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Seasonal Changes of Nutrient Stoichiometry in the Tidal Mangroves Estuary, Bangladesh

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ABSTRACT

In the current study, the stoichiometry of dissolved nutrients was addressed in the Pasur River estuary (PRE) mangrove ecosystems of Bangladesh to characterize the ecological and nutrient state of the inter-tidal mangroves in light of rising human disturbances from January to December 2019. The findings suggest excess phosphorus (P) relative to nitrogen (N) in these systems, indicating that mangrove coastal habitats along the PRE are severely N-constrained. Since the silica(Si): N ratio in the PRE mangrove estuary was greater than 1, it was concluded that the estuarine mangrove waters receive a significant amount of silica from terrestrial weathering. P can limit primary production in some systems; therefore, managing both N and P is recommended for an optimal management of coastal eutrophication, even though N is likely the main source of eutrophication in most coastal systems in the tropical zone. Excess P in estuaries can also combine with nitrogen (N) and silica (Si) availability to destabilize ecosystems. Through mechanisms such as enhanced Si fluxes, decreasing P in upstream freshwater habitats can also benefit coastal marine ecosystems. These intricate relationships are important while devising strategies to reduce nutrient pollution in coastal areas.

INTRODUCTION

Mangroves are known as a dynamic and highly productive area situated along the coasts of the tropical world **(Srikanth *et al.*, 2016)**. Enhanced nutrient inputs from mangroves, land development projects, farming and related businesses find their way into coastal and marine environments. A higher vulnerability of estuarine waters to environmental pressures owing to eutrophication has been linked to high nutrient concentrations that could boost the mangrove growth rate **(Lovelock *et al.*, 2009)**. In addition to regulating global biogeochemical cycles, mangroves also provide a significant amount of terrigenous organic matter to the neighboring coastal and marine waters **(Dittmar *et al.*, 2006)**. As a natural buffer that distils and recycles nutrients and as a nursery ground for fish, birds, and other animals, the estuary and mangrove ecosystem serve many ecological roles **(Hilaluddin *et al.*, 2020)**. Estuaries, where fresh and salt water meet, are susceptible to strong tidal currents, shifting water depth, fluctuating salinity, and growing sediment concentrations **(Eick & Thiel, 2014)**. For a long time, the idea that nitrogen restriction occurs in saltwater and phosphorus limitation in freshwater was recognized as conventional wisdom **(Correll, 1998)**. When compared to places with fewer nutrition sources, mangroves expand more rapidly in those with more. **Redfield (1958)** determined that a 16:1 (molar concentration) DIN:DIP ratio of inorganic nutrients (N/P ratio) is best for phytoplankton growth. Increased nutrient inputs from farming, agribusiness, and other land-use practices find their way into the ocean and bay environments. Phytoplankton absorbs nutrients at a 16:1=N:P ratio near the surface. Phytoplankton may also take in nutrients in a variety of ratios, which is useful in cases where there may be an abundance or deficiency of specific nutrients on the water's surface. Significant deviations from 16 at low N/P ratios may suggest potential nitrogen limitation of phytoplankton primary production, while significant deviations at high N/P ratios may indicate potential phosphorus limitation.

Anthropogenic nutrient loading of nitrogen (N), phosphorus (P), and silica (Si) in coastal ecosystems through river discharge has become a growing problem worldwide in the twenty-first century **(Hagy *et al.*, 2004; IPCC, 2014; Paerl *et al.*, 2014)**. Enhanced nutrient inputs from upstream catchment activities, atmospheric deposition, and local effluents create nutrient loading of coastal waters. Ecological and economic damage can be a consequence of algal blooms, macroalgae development, biodiversity loss, oxygen depletion, sedimentation, fish mortality, and dead zones **(Howarth *et al.*, 2011)**. Discharges of nutrient-rich organic pollutants into mangroves from neighboring agriculture, aquaculture, and other industrial practices alter the biogeochemistry of nutrients and have a negative impact on coastal water quality and production **(Agoramoorthy *et al.*, 2008)**. Shifts in nutrient stoichiometric ratios (Si:N, N:P, and Si:P) have a major effect on the dynamics of the coastal food web **(Zhao *et al.*, 2005)**.

