



PARTICLE-BOUND NUTRIENTS IN AND AROUND THE *SUNDARBANS*, SOUTHWEST BANGLADESH

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Abstract: The study deals with the nature of solute load as well as the spatial distribution and the biogeochemical processing of the C, N and P in the suspended sediments from rivers in and around the *Sundarbans* collected during August-September 2002. The geochemistry of the solute load suggests that oceanic surface processes are important in and around the *Sundarbans* ecosystem and subduing the continental carbonate weathering processes prevailing over the Bengal basin. Despite a low concentration, significant spatial variation in Total Organic Carbon (TOC) and Total Nitrogen (TN) content in the suspended sediments exist in and around the *Sundarbans*, where as Plant Available Phosphorus (PAP) does not show any significant spatial variation. Excellent correlation between TOC and TN suggests regulation of TN by organic matter. However, the presence of considerable amount of inorganic nitrogen (ca. $\sim 0.10 \text{ mg.g}^{-1}$) may be estimated from such relationship, which is more important in the periphery (ca. $\sim 0.19 \text{ mg.g}^{-1}$) than in the interior *Sundarbans* (ca. $\sim 0.03 \text{ mg.g}^{-1}$) and may be of anthropogenic origin. The importance of inorganic nitrogen is also evident from the low TOC: TN ratio (varying from 2.96 to 6.42) in the ecosystem which could also be attributable to the almost complete degradation of the organic matter. Negative and poor/no correlation between PAP with TOC and TN suggest that phosphorus is not the only limiting factor in biomass production in the ecosystem.

Key words: The *Sundarbans*, solute load, mangroves, sedimentary nutrients, Bengal basin, Bangladesh

Introduction

The study of C, N and P in an aquatic system is important because of strong biogeochemical coupling among these elements that determine the effectiveness and selectivity of the processes of transformation, elimination or immobilization of nutrients during their transfer through aquatic continuum (Billen, 1993). Meybeck (1993) has described the multiple sources of C, N, P and S in river borne materials. The natural concentrations of these elements are very variable and depend on weathering conditions, soil thickness and climate. However, since N and P are derived and regulated by soil activity they are more constant (Meybeck, 1993).

River sediments are major sinks as well as source of nutrients. Particulate phosphorus (organic and inorganic) represents 95% of phosphorus carried by the rivers (Meybeck, 1982). Global particulate nitrogen transport by rivers amounts to $33 \times 10^{12} \text{ g.N.a}^{-1}$; more than 80% of which occurs in rivers having high-suspended matter concentration such as the Ganges, Brahmaputra, Mekong and Huanghe (Ittekkot and Zhang, 1989). On a world average ca. 0.5 gigatons organic carbon is

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transported by the rivers annually to the oceans which is generally equally distributed between dissolved and particulate fraction of the riverine load (Spitzky and Ittekkot, 1991). Nutrient concentrations of large low land rivers often modified by industrial emission, sewage and agricultural effluent, and they are also likely to have their flow regime regulated by dams. The uniqueness of their catchment area, individual climate and geology make it difficult to generalize the characteristics of the drainage basins.

Human activities have profoundly altered nutrient levels in many of the world surface waters. Almost invariably higher nutrient concentrations are found at the lower-most sites along large rivers due to a variety of human activities. Human population density in the watersheds of 42 major rivers of the world was found to explain 76% of the variation in average annual nitrate concentration (Peierls *et al.*, 1991). Nutrient concentrations often vary seasonally due to influences of hydrology and changes in anthropogenic inputs (Allan, 1995). These facts imply that river sediments play an essential and significant role in the concentration and transportation of nutrients, and forms an integral part of the global geochemical cycle.

