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Decadal Variation of Nutrient Level in Two Major Estuaries in Indian Sundarbans

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Abstract

The impact of the nutrient level on the water quality in the Hooghly and Matla estuarine complex in Indian Sundarbans was assessed for three decades (1984-2014). Nitrate, phosphate and silicate were used as indicators of nutrient related water quality in the estuarine water. Our first order analysis reflects significant spatio-temporal variations of selected nutrients with relatively higher values in the Hooghly estuary (in the western Indian Sundarbans) compared to the Matla estuary (in the central Indian Sundarbans). Significant variations were observed in dissolved nitrate, phosphate and silicate concentrations between stations and years ($p < 0.01$). Such pronounced variations may be attributed to the location of highly industrialized and urbanized city of Kolkata, Howrah and Haldia port-cum-industrial complex adjacent to the Hooghly estuary. The sudden rise of selected nutrients during premonsoon, 2009 (irrespective of sampling stations) is directly related to AILA, a super-cyclone that occurred in the lower Gangetic delta during 22nd - 25th May, 2009.

Keywords: Indian Sundarbans, Nutrients, AILA, Spatio-temporal variation.

1. Introduction

Coastal waters and estuaries are facing a variety of adverse impacts affecting both the ecosystem and the human health through a sewage-wastewater discharge and the disposal practices that often lead to the introduction of high nutrient loads, hazardous chemicals and pathogens causing diseases. In countries like India, shrimp culture practices and aquaculture waste have magnified the adverse situation (Mitra, 1998; Mitra and Zaman, 2015). In a regional level, like Sundarbans deltaic ecosystem (located at the tail end of the mighty River Ganga), a phenomenon like erosion with the subsequent washing of the top soil from the intertidal mudflats of mangroves also contributes a considerable amount of nutrients in the adjacent aquatic ecosystem. The adverse public health, environmental, socio-economic, food quality, security and aesthetic impacts from sewage contamination in coastal areas are well documented (Luger and Brown, 1999; Tyrrel, 1999; Danulat *et al.*, 2002; WHO, 2003). Apart from these causes, erosion of river-banks due to tidal surges also conveys nitrate, phosphate and silicate in the estuarine water (Mitra *et al*., 2009), which may have a far reaching effect on the environment. However, very few studies have focused on the trend of nutrient load in the estuarine waters based on the past long-term data bank. The present paper is a road map towards this direction in the frame work of Indian Sundarbans.

2. Materials and Method

2.1. Study area

The mangrove dominated Indian Sundarbans in the lower Gangetic delta region at the apex of Bay of Bengal is inhabited by some 4.2 million populations. Two major estuaries in this delta complex are Hooghly (in the western sector) and Matla (in the central sector). There is

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a multitude of industries located on the western bank of the Hooghly estuary. Apart from this, a large number of tourism units and shrimp culture farms are also located adjacent to the Hooghly estuary. A number of studies are available on the salinity profile, surface water temperature, and pH of the area (Mitra, 1998; Mitra and Bhattacharya, 1999; Mitra, 2000; Majumder *et al.*, 2002; Panja *et al*., 2003; Banerjee *et al.*, 2005; Mitra and Banerjee, 2005; Mitra *et al.*, 2011; Zaman and Mitra, 2014; Mitra and Zaman, 2015; Ray Chaudhuri *et al.*, 2015; Trivedi *et al.*, 2015a; Trivedi *et al.*, 2015b, Chaudhuri *et al.*, 1994). However, very few studies have addressed the long-term variation of the nutrient level in the estuarine waters, although the area is presently experiencing a population growth, industrial activities, mushrooming of shrimp farms, a growth of tourism units and establishment of fish landing stations (Mitra, 2013). Apart from these primary sources of nutrients, the churning action of bed substratum due to wave action and currents conveys silica to the overlying aquatic phase.

2.2. Sample collection

Sampling of surface water was done during the high tide from three stations namely Diamond Harbour, Namkhana (in the Hooghly estuary) and Ajmalmari (in the Matla estuary) (Table 1). Sample collection was carried out during May (premonsoon), September (monsoon) and December (postmonsoon) for a period of 31 years (1984-2014).

