EFFECT OF DIURNAL TIDES ON THE WATER QUALITY PARAMETERS OF A COASTAL RIVER CONNECTED WITH THE BAY OF BENGAL

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ABSTRACT

To study water quality changes and tidal effects, hourly samples were collected on 17-18 June 2022, in the Andharmanik River, Bangladesh. Parameters measured included temperature (28.8-30.6 °C), salinity, dissolved oxygen (5.9-6.33 mg/L), pH (7.15-7.98), TDS, conductivity, alkalinity, and hardness. Temperature, DO, and pH showed minimal correlation with water height, while salinity peaked at low tide due to evaporation and no freshwater inflow. Strong correlations were between TDS and conductivity, and water height and several parameters. Most measurements varied with the tide, offering a key baseline data for the region.

RÉSUMÉ: Effet des marées diurnes sur les paramètres de qualité de l'eau d'un fleuve côtier relié au golfe du Bengale.

Pour étudier les variations de la qualité de l'eau et les effets des marées, des échantillons horaires ont été prélevés les 17 et 18 juin 2022 dans la rivière Andharmanik, au Bangladesh. Les paramètres mesurés étaient les suivants: la température (28,8-30,6°C), la salinité, l'oxygène dissous (5,9-6,33 mg/L), le pH (7,15-7,98), les solides dissous totaux (TDS), la conductivité, l'alcalinité et la dureté. La température, l'oxygène dissous et le pH présentaient peu de corrélation avec la hauteur de l'eau, tandis que la salinité atteignait un pic à marée basse, en raison de l'évaporation et de l'absence d'apport d'eau douce. De fortes corrélations ont été observées entre les TDS et la conductivité, ainsi qu'entre la hauteur d'eau et plusieurs autres paramètres physico-chimiques. La majorité des mesures ont montré une variation liée à la marée, fournissant des données de référence essentielles pour cette région côtière.

REZUMAT: Efectul mareelor diurne asupra parametrilor calității apei unui râu de coastă conectat la Golful Bengal.

Pentru a studia variațiile calității apei și efectele mareelor, s-au prelevat probe din oră în oră în perioada 17-18 iunie 2022 în râul Andharmanik, Bangladesh. Parametrii măsurați au inclus temperatura (28,8-30,6 °C), salinitatea, oxigenul dizolvat (5,9-6,33 mg/L), pH-ul (7,15-7,98), TDS, conductivitatea, alcalinitatea și duritatea. Temperatura, oxigenul dizolvat și pH-ul au arătat o corelație minimă cu nivelul apei, în timp ce salinitatea a atins un vârf la reflux din cauza evaporării și a lipsei de aflux de apă dulce. S-au observat corelații puternice între TDS și conductivitate, precum și între nivelul apei și mai mulți parametri. Majoritatea rezultatelor au variat în funcție de maree, oferind date pentru această zonă și râuri de coastă învecinate.

INTRODUCTION

Deltas and estuaries are dynamic habitats influenced by both freshwater flowing from rivers and ocean seawater (Boicourt, 1993). Regular changes in water levels known as tides are seen in oceans and other large bodies of water, and they are primarily caused by the moon's gravitational pull, with the sun playing a supporting role (Singaraja et al., 2016). Semidiurnal tides are characterized by two high tides and two low tides occurring within a 24-hour period, with a roughly equal interval between each high and low tide (Herring and Dong, 1994). During high tide, the estuary experiences an inflow of seawater, causing a significant rise in the water level (Leuven et al., 2019). As seawater flows into the estuary, it brings nutrients and sediments, contributing to the ecological diversity and productivity of the region (Nixon et al., 1986). The fluctuation in water levels during tidal cycles also plays a crucial role in the life cycles of various marine species, facilitating activities such as feeding, reproduction, and migration (Khojasteh et al., 2021). Tides, for example, can have an impact on river water quality characteristics (Gasim et al., 2015). The relationship between tides and water quality is especially important in estuaries and tidal rivers, where tidal water movement can influence numerous essential parameters (Cereja et al., 2022). The crucial life support for aquatic organisms (such as fishes, amphibians, reptiles, and mammals) lies in the physicochemical characteristics of water (Bănăduc et al., 2023, 2016; Pinheiro et al., 2021). Parameters like pH, temperature, salinity, dissolved oxygen, alkalinity, and hardness play a significant role in influencing these organisms (Mariu et al., 2023). The evaluation of these abiotic and biotic factors helps assess the overall health of the aquatic environment (Davies, 2014).