In the dry season of the Pasur River estuary, only one study has been conducted to establish nutrient stoichiometry **(Shefat *et al.*, 2020)**. The sustainable management of coastal resources depends on a thorough investigation of the nutrient structure and stoichiometry; no comprehensive investigation has been performed to date in Bangladesh mangroves. Hence, the present study was undertaken to characterize the ecological and nutrient state of the inter-tidal estuarine mangroves ecosystem.

MATERIALS AND METHODS

Study area, sample collection and laboratory analysis

This research was conducted at the Pasur River estuary, located in the southwestern region of Bangladesh's Sundarban Mangrove Forest, from January to December 2019. Fig. (1) depicts the study area and the locations of the sampling sites. A 1.5L water sampler (Wildco-1520) was used to collect the samples; vacuum machine was then used to filter the water via Whatman GF/F (0.45) filter paper and refrigerated under dark conditions until laboratory analysis. A conductivity-temperature-depth (CTD) profiler (*In-Situ* Inc., Lincoln Ave., Fort Collins, CO, USA; Model: In-Situ Aqua TROLL 200) was used to determine the salinity of the water. Spectrophotometric analysis was used to determine nitrate, nitrite, ammonia, phosphate, and silica concentrations in water samples collected from a depth of 0 to 0.5 meters (the euphotic layer) at five different sampling stations.