Tropical seas such as the Bay of Bengal and the Arabian Sea receive *via* rivers large quantities of land derived organic matter both in the dissolved and in the particulate phases, which has already undergone significant biogeochemical alteration on land. The relative stability and low nutritive value of this material enable its accumulation in the deep sea water column and sediments (Ittekkot *et al.*, 1986). It has been estimated by Ramesh *et al.* (1995) that the transfer of dissolved organic carbon and particulate organic from the Himalayan rivers is about 7.6 and 9 million tons *per year* respectively. Concentration of particulate phosphorus is always high in all Indian rivers. The flux of particulate phosphorus and particulate inorganic phosphorus from the Indian rivers to the ocean is 19.5×10^{10} g.yr⁻¹ and 1.5×10^{12} g.yr⁻¹ respectively (Ramesh *et al.*, 1995). No such study has yet been noticed regarding N in the subcontinent. However, on global basis, Galloway *et al.* (1995) estimated that coastal oceans receive about 41×10^{12} g.N.yr⁻¹ *via* rivers, much of which is buried or denitrified. They have observed that two-thirds of the increase in anthropogenic N-fixation will occur in Asia by the year 2020 which will account for over half of the global anthropogenic N-fixation. Thus considering the rapid change in land use pattern in the tropics and disproportionate human population distribution, substantial transport of nitrogen by the rivers to the sea can be very much presumed. The transfer of biogenic elements (C, N and P) from the Ganges-Brahmaputra-Meghna (G-B-M) drainage regime could be important factor in their global cycle. However direct measurement of nutrients – carbon, nitrogen and phosphorus – in sediments and dissolved loads are rather limited in Indian rivers (Subramanian and Ittekkot, 1991) except that of Datta *et al.* (1999) and Gupta *et al.* (1997).

This paper deals with the nature of solute load, and spatial distribution and the biogeochemical processing of the C, N and P in the suspended sediments from the rivers in and around the *Sundarbans* mangrove ecosystem the knowledge of which might pave the way for understanding various management issues.

Materials and Methods

Study Area: The study area is situated in and around the *Sundarbans* mangrove ecosystem on the southwest of coastal Bangladesh lying within the latitudes 21°31' and 22°30' N and longitudes 89° and 90° E covering about 5700 km² (Fig. 1). The area (covering a east-west distance of around 125 km) spatially represent a component of the *western* coastline of Bangladesh that has a near east-west orientation - extending from *Hariabangha* channel along the Indo-Bangladesh border in the west to the *Sandwip* channel in the east and covers a coastline of about 380 km. This entire

coastline has been formed by delta building processes of the G-B-M system and is geologically of Recent age (Umitsu, 1993; Barua, 1991; Alam *et al.*, 1990; Morgan and McIntire, 1959).

The *Sundarbans* represents one of the largest single track mangrove forests of the world (Siddiqi, 2001). This area represents a physiographically immature delta (Rasid, 1991) which is considered tectonically most active (Goodbred Jr and Kuehl, 2000; Umitsu, 1993; Valdiya, 1984; Coleman, 1969; Morgan and McIntire, 1959), low elevated (Milliman *et al.*, 1989) and frequently flooded (Rasid and Paul, 1987) regions of the world. Because of the favorable physical environment, biologically this ecosystem is one of the richest in the world. The detail of physical and biological environments of the study area may be seen in Hoque and Datta (2005) and Siddiqi (2001).

Sampling Protocol: The sampling stations are indicated in Fig. 1. The sampling trajectory in this study had two components. The first one was stationed along a route represented by the rivers such as *Nilganga*, *Agunmukh*, *Lohalia*, *Patuakhali*, *Kirtankhola*, *Shugandha* and *Boleswar* situated on the east periphery of the *Sundarbans* and is indicated by station numbers 01 through 07 in Fig. 1. This component is named in this study as the *Peripheral Component*. The second component was represented by the route along the rivers *Ghashia Khal*, *Rupsha*, *Shibsha* and *Pasur* and is indicated by the stations 08 through 11 in Fig. 1 and termed as the *Interior Component* situated within the *Sundarbans*.

Suspended sediments and river water were collected only during August-September 2002 from the said stations (because of our limitations to accessibilities) distributed uniformly all over the study area. The sampling stations are situated at pre-selected locations representative of the river course and avoiding sites of instant tributary effect and other apparent sources of pollution.

