochin

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Estuarine system and forms the southern part of the Vembanad lake. The high economic and biogeochemical importance stimulated our efforts for the detailed and continuing investigation. The main thrust of our studies was on the biological and pollution aspects. Previously, no serious effort had been directed towards the assessment and characterization of the nutrient dynamics in this system. These studies are significant because this wetland ecosystem is an extension of the tropical Cochin Estuary and receives inflow from five rivers.

2. Study Site

The area of study, Kuttanad Waters, is a part of the Cochin Estuarine system and forms the southern part of Vembanad Lake. The lake is connected to Arabian Sea at Cochin, India (Fig.1). This connection (only a short distance north of the enlarged portion of Fig.1) is the only source for tidal intrusion to the lake. Tides are semidiurnal and show a substantial range. The area of study, extends from 9°28′ to 10°10′N (Lat) and 76°13′ to 76°31′E (Long) and runs parallel to the southern part of the west coast of India. The hydrographic features of this part of the estuary are controlled mainly by discharges from five rivers (Manimala, Meenachil, Pamba, Achenkoil and Muvattupuzha) and also by tidal intrusions of saline waters from the Cochin Estuarine system. The Pamba and Manimala Rivers join together before meeting the Achenkoil River and eventually enter Vembanad Lake in its southernmost part. The Meenachil River enters near the middle of the lake, whereas the Muvattupuzha River enters at the northern part in the downstream region (not seen in Fig.1). The average depth of all the rivers varies between 1.5 to 10 meters. The lake, adjoining canals, and rivers have supported a lucrative fishery. During a southwest monsoon, severe floods seriously affect this cultivatable land. Agriculture, fishing, shell collection, lime production, tapping from coconut palms and duck farming are the main occupations of the people of Kuttanad area.

The Kuttanad area is rightly called the “Rice Bowl of Kerala”. This wetland system contributes nearly 20% of the total rice production of the State of Kerala. The aquatic system is highly productive and also contains substantial fishery resources. The total agricultural area is ~54935 ha. The amount of artificial fertilizers used in this area is about 8409 tons per year.

Thanneermukkam barrier, a type of hydraulic control (Fig.1), was commissioned in 1976 to help prevent the intrusion of saline water into Kuttanad paddy fields during December to March and thereby protect the ‘Punja’ crop. This barrier was originally envisaged to be closed for a period of three months (15 December to 15 March) every year while control gates remained open during monsoon months to facilitate the evacuation of floodwater. However, alterations in the operation schedule, such as the prolonged closure period up to April–May, brought some adverse effects and caused serious conflicts between fishermen and agriculturists. The deterioration of the water quality, after the construction of Thanneermukkam barrier, is suspected to be one of the reasons for the massive spread of fish diseases and fish mortality during recent years. Furthermore, the zone of salinity gradient shifted towards the north end of the lake.

The areas of investigation and station locations are given in Figure 1. The region lying between the Thanneermukkam barrier and the coastal Town of Alleppey was subdivided into three zones within which nine stations were selected for sampling. The first zone contains Stations 1 to 4, the second zone Stations 5 to 7 and the third zone Stations 8 to 9. All the zones exhibit a riverine character during the monsoon season. Zone 1 is completely riverine in nature during both the pre-monsoon and post-monsoon seasons. The main cultural activity in this area is agriculture. During the pre-monsoon season, the second zone shows estuarine characteristics but is dominated by fresh water during the other two seasons. Stations in the third zone are estuarine in nature during both pre- and post-monsoon seasons.