Bangladesh is classified as a riverine country due to the presence of several rivers throughout the region (Rahman, 2015). The coastline of Bangladesh stretches 710 km from the Sundarbans mangrove forest in the southwest to the coral island of St. Martin's in the southeast (Shamsuddoha and Islam, 2016). The southern and southwestern coasts of Bangladesh are home to a diverse coastal and estuarine habitats blessed with mangrove forests, seagrass, seaweeds, etc. The Andharmanik River, located in the southern region of Bangladesh, specifically in Kalapara Upazila, Patuakhali, Bangladesh, is an important coastal river. Its close location to the Bay of Bengal makes it a highly productive coastal water body, teeming with fish and other aquatic organisms (Roy et al., 2022). Not far from the estuary of this river is where the Sundarbans, the biggest mangrove forest in the world, starts. The rich soils that line its banks are ideal for agriculture, especially rice and fish aquaculture and the local communities depend on the 40 km long river for their survival. It is also one of the six Hilsa sanctuaries in Bangladesh for the protection of juvenile Hilsa (Ali et al., 2020). The tidal pattern of the river is semidiurnal (two high tides and two low tides/day) and it's mesotidal (tidal range 3-4 m at spring tide) based on the amplitude (Kamal and Khan, 2009). Along these river's banks, a growing number of construction projects are taking place, including the development of the Payra seaport and a 1,320-megawatt coal-fired power plant (Mirza, 2021).

The research on the tidal influences on the physicochemical properties of coastal rivers in Bangladesh is very scanty. Although some pertinent studies have been conducted across the globe. The Tiakhali River, which flows from the Andharmanik River, had all of its physicochemical parameters within the ideal range except for temperature which was slightly higher than the other coastal rivers of Bangladesh (Khan et al., 2023).

A thorough analysis of the biological and environmental data from 21 estuaries around the Bangladesh coast during the previous 35 years was conducted by Rakib et al. (2022) and reported monsoon patterns, nutrient inflow, salinity intrusion, riverine discharge, siltation, and human interventions, all caused major variations in the physico-chemical and geological parameters in estuaries. The estuaries are now at ecological risk due to probable metal contamination that is likely caused by the sources of diesel and gasoline from mechanized fishing trawlers and home disposals (Rakib et al., 2022). 85% of the samples from the Rupsha River have levels of heavy metals (Cd, Ni, As, Pb, and Cr) that are above-permitted limits and constitute a moderate ecological risk (Samad et al., 2015). Singaraja et al. (2016) conducted research on the southeast coast of Tamilnadu, India, studying the impact of tides on groundwater dynamics in shallow coastal aquifers. They observed the water table fluctuations over a 24-hour period, with measurements taken at two hours intervals, and established a correlation between tidal variations and these fluctuations. Nandy et al. (2018) carried out research examining alterations in key water quality indicators (such as surface water temperature, salinity, dissolved oxygen, pH, nutrient levels, and pigment concentrations) within a short time interval. The study also took into account tidal fluctuations during various phases of the tidal cycle within the Sundarban estuarine system in India. Ratnayake et al. (2018) studied how seasonal variations and tidal effects impact the changes in water quality within the coastal Bolgoda Lake system in Sri Lanka. Gasim et al. (2015) evaluated the water quality parameters of the Paka River with tidal influence in Terengganu, Malaysia.

Therefore, the objective of this study was to monitor the effects of diurnal tides on the water quality parameters of tide-induced Andharmanik River connected with the Bay of Bengal, Bangladesh, throughout the day.

MATERIAL AND METHODS

Background

This investigation was carried out on the Andharmanik River, located in the southern coastal region of Kalapara, Patuakhali, Bangladesh. The river is tidally driven and distinctively opens into the Bay of Bengal at both its upstream and downstream ends, making it hydrologically unique. The study was conducted on the southern coastal Andharmanik River of Kalapara, Patuakhali, Bangladesh, which is a tidally induced river and it’s a unique river as it opens to the Bay of Bengal on both sides. The study was conducted on a sunny day and there was no cloud or fog for 24 hours at one hour intervals from 12:00 h on 17th June to 11:00 h on 18th June in 2022 including two high tides (at 12:16 h, water height of 3.3 m and 0:38 h, water height 2.9 m) and two low tides (at 18:51 h, water height 0.8 m and 6:59 h, water height 0.9 m) in the front of the Riverine Sub-Station, Bangladesh Fisheries Research Institute, where the area is covered by many mangrove species like *Sonneratia alba*, *Acanthus ilicifolius*, *Avicennia marina*, etc. The below figure 1 depicts the study sites’ geographical positions.