Water samples for suspended sediments were collected in pre-washed 20-L plastic bottles from the mid-channel at a depth of 50-100 cm from the surface (but not maintaining tidal cycle and no replications) and were kept in the laboratory for a week. The suspended sediments were then separated by decantation and dried up at room temperature. Water samples for ion-chemistry were collected in pre-washed 1-L polyethylene bottles and kept air tight and transferred to the laboratory for analysis of dissolved major ions.

The pH and alkalinity in water samples was measured in the field using Consort C 425 portable pH-EC meter and micropipette-burette respectively. Standard analytical procedures were followed for determining ion-chemistry (Ramesh and Anbu, 1996; Eaton *et al.*, 1995). The suspended sediments were grounded and processed for determination of Organic Carbon, Kjeldhal Nitrogen

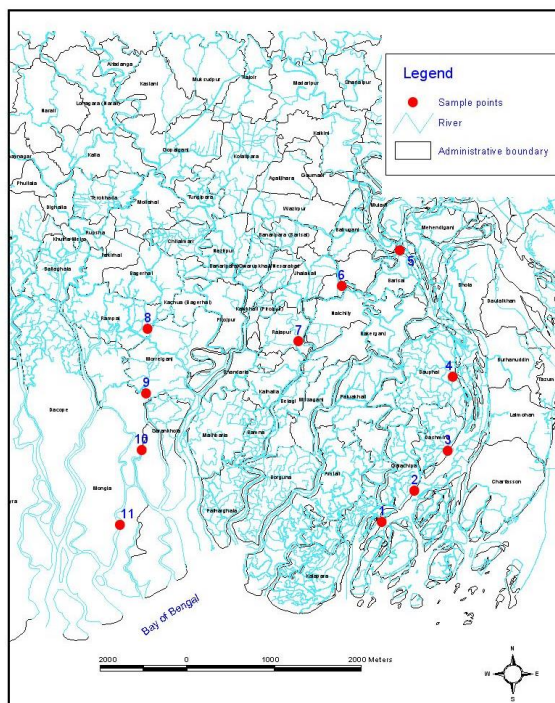


Fig. 1: The *Sundarbans* and the surrounding area with sampling stations.

and Plant Available Phosphorus following standard analytical methods (Jackson, 1973; Olsen *et al.*, 1954).

Results

Major dissolved ions: The major ion-chemistry is presented in Table 1. The analytical precision have not been ascertained because of incomplete analysis. However, our assumption is that, the contribution of ions in water chemistry not analyzed here is quantitatively minor.

Table 1. Major ion chemistry of the rivers in and around the *Sundarbans*.

Sample No	Location	Date	Parameters in mg.l ⁻¹ except pH							
			pH	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	HCO ₃ ⁻	Cl ⁻	PO ₄ ³⁻
<i>Peripheral Component</i>										
# 01	Nilganga River at Khepupara	Sept 12, 2002	7.1	41	10	163	10	130	279	0.019
# 02	Agunmukh	Sept 12, 2002	7.0	14	12	07	03	110	26	0.01
# 03	Lohalia River at Golachipa	August 26, 2002	6.9	17	15	08	04	120	26	0.0052
# 04	Patuakhali River at Patuakhali	August 26, 2002	7.1	14	05	05	04	90	25	0.005
# 05	Kirtankhola River at Barishal	August 25, 2002	7.0	12	07	06	04	80	30	0.01
# 06	Shugandha River at Jhalokati	August 25, 2002	7.2	14	12	06	03	90	25	0.015
# 07	Boleshwar	August 25, 2002	7.0	19	13	17	04	100	55	0.03
<i>Interior Component</i>										
# 08	Ghashia Khal at Ramphal	August 25, 2002	7.4	45	19	168	07	110	270	0.02
# 09	Monkey Point	September 19, 2002	7.1	21	17	33	05	110	61	0.01
# 10	Shibsha River at Akrampoint	September 18, 2002	7.0	33	05	43	07	130	128	0.01
# 11	Sundari Kota at Hiron Point	September 18, 2002	7.2	31	14	35	05	130	63	0.005