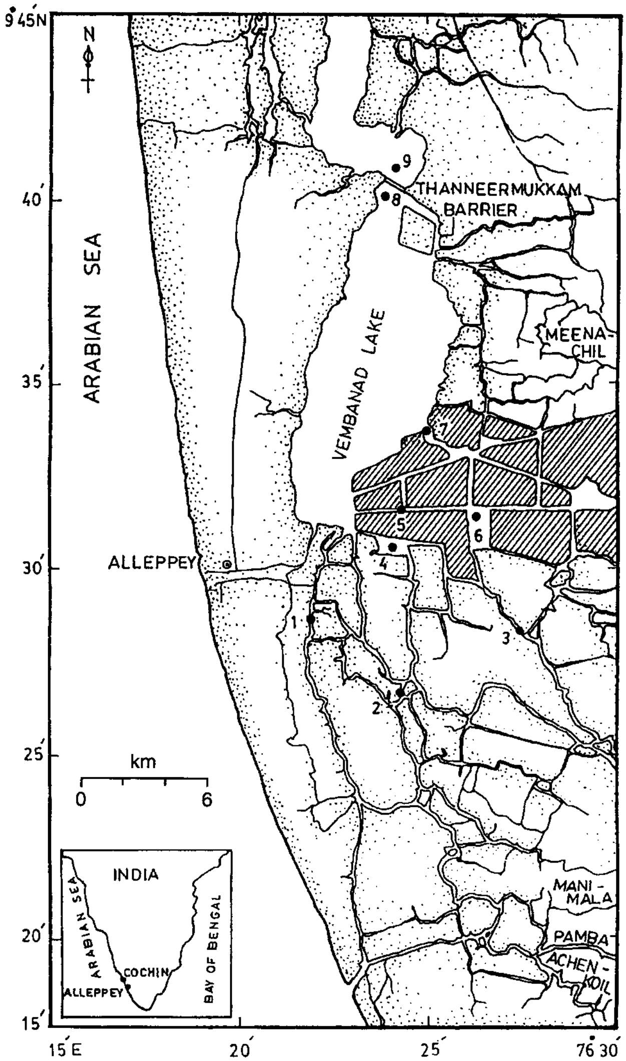

Figure 1. Location of the study area (Sampling stations indicated by numbers from 1–9; [hatched] Wetlands used for agricultural purposes; [dotted] Land).

3. Materials and Methods

Sediment samples were taken at monthly intervals from May 1996 to May 1997 at all nine stations. Sediments were collected using a van Veen grab (0.032 m^2) and then frozen at –4 °C until analyzed. Organic carbon was determined by following the wet oxidation method of Gaudette and Flight (1974). Total nitrogen was determined by the Kjeldhal method and the total phosphorus was determined using perchloric acid digestion described by Strickland and Parsons (1972).

4. Results

4.1. Sediment Organic Carbon

Figure 2 (Organic Carbon) shows the seasonal variation in sediment concentrations of this variable at different stations. Generally, there were increases in the concentrations of organic carbon during the post-monsoon season in Zone I and Zone III. The pre-monsoon values in Zone II were higher. During the pre-monsoon period, the maximum organic carbon content for Zones I, II and III were 32.32, 24.34 and 8.65 mg g^{-1} and the minima were 21.78, 16.11 and 8.04 mg g^{-1} respectively for the three zones. During the monsoon periods, all the zones showed lower values. The concentrations in Zone I ranged from 10.09 to 6.5 mg g^{-1}, in Zone II from 3.71 to 3.33 mg g^{-1}, and in Zone III from 5.11 to 7.39 mg g^{-1}. During the post-monsoon period, the maximum and minimum values observed in Zones I and II were 31.47 and 21.09, and 21.85 and 19.02 mg g^{-1}, respectively. In Zone III the values varied between 21.04 and 1.21 mg g^{-1}.

4.2. Total Phosphorus of the Sediment

Station variations in total sediment phosphorus are also shown in Figure 2 (Total P). Generally concentrations are higher in the post-monsoon periods and lower in the regular monsoon period. During pre-monsoon periods, phosphorus concentration in Zones I, II, and III varied between 0.92 and 1.59 mg g^{-1}, 0.47 to 20 mg g^{-1}, and from 0.12 to 0.38 mg g^{-1} respectively. During the monsoon period, the highest concentration in Zone I, II and III were 1.07, 0.76 and 0.22 mg g^{-1}. The corresponding lowest values were 0.77, 0.27 and 0.12 mg g^{-1}. During the post-monsoon period the highest and lowest concentrations were 1.83 and 1.45 mg g^{-1} in Zone I, 0.57 and 2.41 mg g^{-1} in Zone II, and 0.63 and 0.89 mg g^{-1} in Zone III.

