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Seasonal and Tidal Dynamics of Nutrients and Chlorophyll *a* Concentration in Water at the Sundarbans Mangrove Ecosystems of Bangladesh

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Abstract

The seasonal and tidal variations of physicochemical parameters, nutrient concentrations and chlorophyll *a* concentration from the water of Passur river and Koromjol canal in the Sundarbans mangrove ecosystems were investigated during March 2018 to February 2019. Samples were collected from five sampling stations during March, August and November where these months were considered as pre-monsoon, monsoon and post-monsoon seasons, respectively. The nutrients NH_3-N, NO_3-N, PO_4-P, SO_4 and Chlorophyll *a* concentrations were found 0.001 to 0.09, 3.5 to 50, 0.06 to 5.4, 30 to 272 and 0.18 to 1.75 mg/L, respectively, during high tides, and 0.001 to 0.39, 4.2 to 47, 0.1 to 2.75, 20 to 179 and 0.218 to 1.88 mg/L, respectively, during low tides. The NO_3-N was very high than suitable limit during both tides at monsoon and post-monsoon season. The PO_4-P was found moderately high during both tides at all stations. The SO_4 was found to be 187.8 and 76.87 mg/L during high tide, and 135.4 and 95.73 mg/L during low tides in pre-monsoon and post-monsoon, respectively, that were very high than water quality standards. The Passur river and the Koromjol canal were fluctuating seasonally and tidally in some magnitude and their variations can alter the water quality as well as the density and distribution of living organisms.

Keywords

Bangladesh, Chlorophyll *a*, Nutrients concentration, Sundarbans mangrove ecosystems, Tidal dynamics

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Introduction

Sundarbans, the world's largest mangroves ecosystem covering 6000 km^2 in Bangladesh, provides extensive variety of ecosystem as well as economic services with ecological importance of rich biodiversity including 355 species of birds, 49 species of mammals, 87 species of reptiles, 14 species of amphibians, 234 species of floras and 300 species of fishes (Rahaman *et al*., 2013). The Sundarbans also unswervingly supports the livelihood of about 7 million people breathing in the surroundings of the forest (Rahaman *et al*., 2013; Hossain *et al*., 2016). Aquatic environment of the Sundarbans is extremely complex in nature due to its dynamic coastal processes where the abiotic and biotic resources are highly variable in response to the processes (Rahaman *et al*., 2013). Mangrove ecosystems are important contributors of organic carbon and other nutrients to the adjacent coastal ecosystems and provide nutrients for phytoplankton growth, thus enhancing secondary production and promotion of commercial fisheries.

The distribution and behavior of nutrients are usually affected by tidal, seasonal and weather conditions (Senthilkumar *et al*., 2008). By this process, suspended matter, nutrients, heavy metals and other compounds from inland waters are deposited in mangrove environment (Hoq *et al*., 2006). Besides, anthropological activities as resource extraction, fishing, shrimp farming, agriculture and tourism also affect mangrove ecosystem. Consequently, the valuable ecosystem of Sundarbans has been subjected to considerable degradation (Rahman *et al*., 2013; Rahman *et al*., 2015). Nutrients exchange between land and sea in mangrove forest relatively depend on the availability and sources of water. Freshwater of the rivers originating from the Ganges meet in the intertidal rivers of Sundarbans, a region of transition between the freshwater and the saline water of the Bay of Bengal. Numerous rivers as Rupsha, Passur, Shibsa, Bhola, Baleshwar, Arpangashia, Kholpetua, Malancha, etc. sweeping into the Bay of Bengal through the Sundarbans and carry enormous amounts of nutrients that differ with streams and periods, affecting the productivity (Rahman *et al*., 2013). On the other hand, worldwide, mangrove nutrients loads have progressively increased in contemporary decades as a result of increasing population and industries. Accordingly, these increased nutrients may trigger the primary production and act as source of carbon, phosphorous, nitrite and sulphate in waters. Quality of water as habitat is most important for biodiversity of aquatic system and the quality of water varies with season and climate. So, assessing the water productivity with tide and time is very essential (Akhter *et al*., 2018; Kathiresan and Bingham, 2001).

For maintaining the productive as well as balanced aquatic environment, nutrients are the prime crucial elements (Islam *et al*., 2014). Phosphorus and nitrogen are the primary nutrients that in excessive amounts pollute the aquatic environment. Phosphorus occurs in dissolved organic and inorganic forms or attaches to sediment particles. When it remains in the sediments it is generally not available for use by algae; however, various chemical and biological processes can allow sediment phosphorus to be released back into the water (Rahaman *et al*., 2013; Rahman *et al*., 2014; MCPA, 2008; Islam *et al*., 2017). Sulphate can be found in the environment as a result of atmospheric and terrestrial processes. Major natural contributors of sulphate to the environment are sulphur released from erosion of evaporate deposits and sulphide containing rocks and minerals. One third of the sulphur reaching the environment is anthropogenic in the form of sulphate, sulphuric acid, hydrogen sulphide and SOx (Moreno-Casas *et al*., 2009). Chlorophyll *a* is the pigment that allows plants and algae to photosynthesize, in which plants use the sun’s energy to convert carbon-dioxide and water into oxygen and cellular material. It also absorbs energy from

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wavelengths of violet-blue and orange-red light, while reflecting green-yellow light (Suzuki *et al*., 1997; Islam *et al*., 2019).

All aquatic organisms depend directly on nutrients for their survival, growth and reproduction. Some nutrient levels are related to the chlorophyll *a* availability of the water body, which means the availability of phytoplankton in the water. Thus, nutrient availability is directly related to the productivity of the water body. A shortage of nutrients causes the water body to be unproductive, and an excess of nutrients causes eutrophication by algal bloom and makes the water toxic (Islam *et al*., 2017; Islam *et al*., 2019). Thus, the nutrient concentration must be within suitable limit for a good aquatic environment and for better production of aquatic organisms (Rahaman *et al*., 2013). Apart from the importance of nutrients dynamics in mangrove waters, very few attempts have been made to investigate the concerns. The present study was an attempt to enumerate the nutrients and chlorophyll *a* concentration in water with seasons and tide in selected five locations in the Sundarbans mangrove forest of Bangladesh.

Materials and Methods

Study area: The study area is in the Bangladesh part of Sundarbans that lies between the geographical coordinates of 21º 45' to 22º 30' N and 89º 00' to 90º 00' E. Sundarbans is the prime example of the estuary of the Ganges and the Brahmaputra river systems in the Bay of Bengal. This biologically and ecologically rich and diverse eco-region is located in Khulna and Bagerhat districts under Khulna division of Bangladesh. The area experiences a subtropical monsoon climate with an annual rainfall of 1600 to 1800 mm and severe cyclonic storms (Haque, 2008). The study area was divided into five sampling stations namely S1: Passur river (22º03.107′N to 089º58.329′E), S2: Passur river (22º25.680′N to 089º35.680′E), S3: Koromjol canal (22º25.733′N to 089º35.406′E), S4: Koromjol canal (22º25.702′N to 089º35.130′E) and S5:Koromjol canal (22º25.726′N to 089º34.944′E).