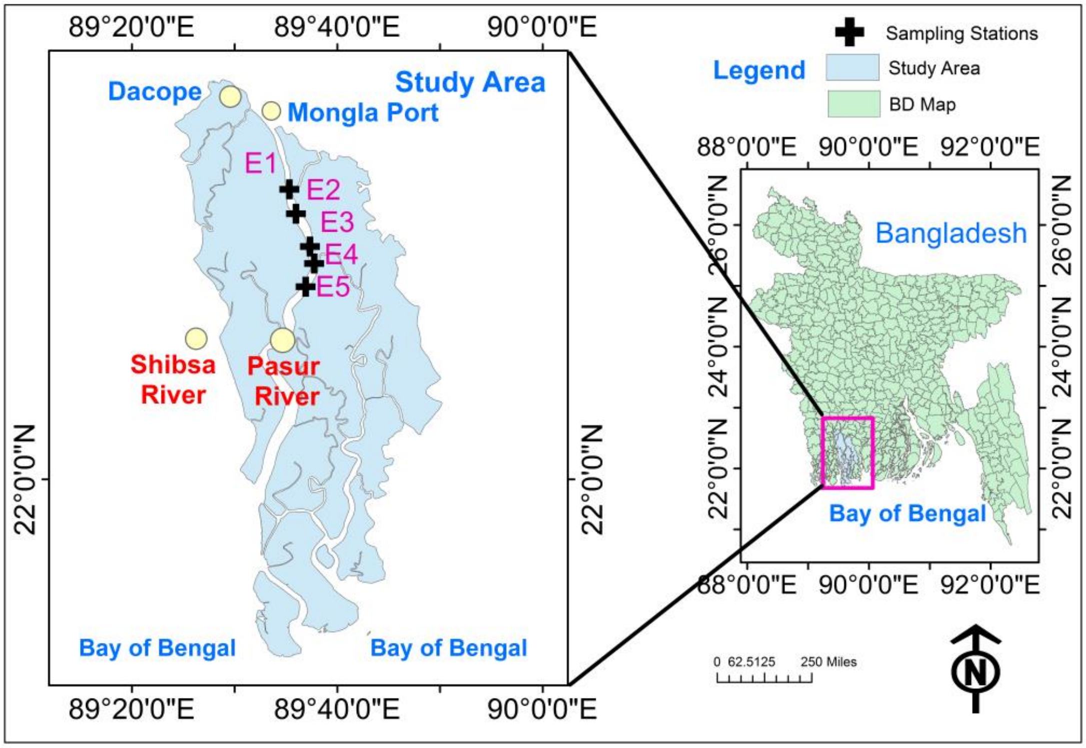


Fig. 1. Study area

Statistical analysis

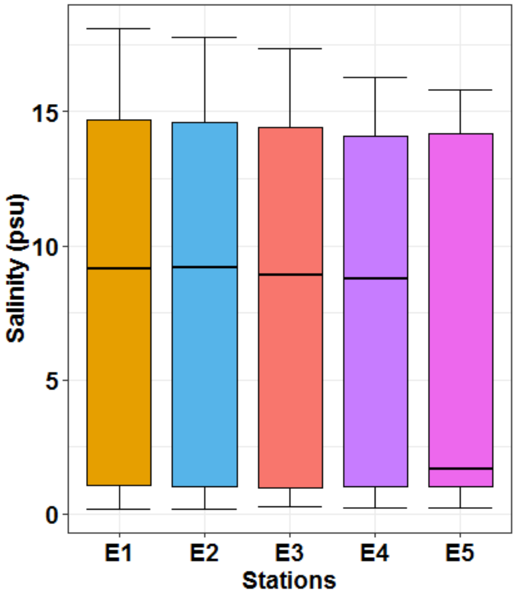
R 4.0.3 **(Galili *et al.*, 2017)** was used to generate boxplots. All physical, chemical, and nutritional variables were given descriptive statistics (mean, range, and standard error) calculated with R. To identify the most important environmental factors and how they fluctuate in the estuary, principal component analysis (PCA) was used **(Galili *et al.*, 2017)**.

RESULTS

Physicochemical parameter

Figs. (2 and 3) depict seasonal changes in water quality at the study sites. In our study, although we did not observe statistically significant differences in water variables across different spatial locations ($P > 0.05$), we did find significant temporal variations in these variables ($P < 0.05$). This suggests that while the water quality parameters were consistent across various locations, they fluctuated significantly over time. Seasonal differences in salinity, dissolved inorganic nitrogen (DIN), dissolved inorganic phosphate (DIP), and silica were statistically significant ($P < 0.05$). Throughout the time frame of the investigation, researchers found a wide range of salinities. Salinity readings ranged from 0.19 psu (E2) to 18.1 psu (E1) (Fig. 3). Depending on how far inland the stations were from the ocean, the salinity readings were different. Salinity varied by season, averaging between 6.88 and 8.43psu. During the dry season, the average salinity was 11.0psu, but during the wet season, it was just 0.29psu (Fig. 2).

Dissolved inorganic nitrogen (DIN) was measured to be 0.70mg/ L during the dry season and 0.19mg/ L during the wet season (Fig. 2). Fig. (3) displays a range of mean seasonal DIN values from 0.45 (E5) to 0.65 (E2). There was a noticeable disparity in the nutrient seasonal pattern between the locations. The wet season had higher NO_3 levels than the dry season. Dissolved PO_4 levels also showed a seasonal trend at the sampling locations. From the rainy to the dry season, researchers observed that mean amounts of PO_4 dropped. Fig. (2) shows that dissolved inorganic phosphate (DIP) concentrations were at their highest during the wet season (3.47mg/ L) compared to dry season (0.54mg/ L). Post hoc analysis showed no significant difference ($P> 0.05$) across stations, despite the fact that dissolved silica showed a large seasonal change. During the dry and wet seasons, the average concentration of silica was 1.83 and 3.83mg/ L, respectively (Fig. 2).


Salinity (psu)
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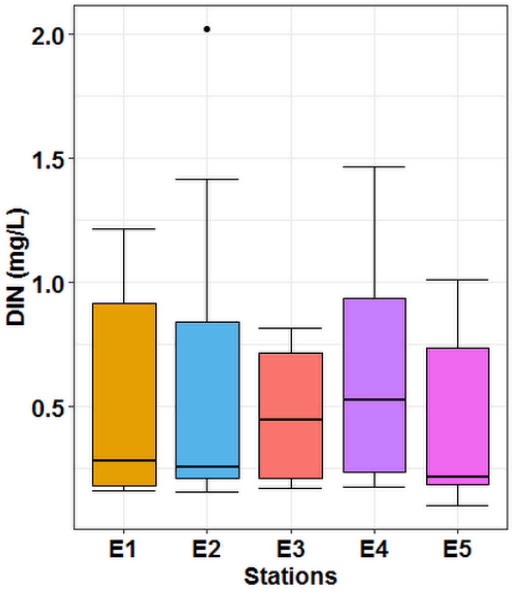
5
10
15
E1
E2
E3
E4
E5
Stations