4.3. Total Nitrogen of the Sediment

Observed values for total sediment nitrogen are shown in Figure 2 (Total N) as well. During the pre-monsoon period, total nitrogen concentrations in Zones I, II and III ranged from 4.48 to 6.72, 3.36 to 7.84 and 3.92 to 5.04 mg g^{-1} respectively. During the monsoon period, the lowest and highest concentrations observed in Zones I, II, and III were 4.48 and 6.72, 7.28 and 7.84, and 2.24 and 3.36 mg g^{-1} respectively. The corresponding ranges in the post-monsoon season for Zones I, II, III were 5.62 to 7.28, 5.6 to 7.84 and 6.72 to 7.82 mg g^{-1}.

5. Discussion

Generally the estuarine sediments, which are either brought from the land and/or generated in the water column, are considered to be the storehouse of organic matter. Thus a high organic content in these sediments is a natural feature. In the sediments of Cochin Backwaters, high organic carbon content was also reported by others (SANKARANARAYANAN and PANAMPUNNAYIL, 1979; NAIR, 1992; BEENAMMA, 1993; JAYASREE, 1993). However, the riverine zone of the Backwater system was low in organic matter. The riverine sediments had higher fractions of sand whereas the estuarine sediments had higher fractions of silt and clays. In the present study, Zones I and II were found to have significantly higher concentrations of organic matter than Zone III. The influence of the sediment texture is evident from the values of organic carbon measured during the monsoon season. In all Zones, grain size analyses have shown that sediments in monsoon season were dominated by sand and low concentrations of organic carbon. The flushing of sediments by the floodwaters of the rivers may also keep the organic carbon content low during the monsoon season.

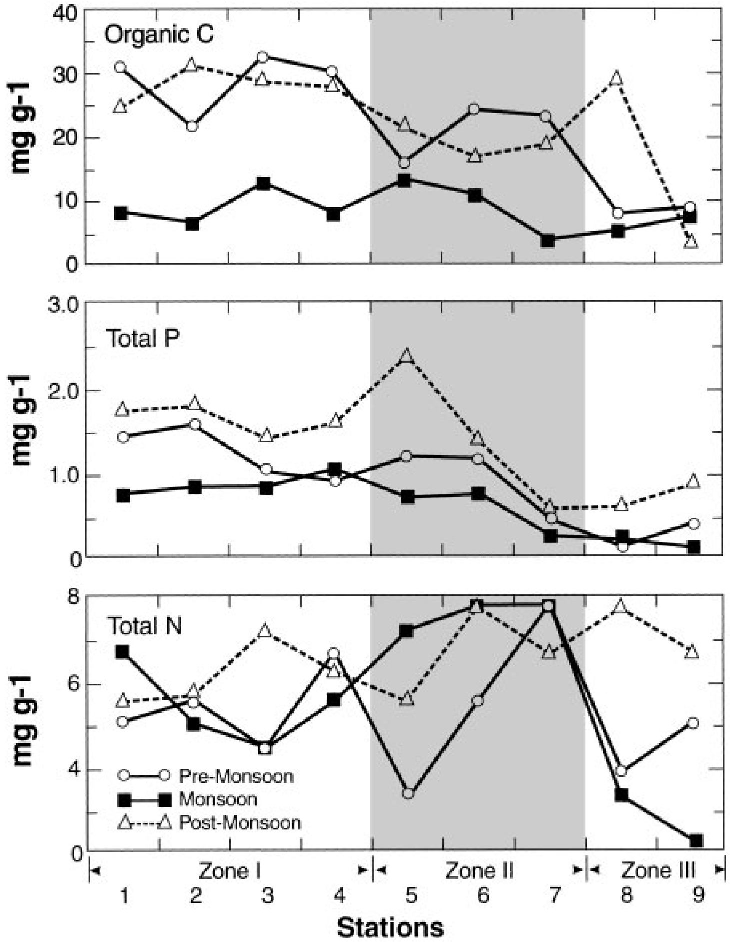

Figure 2. Seasonal variations in concentrations (mg g^{-1}) of Organic Carbon, Total Phosphorus, and Total Nitrogen in sediments from different sampling stations and zones within the Kuttanad Waters of southern India. Note differet scales.