For monitoring the tidal influence on the physicochemical parameters of water, high-quality dried plastic bottles were used to collect the surface water (within 30 cm depth) from the selected site of the river. The bottle was thoroughly cleaned with river water before collecting the water sample at the appropriate time interval. During in-situ measurement, water temperature and pH were determined by using a pocket pH meter (HANNA HI98107, Romania), salinity, dissolved oxygen (DO), total dissolved solids (TDS), and conductivity were determined by using a multiparameter (HANNA HI19894, Romania). Total alkalinity was measured by using the alkalinity test kit (HANNA HI3811, Romania), while total hardness was measured by using the hardness test kit (HANNA HI3812, Romania). Water level fluctuation was measured by a portable depth echosounder (0.6 to 100 m depth). Data were analyzed for scatter plots using MS Office (Excel 365) and Pearson correlation coefficient by using R studio (version 4.1).

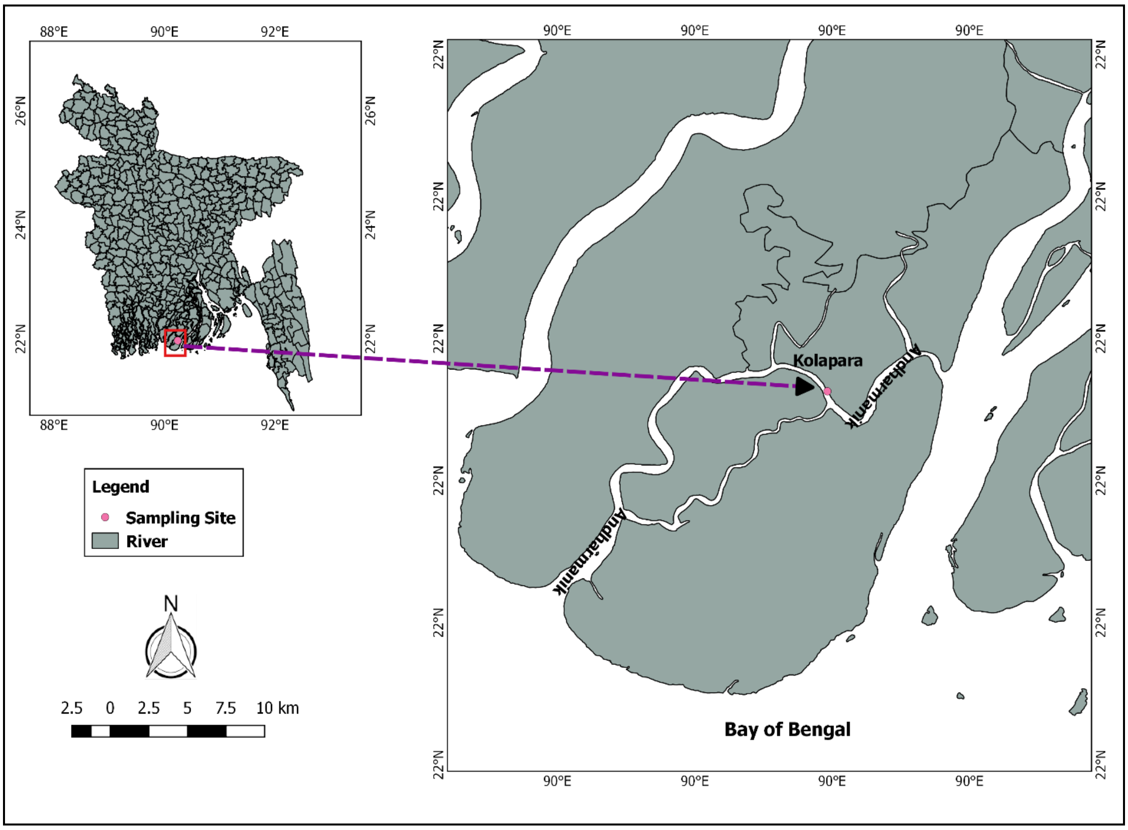

Figure 1: Map containing study area on the Andharmanik River connected with the Bay of Bengal, Bangladesh.

RESULTS AND DISCUSSION

The rising water levels during the sampling period were accompanied by corresponding changes in multiple water quality parameters, reflecting the dynamic influence of tidal fluctuations. The minimum, maximum, and mean values of all parameters during diurnal tides are presented in the below table 1.

Table 1: The minimum, maximum, and mean (±standard deviation) values.

