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ORIGINAL ARTICLE

Short-term variations in surface water properties in the Sundarban Estuarine System, India

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Abstract High resolution measurements were carried out to understand the short-term (<1 h) variability of surface water quality parameters in mangrove-dominated Sundarban Estuarine System of West Bengal, India during flood phases of spring-neap tidal cycle in a peak monsoon season August 2014. We observed that tidal propagation of both phases strongly influenced the water quality properties. During spring tide salinity, DO, pH, nitrate, phosphate, silicate, chlorophyll *a* and phaeopigments concentration exhibited increasing trends; whereas at neap tide nitrate, ammonia and chlorophyll *a* showed decreasing trends. Average nutrient concentrations were much higher during neap tide than spring tide. All the measured water quality parameters varied in every 15-min interval influenced by the tidal current, mangrove litter fall, re-suspension of bottom sediment and river runoff. The effect of tidal amplitude was observed to be the important factor in determining the variability in most of the water quality parameters.

Keywords Sundarban Estuarine System · Water quality · Monsoon · Spring–Neap Tide

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Introduction

Estuaries play an important role in biogeochemical cycle because of their capability to regulate a huge amount of river-borne major and minor elements entering the coastal environment. Estuarine ecosystems are complex, dynamic and experience strong gradients in water quality properties and complex hydrodynamic processes (Mitra et al. 2011). The distribution of nutrients and other environmental parameters in estuarine waters plays pivotal role in controlling biogeochemistry of estuaries. The Sundarban Estuarine System (SES) is a unique ecosystem, covered by mangrove vegetation which is very much tidally induced and all parts of the SES are propagated by the dominated semi-diurnal tide with an overall northward amplification (Chatterjee et al. 2013). Different physico-chemical parameters such as salinity, pH, dissolved oxygen (DO), chlorophyll and some essential micro-nutrients (N, P, S) are very much significant in controlling the productivity of estuarine system (Manasrah et al. 2006; Nixon et al. 1986). This mangrove-dominated estuarine region also provides major pathways for nutrient recycling and acts as a natural filter for pollutants coming from the human settlements and industrial area in its northern part. Measurements at hourly intervals or time series study are more common practice to study the changes in properties with diurnal and/or tidal variability, but sub-hourly changes of such environmental parameters have not been done earlier from this region, though Anand et al. (2014) had been reported variations in sub-hourly biogeochemical properties from Zuari estuary, central western part of India. The sub-hourly sampling strategy in an estuarine system is very essential to understand the intra-tidal variability of nutrients and the effect of tidal straining and suspended sediment on water column stratification (Uncles 2002). Cassidy and Jordan (2011) suggested that sub-hourly monitoring provides an opportunity to assess the actual transport of different nutrients loads in water. Moreover, these sampling frequencies were found to be sufficient for accurately determining the full range run-off related discharge of specific nutrient concentrations. Therefore, the present study was conducted to understand the changes of some important water quality parameters (surface water temperature, salinity, dissolved oxygen, pH, nutrients and pigments concentration) within shorter time scale along with the tidal variations during different phases of tidal cycle at SES.

Materials and methods

The study was performed at a fixed station Kaikhali (22°01′17.09″N/88°36′50.7″E) which is situated at the central zone of Indian Sundarban and it also a starting point of Matla and Thakuran river (the two major riverine systems at SES) (Fig. 1). The station is situated at the right bank of river Matla and fully covered by dense mangrove forest. The station is about 10 m depth during high tide. The SES is always maintained by the semi-diurnal tides at their mouths and the freshwater received as local runoff. The major portion of the local runoff comes annually from the summer monsoon rainfall, ranging between 1500 and 2500 mm/year in this region and the floods resulting from the freshwater accumulation in the upstream parts of the river Ganga (Chatterjee et al. 2013).