Although the estuarine and riverine sediments generally show higher and lower phosphorus concentrations respectively, we found just the opposite. Our riverine section (Zone I and Zone II) showed high values and the estuarine zone III gave the low values. Earlier studies in the Cochin Backwater system area indicated that our general finding holds for this system (Nair, 1990; Nair, 1992; Jayasree, 1993). Our findings reflect the conditions prevailing in the Kuttanad Waters, i.e., the riverine zones are integral parts of the agricultural activities. The shallow watershed character and its flushing promote a high concentration of phosphorus in the sediments. The discharges from agriculture drains contain substantial remains of phosphorus fertilisers which may be contributing to the higher phosphorus concentrations noted in pre-monsoon and post-monsoon sediments. The flushing of the sediment during monsoon seasons can lead to the lower concentrations observed in this season. Zone III is estuarine and its sandy character may also contribute to its comparatively low concentrations of phosphorus. The post-monsoonal maximum is a general observation in estuarine conditions (SANKARANARAYANAN and PANAMPUNNAYIL, 1979; ANIRUDHAN, 1988; NAIR, 1992; JAYASREE, 1993; BEENAMMA, 1993).

The distribution of nitrogen generally parallels the distribution of phosphorus. In most natural systems, a ratio is maintained between nitrogen and phosphorus. Our observed values were significantly higher than those reported by some other workers (ANIRUDHAN, 1988; NAIR, 1990; NAIR, 1992; JAYASREE, 1993; BEENAMMA, 1993).

C/N, C/P and N/P ratios

The general chemical characteristics and fertility of the water bodies like Kuttanad Waters will be influenced by contributions from the land, agricultural operations, and possible diagenetic processes. Thus, nutrient dynamics will be dependent on the anthropogenic input, uptake, regeneration and sedimentary processes. Analyses of C/P, C/N and N/P ratios can help shed light on nutrient processing. The observed values of these ratios are given in Table 1.

Zones I and II had the minimum C/P ratios during the monsoon and the maximum during the pre-monsoon. Zone III had its maximum C/P ratios during the monsoon and minimum during the post-monsoon periods. Zones I and II showed similar trends in the C/N and N/P ratios whereas Zone III had its maximum C/N and N/P ratios during the monsoon and pre-monsoon, and minimum during the pre- and post-monsoon periods respectively. Some ratios of carbon, nitrogen and phosphorus reported elsewhere are given in Table 2 for comparison. For example, SANKARANARAYANAN and PANAMPUNNAYIL (1979) reported a C/P ratio which varies between 2.25 and 37.51 for the sediments of Cochin Backwaters. QASIM and SANKARANARAYANAN (1972) reported that the detritus of Cochin Backwaters had a C/P ratio of 22.61 to 60.4 with an average of 41.0. Studies on the various constituents of the sediments of Cochin Backwaters by several authors (QASIM and SANKARANARAYANAN, 1972; SANKARANARAYANAN and PANAMPUNNAYIL, 1979; NAIR, 1992; BEENAMMA, 1993) revealed that the surface layers of sediment are composed mostly of settled detritus. In our present study the C/P ratios ranged between 15.37 and 36.77 with an average of 21.34. Although the aquatic plant material has a high C/P ratio, ratios in the coastal and estuarine sediments are lower. The lower C/P ratio in the latter case is attributed to phosphorus contributions from the land.

SANKARANARAYANAN and PANAMPUNAYIL (1979) reported an average C/N ratio of 6.4 for the Cochin Backwaters but QASIM and SANKARANARAYANAN (1972) found an average ratio of 7.6 for detritus from the same area. Studies on the west coast of India during the cruises of RV Meteor gave a C/N ratio between 1 and 8 whereas the shelf sediments of Arabian

Table 1. Seasonal variations of C/P, C/N, and N/P ratios in sediments.