Sample collection: The water samples were collected from 5 stations at Sundarbans mangrove forest during March, August and November in 2018 that can be named as pre-monsoon (March to May), monsoon (June to October) and post-monsoon (October to February) seasons, respectively. To analyze the water quality parameters, 500 ml water was collected from each sampling points in plastic bottles with double stoppers. Before sampling, the bottles were cleaned and washed with detergent solution and treated with 5% HNO_3 overnight. The bottles were finally rinsed with deionized water and dried. After sampling, the bottles were screwed carefully and marked with the respective identification number and brought to laboratory.

Sample analysis: The samples collected from Passur river and Koromjol canal were analyzed and compared with the standard level of water quality parameters. The following analyses were done from the collected water samples: temperature, pH, dissolved oxygen (DO), salinity, electrical conductivity (EC), total dissolved solids (TDS), ammonia (NH_3-N), nitrate (NO_3-N), phosphate (PO_4-P), sulfate (SO_4) and chlorophyll *a*. The study was conducted through experimental method and experimental data were collected and processed carefully. The physico-chemical parameters were analyzed in the laboratory of the Department of Environmental Science and Resource Management of the Mawlana Bhashani Science and Technology University, Tangail. Temperature and pH were determined by the thermometer and digital pH meter, respectively. Buffer solution containing pH 7.0 was used to calibrate the digital pH meter. Salinity was analyzed by Mohr's

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method (Eaton *et al.*, 1995). The DO was determined by digital DO meter where sodium thiosulphate (0.025N) was used as a reagent. EC and TDS were determined by EC and TDS meter, respectively. Samples were analyzed in the Water Quality Laboratory of Bangladesh Fisheries Research Institute (BFRI), Mymensingh, for measuring concentrations of NH_3-N, NO_3-N, PO_4-P and SO_4. A high-definition spectrophotometer was used for estimating the concentration of major water nutrients. During analysis, PO_4-P and SO_4 were determined by the PhosVer 3 (USEPA, 2008) and SulfaVer 4 method (Ajwa and Tabatabai, 1993), respectively; while NH_3-N was measured by Salicylate method (Le and Boyd, 2012); and NO_3-N was measured by Cadmium Reduction method (EPA, 2007). Seasonal and tidal variations of nutrient concentrations were evaluated by calculating means and standard errors from the total number of samples taken for each analytic method during high and low tide within each sampling date**.** The chlorophyll *a* of water samples was analyzed by 90% acetone method in the Biochemistry and Molecular Biology Laboratory of the Mawlana Bhashani Science and Technology University.

Data analysis: The collected data were compiled and tabulated in proper form and were subjected to statistical analysis. The Microsoft Office Excel software was used to present and interpret the collected data accordingly.

Results and Discussion

Physico-chemical water quality

Temperature: The temperature ranged from 25.6 to 28.7, 22.3 to 24.3 and 24.1 to 25ºC during high tide, and 25.4 to 28.2, 23.8 to 24.3 and 24 to 24.9ºC during low tide over pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 1). During high tide, the highest and lowest temperatures were 28.47 and 22.36ºC at S3 in pre-monsoon and at S1 in monsoon season, respectively. Conversely, during low tide, the highest (28.17ºC) and lowest (23.9ºC) temperatures were found at S1 in pre-monsoon and at S2 in monsoon, respectively. The water temperature ranged from 23 to 27ºC along the mangrove area of Kundapur (Kumar and Kumara, 2011) and ranged from 26 to 28ºC at the Vedaranyam mangrove forest (Ramamurthy *et al*., 2012).

pH: The pH ranged from 7.80 to 8.55, 7.60 to 8.65 and 7.96 to 8.68 during high tide, and 8.20 to 8.70, 8.10 to 8.62 and 8.30 to 8.70 during low tide at pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 1). During high tide, the highest pH was 8.55 at S3 in post-monsoon and lowest was 7.82 at S3 in monsoon season. During low tide, the highest (8.66) and lowest (8.2) pH were found at S2 in post-monsoon and at S4 in monsoon season, respectively. The pH was higher during low tide than high tide at maximum stations over the three seasons.

DO: The DO concentration ranged from 7.85 to 11.68, 7.85 to 12.54 and 8.48 to 13.13 mg/L during high tide, and 7.45 to 8.61, 8.66 to 12.48 and 8.65 to 14.39 mg/L during low tide in pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 1). In high tide, the highest DO (11.87 mg/L) was found at S1 during post-monsoon than pre-monsoon (11 mg/L) at S1 and monsoon (11.76 mg/L) at S5. On the other hand, the lowest (8.12 mg/L) was found at S3 during monsoon followed by pre-monsoon (8.52 mg/L) at S3 and post-monsoon (9.77 mg/L) at S4. In low tide, the highest (11.33 mg/L) was found at S5 during post-monsoon than pre-monsoon (10.87 mg/L) at S3 and monsoon (11.14 mg/L) at S3. However, the lowest (8.79 mg/L) was found at S4 during pre-monsoon than monsoon (9.26 mg/L) at S4 and post-monsoon (8.92 mg/L) at S3. The higher level

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of DO in post-monsoon (4.37 to 7.03 mg/L) and dry winter (4.37 to 6.23 mg/L, whereas the monsoon period showed a lower DO (3.90 to 4.63 mg/L) in the river water of the Sundarbans (Rahaman *et al*., 2013).

Salinity: The salinity ranged from 0.134 to 0.251, 0.093 to 0.187 and 0.165 to 0.361% during high tide, and 0.117 to 0.210, 0.099 to 0.192 and 0.158 to 0.317% during low tide in pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 1). During high tide, the highest (0.321%) and lowest (0.110%) salinities were found at S4 in post-monsoon and at S2 in monsoon period, respectively. During low tide, the highest and lowest salinities were 0.280 and 0.122%in post-monsoon and monsoon season at same station (S4), respectively. The water salinity of the Sundarbans mangrove forest steadily increased to its maximum in pre-monsoon and started declining in monsoon season (Hoq *et al*., 2006), and ranged from 1.2 to 2.0% during high and low tide in the western part of Sundarbans (Sarkar *et al.*, 2013).

EC: The EC ranged from 756 to 3257, 712 to 2765 and 1706 to 1799 µs/cm with mean contents of 1599.79, 1482.86 and 1746.06 µs/cm during high tide in pre-monsoon, monsoon and post-monsoon, respectively (Table 1). In high tide, the highest EC was 2749.33 µs/cm at S5 and lowest was 745 µs/cm at S1 during monsoon season. In low tide, the highest and lowest EC were 3241.33 µs/cm at S3 and 343.33 µs/cm at S1 during pre-monsoon and monsoon seasons, respectively. The EC contents were lower during the monsoon than the pre-monsoon period in the eastern part of the forest (Hoq *et al*., 2006). The EC contents were recorded moderately higher in the Sundarbans western part than the present contents of EC in Sundarbans water (Rahman *et al*., 2013).