Studies were conducted in two phases: (1) flood phase of spring tide; 10th August 2014 and (2) flood phase of neap tide, 17th August 2014. Water samples were collected at 15 min intervals for three and half hours (Fig. 1). Only surface water (from 30 cm depth) was collected using 5-liter Niskin-Water Sampler. Temperature and pH of collected water samples were recorded in situ, using mercury thermometer and digital pH meter (Systronics, Model no. 362), respectively. Dissolved oxygen (DO) concentration in the collected estuarine water was measured by Winkler titration method (Grasshoff et al. 1999). Samples for nutrient analysis, after the collection, was filter through Whatman GF/F filter paper (mesh size-0.7 µm) and stored in 1-litre plastic bottles. After collection, the samples were stored in ice-box and transported to laboratory. Nutrients were analyzed following the method of Grasshoff et al. (1999). For chlorophyll *a* and phaeopigments analysis 1 L of the seawater was collected in dark bottle and filtered through a glass fiber filter (GF/F filter paper, mesh size-0.7 µm); pigments are extracted from filter in 90% acetone and kept overnight at 4 °C. After that the sample was centrifuged at 5000 rpm for 10 min for collecting the supernatant and their concentration was estimated spectrophotometrically according to (Strickland and Parsons 1972). All the samples were analyzed on the same day

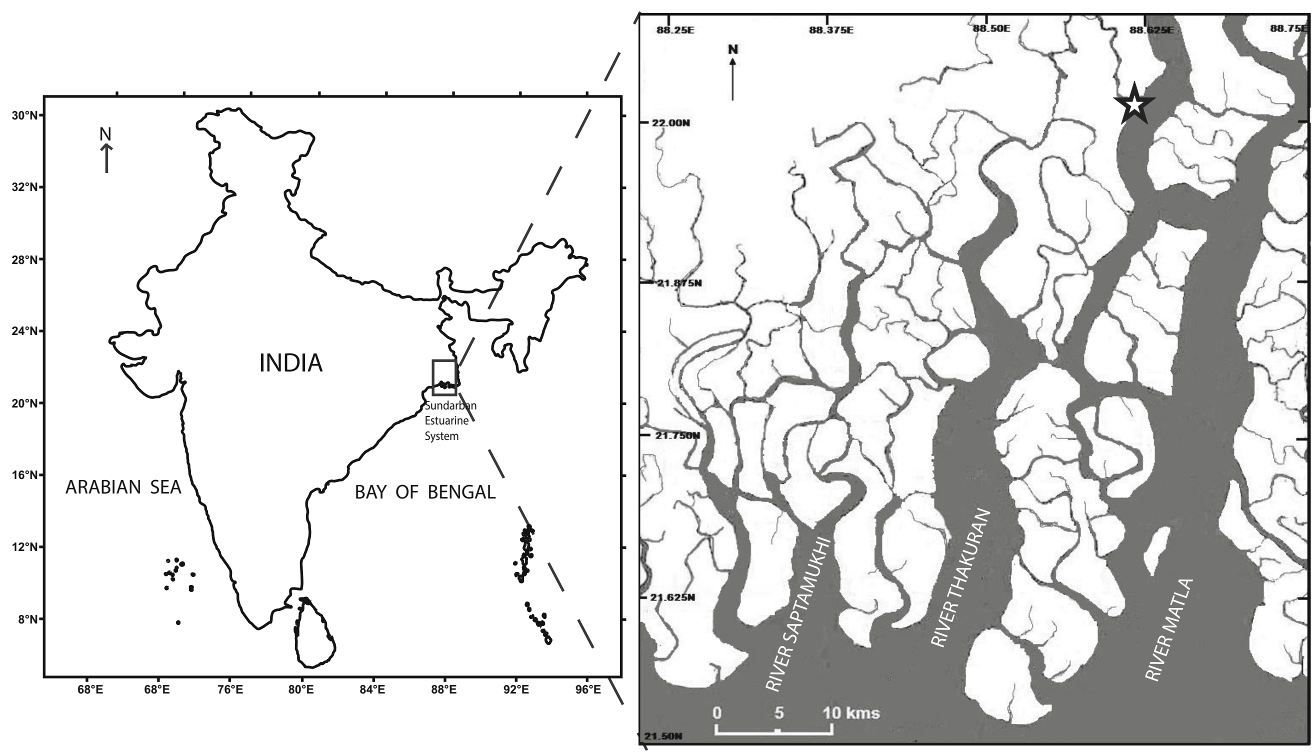


Fig. 1 Map of the study area showing the sampling station

(except chlorophyll *a* and phaeopigments) after bringing them to the laboratory.