DIN (mg/L)
0.5
1.0
1.5
2.0
E1
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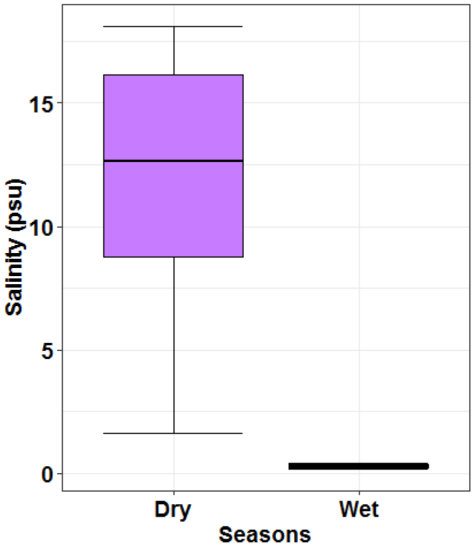
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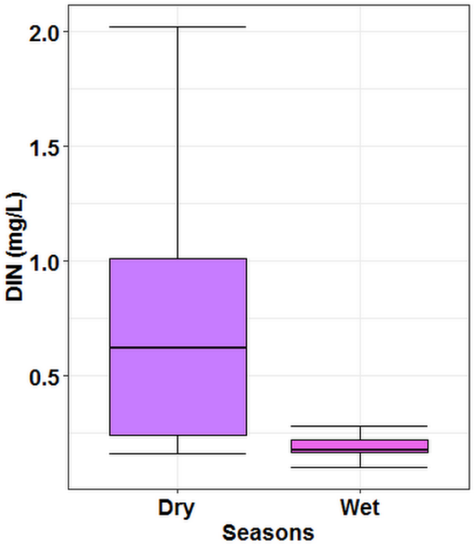
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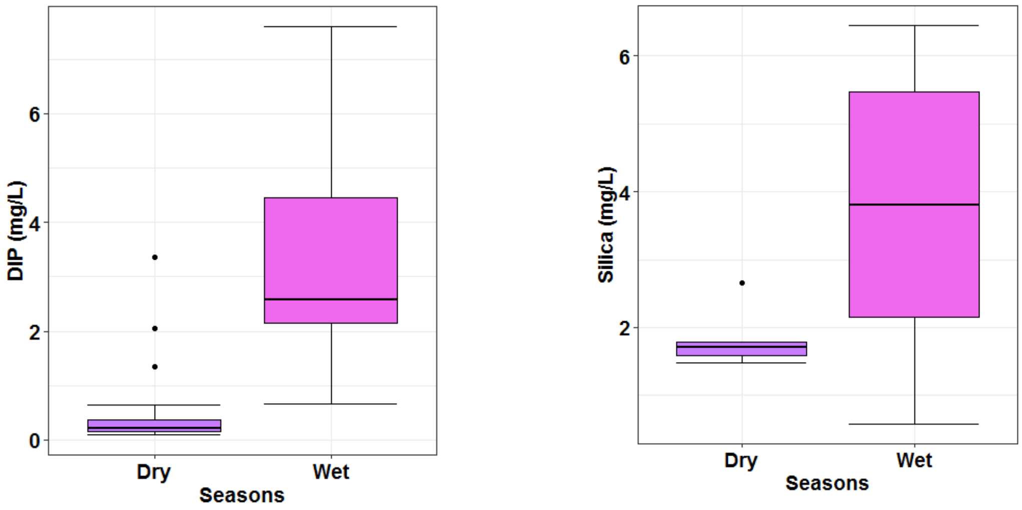