TDS: The TDS ranged from 638 to 3456, 306 to 2213 and 1139 to 1402 ppm during high tide, and 351 to 3461, 213 to 2244 and 1254 to 1448 ppm during low tide over pre-monsoon, monsoon and post-monsoon seasons, respectively (Table 1). During high tide, the highest (3239.66 ppm) was found at S5 in pre-monsoon than post-monsoon (1892.33 ppm) at S4 and monsoon (2135.66 ppm) at S5. On the other hand, the lowest (317 ppm) was found at S3 than 470.33 ppm at S1 and 498 ppm at S2 in monsoon season. During low tide, the highest TDS concentration was found 3158.33 ppm at S5 in pre-monsoon followed by 2191.66 ppm at S3 and 2220.66 ppm at S4 in monsoon season. However, the lowest was found 221.66 ppm at S2 in monsoon than post-monsoon (258.66 ppm) at S1 and pre-monsoon (423.33 ppm) at S1. With the decay of plants and animals, dissolved organic particles are released and can contribute to the TDS concentration in Sundarbans water. The mean TDS concentrations ranged from 1716.67 to 1870, 2100 to 2263.33 and 902.67 to 1319 ppm during pre-monsoon, monsoon and post-monsoon season, respectively (Rahman *et al*., 2013).

Nutrients in water

Ammonia (NH_3-N): The mean NH_3-N concentrations were 0.035, 0.037 and 0.07 mg/L during high tide in pre-monsoon, monsoon and post-monsoon, respectively (Figure 1). During high tide, the highest (0.06 mg/L) was found at S2 and S5 in post-monsoon whereas lowest (0.002 mg/L) was found at S2 in pre-monsoon season. The mean NH_3-N concentrations were 0.078, 0.034 and 0.052 mg/L during low tide in pre-monsoon, monsoon and post-monsoon season, respectively (Figure 2). During low tide, the highest (0.17 mg/L) and lowest (0.02 mg/L) both were found in pre-monsoon season at S3 and S5, respectively. Changes of NH_3-N concentrations during high and low tides were very diminutive. The NH_3-N concentrations ranged from 0.001 to 0.33 mg/L in Sundarbans

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water (IWM, 2003), which are closely similar with recorded NH_3-N concentrations during low tide at pre-monsoon season in the present study.

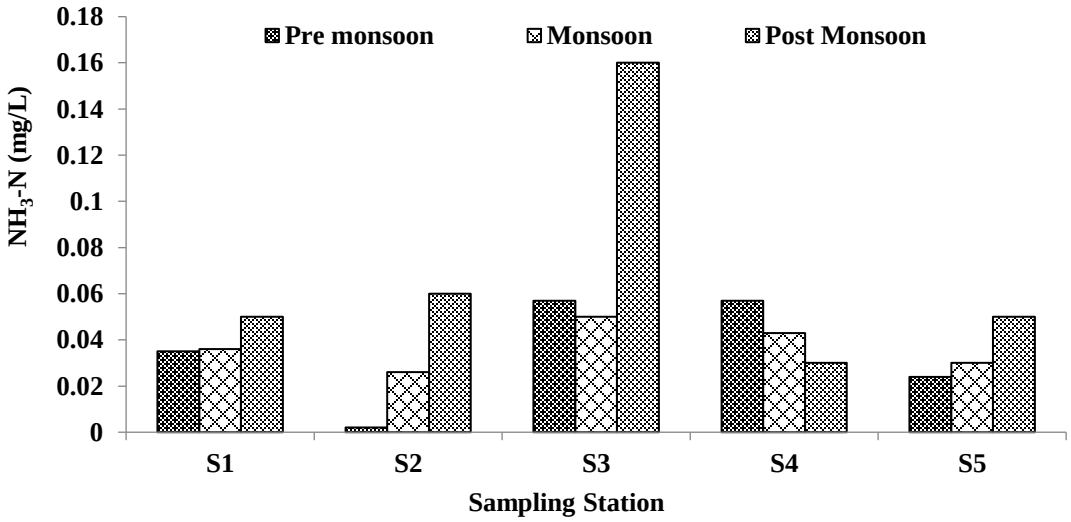

Figure 1: Seasonal variations of NH_3-N concentrations in water during high tide at different stations

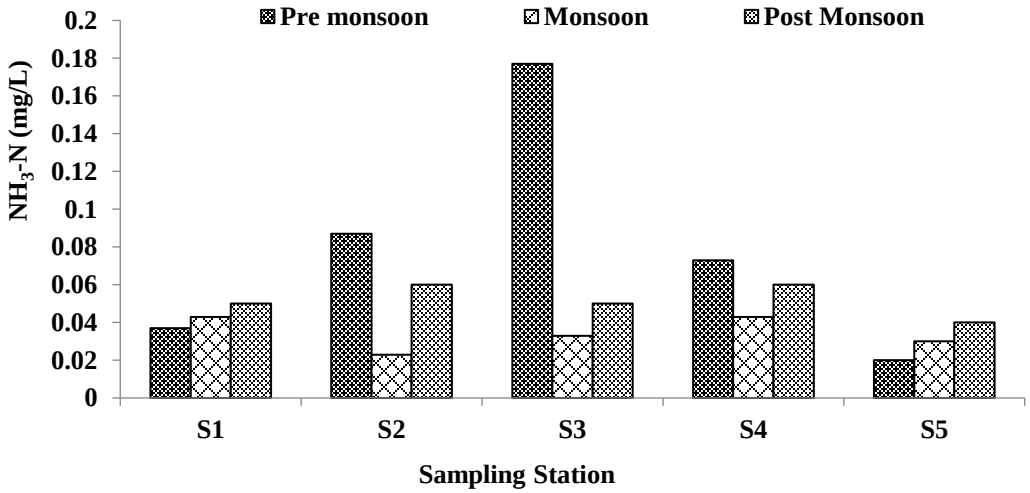

Figure 2: Seasonal variations of NH_3-N concentrations in water during low tide

Nitrate (NO_3-N): The NO_3-N concentrations ranged from 3.5 to 12.3, 8.4 to 27.2 and 5 to 50 mg/L during high tide, and 6.1 to 12.2, 4.2 to 28.2 and 10 to 47 mg/L during low tide in the study area at pre-monsoon, monsoon and post-monsoon seasons, respectively. During high tide, the highest 31.67 mg/L at S3 and the lowest 8.87 mg/L at S1 were found in post-monsoon and pre-monsoon season, respectively (Figure 3). During low tide, the highest 31.67 mg/L and the lowest 7.8 mg/L were found at S3 in post-monsoon and at S2 in pre-monsoon season, respectively (Figure 4). Mean concentrations of NO_3-N were found 9.48, 19.07 and 22.6 mg/L during high tide, and 9.33, 17.2

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and 23.2 mg/L during low tide over pre-monsoon, monsoon and post-monsoon seasons, respectively. The NO_3-N concentration was found 0.04 to 0.46 mg/L with an average of 0.15 mg/L over the three sampling seasons (Rahman *et al*., 2013).