Parameters	Minimum	Maximum	Mean ± SD
Water temperature (˚C)	28.8	30.6	29.66±0.56
Dissolved oxygen (mg/L)	5.9	6.33	6.06±0.15
pH	7.15	7.98	7.68±0.20
Salinity (PSU)	1.37	4.71	3.14±1.21
Total dissolved solids (mg/L)	1340	4267	2903.79±1055.75
Conductivity (µS/cm)	2680	8538	5807.50±2109.56
Total alkalinity (mg/L)	51	93	71.00±12.94
Total hardness (mg/L)	127	483	284.50±115.09

The temperature of the water of the Andharmanik River varied from 28.8-30.6˚C within 24 hours (Fig. 2), showing minimal fluctuation in water temperature. Moreover, the results showed that water height may not significantly influence this parameter (Fig. 3). The water temperature was highest in 15.00 and 16.00 h during the daytime and decreased from the afternoon (17.00 h) to morning (5.00 h). Optimal water temperature is crucial for the survival, growth, and reproduction of aquatic life (Kasan et al., 2023). The present study's temperatures were below 32°C and favorable for the river's aquatic species. River or stream temperatures shouldn't be higher than 32°C since high temperatures diminish DO and can kill fish (Rahman et al., 2021; Uddin et al., 2015).

Dissolved oxygen (DO) refers to the amount of oxygen gas (O_2) that is present in water bodies. It is a significant parameter in all the aquatic ecosystems, as it plays a continuous vital role in supporting aquatic life (Nandy et al., 2018). In contrast to a usual level of 6 mg/L or above (Kasan et al. 2023), a DO level below 1 mg/L is harmful to aquatic life and indicates water pollution (Uddin and Jeong 2021). The experiment's findings showed that the Andharmanik River's DO concentrations ranged from 5.9 to 6.33 mg/L (Fig. 2), indicating a suitable DO for aquatic organisms. The results also suggest that water height may not significantly influence water dissolved oxygen levels (DO). Instead, there appears to be a positive correlation between water temperature and DO levels, as depicted in figure 3. Specifically, it is observed that as temperatures rise, DO levels tend to increase, while conversely, DO levels decrease after sunset when temperatures decrease. In the Passur-Rupsa Estuary, it was discovered that the relationship between temperature and DO was inversely correlated ($r = –0.252$) (Rouf, 2022). The DO concentration is greatly influenced by biological activities in the estuarine system, the higher temperature increases the biological activities such as photosynthesis thus increasing DO during the daytime, and on the other hand the lower temperature reduces the biological activities thus decreasing the DO concentration during the night (Haddout et al., 2022).

The pH determines the alkalinity or acidity of a river's organic and mineral content. Since both high and low pH levels may be detrimental to aquatic species, it is essential to evaluate their viability (Uddin and Jeong, 2021). According to DoE (1997), the ideal pH range for irrigation and fish culture is between 6.5 and 8.0, while the typical pH range for river water systems is 6.5 to 8.5. The average pH value in this research was 7.68 ± 0.20 (Fig. 2), indicating that the water was slightly alkaline. The findings reveal that the pH level may not be affected by water height (Fig. 3).

The salinity of the studied Andharmanik River was higher (4.71 PSU) at low tide and lower (1.37 PSU) at high tide (Fig. 2), owing to local evaporation and the lack of freshwater inflow. The salinity of Andharmanik River is inversely correlated (correlation coefficient, $r = –0.57$) with tidal fluctuations (Fig. 5). The Andharmanik River has "inverse estuary" features, a river system where freshwater input is less than the losses due to evaporation, and thus low tide results in higher salinity and high tide results in lower salinity. This is a characteristic of some mangrove ecosystems that are frequently seen during extended dry spells with significant evaporation rates (Kitheka, 1996; Wolanski, 1986). Since porewaters may move into the water and raise the amount of salts, they may be the cause of the increased salinity during low tide as found by Barnes et al. (2006) and Bouillon et al. (2007). These characteristics make the Andharmanik River distinct from other rivers in Bangladesh and likely contribute to its recognition as a vital nursery ground for the country's coastal fish species.