Fig. 2. Seasonal variations of measured water variables at different stations

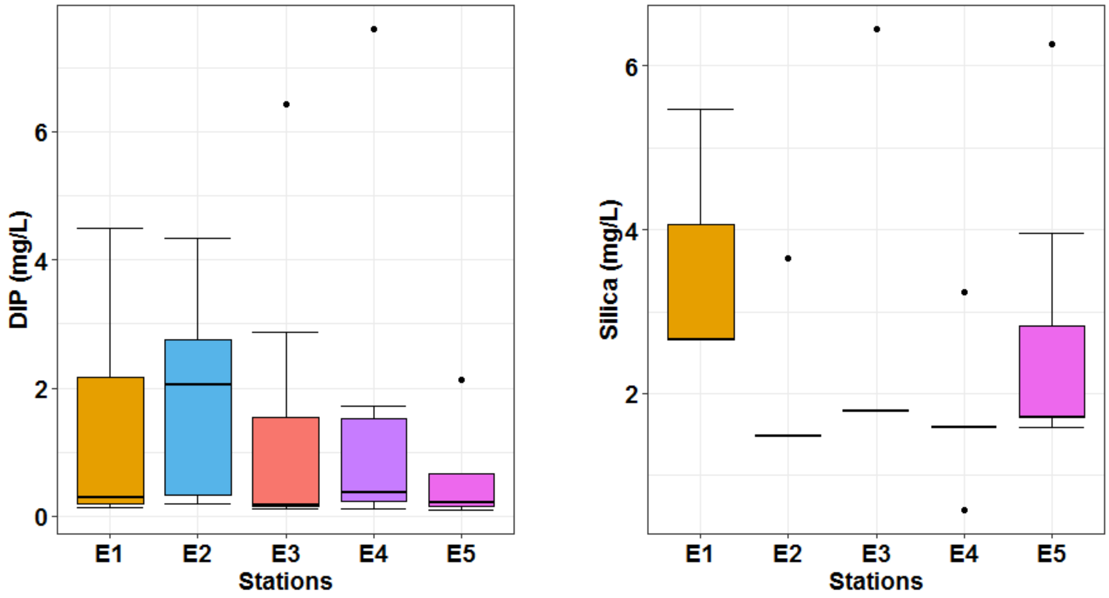

Fig. 3. Spatial variations of measured water variables at different stations

PCA is the simplest eigenvector-based multivariate analysis presented in Fig. (4). The multivariate analysis (PCA) test showed a seasonal gradient for the water quality parameters, forming two different groups for the dry and wet seasons (Fig. 4). According to PCA, the first PC explains 49.8% of the variation, and the second PCA adds another 20.9% to that explanation (Fig. 4). Collectively, the first four axes accounted for 92.6%

of the variance in the environmental data (Fig. 4). The first axis's variability was established by NH_4, salinity, and DIN. While other factors showed a favorable connection, salinity actually played a negative role. The second axis had a robust relationship with variables like NO_2 and NO_3. In Fig. (5), we have a representation of the correlation matrix between the various measures of water quality. There was a positive relationship between water salinity and NH_4 ($r = 0.74$; $P < 0.05$) and DIN ($r = 0.78$; $P < 0.05$). During the period of the investigation, there was a statistically significant inverse relationship between salinity and NO_3 ($r = -0.64$; $P < 0.05$).