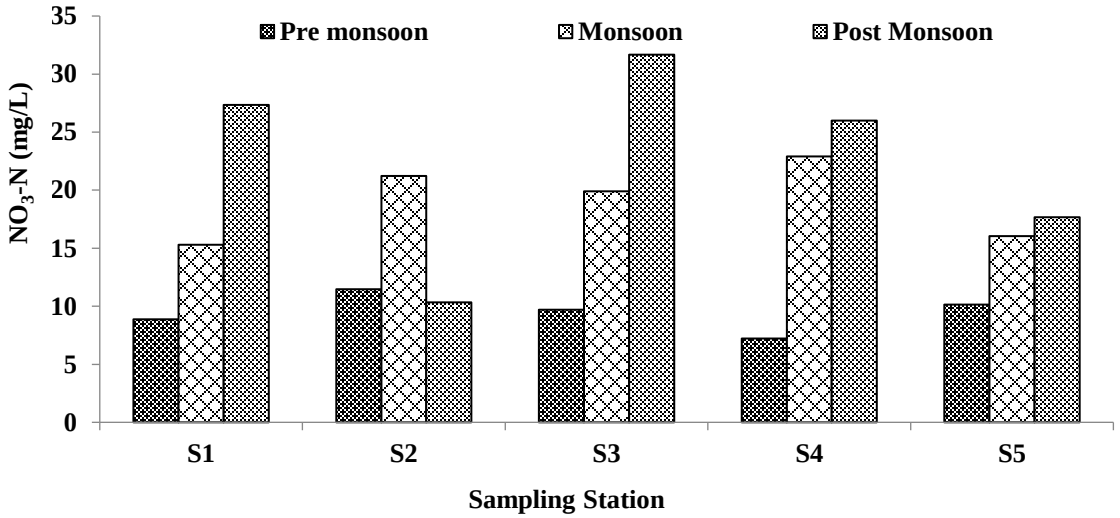

Figure 3: Seasonal variations of NO_3-N concentrations in water during high tide at different stations

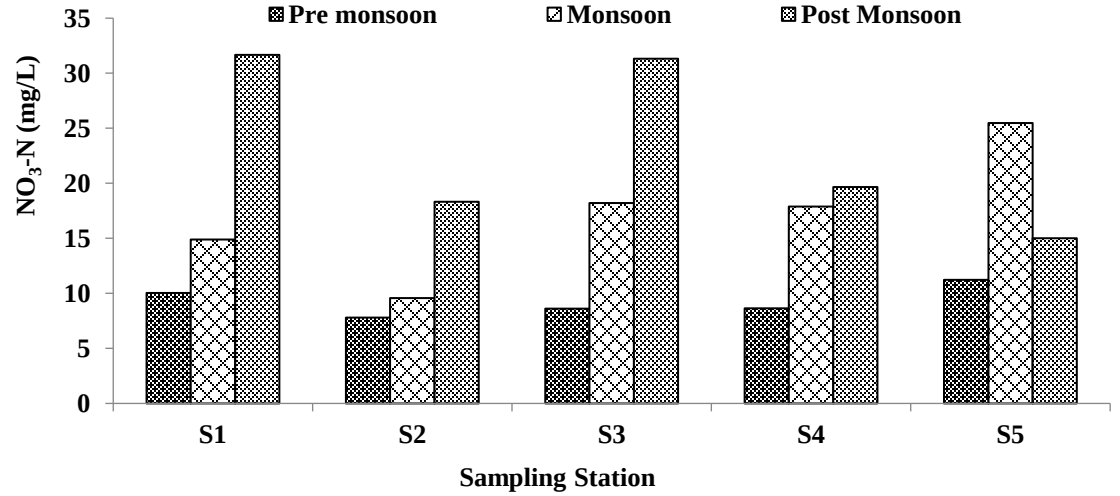

Figure 4: Seasonal variations NO_3-N concentrations in water during low tide at different stations

Phosphate (PO_4-P): The PO_4-P concentrations ranged from 0.27 to 5.4, 0.06 to 1.57 and 0.48 to 1.98 mg/L during high tide, and 0.41 to 2.75, 0.1 to 1.61 and 0.79 to 1.63 mg/L during low tide over pre-monsoon, monsoon and post-monsoon seasons, respectively. During high tide, the highest PO_4-P concentrations 4.44 mg/L was found at S1 in pre-monsoon than 1.27 mg/L at S4 and 1.57

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mg/L at S5 both in post-monsoon season, and lowest PO_4-P concentration 0.28 mg/L was found at S3 in monsoon than 0.36 mg/Lat S5 and 0.39 mg/L at S2 both in monsoon season (Figure 5).

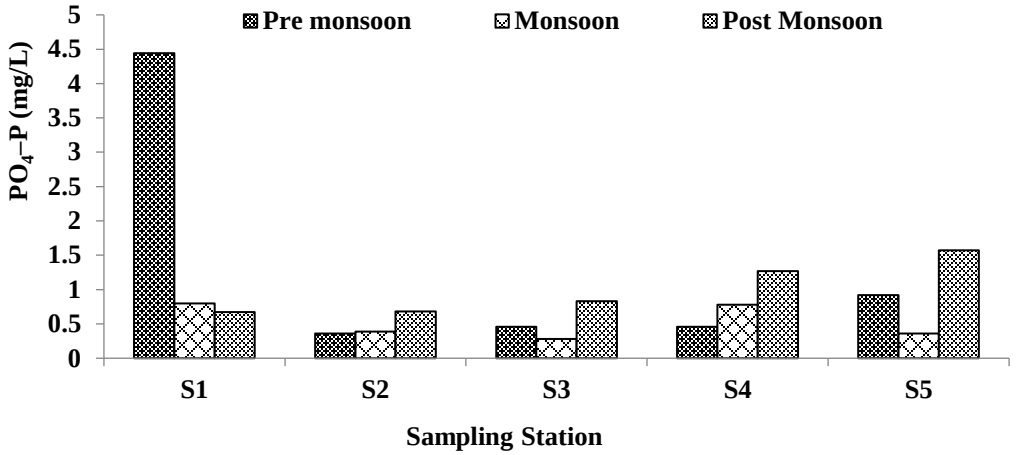

Figure 5: Seasonal variations of PO_4-P concentrations in water during high tide

During low tide, the highest PO_4-P concentrations 2.48 mg/L was found at S1 in pre-monsoon than 1.11 mg/L at S3 and 1.31 mg/L at S4 both in post-monsoon, and the lowest PO_4-P concentrations 0.15 mg/L was found at S4 in monsoon than 0.26 mg/L at S5 and 0.48 mg/L at S1 both in monsoon season (Figure6). Mean PO_4-P concentration during high tide 1.33, 0.52 and 1.004 mg/L, and during low tide 0.95, 0.43 and 1.15 mg/L were found over pre-monsoon, monsoon and post-monsoon seasons, respectively. The mean phosphate concentrations as PO_4-P measured at different tidal cycles over three sampling seasons were generally low, ranged from 0.05 to 0.42 mg/L with an average of 0.12 mg/L (Rahaman *et al*., 2013). A relatively low concentration of PO4-P was found 0.009 to 0.582 mg/L with an average of 0.115 mg/L in the mangrove area (IWM, 2003). The DoE defines the EQS of PO_4-P as between 6 and 10 mg/L (DoE, 1991).