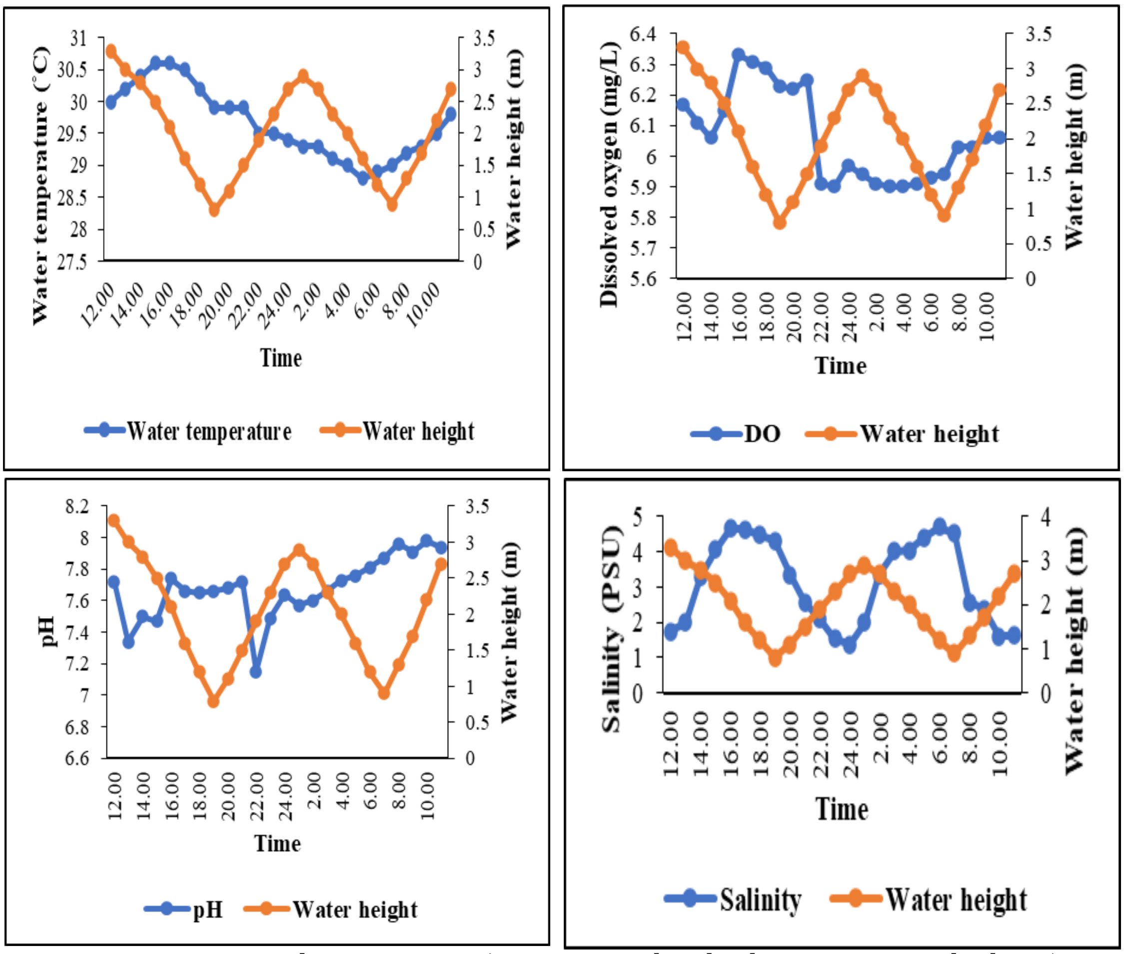

Figure 2: Water quality parameters (temperature, dissolved oxygen, pH, and salinity) variation with diurnal tides of the surface waters in the studied tidal coastal river.

Total dissolved solids (TDS) and conductivity are two commonly used indicators of water quality, particularly in coastal environments. TDS concentration indicates the presence of inorganic salts and trace quantities of organic materials in water, while conductivity measures the capacity of water to conduct electrical current (Rusydi, 2018). The TDS in the current study varied from 1,340 to 4,267 mg/L (Tab. 1 and Fig. 3), which is within the permissible limits (Prasanna and Ranjan, 2010). The results from the experiment found that there was a negative correlation ($r = -0.55$) between TDS and water height, but a highly positive correlation exists between TDS and salinity, conductivity, total alkalinity, and total hardness (Fig. 5). The conductivity in this experiment was almost double of TDS and supports the study of McNeil and Cox (2000) and Rusydi (2018) and ranged from 2,680 to 8,538 µS/cm (Fig. 4) and found that there was a negative correlation ($r = -0.57$) between conductivity and water height but a highly positive correlation between conductivity and salinity, TDS, total alkalinity, and total hardness (Fig. 5). As the salinity increases, the TDS and conductivity also increase; as the salinity decreases, the TDS and conductivity also decrease (Rusydi, 2018). However, TDS and conductivity are salinity indicators, making them a particularly helpful tool for analyzing seawater incursion (Han et al., 2011; Moujabber et al., 2006).