Table 1. Location of sampling stations

Stations	Geographical locations	
	Latitude	Longitude
Diamond Harbour	22°11'4.2"N	88°11'22.2"E
Namkhana	21°45'53.7"N	88°13'51.5"E
Ajmalmari	21°49'42.9"N	88°37'13.7"E

2.3. Nutrient analysis

Surface water samples collected for nutrient analysis were filtered through a 0.45 μm polycarbonate filters (Millipore 47 mm diameter) and then deep frozen for further analysis in the laboratory. The standard spectrophotometric method of Strickland and Parsons (1972) was adopted to determine the nutrient concentrations in surface water. Nitrate was analyzed by reducing it to nitrite by means of passing the sample with ammonium chloride buffer through a glass column packed with amalgamated cadmium filings and finally treating the solution with sulphanilamide. The resultant diazonium ion was coupled with N – 1 - napthyl ethylene diamine to give an intensely pink azo dye. Estimation of the phosphate was carried out by treating an aliquot of the sample with an acidic molybdate reagent containing ascorbic acid and a small proportion of potassium antimony tartarate. The dissolved silicate was analyzed by treating the sample with acidic molybdate reagent. The resultant silico-molybdic acid was reduced to molybdenum blue complex by ascorbic acid and incorporating oxalic acid prevented formation of similar blue complex by phosphate.

2.4. Statistical analysis

ANOVA was performed in order to analyze whether the selected nutrients vary significantly between years and stations ($p < 0.01$).

3. Results

We noted the significant spatio-temporal variations of nitrate, phosphate and silicate in the study region. Also, the sudden rise of the nutrient level during premonsoon, 2009 is attributed to super-cyclone, AILA that contributes nutrients through the massive erosion of river banks, washing of top soil of intertidal mudflats along the estuaries and churning of the river bed.

3.1. Dissolved Nitrate

At Diamond Harbour, the dissolved nitrate concentration ranged from 20.84 ppm (during premonsoon in 1984) to 48.15 ppm (during premonsoon in 2009). At Namkhana, the dissolved nitrate concentration ranged from 18.90 ppm (during premonsoon in 1984) to 43.44 ppm (during premonsoon in 2009). In the case of Ajmalmari, the values ranged between 9.44 ppm (during premonsoon in 1984) to 24.89 ppm (during premonsoon in 2009).

In both Diamond Harbour and Namkhana of the Hooghly estuarine system, the nitrate increased 9.49 μg at l^{-1}/ decade and 10.57 μg at l^{-1}/ decade, respectively. In Ajmalmari, located in the Matla estuarine complex, the increase was relatively low (5.98 μg at l^{-1}/ decade).

3.2. Dissolved Phosphate

At Diamond Harbour, the dissolved phosphate concentration ranged from 1.54 ppm (during premonsoon in 1984) to 6.99 ppm (during premonsoon in 2009). At Namkhana, the dissolved phosphate concentration ranged from 0.98 ppm (during premonsoon in 1984) to 6.05 ppm (during premonsoon in 2009). Ajmalmari, the station in the Matla estuary, exhibited a phosphate value from 0.56 ppm (during premonsoon in 1984) to 2.96 ppm (during premonsoon in 2009). In both Diamond Harbour and Namkhana of the Hooghly estuarine system, the phosphate increased 1.96 μg at l^{-1}/ decade and 2.11 μg at l^{-1}/ decade, respectively. In Ajmalmari, located in the Matla estuarine complex, the rate of the increase was 0.92 μg at l^{-1}/ decade.

3.3. Dissolved Silicate

At Diamond Harbour, the dissolved silicate concentration ranged from 101.83 ppm (during premonsoon in 1984) to 242.78 ppm (during premonsoon in 2009). At Namkhana, it ranged from 44.68 ppm (during premonsoon in 1984) to 211.49 ppm (during premonsoon in 2009). In the case of Ajmalmari, the silicate ranged from 31.43 ppm (during premonsoon in 1984) to 111.99 ppm (during premonsoon in 2009). In both Diamond Harbour and Namkhana of the Hooghly estuarine system, the silicate increased 64.57 μg at l^{-1}/ decade and 54.56 μg at l^{-1}/ decade, respectively. The rate of the increase was 31.18 μg at l^{-1}/ decade in Ajmalmari, which is relatively low compared to the stations selected in the Hooghly estuary.

The temporal variations of the selected nutrients during 1984-2014 are shown in Figures. 1- 9.