	Zone	C/P	C/N	N/P
Pre-monsoon	I	22.85	5.27	4.33
	II	22.41	3.80	5.89
	III	32.12	1.86	17.23
Monsoon	I	10.55	1.74	6.07
	II	15.82	1.22	12.97
	III	36.77	2.23	16.47
Post-monsoon	I	16.91	4.58	3.69
	II	15.37	2.75	5.56
	III	19.39	2.07	9.36

Table 2. Comparative values of C/N, C/P, and N/P ratios from a variety of investigations.

Region	Ratios	References
India:	C/P 2.25 to 37.5	SANKARANARAYANAN
– Cochin Backwaters	C/N 2.3 to 16.9	and PANAMPUNNAYIL (1979)
	N/P 1.2 to 4.07	
– Cochin Backwaters	C/P 22.6 to 60.4	QASIM and
	C/N 5 to 10.5	SANKARANARAYANAN (1972)
– Cochin wetland Sediments	C/P 15.37 to 36.77	
	C/N 1.22 to 5.27	PRESENT STUDY
	N/P 3.69 to 17.23	
– Natural Plankton	N/P 13.8	SEN GUPTA *et al.* (1976)
– Culture Plankton	N/P 18.2	
– Sediments of Mandovi	C/P 1.53 to 38.5	NASNOLKAR *et al.* (1996)
Estuary, Goa	C/N 0.21 to 2.0	
	N/P 2.92 to 37.51	
USA (California):		
– Sediments of Catalina	N/P 5.8(average)	RITTENBERG *et al.* (1955)
– Sediments of Santa Barbara	N/P 3.3(average)	
– Sediments of Santa Monica	N/P 1.4(average)	
Pacific ocean:		
– Completely oxidized Sediments	C/N 2.2 to 5.0	MULLER (1977)
Arabian Sea:		
– Shelf Sediments	C/N 2.48 to 37.5	BHOSLE *et al.* (1977)
	C/P 1.0 to 8.0	
Finland:		
– Coastal Waters of the	C/N 7.4	HEISKANEN and
Archipelago Region	C/P 42	TALLBERG (1999)
	N/P 72	

Sea had values ranging from 2.48 to 37.5 (BHOSLE *et al.*, 1977). The high sediment shelf ratios were attributed to the degradation of complex proteins. Very low values of C/N, 0.2 to 2.0, were reported by NASNOLKAR *et al.* (1996) in the Mandovi Estuary along the west coast of India. Generally, high C/N ratios are more characteristic of marine organic matter and low ratios those of fresh water. In our study, the C/N ratio ranged from 1.22 to 5.27 and averaged 2.83. The comparison of our values, with those of the earlier reports for the Cochin Backwaters and other water masses, clearly indicates the contribution of terrestrial or fresh water organic matter to the sediment. The significant observation in our study is that C/N ratios are higher in the pre-monsoon and lower in the monsoon periods. One explanation for this is that substantial contributions of nitrogen from fertilizers alter the C/N ratios in the sediment. There is a reduced discharge from the land during the pre-monsoon period and so seasonal variations in the C/N ratio might be expected during other periods as well.

The N/P ratios are also reduced during the pre- and post-monsoon periods. Obviously, any decrease in ammonia nitrogen or increase in phosphorus will modify the N/P ratios.

The C/N values, when analysed along with N/P values, indicate substantial modification in the organic matter as well as the phosphorus content. The low C/N ratios are associated with a normal N/P ratio in Zone III as well as normal C/N and N/P ratios in Zone II. However, we do not suggest that this complex and dynamic system is static. We suspect that the higher quantities of phosphorus and nitrogen, and varying ratios, reflect the application of bio-manures to the land and subsequent (but altered) nutrient transport to various aquatic zones. The C/P, C/N, or N/P ratios may be altered further in these zones.

In conclusion this complex wetland ecosystem contains substantial contributions from anthropogenic sources. The shallowness of the water body, and substantial amounts of organic matter, may be acting as a limiting factor in the diagenetic processes. The complex nature of the ratios suggests this also.

6. Acknowledgement

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