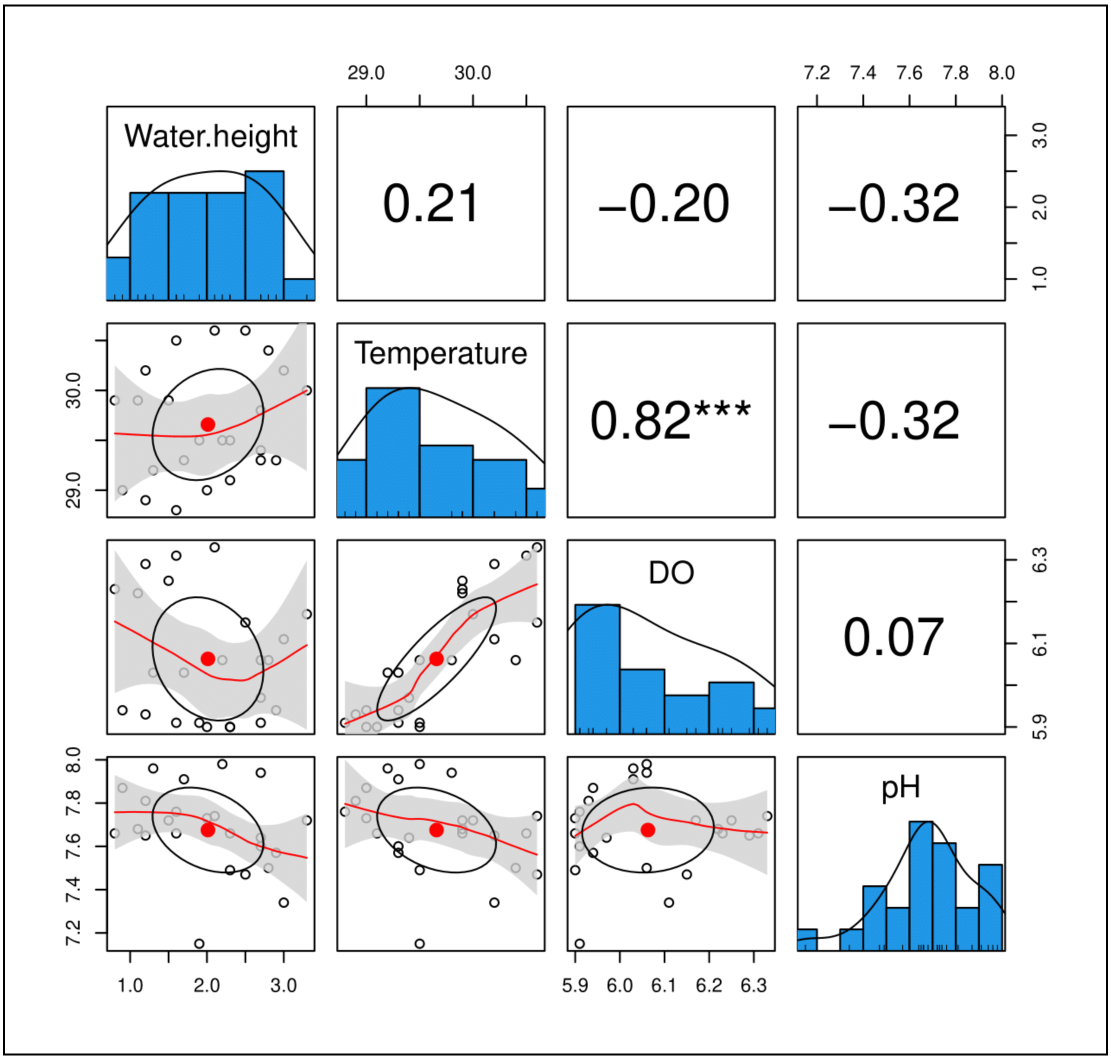

Figure 3: Correlation among different water quality parameters
(water height, temperature, dissolved oxygen, and pH)
in surface waters of the tidal coastal studied river.

The estuary's capacity to neutralize acidic contaminants from rain precipitations or humans wastewater is determined by the alkalinity (Anitha and Kumar, 2013). The total alkalinity in the current findings of this research varied from the values 51 to 93 mg/L in the Andharmanik River and it was lower at high tide and higher at low tide (Fig. 4). The obtained results from our experiment found that there was a negative correlation (r = –0.51) between the total alkalinity and the water height but a highly positive correlation between total alkalinity and salinity (r = 0.97), TDS (r = 0.98), conductivity (r = 0.97), and total hardness (r = 0.97) (Fig. 5).