Results and discussion

At study station, different water quality properties were changed significantly in time to time with rising water level. The average value of all parameters during spring tide and neap tide are described in Table 1. Figure 2 showed that the water level fluctuation in study station during study periods. Changes of different physico-chemical characteristics in every 15 min interval are plotted in Figs. 3, 4. During monsoon season due to high freshwater influx and strong tidal action causes turbulence which significantly alters the biogeochemical properties.

The surface water temperatures were varied between 29.50 and 30.75 °C, which indicates very little variations in water temperature and water level may not affect this parameter and owing to this reason the average temperatures during both experiments were more or less same (~30 °C). Due to monsoon season, the rainfall always influenced the salinity value during sampling period. The highest salinity was observed during flood phase of spring tide, i.e., 21 psu. The increasing nature of salinity was also observed with water level rise at both spring and neap phase, but the average salinity of spring tide (15.40 psu) was slightly higher than neap tide (15.13 psu). Average salinity was found to be 12.07 ± 3.82 and 13.80 ± 4.28 psu during spring and neap tide, respectively. The pH of surface water recorded during sampling period was higher than 7, a minute alkaline nature of this region with low variations suggests that the surface water in this part of Sundarban remained well buffered and the DO values at this region shows the estuarine water carries moderately oxygenated water (>4 mg L^{-1}) (Sarkar et al. 2007). Dissolved oxygen (DO) plays a crucial role in every aquatic system and its variation always depends upon the photosynthesis, degradation of organic matter and some chemical reaction (Garnier et al. 2000). Average concentration of DO was higher (5.45 ± 0.79 mg L^{-1}) during spring tide than in neap tide (4.91 ± 1.03) and the maximum value observed with water level rise in both occasions, which indicate sea water content more oxygenated water than estuarine complex (Figs. 3, 4).

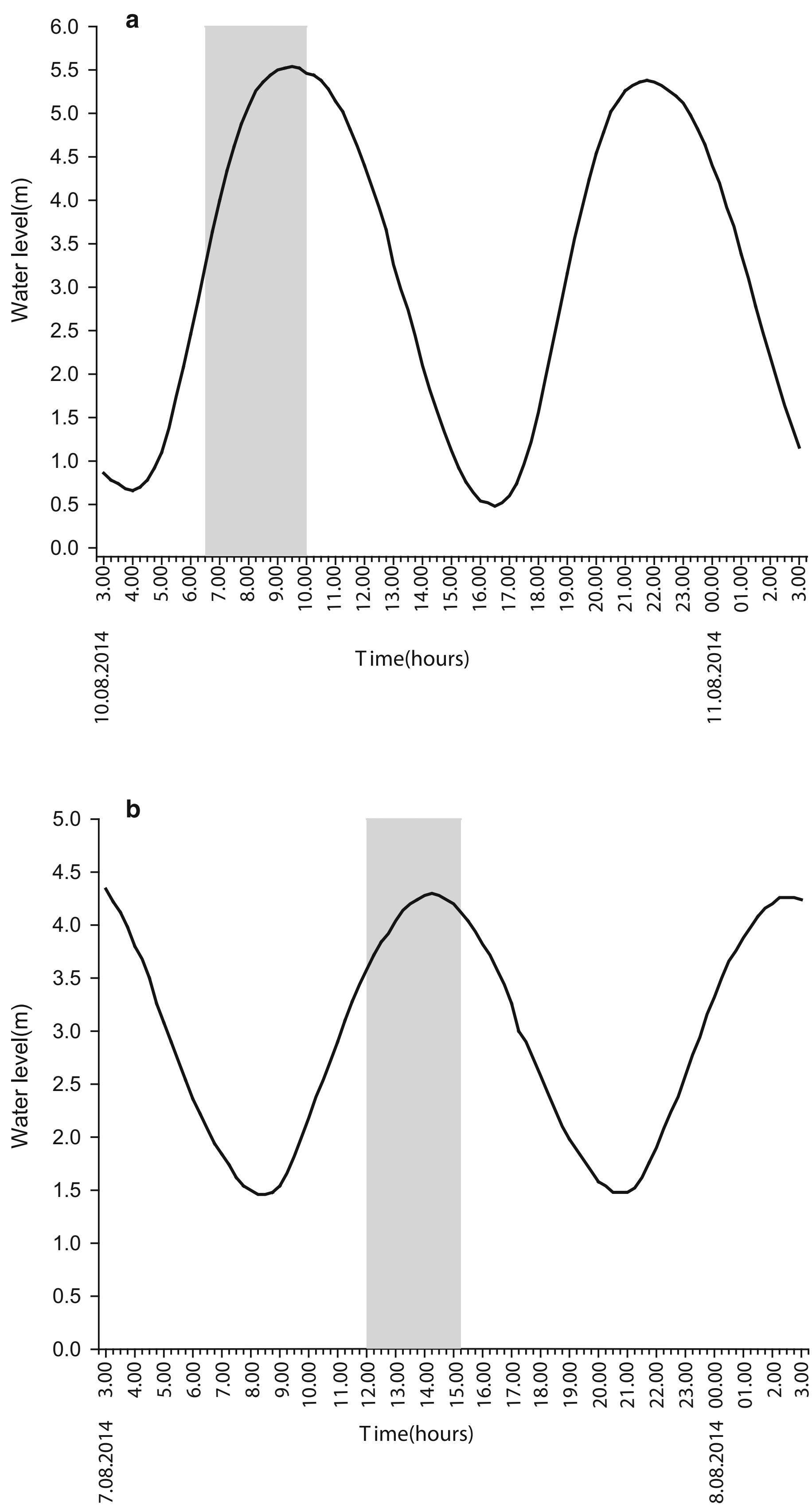
Table 1 Average concentration of various water quality properties observed during the study periods