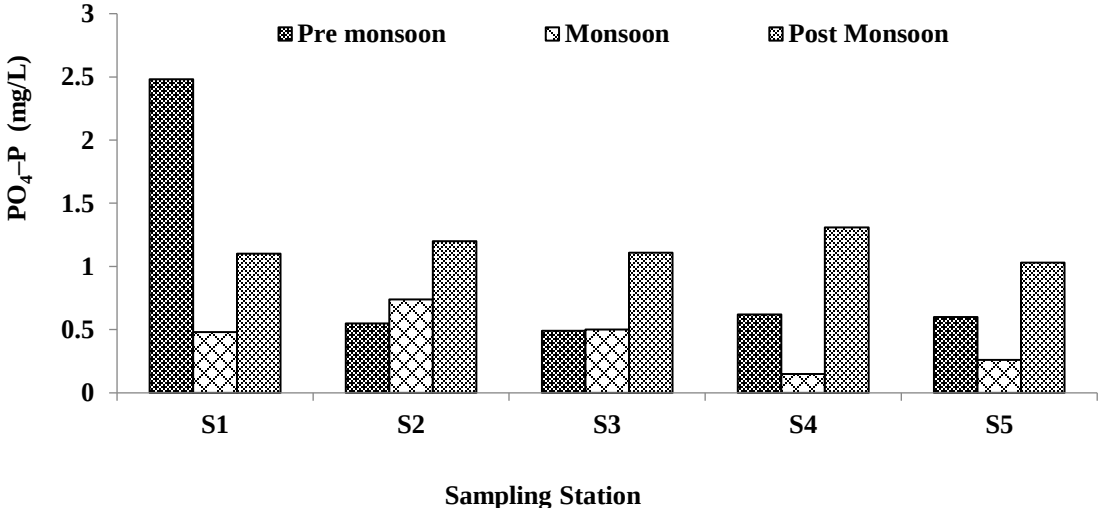

Figure 6: Seasonal variations PO_4-P concentrations in water during low tide at different stations

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Sulfate (SO_4): The SO_4 concentrations ranged from 119 to 272, 30 to 90, 32 to 130 mg/L with mean concentrations 187.8, 53.19 and 76.87 mg/L found during high tide in pre-monsoon, monsoon and post-monsoon, respectively. During high tide the highest 264 mg/L at S2 and the lowest 40 mg/L at both S3 and S1 were found in pre-monsoon, and monsoon and post-monsoon season, respectively. In high tide, the SO_4 values at maximum sampling stations were between suitable range during monsoon season which were found slightly increased during post-monsoon and highly increased during pre-monsoon (Figure 7). The SO_4 concentrations ranged from 69 to 179, 20 to 80, 60 to 130 mg/L with mean concentrations 135.4, 45.8 and 95.73 mg/L found during low tide over pre-monsoon, monsoon and post-monsoon, respectively. During low tide, the highest 176 mg/L and the lowest 31 mg/L were found at S3 in pre monsoon and at S5 in monsoon period, respectively. In low tide, the SO_4 values at maximum sampling stations were between suitable range during monsoon season which were found moderately higher during post monsoon and extremely higher during pre-monsoon (Figure 8).

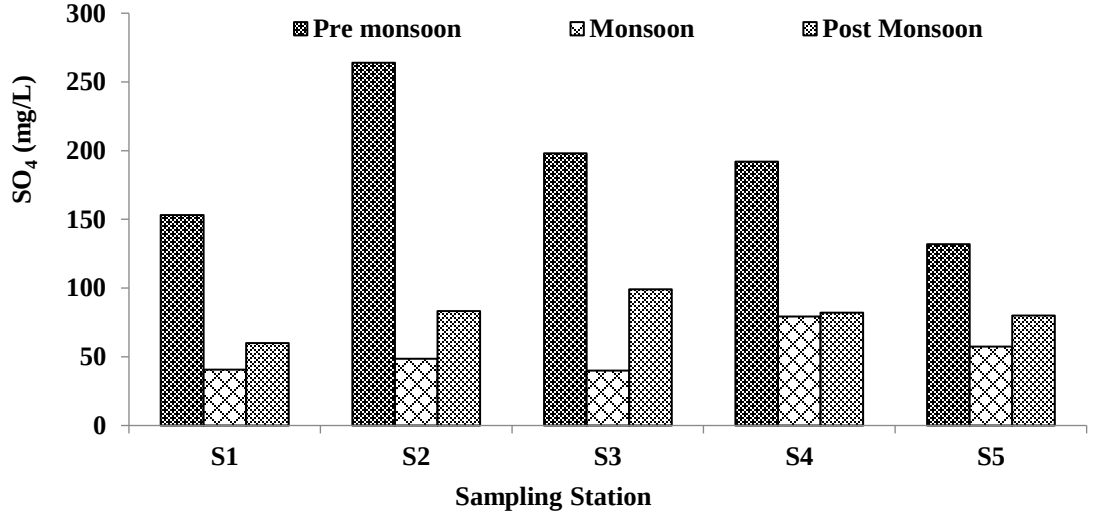

Figure 7: Seasonal variations of SO_4concentrations in water during high tide at different stations

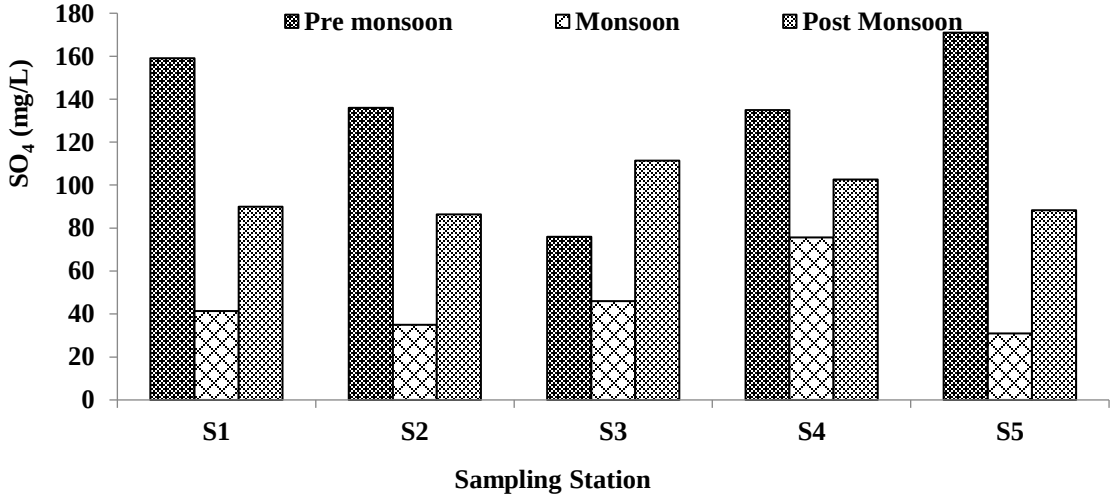

Figure 8: Seasonal variations of SO_4 concentrations in water during low tide at different stations