The amount of divalent metal ions in water, typically calcium and magnesium, is measured as water hardness and is often affected by the geology of the area, the source of water, and human activities (Prasanna and Ranjan, 2010). The total hardness of the Andharmanik River was higher at low tide and lower at high tide (Fig. 4). The mean total hardness in the current study was 284.50 ± 115.09 mg/L (Tab. 1) which supports the findings of Joshi et al. (2009) and Flura et al. (2023). The results showed that there was a negative correlation (r = –0.57) between total hardness and water height but a highly positive correlation between total alkalinity and salinity, TDS, conductivity, and total alkalinity (Fig. 5). The present study focused on a highly dynamic region that experiences strong tidal influences due to its close connectivity with the Bay of Bengal, resulting in rapid fluctuations in all water quality parameters.

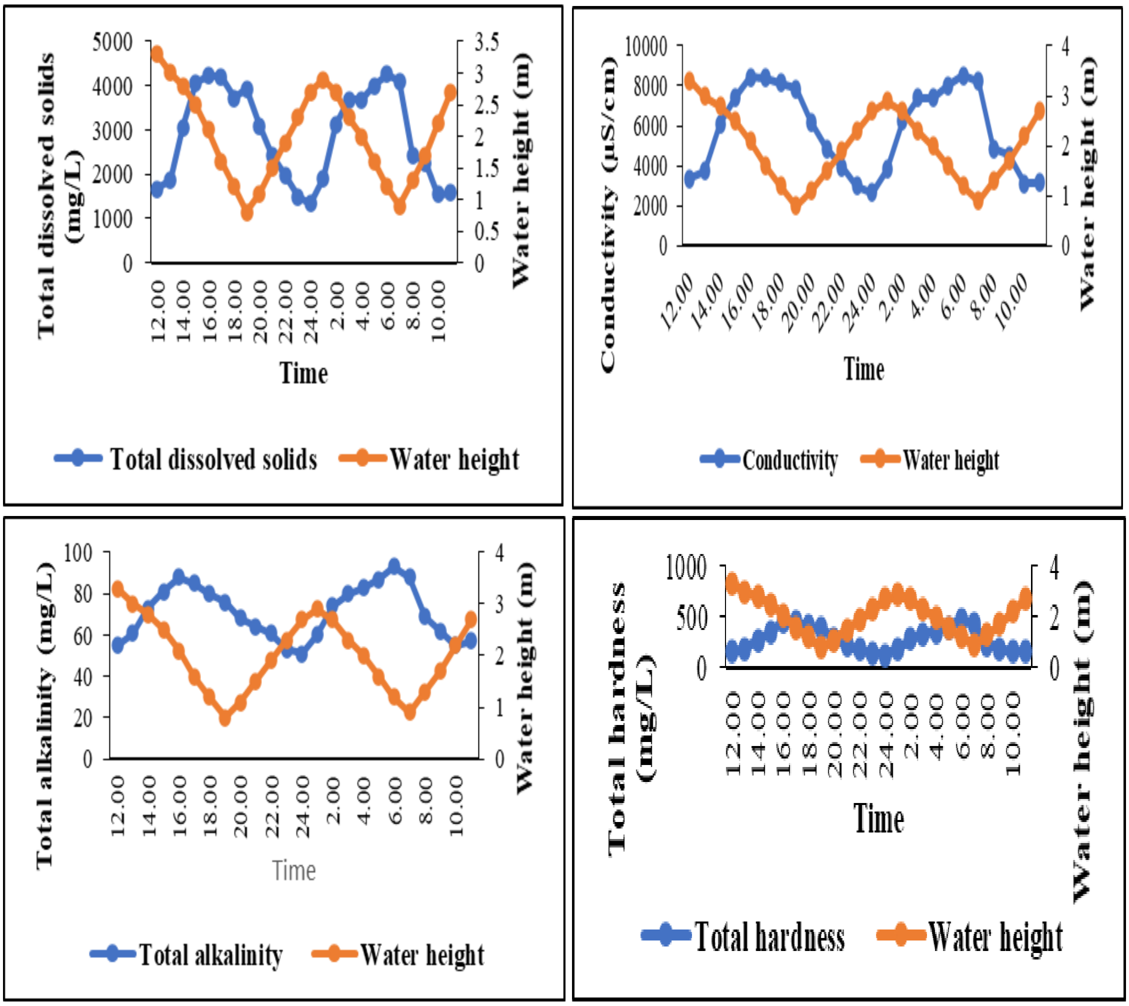

Figure 4: Water quality parameters
(total dissolved solids, conductivity, total alkalinity, and total hardness)
variation with diurnal tides in the surface waters of the studied tidal coastal river.