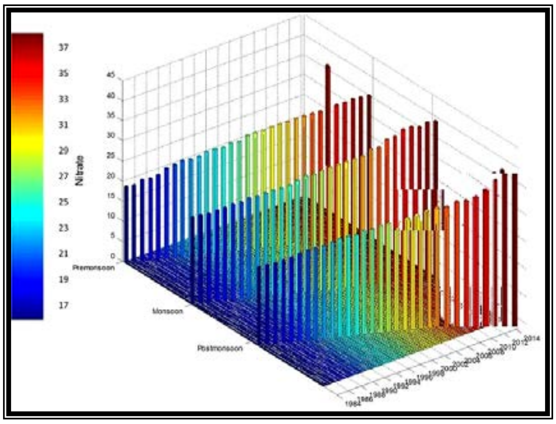

Figure 1. Dissolved Nitrate (in µg at l^{-1}) in Diamond Harbour during 1984 – 2014

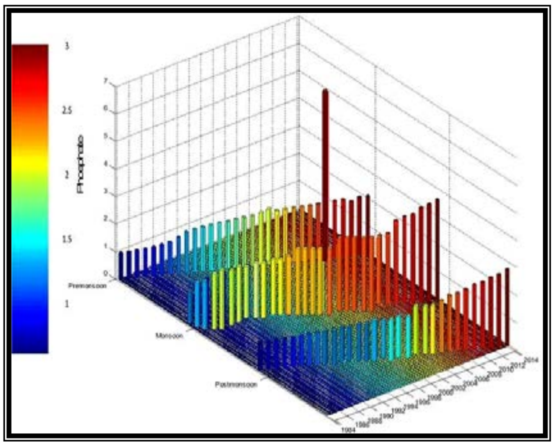

Figure 2. Dissolved Phosphate (in µg at l^{-1}) in Diamond Harbour during 1984 – 2014

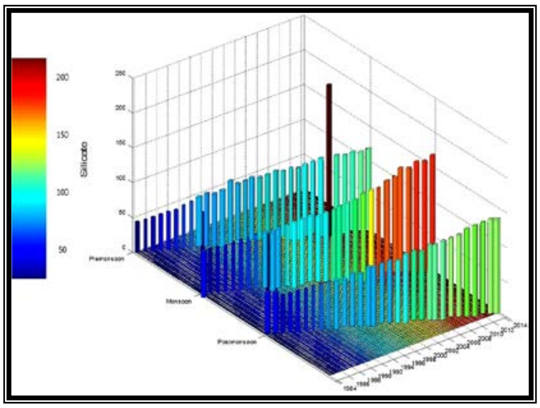

Figure 3. Dissolved Silicate (in µg at l^{-1}) in Diamond Harbour during 1984 – 2014