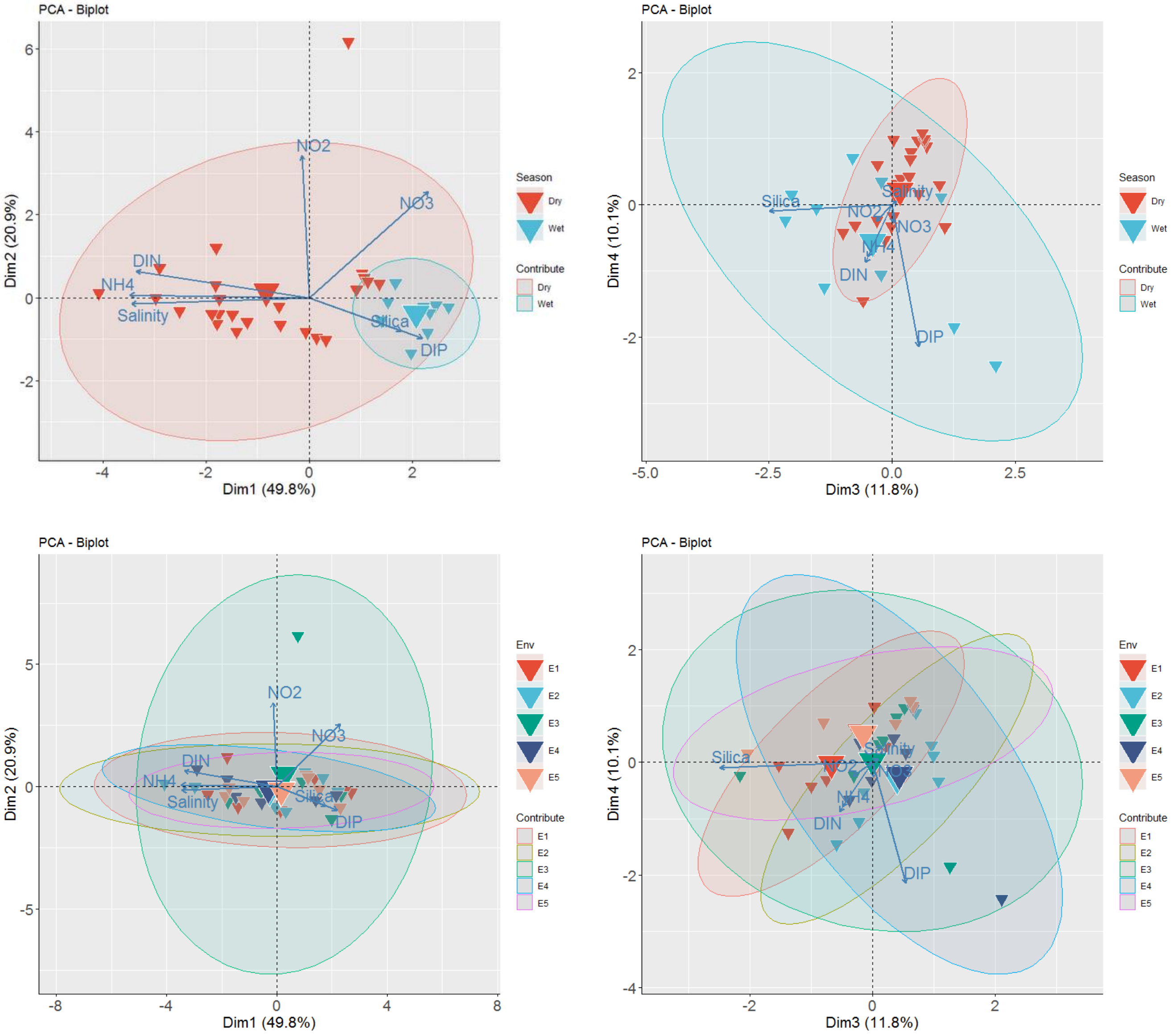

Fig. 4. Principal component analysis

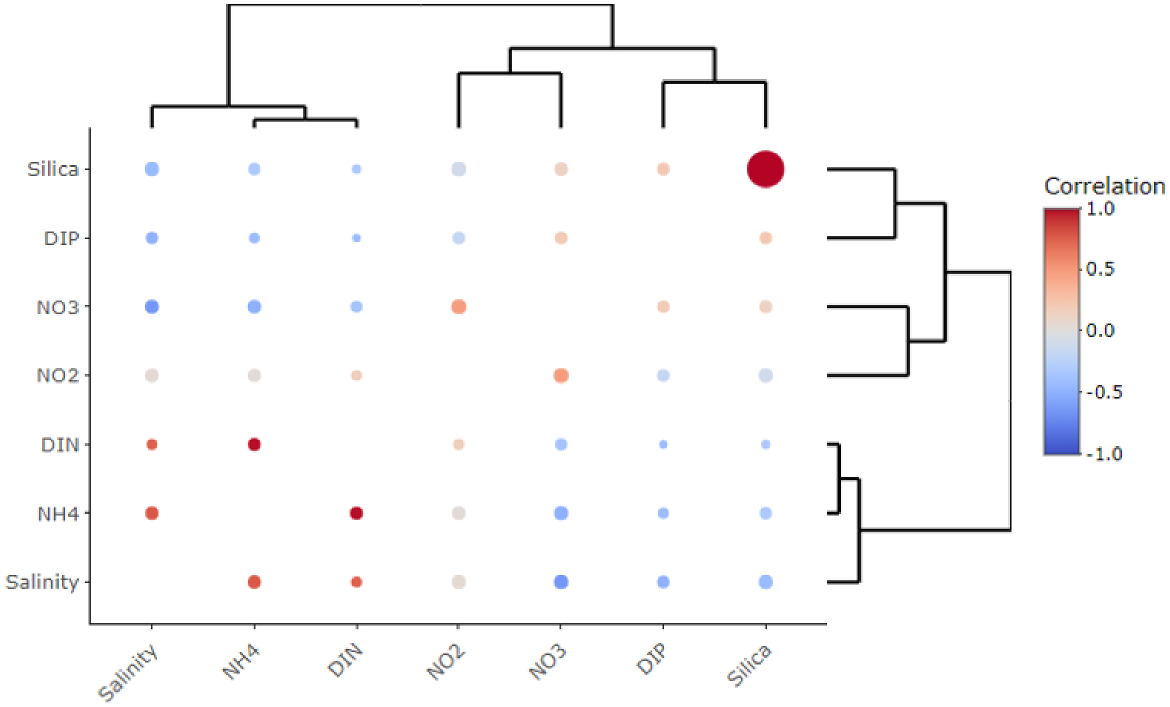

Fig. 5. Correlation heatmap of water quality parameters

Dissolved nutrients and eutrophication in mangrove waters

The nutrient composition of different environments varied greatly from one another. Table (1) shows that the highest DIN concentration was found at sample station E2 (0.65mg/ L), followed by E4 (0.64mg/ L), E1 (0.55mg/ L), E3 (0.46mg/ L), and E5 (0.45mg/ L). Similarly, E2 (1.82mg/ L) has higher DIP levels than E4 (1.65mg/ L), E3 (1.45mg/ L), E1 (1.38mg/ L), and E5 (0.57mg/ L). The estuary water's N:P atomic ratio, on average, was 0.78 in the E5 and 0.32 in the E3 (Table 1), reflecting the differences in N and P distribution. In addition, the Si:N ratio in Pasur River mangrove estuarine water ranged from 6.26 in the E1 to 2.61 in the E4 (Table 1). The Si:P ratio was 4.6 at the E5 station and 0.98 at the E2 site.

Table 1. Dissolved nutrients and atomic ratios in the Sundarbans mangrove ecosystems

	DIN (mg/L)	DIP (mg/L)	Silica (mg/L)	N: P ratio	Si: N ratio	Si: P ratio
E1	0.55	1.38	3.45	0.39	6.26	2.51
E2	0.65	1.82	1.79	0.35	2.76	0.98
E3	0.46	1.45	2.44	0.32	5.21	1.68
E4	0.64	1.65	1.68	0.38	2.61	1.01
E5	0.45	0.57	2.66	0.78	5.88	4.60

DISCUSSION

The primary driving force behind the lower salinity gradients in the wet season compared to the dry season is the discharge of freshwater into the estuary. Further, changes in salinity have been linked to alterations in the composition of plankton communities in mangrove ecosystems **(Saifullah *et al.*, 2014)**. High salinity in estuaries means that diatoms predominate, but when the salinity drops, the green algae take over upstream **(Nursuhayati *et al.*, 2013)**. Since estuary regions are continuously susceptible to alteration due to marine, freshwater, and other environmental perturbations, estuarine ecosystems are extremely dynamic **(Rabalais *et al.*, 2002)**. There is a gradient of nutrient limitation for biological productivity from fresh to estuarine to marine environments. Although there are always outliers, shifts in the primary nutrients, like nitrogen and phosphorus, may drive shifts in the limiting nutrients along the three zones. Anthropogenic and industrial loadings of nitrogenous and phosphorous chemicals via rivers enrich the PRE during the dry season, when river flow and tidal mixing are limited. Anthropogenic and industrial operations, such as those at ports, fertilizer plants, iron ore processing plants, dye and pigment processing plants, caustic soda plants, petroleum refineries, and other facilities, are a constant threat to PRE **(Shruthi *et al.