* Sample number refers to Fig. 1

Particulate C, N and P: The concentrations of C, N and P in the suspended sediments from the *interior* and *peripheral* components are presented in Table 2. The spatial distribution of total organic carbon (TOC) concentration is relatively narrow in the *peripheral* component (0.77 to 1.15 mg.g⁻¹) with a mean of 0.98 ± 0.14 mg.g⁻¹. However, such range of concentration is quite wide in the interior component varying from 1.55 to 2.18 mg.g⁻¹ (mean of 1.74 ± 0.30 mg.g⁻¹).

Table 2. C, N and P concentration in the suspended sediments from rivers in and around the *Sundarbans*.

Sample No	Location	Date	TOC mg.g ⁻¹	TN mg.g ⁻¹	Avail P in µg.g ⁻¹
<i>Peripheral Component</i>					
# 01	Nilganga River at Khepupara	September 12, 2002	0.96	0.24	8.80
# 02	Agunmukh	September 12, 2002	1.03	0.20	8.40
# 03	Lohalia River at Golachipa	August 26, 2002	0.89	0.16	7.20

# 04	Patuakhali River at Patuakhali	August 26, 2002	0.77	0.26	5.40
# 05	Kirtankhola River at Barishal	August 25, 2002	1.15	0.23	8.40
# 06	Shugandha River at Jhalokati	August 25, 2002	0.89	0.21	12.0
# 07	Boleshwar	August 25, 2002	1.15	0.25	8.10
<i>Interior Component</i>					
# 08	Ghashia Khal at Ramphal	August 25, 2002	1.55	0.30	10.40
# 09	Monkey Point	September 19, 2002	1.67	0.26	8.00
# 10	Shibsha River at Akrampoint	September 18, 2002	1.55	0.31	8.60
# 11	Sundari Kota at Hiron Point	September 18, 2002	2.18	0.40	6.40

*Sample number refers to Fig. 1

The variation in TOC of both the components is also statistically significant (F value 33.82, p value 0.00025) and show an increase in the *interior* component. The total nitrogen (TN) concentration in the suspended sediments follow closely the spatial distribution pattern of TOC in both the components. The TN varies from 0.16 to 0.26 mg.g⁻¹ in the *peripheral* component (mean 0.22 ± 0.034 mg.g⁻¹) while it varies from 0.26 to 0.40 mg.g⁻¹ in the *interior* component (mean 0.32 ± 0.059 mg.g⁻¹). The differences in TN content between the two components of the sampling trajectory are statistically significant (F value 12.041, p value 0.007). The spatial concentration of Plant Available Phosphorus (PAP) in suspended sediments from in and around the *Sundarbans* is very similar. The PAP content varies from 5.4 to 12 µg.g⁻¹ in the *peripheral* component (mean 8.33 ± 1.98 µg.g⁻¹) and from 6.4 to 10.4 µg.g⁻¹ in the *interior* component (mean 8.35 ± 1.65 µg.g⁻¹). The difference in PAP content between the components is statistically insignificant (F value 0.0003, p value 0.986).

Discussion

Nature of solute load: The river systems studied covers a large low-lying region of the Bengal basin, and it is essential to study the hydro-chemical processes in this region for better understanding of the land-ocean interaction affecting the balance and their bearing on the particulate nutrients in the river system.

