INVESTIGATION OF TIDAL IMPACT ON NUTRIENT EXCHANGE IN SOME COASTAL RIVERS IN SOUTH-WEST BANGLADESH

By

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POST GRADUATE DIPLOMA IN WATER RESOURCES DEVELOPMENT

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INVESTIGATION OF TIDAL IMPACT ON NUTRIENT EXCHANGE IN SOME COASTAL RIVERS IN SOUTH-WEST BANGLADESH

A Project Report

By

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Student ID: 1018281016

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CERTIFICATE OF APPROVAL

The project report titled "INVESTIGATION OF TIDAL IMPACT ON NUTRIENT EXCHANGE IN SOME COASTAL RIVERS IN SOUTH-WEST BANGLADESH", submitted by Md. Zahurul Islam, Student ID: 1018281016, Session: October 2018, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Post Graduate Diploma (PG.Dip.) in Water Resources Development on 20 November, 2021.

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It is hereby declared that this project paper or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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Md. Zahurul Islam

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Md. Zahurul Islam.

ABSTRACT

The objective of this research was to investigate the influence of tides on nutrient concentrations in the Pasur and Baleshwar rivers of southwest Bangladesh. The sampling of river water was carried out to study the variation of salinity and nutrient concentrations at different tidal phases during both spring and neap durations. Water samples were collected from the Mongla station of the Pasur river and Sarankhola station of the Baleshwar River for salinity and dissolved nutrients (NO_3^-, PO_4^{3-}, NO_2^- and NH_3–N). The results revealed that the nutrients are significantly influenced by variations in tidal water levels. Expected patterns for salinity variation with tidal water level fluctuation were observed both at the Pasur River and at the Baleshwar River during the tidal cycles of spring tide and neap tide. At both the sites, salinity was relatively higher during spring periods compared to neap periods: 573 μS/cm during spring tide and 559 μS/cm during neap tide at Pasur River; and an average of 433 μS/cm during spring tide and 430 μS/cm during neap tide at Baleshwar River. The fluctuations of salinity during the tidal phases were found to be very small even during the winter season: 57 μS/cm during the spring period with a 2.91 m tidal range and 26 μS/cm during the neap period with a 2.44 m tidal range in the Pasur River; while it was only 37 μS/cm during the spring period with a 2.18 m tidal range and only 38 μS/cm during the neap period with a 1.94 m tidal range in the Baleshwar River. From the measured data, it was found that during neap tide in the Pasur River pH fluctuated from 7.77 to 8.1; nitrate fluctuated between 2.8 to 4.3 mg/l, ammonia 0.14 to 0.29 mg/l, nitrite 0.02 to 0.032 mg/l, phosphate 0.2 to 0.5 mg/l and alkalinity 110 to 125 mg/l. In the same river, during spring tide, pH fluctuated from 7.7 to 8.11, nitrate fluctuated between 2.8 to 4.8 mg/l, ammonia 0.14 to 0.30 mg/l, nitrite 0.02 to 0.03 mg/l, phosphate 0.3 to 0.5 mg/l and alkalinity 110 to 125 mg/l. In the Baleswar River, during the neap tide, pH varied from 7.98 to 8.17, nitrate fluctuated between 2.6 to 4.6 mg/l, ammonia 0.13 to 0.31 mg/l, nitrite 0.01 to 0.022 mg/l, phosphate 0.2 to 0.6 mg/l and alkalinity 105 to 130 mg/l. In the same river, during spring tide, pH ranged from 7.99 to 8.19, nitrate fluctuated between 2.1 to 5.4 mg/l, ammonia 0.15 to 0.28 mg/l, nitrite 0.011 to 0.021 mg/l, phosphate 0.2 to 0.7 mg/l and alkalinity 105 to 120 mg/l. During both the spring and neap periods, nitrate, nitrite, and phosphate concentrations decrease as the tidal water level rises and vice versa. So, it appears that constituents of nitrate, nitrite, and phosphate are supplied from the upstream sides of the Pasur and Baleshwar Rivers to the sampling sites, which can be primarily attributed to the agricultural and municipal runoffs. In the case of ammonia, during both the spring and neap periods, it was found that concentration increased with the rise of tidal water levels and vice versa for both the Pasur and Baleshwar rivers. So, it appears that ammonia was supplied from the seaside towards upstream through both the river systems. Comparison of peak values of ammonia concentration between Pasur and Baleshwar Rivers did not show significant difference which could be related to the impact of Sundarbans Mangrove Forest at the downstream side of Pasur river. So, it was concluded that the sampling locations were too far from the mangrove forest and were not appropriate to make any concrete conclusions on the impact of mangrove forests on the nutrient flux through the selected coastal rivers. The data generated from this study will guide continuing efforts to support the sound management of coastal ecosystems.