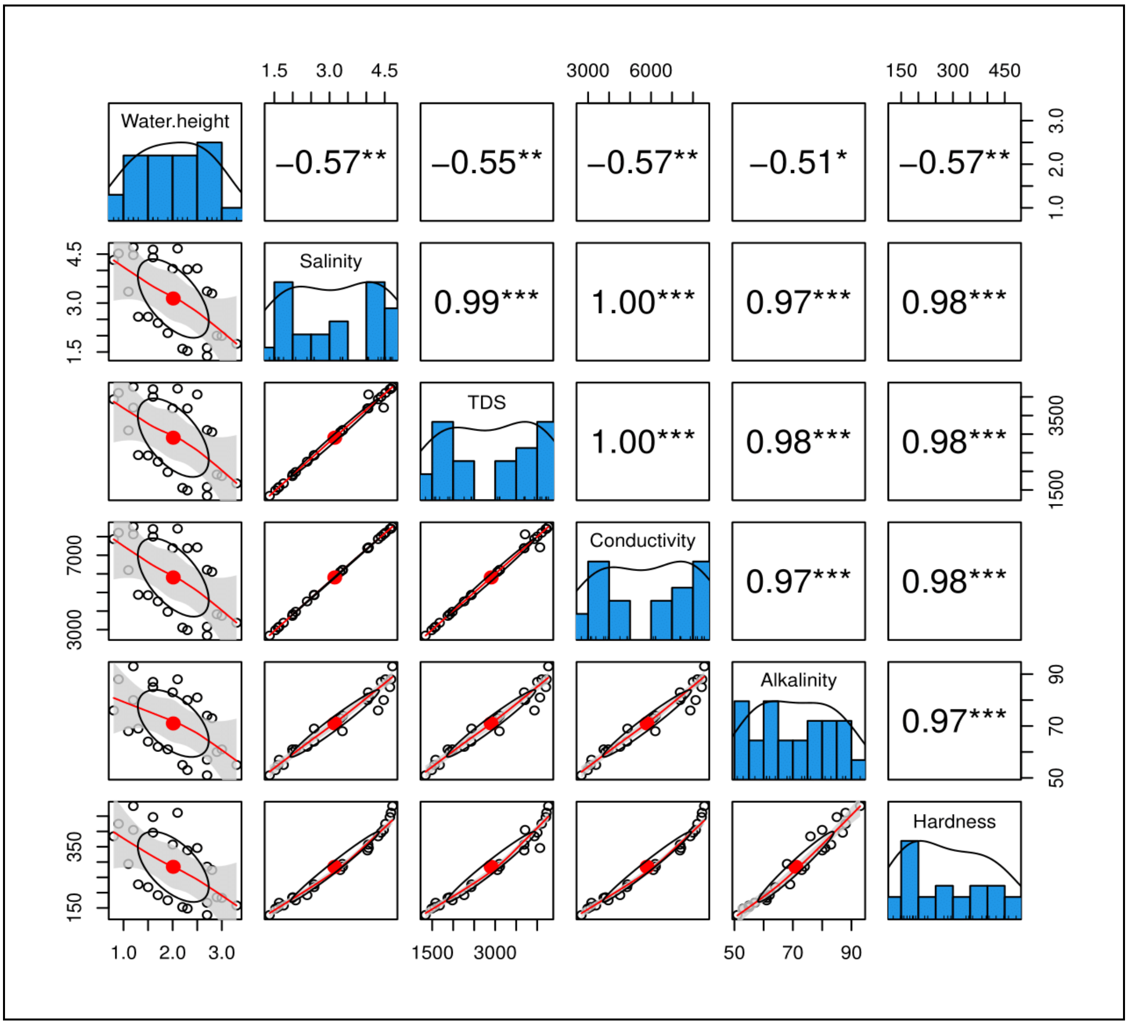

Figure 5: Correlation among water quality parameters (height, salinity, total dissolved solids, conductivity, total alkalinity, and total hardness) in the surface waters of the studied river.

CONCLUSIONS

Like other tropical nations, Bangladesh has rich and dynamic estuarine ecosystems where ecological drivers change every day and even every hour. In the current investigation, key water quality parameters were measured at hourly intervals over a 24-hour period in the Andharmanik River, a coastal waterway connected to the Bay of Bengal. The current study emphasized how crucial hourly sampling is in a specific area where water quality variables fluctuate in response to tidal elevation. Despite these fluctuations, the parameters of the water quality typically fall within ranges that are favorable for the survival of aquatic life, underscoring the river's significance as a critical habitat for coastal fish species. It is crucial to monitor these water quality parameters and understand their interactions with tidal cycles to ensure the well-being of the river's ecosystem. This study will provide important data on diurnal tides in the Andharmanik River and serve as a baseline for comparative analysis with nearby impacted rivers. Future research should explore the long-term trends in water quality across different seasons and lunar phases.

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