The pH of water varies within a narrow limit of 6.9 to 7.2 in the *peripheral* component and of 7.0 to 7.4 in the *interior* component; more alkaline water being in the *interior* component. However, the abrasion pH of most of the major minerals lies within this range (Ollier, 1969), and known to be abundant in the Bengal drainage basin (Alam *et al.*, 1990). The pH of the interior component is narrowly higher (7.18 ± 0.171) than the peripheral component (7.04 ± 0.098), and such difference is not statistically significant (F value 2.766; p value 0.131). Both the component is representing a transport-limited drainage basin (as described by Carson and Kirkby, 1972). However, the higher pH in the interior component be related to intense photosynthetic activities by aquatic organisms in the *interior* component (as explained in Hem, 1970), which is assumed to be significant in the *Sundarbans* ecosystem because, in general, the biological productivity is more in mangroves compared with the river systems.

The dissolved alkali earth elements viz., Ca and Mg makes up 23 to 74% of the total major cations, and do not show any trend regarding proximity to the shoreline (Fig. 2); except that, relative to Mg the *interior* component contains slightly more Ca than that of the *peripheral* component. This difference in Ca content between the two components is also statistically

significant (F value 4.825; p value 0.056). The Ca also shows very poor correlation coefficient ($r = 0.28$) with Mg. This suggests that both the alkali earth may not be of co-origin. Stallard and Edmond (1987) suggested a 1:1 relationship between (Ca+Mg) and HCO_3 on an equivalent basis in a carbonate dominated water chemistry. Such relationship do not exists in the present case (Fig. 3). Compared with Na and K ions together the alkali earths are less important in the *interior* of the *Sundarbans* (Fig. 4). It may be assumed that the oceanic influence and the biological activities might have subduing locally – particularly in the *Sundarbans* - the continental carbonate weathering processes as prevailed in most of the Bengal basin (Datta and Subramanian, 1997a).

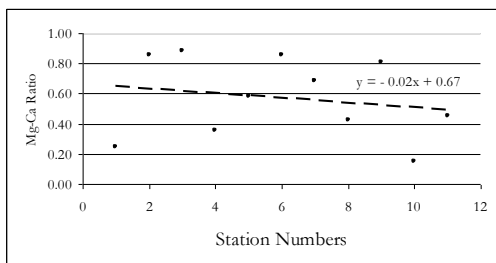


Fig. 2: Plot showing spatial variation of dissolved Magnesium-Calcium ratio (wt./wt.) (Station numbers refers to Fig. 1)

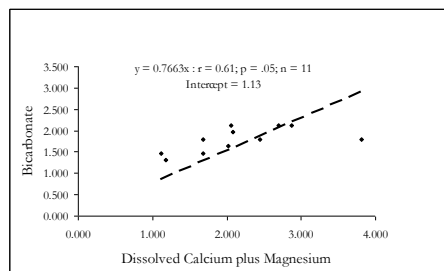


Fig. 3: Plot showing (Ca+Mg) versus Bicarbonate in meq.l^{-1} in and around the *Sundarbans*.

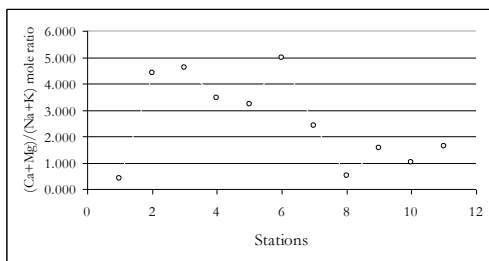


Fig.4: Plot showing (Ca+Mg)/(Na+K) mole ratio in and around the *Sundarbans* (Station numbers refers to Fig. 1).

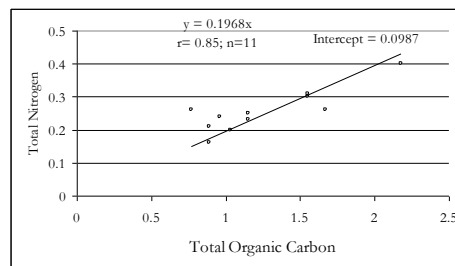


Fig.5: Relationship between TOC and TN ratio (wt./wt.) in suspended sediments in and around the *Sundarbans*.