*, 2011)**. When it comes to regulating species composition, nutrient loadings play a vital role. It has been shown that changes in fertilizer loadings affect plankton species composition **(Krishnan *et al.*, 2020)**. Changes in land-use, urbanization, and industry are the primary causes of elevated DIN levels **(Cho *et al.*, 2004)**. Similarly, the allochthonous nutrients from human disturbances change the nutritional structure and biogeochemistry of mangrove estuaries, leading to large increases in dissolved N and P concentrations **(Rahman *et al.*, 2009)**. During the wet season, nitrate and phosphorus levels were higher. With the onset of the non-monsoon season, high salinity prevails, and the entrainment of important nutrients like nitrate, silica, and phosphate during the wet season from river discharges and anthropogenic activities is being saturated. The increased nutrient concentrations during the rainy season are likely the result of nutrients being eroded, dissolved, and transported from neighboring catchments into the source regions of each system. The greater standing mass of mangrove litter produced during the rainy season is another potential source of nutrients **(Duke *et al.*, 1981)**. In general, silica concentrations were high during the rainy season. Siliceous primary producers, such as diatoms, rely heavily on dietary silica **(Sospedra *et al.*, 2018)**. The silica used is primarily sourced from the runoff of rivers. The prevalence of noxious algal blooms and hypoxia/anoxia in coastal waters is positively correlated with nutrient (particularly nitrogen) levels **(Xu *et al.*, 2008; Beman *et al.*, 2005)**. A lack of nitrogen, phosphorus, and silica limits primary productivity in coastal environments. The quantity of biological N fixation, the amount of preferential storage, recycling, or loss of N or P in the ecosystem, and the ratio of external N:P in inputs to the ecosystem all influence nutrient availability **(Vitousek & Howarth,**