Parameters	Spring tide	Neap tide
Water temperature (°C)	30.17	30.05
Dissolved oxygen (mg L^{-1})	5.45	4.91
Salinity (psu)	15.40	15.13
pH	7.26	7.33
Nitrite (μM)	0.37	0.89
Nitrate (μM)	8.40	20.79
Ammonia (μM)	0.20	0.25
Phosphate (μM)	0.97	2.46
Silicate (μM)	36.53	49.45
Chlorophyll *a* (μg L^{-1})	2.96	1.34
Phaeopigments (μg L^{-1})	0.36	0.26

Generally, the chlorophyll *a* considered as the most dependable indicator for phytoplankton biomass, and the ratio of chlorophyll *a* and phaeopigments provides primary information on the biology and physiology of phytoplankton (Tripathy et al. 2005). Significantly a higher ratio of chlorophyll *a*/phaeopigments observed during spring tide (8.17 μg L^{-1}) than in neap tide (5.23 μg L^{-1}) at the study area. The average concentration of chlorophyll *a* and phaeopigments observed maximum during spring tide (2.96 ± 0.77 and 0.36 ± 0.16 μg L^{-1}, respectively) and minimum during neap tide (1.34 ± 0.70 and 0.26 ± 0.25 μg L^{-1}, respectively). Higher concentration of pigments (phytoplankton or plant materials) during spring tide might be the effect of seawater influx into the estuary and could be recognized by the high oxygenated water mass at same time.

Changes of dissolved inorganic nutrients in estuarine water depends upon a number of factors, including the extent of fresh water, oxygen availability, standing stocks and primary producers of the estuary (Boto and Wellington 1988; Mwashote et al. 2005). In our study area, the concentration of all nutrients averagely lower during spring tide (Table 1), which indicates the seawater is not the source of nutrients in this estuary and the water mass during neap tide shows averagely higher nutrients concentration. Similarly, Balls (1992) and Page et al. (1995) reported nutrients concentration decreased with increasing salinity, due to dilution of nutrients enriched water by tidal sea water. Moreover, primary producer utilize nutrients for their growth and metabolism during spring tide; therefore, the average dissolved oxygen, chlorophyll *a* and phaeopigments concentration recorded higher during spring tide than in neap tide in the present study. The average nitrate and phosphate (N:P) ratio at entire study period was found to be 9:1 (during spring tide) and 8:1 (during neap tide) which is comparatively lower than the normal Redfield ratios (16:1), and it could be attributed to the enrichment of these nutrients through external inputs (Redfield et al. 1963). The low N: P ratio in the surface water in both phases might be the effect of slow regeneration of nitrate compared to phosphate and the deficiency in the ratio of dissolved inorganic nitrogen and