Sodium constitutes 17 to 73% of the total cations in the region (Table 1) and follows closely the spatial distribution pattern of chloride ions with $r = 0.99$. This suggests co-origin of both the species. The differences in concentrations of sodium and chloride ions between the *peripheral* and the *interior* components also statistically insignificant (F value 1.06, p value 0.33 for Na; F value 1.14 and p value 0.31 for Cl). Most of the chloride and the sodium ions are presumed to be of marine origin because circulation of chloride ions is largely a physical process (Hem, 1970) and the area studied is known to be a tidal zone.

Thus it may be concluded that oceanic processes is important in the study area and subduing most of the continental geochemical processes controlling the water chemistry of the Bengal basin. Moreover, biological processes have an important bearing on the water chemistry of the *Sundarbans*.

Distribution of C, N and P in the suspended sediments: The concentration of organic carbon in suspended sediments depends on many factors such as physical condition of water flow, sediment load and geological characteristics (Probst *et al.*, 1994). Particulate organic carbon (POC) in suspended matter of the Ganges is high (50 to 60 mg.g^{-1}) during periods of low sediment discharge and low (7.8 to 9.0 mg.g^{-1}) during high sediment discharge periods (Ittekkot *et al.*, 1985; Subramanian *et al.*, 1985; Chowdhury *et al.*, 1982). Ittekkot *et al.* (1986) also observed that

organic matter during high discharge periods had low concentration of labile constituents such as sugars and amino acids, and was thus more biodegraded than that carried during the low discharge period. During high flow the contribution to suspended sediments comes mostly from re-suspension of bed sediments and bank scour (Datta and Subramanian, 1997b), which indicates that degradation of organic matter by biogeochemical processes in the bed sediments is of considerable importance in determining organic carbon content of the suspended sediments. Samples in this study was collected during monsoon – thus representing period of high discharge and the TOC show a low concentration compared with the G-B-M (Datta *et al.*, 1999) and such low concentration may be attributed to the grain-size effect. The higher concentration of TOC in the *Sundarbans* with respect to its periphery may be attributed to the high biomass production in the mangroves along with such factors as water flow, sediment load and the biogeochemical processes as mentioned earlier.

The floodplain soils of the Ganges in general are poor in nitrogen and phosphate (Saheed, 1995), and the relatively low content of TN in the present study may be attributed to the low content of TN in the bulk bed sediments (Datta *et al.*, 1999).

The PAP content in suspended sediments is low compared with that from bulk bed sediments of the G-B-M system (Datta *et al.* 1999). The inorganic processes play a dominant role in regulating phosphate in turbid rivers (Lebo, 1991; Fox, 1993). However, apatite saturation plays a minor role in limiting dissolved phosphate in the Lower G-B-M system (Datta, 1999) and importance of iron and/or aluminium hydroxide (Fox, 1993; Bolan *et al.*, 1985) is presumed. Dissolved phosphate is relatively high in concentration during pre-monsoon and monsoon in the Lower G-B-M system compared with that during low discharge period, and is attributed to agricultural waste and high turbidity which restrict biomass productivity (Datta, 1999). The relatively large standard deviation value indicates probable local influence of fertilizer applications in the floodplain and its consequent runoff to the rivers. Another likely reason is that the affinity of clays for phosphates lies between calcite and goethite (House and Casey, 1989). In river sediments the situation is complicated by the presence of compounds such as iron oxides and hydroxides which compete with phosphates for the surface of minerals. These facts could be responsible for low content and large standard deviation of PAP in and around the *Sundarbans*.