1991). Most likely, nitrogen (N) is the nutrient that causes the most eutrophication in these systems. The nutrient composition of different environments varied greatly from one another. Anthropogenic nutrient contamination is mostly to blame for the large departure of nutrient ratios in the PRE mangrove estuary from the Redfield ratio.

According to the Redfield ratio, which establishes a typical molar ratio of nitrogen to phosphorus (N:P) as 16:1 **(Redfield, 1958; Downing, 1997)**, an excess of phosphorus relative to nitrogen is indicated when the N:P ratio in the water falls between 0.32 and 0.78. This range suggests that phosphorus is present in excess compared to nitrogen in these systems (Table 1). The high rates of phosphorus input from rivers and phosphorus released from benthic organisms in the PRE mangrove estuary make nitrogen a limiting nutrient (Table 1). Firstly, there may be an excess of phosphorus in the estuary mangrove waters because the N:P ratio is lower. Secondly, mangrove waters may undergo selective nitrogen loss by denitrification. Last but not least, nitrogen takes a lot longer to rebuild than phosphorus does **(Vitousek and Howarth, 1991)**. Besides the obvious changes in production and oxygen levels, eutrophication often causes shifts in the composition of benthic fauna, flora, and phytoplankton **(NRC, 2000)**. Reducing coastal eutrophication requires nitrogen restrictions in coastal waterways. P availability drives some of these shifts since various primary producers can be favored by varying N availability. Some unwelcome macro-algal species, for instance, can become dominant when P concentrations are too high in the benthos **(Conley, 2000)**. Diatoms are the only phytoplankton that need Si, therefore, fluctuations in Si availability induce other shifts. When the N:P ratio is low, excessive concentrations of inorganic P can encourage toxic algal blooms, such as those caused by Phaeocystis and several species of dinoflagellates **(Cugier *et al.*, 2005)**. Due, in large part, to a lack of dissolved silica, the Si:N ratio in PRE is low, which has a negative impact on diatom productivity. Since the Si:N ratio in the PRE mangrove estuary was greater than 1, it can be concluded that the estuarine mangrove waters receive a significant amount of silica from terrestrial weathering. The Si:P stoichiometry can potentially be affected by a decrease in terrestrial silicate loadings or an increase in phosphorus loadings.

CONCLUSION

The biosphere found in and around mangroves is noted for being active and extremely productive, providing significant nutrients and energy and regulating biogeochemical cycles in the coastal and marine environment. Nutrient stoichiometric ratios in the PRE showed a significant departure from the Redfield ratio, indicating that mangroves were not eutrophized. Due to nutrient enrichment, increased phytoplankton development and high biological productivity result from elevated levels of dissolved inorganic nitrogen and phosphorus in mangrove sediments. Our research also showed that in a natural, unpolluted ecosystem like the PRE mangroves, the biogeochemical cycles of nitrogen and phosphorus are not greatly affected. In this field of study area, there is a dearth of literature addressing these issues. The quantities and composition of nutrients in coastal waters must be monitored over long periods of time in order to identify trends. The study's findings will serve as a benchmark for managers as they evaluate and work to improve tidal brackish water mangrove creek ecosystems.

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DECLARATION OF INTEREST'S STATEMENT

The authors declare no conflict of interest.

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