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Chlorophyll *a* in water

The concentrations of chlorophyll *a* ranged from 0.611 to 0.840, 0.217 to 1.168 and 0.180 to 1.75 mg/L during high tide, and 0.638 to 0.883, 0.218 to 1.189 and 0.69 to 1.88 mg/L during low tide over pre-monsoon, monsoon and post-monsoon season, respectively. During high tide, the highest 1.29 mg/L and the lowest 0.345 mg/L were found at S1 in post-monsoon and at S3 in monsoon seasons, respectively (Figure 9). In high tide the chlorophyll *a* concentrations 0.345 mg/L at S3 during monsoon and 0.52 mg/L at S2 during post-monsoon, were found similar to the standard range. During low tide, the highest 1.58 mg/L and the lowest 0.464 mg/L were found at S4 in post-monsoon and S2 in monsoon seasons, respectively (Figure 10). In low tide the concentrations of chlorophyll *a* 0.464 mg/L at S2, 0.569 mg/L at S3 and 0.539 mg/L at S4 during monsoon season were similar to the standard value. Mean concentration of chlorophyll *a* were found 0.788, 0.973 and 0.964 mg/L during high tide, and 0.789, 0.649 and 1.428 mg/L during low tide over the pre-monsoon, monsoon and post-monsoon seasons, respectively.

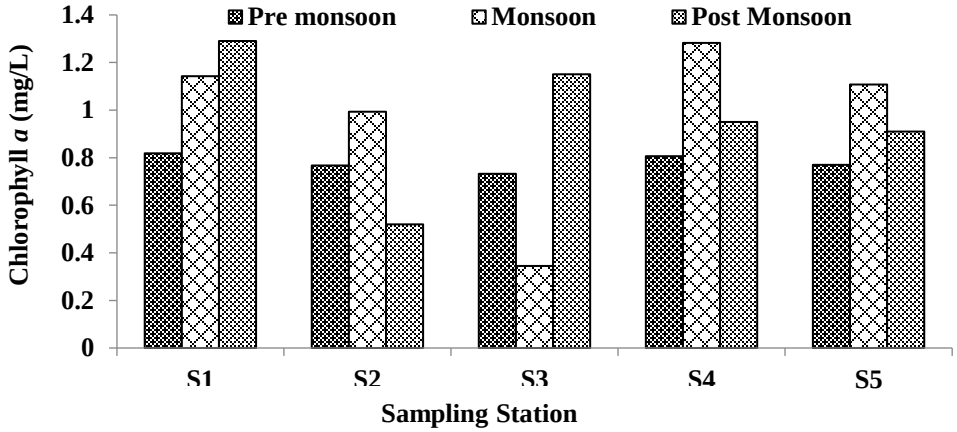

Figure 9: Seasonal variations of chlorophyll *a* concentration in water during high tide

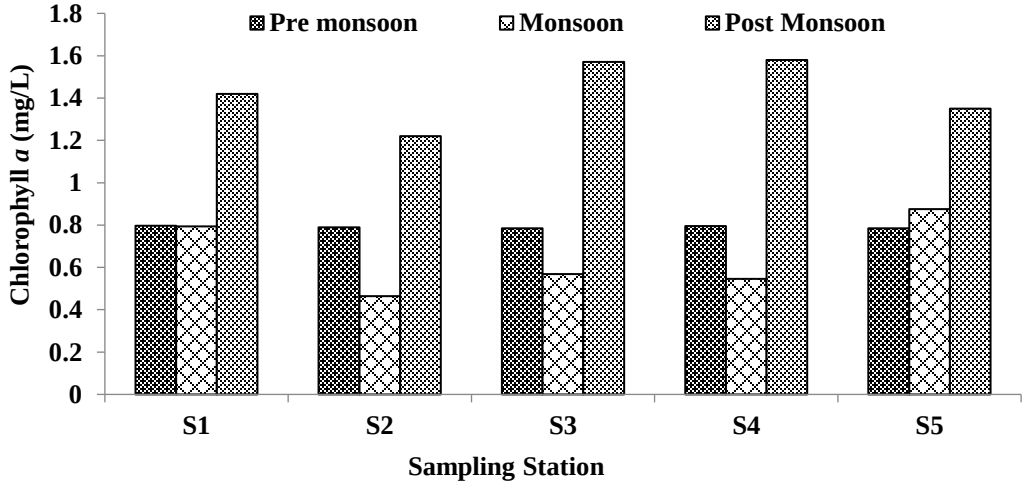

Figure 10: Seasonal variations of chlorophyll *a* concentration in water during low tide

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Seasonal and tidal dynamics of physicochemical properties in water

Variation of temperature from pre-monsoon to monsoon season (25.66 to 22.37 at S1, 28.47 to 23.63 at S3, 28.43 to 24.13ºC at S4) in both tides were observed during the study period, whereas a slight variation was found from high tide to low tide over maximum stations such as 22.37 to 23.90 at S2, 23.63 to 24.13ºC at S3 (Table 2). The pH ranged from 7.82 to 8.55 and 8.2 to 8.66 over all sampling seasons during high and low tide, respectively. The pH at maximum sampling statiopns during monsoon season (8.49 at S2, 8.06 at S3) slightly decreased during monsoon (8.16 at S2, 7.82 at S3) which gradually increased (8.23 at S2, 8.55 at S3) during post monsoon season (Table 2). The DO ranged from 8.52 to 11.0, 8.12 to 11.46 and 8.93 to 11.87 mg/L during both tides over pre-monsoon, monsoon and post-monsoon season, respectively (Table 2).

Salinity ranged from 0.111 to 0.321% and 0.130 to 0.281% at all sampling stations over three seasons during high tide and low tide, respectively (Table 3). During pre-monsoon and monsoon season EC values showed a greater change from S1 to S3 between high and low tide (Table 3). In S1 and S2 during monsoon, in S3 and S4 during pre-monsoon and post-monsoonseason, showed a great difference of TDS concentrations between high and low tide (Table 3).

Seasonal and tidal dynamics of nutrients and Chlorophyll *a* in water

The NH_3-N concentrations ranged from 0.002 to 0.06 and 0.02 to 0.177 mg/L at all sampling stations over three seasons during high and low tide, respectively (Table 4). From S1 to S5, NO_3-N concentrations showed a highly difference between high and low tide both pre-monsoon and post-monsoon. In post-monsoon, NO_3-N concentrations showed slight change between two tides at all stations (Table 4). In all stations, PO_4-P was found very higher than the suitable range (0.005 to 0.2 mg/L) during both tides at pre-monsoon and monsoon season. In monsoon season, PO_4-P was found higher during both tides but they remained lower than the two remaining seasons (Table 4).