Relationship among C, N and P in the suspended sediments: Excellent correlation exists between TOC and TN in the suspended sediments in and around the *Sundarbans* ($r = 0.85$; p value 0.05) which suggests that the TN content is regulated by organic sources. However, the intercept on the TN axis refers to the small amount (ca. $\sim 0.10 \text{ mg.g}^{-1}$) of inorganic nitrogen present in the sediments (Fig. 5). The relatively low TOC values associated with low TN concentration in the *peripheral Sundarbans* means less accumulations of organic matter (and hence organic nitrogen) in the sediments and the intercept on the TN axis refers to the relatively more amount (ca. $\sim 0.19 \text{ mg.g}^{-1}$) of inorganic nitrogen present in the sediments. On the other hand, relatively high TOC values in the *interior Sundarbans* with high TN concentration means relatively high accumulation of organic matter (and hence organic nitrogen) in the sediments. This is quite evident from the fact that the intercept on the TN axis in the *interior Sundarbans* refers to the small amount (ca. $\sim 0.03 \text{ mg.g}^{-1}$) of inorganic nitrogen present in the sediments. Therefore, at low organic nitrogen concentration the TOC:TN ratio is influenced by relatively increased amount of inorganic nitrogen which might be added from inorganic sources such as fertilizers. Thus anthropogenic sources of nutrients (such as nitrogen) is relatively less important in the *interior Sundarbans* as compared with the *periphery*.

Few stations (such as stations 01, 04, 06 and 07 all in the *peripheral Sundarbans*) lying above the regression line in Fig. 5, indicates TN rich areas. If inorganic nitrogen is constant in these samples the data plotted on the TN rich areas suggest that planktonic organic carbon is more abundant in

these areas compared to that in the area plotted under the regression line. The assumption that inorganic nitrogen in the samples remains constant is based on the intercept on the TN axis in Fig. 5 which although not analyzed indicates the amount of inorganic nitrogen in the samples. Because of the strong correlation between TOC and TN, it could be inferred that any increase or decrease in TOC will be associated with similar changes in organic nitrogen. However, the interior *Sundarbans* is supposed to be an area of high biological activities.

The mass TOC:TN ratio in and around the *Sundarbans* varies from as low as 2.96 to as high as 6.42. The ratio is 5.51 ± 0.41 in the *interior* component and is 4.50 ± 0.75 in the *peripheral* component. This ratio shows statistically significant variation (F values 4.077, p value 0.074) between the *peripheral* and the *interior* component of the sampling trajectory. The low TOC:TN values could be due to the almost complete degradation of the organic matter as has been observed by Paramasivam and Breitenbeck (1994) in the lower Mississippi delta. The lower TOC:TN values in and around the *Sundarbans* may also be due to the presence of higher content of inorganic nitrogen compounds such as nitrate, nitrite and ammonia in the suspended sediments.

The PAP shows very poor correlation with TOC and TN ($r = -0.11$ and $r = -0.23$ respectively; $p = .05$; $n = 11$) in and around the *Sundarbans* and thus of inorganic origin and may be regarded as of anthropogenic sources. The PAP shows low concentration in both the *peripheral* and the *interior Sundarbans* as compared with that of the bottom sediments from the Bengal drainage basin (Datta *et al.*, 1999). The correlation coefficient ($r = -0.11$; $n = 11$ at level of significance $p = 0.05$) between PAP and TOC shows that phosphorus is not the only limiting factor in the production of biomass in and around the *Sundarbans*.

Conclusion

The *Sundarbans* mangrove ecosystem and its adjoining areas are formed by the delta building processes of the G-B-M river system and is of very recent geological origin. The transition property of this region is very much evident from the nature of solute load where the dissolved alkali earth elements play a minor role in regulating water chemistry. Sodium and chloride ions show a definite abundance, and thus the oceanic processes are important. The continental geochemical processes controlling the water chemistry in the Bengal basin as a whole is subdued to some extent in this transition zone. Moreover, biological processes have an important bearing on the water chemistry of the *Sundarbans*.

The TOC and TN concentrations in suspended sediments show close relationship in their spatial distribution pattern; however, the concentrations are low compared with that of other river systems in the Bengal basin. The PAP is also quantitatively low and presumed to be of anthropogenic origin. The low TOC:TN ratio indicates dominance of inorganic nitrogen in the ecosystem which is more in the *peripheral Sundarbans*.

The major limitation in this study lies with the sampling program where *diurnal* and *seasonal* variations could not have been taken into account because of lack of logistic support.

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