Fig. 2 Sea level changes on the sampling station during study period. **a** Flood phase of spring tide; 10th August 2014, **b** flood phase of neap tide, 17th August 2014. The *shaded portions* indicate sampling periods



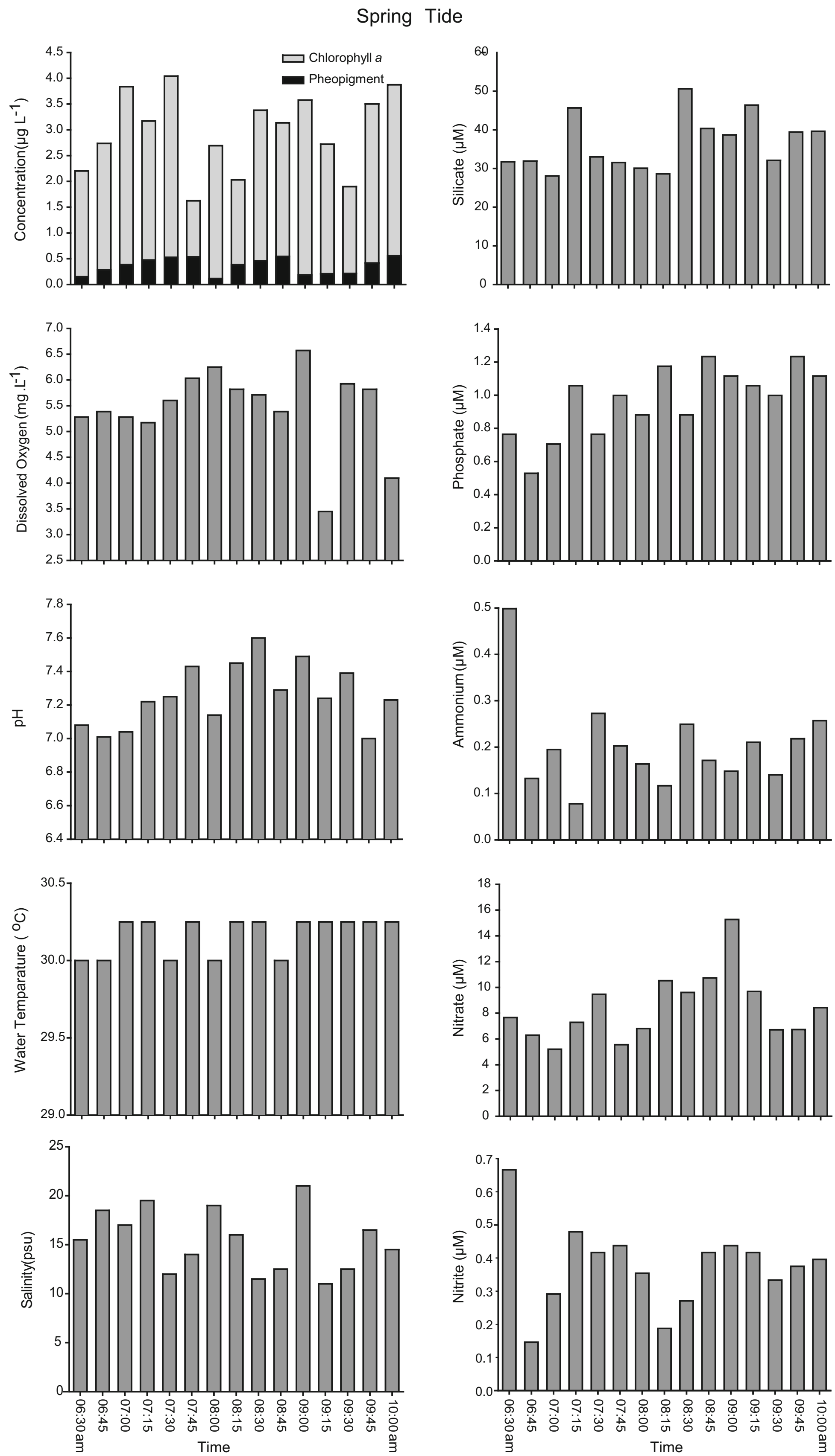
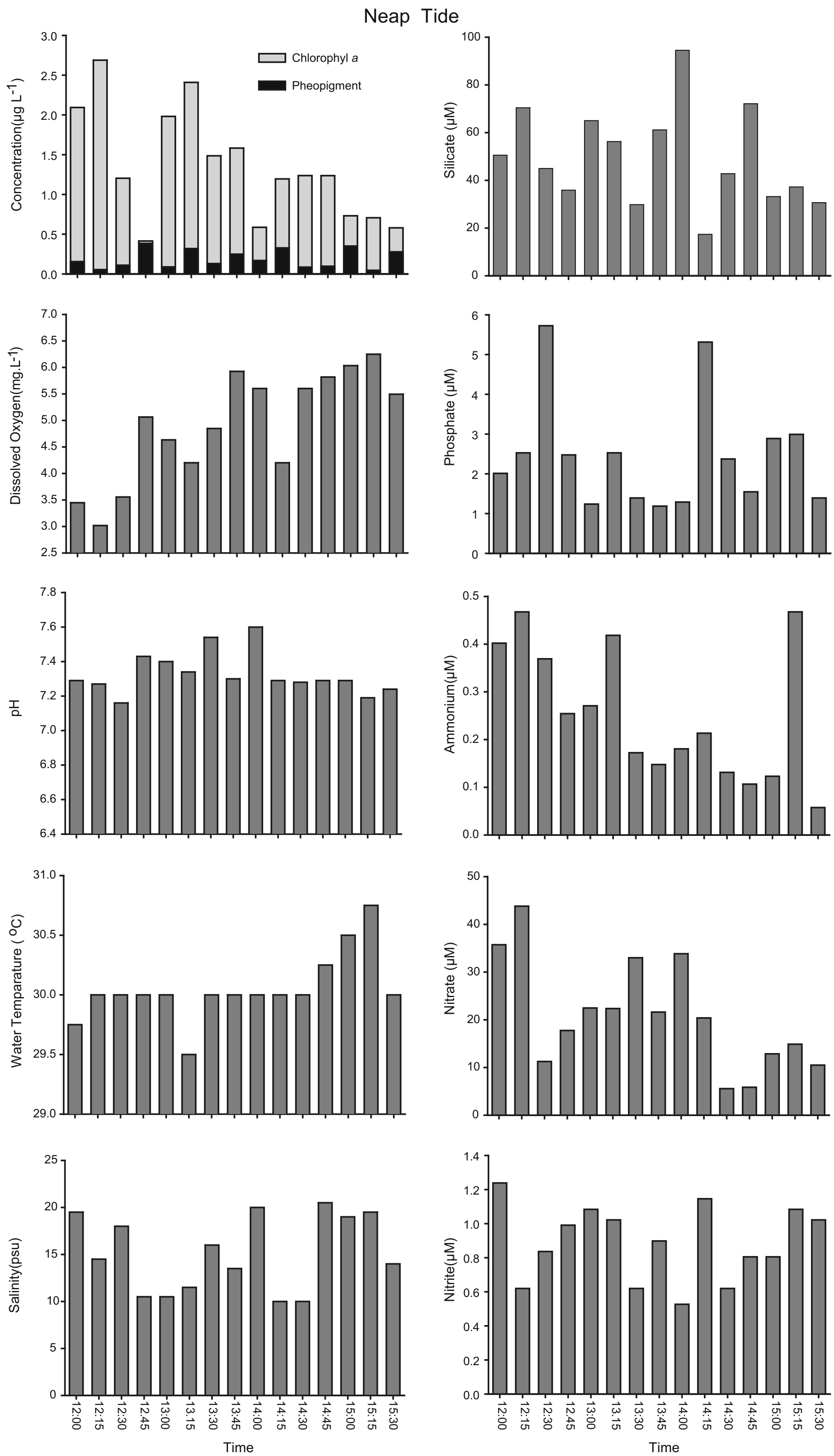


Fig. 3 Short-term variation of different water quality parameters during the flood phase of spring tide

Fig. 4 Short-term variation of different water quality parameters during the flood phase of neap tide



phosphorous in many coastal areas may indicate the importance of nitrogen in photosynthesis (Tripathy et al. 2005).