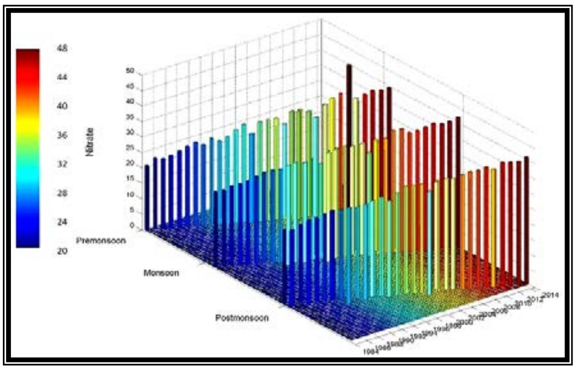

Figure 4. Dissolved Nitrate (in µg at l^{-1}) in Namkhana during 1984 – 2014

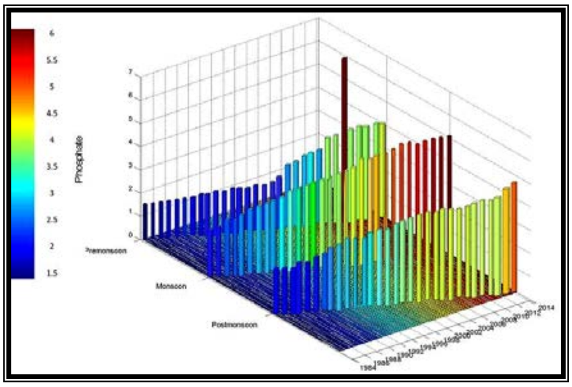

Figure 5. Dissolved Phosphate (in µg at l^{-1}) in Namkhana during 1984 – 2014

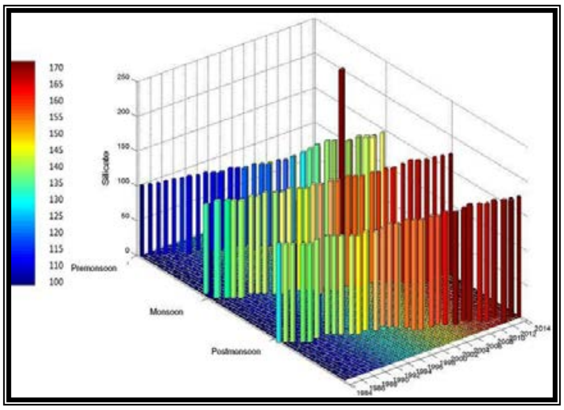

Figure 6. Dissolved Silicate (in µg at l^{-1}) in Namkhana during 1984 – 2014

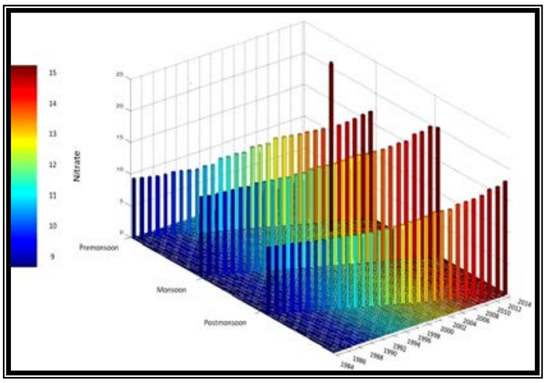

Figure 7. Dissolved Nitrate (in µg at l^{-1}) in Ajmalmari during 1984 – 2014

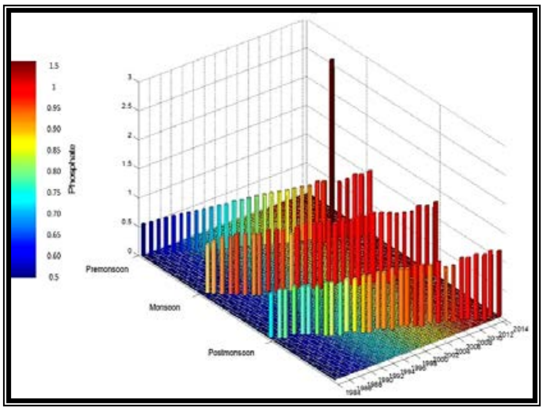

Figure 8. Dissolved Phosphate (in µg at l^{-1}) in Ajmalmari during 1984 – 2014

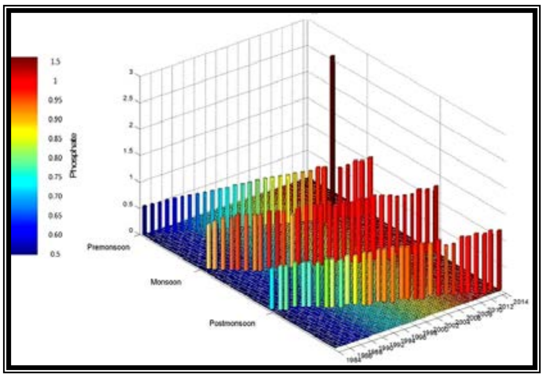

Figure 9. Dissolved Silicate (in µg at l^{-1}) in Ajmalmari during 1984 – 2014

4. Discussion

The enrichment of the aquatic system by nutrients has both a natural and an anthropogenic origin. The main sources of nutrient input in the present study area are run-off from the adjacent landmasses (Mitra, 2013), erosion and leaching (Mitra *et al.*, 2009), sewage from cities and industrial wastewater (Mitra and Choudhury, 1993; Mitra, 1998; Bhattacharyya *et al.*, 2013), untreated sewage disposal from shrimp farms and tourism units (Mitra, 2013; Zaman and Mitra, 2014; Mitra and Zaman,2015). The atmospheric deposition of nitrogen (from combustion gases) can also be important for Hooghly estuarine system and its surrounding area as multifarious industries are concentrated in this estuarine region. The effects of nitrogen on marine and estuarine systems, the pathways for nitrogen transport between land and aquatic habitats, and the positive correlation between nitrogen and primary production and often secondary production (i.e., fishery yields) have been widely reviewed (Hecky and Kilham, 1988; Howarth, 1988; Rabalais, 2002).

Most of the phosphorus pollution in the present study area comes from the households and industries including phosphorus-based detergents which are widely used in thickly populated cities of Kolkata, Howrah and Haldia industrial complex adjacent to the Hooghly estuary.