The SO_4 ranged from 76 to 264, 31 to 79.33 and 40 to 111.33 mg/L during both tides over pre-monsoon, monsoon and post-monsoon season, respectively (Table 5). Chlorophyll *a* concentrations ranged from 0.345 to 1.29, and 0.464 to 1.58 mg/L at all stations over three seasons during high and low tide, respectively. During high tide in pre-monsoon season, chlorophyll *a* concentration 0.818 mg/L at S1 and 0.806 mg/L at S4 was higher than the value found in low tide. In monsoon season, chlorophyll *a* concentations were found higher during high tide than low tide at all samplimng stations. During low tide, chlorophyll *a* concentrations were found higher than the high tide at all stations (Table 5). The chlorophyll *a* concentrations of the present study was almost similer of the standard when compared with previous studies (Table 6).

Conclusion

Nutrients balance of the Sundarbans mangrove ecosystem was influenced by the tidal cycle and seasonal variations as revealed by the changes in nutrients and chlorophyll *a* in water at different seasons. The effect of tidal amplitude was important in determining in the extent of variations in nutrient and chlorophyll *a* concentrations. Water quality of Passur river and Koromjol canal during different tides and seasons has impact on the nutrients and chlorophyll *a* concentrations. The upstream and downstream flowing of water, fluctuations of tides and different seasons have greater impact on water quality of mangrove ecosystem. As a result, major nutrients and chlorophyll *a*

concentration in river water could have some effects on aquatic ecosystem in the Sundarbans mangrove.

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Table 1. Seasonal and tidal variation of physicochemical parameters with seasons

Parameter	Seasonal and Tidal Variation						Standard
	Pre-monsoon		Monsoon		Post-monsoon		
	HT	LT	HT	LT	HT	LT	
Temp. (ºC)	27.25±1.47 (25.6 to 28.7)	26.46±1.05 (25.4 to 28.2)	23.34±0.92 (22.3 to 24. 3)	24.13±0.14 (23.8 to 24.3)	24.57±0.15 (24.1 to 25.0)	24.56±0.15 (24.0 to 24.9)	25 to 30 (Rahaman *et al*., 2013)
pH	8.35±0.16 (7.80 to 8.55)	8.52±0.09 (8.2 to 8.7)	8.25±0.26 (7.60 to 8.65)	8.29±0.06 (8.0 to 8.6)	8.41±0.13 (7.96 to 8.68)	8.57±0.06 (8.3 to 8.7)	6.5 to 8.5 (DoE, 2011)
DO (mg/L)	9.84±1.04 (7.85 to 11.68)	9.79±0.78 (7.45 to 11.48)	9.56±1.34 (7.85 to 12.54)	10.41±0.83 (8.66 to 12.48)	10.6±0.78 (8.48 to 13.13)	10.31±2.02 (8.65 to 14.39)	7.5 to 8.5 (Hoq *et al*., 2007)
Salinity (‰)	0.17±0.03 (0.13 to 0.25)	0.16±0.02 (0.12 to 0.21)	0.14±0.01 (0.09 to 0.19)	0.13±0.01 (0.09 to 0.19)	0.24±0.06 (0.17 to 0.36)	0.23±0.04 (0.16 to 0.32)	0.5 to 30.0 (Rahaman *et al*., 2013)
EC (µs/cm)	1599.79±961.73 (756 to 3257)	1945.53±1336.9 (351 to 3857)	1482.86±10006.2 (712 to 2765)	1795.13±1324.25 (102 to 2790)	1746.06±15.23 (1706 to 1799)	1742.99±21.01 (1700 to 1789)	>1500 (EQS,1991)
TDS (ppm)	1518±1069.81 (638 to 3456)	1812.86±1219.78 (351 to 3461)	988.33±799.87 (306 to 2213)	1400.12±1059.78 (213 to 2244)	1291.13±105.65 (1139 to 1402)	1371.39±40.95 (1254 to 1448)	500 to 30000 (Wahid *et al*., 2007)

Note: HT = High Tide, LT = Low Tide.

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Table 2: Seasonal and tidal dynamics of temperature, pH and DO in Sundarbans water

Stations	Season	Temperature (ºC)		pH		DO (mg/L)	
		HT	LT	HT	LT	HT	LT
S1	Pre-monsoon	25.66±0.06	28.17±0.06	8.47±0.06	8.38±0.18	11.00±1.0	10.13±1.18
	Monsoon	22.37±0.06	24.23±0.06	8.4±0.2	8.31±0.16	9.54±1.16	11.01±1.51
	Post-monsoon	24.73±0.25	24.73±0.06	8.41±0.14	8.49±0.19	11.87±1.51	10.8±1.42
S2	Pre-monsoon	25.63±0.06	26.57±0.15	8.49±0.05	8.61±0.10	10.3±1.13	9.79±0.42
	Monsoon	22.37±0.06	23.9±0.17	8.16±0.16	8.25±0.13	9.27±1.33	9.79±1.21
	Post-monsoon	24.43±0.32	24.83±0.12	8.23±0.24	8.66±0.05	10.38±1.73	9.54±0.56
S3	Pre-monsoon	28.47±0.25	26.4±0.10	8.06±0.25	8.6±0.05	8.52±0.62	10.87±0.41
	Monsoon	23.63±0.59	24.13±0.06	7.82±0.19	8.32±0.2	8.12±0.31	11.14±0.65
	Post-monsoon	24.6±0.10	24.57±0.25	8.55±0.07	8.59±0.12	10.29±2.2	8.93±0.25
S4	Pre-monsoon	28.43±0.06	25.57±0.21	8.39±0.04	8.52±0.03	8.99±1.48	8.79±1.67
	Monsoon	24.13±0.06	24.17±0.06	8.4±0.2	8.2±0.22	9.14±0.66	9.26±0.53
	Post-monsoon	24.4±0.26	24.57±0.23	8.34±0.26	8.6±0.07	9.77±1.19	10.95±2.22
S5	Pre-monsoon	28.06±0.06	25.6±0.10	8.33±0.15	8.49±0.07	10.4±0.50	9.39±1.56
	Monsoon	24.23±0.06	24.23±0.12	8.45±0.23	8.38±0.22	11.46±1.09	10.87±1.57
	Post-monsoon	24.7±0.30	24.37±0.47	8.52±0.14	8.52±0.16	10.68±2.23	11.34±2.65

Note: HT = High Tide, LT = Low Tide.