The uncertainty ranges of all nutrients had been recorded during both study periods (Figs. 3, 4). Variation of nitrite was observed between 0.146 to 0.667 and 0.526 to 1.239 μM during spring and neap tide, respectively. The mean value of nitrate was found to be lower during spring tide (8.40 ± 2.59 μM) than in neap tide (20.79 ± 11.46 μM). Average phosphate concentration was recorded as 0.97 ± 0.21 and 2.46 ± 1.39 μM during spring and neap tide, respectively. Ammonia concentration remained almost stable, varied between 0.20 ± 0.10 μM during spring tide and 0.25 ± 0.14 μM during neap tide, but concentration of silicate found maximum during neap tide (49.45 ± 20.42 μM) compared to spring tide (36.53 ± 7.04 μM).

At Zuari estuary, Anand et al. (2014) found increasing trends for all nutrients and chlorophyll *a* concentration with rising of water level in their experiments for 1 h but when the experiments continued for longer time duration (present study) these parameters showed different phenomenon. During spring tide, the salinity, DO, pH, nitrate, phosphate, silicate and phaeopigments concentration exhibited increasing trends, whereas nitrite concentration showed decreasing trends but not clear for ammonia and chlorophyll *a* (Fig. 3). Similarly, during neap tide all water quality properties fluctuated with rising water level. Salinity, DO, pH, nitrite and silicate exhibited increasing trends, where nitrate, ammonia, and chlorophyll *a* showed decreasing trends, average phosphate and phaeopigments concentration remained unchanged during neap tide (Fig. 4). The phosphate concentration ranged between 0.6 and 1.2 μM during spring tide, when water level and entire water mass is higher, but the value is much higher (ranges between 1 and 3 μM) during the neap tide. In a tidal estuary at Japan, Montani et al. (1998) observed high phosphate concentration in mid salinity zone and this fact was attributed to a release of phosphate from suspended particles or reduce sediments with the effect of phosphate buffer mechanisms. During neap phase, phosphate concentration showed stable with water level rise but comparatively an increasing trend was found during spring phase. The reason behind this might be the input of phosphate from sediment pore water partially regenerated through biological processes from the surrounding river banks or islands which always submerged fully or partially, depending on the water level, during highest high tide. In Bertioga Channel, Brazil, Gianesella et al. (2005) had pointed out when a larger area of mangrove forest is flooded with spring tide, the mangrove interstitial waters promote larger amount of phosphate in water column.

The present study highlights the area is very much dynamic and always influenced by strong tidal effects, which alter the entire water quality properties within a short time interval. Gianesella et al. (2000) suggested that the main source of nutrients in a tropical estuarine channel is land drainage, particularly in the area surrounded by dense mangrove vegetation. Previous study by Mukhopadhyay et al. (2006) suggested that mangrove-dominated estuary is a good source of nutrients, and its concentrations fully depend on mangrove litter fall and estuarine transport of nutrients from the surrounding sediments. They also reported that monsoonal run-off increase significant amount of nutrients concentration (53% for dissolve inorganic nitrate, 31% for dissolve reactive phosphate and 32% for silicate) compared to pre-monsoon from coastal region of the Sundarban Estuarine system. Since the present study station is also a complex deltaic ecosystem which is fully covered by mangrove vegetation, therefore, the turbidity current, mangrove litter fall, erosion of bottom sediment, and river runoff continuously influence the water quality properties.

Conclusions

In the present study, different physico-chemical parameters were observed in a short-time period during monsoon season (August 2014) at Sundarban. The present study highlights that sub-hourly sampling of a particular region is very important where all biogeochemical properties fluctuate in every 15-min interval with water level rise. The present baseline information of the sub-hourly changes of physico-chemical characteristics of surface water can be interpreted further for ecological assessment and monitoring of Sundarban Estuarine System, to determine the responsible factors for estuarine biogeochemical processes.

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