Silicate, being an important ingredient of bed material and soil substratum, originates due to erosion, churning action of the water that amplifies during tropical cyclone, which is common in the present geographical locale.

The ratio of nitrogen and phosphorus plays a regulatory role in the phytoplankton diversity spectrum of brackishwater. It determines which of the two elements will be the limiting factor and, consequently, which one has to be controlled in order to arrest the bloom condition (Table 2).

Table 2. Nitrogen / Phosphorus ratios (expressed in weight) for various limiting conditions in freshwater and estuarine/coastal water

Type of waterbody	N-limiting Ratio N/P	Intermediate Ratio N/P	P-limiting Ratio N/P
Freshwater	≤ 4.5	4.5-6	> 6
Estuarine / coastal water	≤ 5	5-10	≥ 10

Source: WHO (2003)

Large marine areas frequently have nitrogen as the limiting nutrient, especially in summer. Intermediate areas, such as river plumes, are often phosphorus-limited during spring, but may turn to silica or nitrogen limitation in summer. When phosphorus is the limiting factor, a phosphate concentration of 0.01 mg l^{-1} is enough to support plankton and concentrations from 0.03 to 0.1 mg l^{-1} or higher will be likely to promote blooms.

In coastal areas, the growth and proliferation of diatoms are promoted by the presence of silica. When the silica concentration is low, diatoms cannot develop. Then, other opportunistic toxic algal species, which are no longer submitted to competition, can grow and form blooms. Species from the genus *Phaeocystis* and several dinoflagellates *(Prorocentrum, Dinophysis, Gymnodynium)* are known to proliferate under such conditions.

In the present study, the N: P ratios in all the selected stations and seasons are greater than 10 (except monsoon season in Namkhana) (Table 3). This implies that the aquatic phase of the present study area is P limiting (WHO, 2003). A high N: P ratio normally increases the standing stock of dinoflagellates and diatoms.

Significant variations in the level of the dissolved nitrate, phosphate and silicate between years and between stations were observed (p < 0.01), which reveals the impact of season and anthropogenic pressure in the present study area (Table 4).

Table 3. Avarage Nitrogen / Phosphorus ratios in different seasons in the three sampling stations

Stations / Seasons	**N/P ratio**		
	Premonsoon	**Monsoon**	**Postmonsoon**
Diamond Harbour	15.53	12.60	17.04
Namkhana	12.26	8.85	10.18
Ajmalmari	14.55	15.39	14.18

Table 4. ANOVA result showing temporal and spatial variations of dissolved nutrients (nitrate, phosphate and silicate)

		Variables	F_{cal}	F_{crit}
Dissolved nitrate	Premonsoon	Between stations	876.8915	3.150411
		Between years	21.43769	1.649141
	Monsoon	Between stations	709.1798	3.150411
		Between years	15.52743	1.649141
	Postmonsoon	Between stations	846.2506	3.150411
		Between years	13.00163	1.649141
Dissolved phosphate	Premonsoon	Between stations	92.25571	3.150411
		Between years	8.000291	1.649141
	Monsoon	Between stations	268.6471	3.150411
		Between years	4.05633	1.649141
	Postmonsoon	Between stations	337.6358	3.150411
		Between years	4.725808	1.649141
Dissolved silicate	Premonsoon	Between stations	517.3935	3.150411
		Between years	21.15371	1.649141
	Monsoon	Between stations	426.0496	3.150411
		Between years	7.435455	1.649141
	Postmonsoon	Between stations	1061.878	3.150411
		Between years	11.78569	1.649141

5. Conclusion

The core findings of the present study are listed here:

1. The main sources of nutrients in the present study area are primarily anthropogenic in nature, although natural disasters (like super cyclone AILA) resulted in a sudden rise in the nutrient level during premonsoon, 2009.
2. The concentrations of nutrients exhibit a gradual increasing trend, which is an evidence of the rising anthropogenic pressure in and around the mangrove dominated Indian Sundarbans.
3. The situation seems to be alarming in terms of nutrient enrichment if a proper management/control measure is not adopted. The policymakers must foster appropriate actions with a true partnership with the private sector. The regulations should also be put in place to force the polluters (from urban areas, industries, shrimp farms and tourism units) to pay the principal cost and also to foster willingness to pay among polluters through the provision of better and efficient services. This should ensure operational sustainability of the services.

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