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Table 3: Seasonal and tidal dynamics of salinity, EC and TDS in Sundarbans water

Stations	Season	Salinity (‰)		EC (µs/cm)		TDS (ppm)	
		HT	LT	HT	LT	HT	LT
S1	Pre-monsoon	0.14±0.01	0.13±0.02	839±97.92	446.33±101.1	740.67±95.2	423.33±70.5
	Monsoon	0.12±0.01	0.13±0.03	745.67±36.4	343.33±319.3	470.33±52.5	258.67±14.3
	Post-monsoon	0.19±0.04	0.19±0.03	1757.33±13.2	1758.33±17.7	1198.33±23.4	1369±42.3
S2	Pre-monsoon	0.15±0.01	0.16±0.01	1012.67±235.1	558±285.7	853.33±214.9	647.67±103.3
	Monsoon	0.11±0.09	0.14±0.05	763.33±27.65	345.67±390.4	498±30.12	221.67±13.32
	Post-monsoon	0.27±0.08	0.19±0.02	1754.67±26.7	1758.33±49.7	1157±22.34	1431±27.73
S3	Pre-monsoon	0.15±0.02	0.17±0.02	848.67±87.2	3241.33±583.3	864±97.55	2171±451.7
	Monsoon	0.12±0.02	0.15±0.05	751.33±34.3	2755.33±19.4	317±18.19	2191.67±24.34
	Post-monsoon	0.19±0.03	0.26±0.04	1730.67±4.9	1718.67±28.9	1389.33±11	1358.33±29.77
S4	Pre-monsoon	0.21±0.04	0.19±0.01	2582.33±624.3	2614.67±622.1	1892.33±104.9	2664±121.01
	Monsoon	0.14±0.05	0.12±0.03	2404.67±586.4	2768±19.47	1520.67±303.5	2220.67±25.77
	Post-monsoon	0.32±0.05	0.28±0.04	1728.33±36.12	1721.33±21.83	1363±15.52	1381±9.54
S5	Pre-monsoon	0.19±0.02	0.18±0.02	2716.33±312.8	2867.33±560.8	3239.67±195.9	3158.33±295.3
	Monsoon	0.14±0.02	0.13±0.01	2749.33±6.11	2763.33±5.51	2135.67±68.04	2108±73.57
	Post-monsoon	0.22±0.03	0.25±0.06	1759.33±34.79	1758.33±25.54	1348±7.55	1317.67±70.23

Note: HT = High Tide, LT = Low Tide.

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Table 4: Seasonal and tidal dynamics of ammonia, nitrate and phosphate in Sundarbans water

Station	Season	NH_3-N (mg/L)		NO_3-N (mg/L)		PO_4-P (mg/L)	
		HT	LT	HT	LT	HT	LT
S1	Pre-monsoon	0.035±0.1	0.037±0.1	8.87±2.2	10.4±0.6	4.44±0.9	2.48±0.3
	Monsoon	0.037±0.02	0.043±0.02	15.3±4.9	14.9±8.93	0.81±0.7	0.48±0.2
	Post-monsoon	0.05±0.01	0.05±0.02	27.33±20.5	31.67±13.9	0.67±0.2	1.1±0.3
S2	Pre-monsoon	0.002±0.001	0.087±0.01	11.47±0.46	7.8±1.5	0.36±0.05	0.55±0.04
	Monsoon	0.027±0.02	0.023±0.02	21.23±3.73	9.57±8.44	0.39±0.14	0.74±0.8
	Post-monsoon	0.06±0.03	0.06±0.02	10.33±6.81	18.33±6.51	0.69±0.17	1.2±0.13
S3	Pre-monsoon	0.057±0.02	0.177±0.19	9.7±2.46	8.6±1.47	0.46±0.09	0.49±0.1
	Monsoon	0.05±0.01	0.033±0.02	19.9±6.65	18.2±6.1	0.28±0.2	0.50±0.11
	Post-monsoon	0.05±0.03	0.05±0.02	31.67±7.64	31.33±4.04	0.84±0.1	1.11±0.1
S4	Pre-monsoon	0.057±0.03	0.073±0.02	7.23±3.4	8.63±1.69	0.46±0.1	0.62±0.13
	Monsoon	0.043±0.03	0.043±0.02	22.9±2.7	17.9±2.61	0.79±0.43	0.15±0.1
	Post-monsoon	0.04±0.02	0.06±0.03	26±14.18	19.67±6.66	1.27±0.25	1.31±0.5
S5	Pre-monsoon	0.024±0.02	0.02±0.02	10.13±2.02	11.23±0.91	0.92±0.12	0.6±0.04
	Monsoon	0.03±0.01	0.03±0.02	16.03±7.02	25.47±2.57	0.36±0.1	0.26±0.1
	Post-monsoon	0.06±0.03	0.04±0.02	17.67±6.5	15±5	1.57±0.5	1.03±0.21

Note: HT = High Tide, LT = Low Tide.

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Table 5: Seasonal and tidal dynamics of sulfate and Chlorophyll *a* concentration in Sundarbans water

Station	Season	SO_4 (mg/L)		Chlorophyll *a* (mg/L)	
		HT	LT	HT	LT
S1	Pre-monsoon	153±17.06	159±12.12	153±17.06	159±12.12
	Monsoon	40.67±11.02	41.33±6.51	40.67±11.02	41.33±6.51
	Post-monsoon	40±12.17	90±26.46	40±12.17	90±26.46
S2	Pre-monsoon	264±8	136±9.64	264±8	136±9.64
	Monsoon	48.67±12.06	35±15.13	48.67±12.06	35±15.13
	Post-monsoon	83.33±40.41	86.33±25.79	83.33±40.41	86.33±25.79
S3	Pre-monsoon	198±16.37	76±7	198±16.37	76±7
	Monsoon	40±9.17	46±7.94	40±9.17	46±7.94
	Post-monsoon	99±29.21	111.33±16.44	99±29.21	111.33±16.44
S4	Pre-monsoon	192±18.73	135±13.08	192±18.73	135±13.08
	Monsoon	79.33±9.02	75.67±5.13	79.33±9.02	75.67±5.13
	Post-monsoon	82±11.27	102.67±13.01	82±11.27	102.67±13.01
S5	Pre-monsoon	132±11.36	171±8	132±11.36	171±8
	Monsoon	57.33±29.69	31±10.15	57.33±29.69	31±10.15
	Post-monsoon	80±36.06	88.33±20.79	80±36.06	88.33±20.79

Note: HT = High Tide, LT = Low Tide.

Table 6: Comparison of chlorophyll *a* and water nutrients of Sundarbans with other estuaries.

Parameters (mg/L)	Present Study	Rahaman *et al*., 2013	Prasad *et al*., 2008	Senthilkumar *et al*., 2008	Prasad *et al*., 2008	Standard (EPA, 2017)
Chlorophyll *a*	0.91	Nd	Nd	10.02	Nd	0.06-0.59
NH_3-N	0.05	0.14	Nd	63.60	11.80	<0.1
NO_3-N	17.05	0.15	6.62	3.90	6.08	0.3-30
PO_4-P	0.95	0.12	0.41	3.25	61.33	0.005-0.20
SO_4	105.90	95.69	0.30	Nd	Nd	2-70