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ABBREVIATIONS AND ACRONYMS

BWDB: Bangladesh Water Development Board

DOE: Department of Environment

EQS: Environmental Quality Standard

MSL: Mean Sea Level

APHA: American Public Health Association

CHAPTER 1

INTRODUCTION

1.1 Background

Along the rivers in the coastal regions, tides increase and decrease water levels and allow the exchange of water and materials between the upper and lower segments of the estuary. These affects the abiotic and biotic processes and water quality in estuaries (Davies and Ugwumba.OA, 2013). For a short time, scale (hours), an outgoing tide in the river creates an advection of water and its constituents downstream. On the other hand, an incoming tide causes the intrusion of water and constituents from the lower estuary. In this way, tidal exchange influences the nutrient concentration, salinity, and suspended particulate matter of an estuary (Montana, Magni, and Shimamoto, 1998). Tides can alter suspended particulate matter, including nutrients in particulate form, through turbulent resuspension of sedimented particulate matter (Gilbert, Needoba, Koch, Barnard, and Baptista, 2013). Previous studies reported high nutrient fluxes along some of the rivers in Bangladesh (Monwar, 2001). The Pasur River flows through the Sundarbans Mangrove Forest area in southwest Bangladesh. It is an extension of the Rupsa River and a distributary of the Ganges (Masud, Sirajul, and Ahmed, 2012). The Baleshwar River, further towards the east, is located on the border of the Bagerhat District and Barguna District. The average depth of the estuary of these two rivers is 5-6 m (Chowdhury, 1993). In the estuarine reaches, the Pasur River receives untreated municipal and industrial wastes and runoff of fertilizers from agriculture from the upstream, while its nutrient load is influenced by the mangrove forest downstream. On the other hand, the Baleshwar River mainly receives agricultural runoff from the upstream and is relatively less influenced by the mangrove forest from the downstream. It is very interesting to see how rivers with large tidal ranges (such as the Pasur and Baleshwar rivers) affect the nutrient exchange and what role the Sundarbans Forest plays. This study aims to investigate how the incoming and outgoing tides impact nutrient concentrations of the Pasur and Baleshwar rivers. In addition, how the mangrove forest influences the nutrient loading along the rivers will also be assessed.

1.2. Objective with specific aims

The overall objective of this research is to investigate the impact of tides on nutrient concentrations along some of the coastal rivers in Bangladesh.

The specific objectives are:

1. To determine the nutrient concentrations during flood and ebb tides in selected coastal rivers of southwest Bangladesh.
2. To assess the impact of mangrove forests on the nutrient flux through the selected coastal rivers of southwest Bangladesh.

1.3 Possible outcomes

The results obtained from the research will be useful to understand the role tides play in nutrient transport in the southwest coastal region of Bangladesh. It is an important aspect of the nutrient cycle in estuaries to particularly comprehend the nutrient availability to support primary production as well as nutrient retention in an estuary. The data obtained from this study will be useful to prepare water, salt, and nutrient budgets like the Land-Ocean Interactions in the Coastal Zone (LOICZ) Biogeochemical Modelling Guidelines (Chowdhury et. al., 2004).

1.4 Limitations of the study

(i). Access to the sampling area was very inconvenient because of the river's broadness and turbulence, which hindered the collection of samples from the middle of the Baleshwar River.

(ii). Secondary data availability was one of the major constraints of the study. For water sampling, samples were collected at two-hour intervals to obtain tidal variations. However, water level data collected from BWDB was at different intervals. So, interpolation was necessary for the water level data to match water sampling time intervals.

It can be mentioned that resampling and laboratory testing was done during December 2021 after the defense as per the recommendation of the examination board members.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter begins with a review of the nutrient problems of the coastal zone of Bangladesh. The review primarily includes an overview of the nutrient pattern in the coastal area and the mangrove contribution to nutrient enrichment in the coastal areas of Bangladesh. The southwest region, which covers the study area of this research, is given special attention.

2.2 The current state of the nutrient problem in Bangladesh's south-west coastal zone

Bangladesh's coastal zones encompass 19 districts along the Bay of Bengal. It is separated into three sections: eastern, central, and western, as well as exposed and inner coasts. The coastline area is 47201 km^2, with 23935 km^2 exposed and 23266 km^2 in the inner categories (Haque, 2006; BBS, 2011; Anisuzzaman et al. 2013). It is home to around 50 million people. Ocean streams, webs, and tides, together with upstream freshwater streams, all contribute to the pollution of these zones. There are over 230 rivers in Bangladesh, and they transport tons of sediment into the Bay of Bengal. These silts contain not only unknown levels of plant nutrients but also massive numbers of hazardous residues from rural chemicals, rapid urbanization, industrial residues, cultivate effluents, sewage transfer, and unplanned extraction of coastal assets. Although the use of N, P, and K fertilizers has increased from 1981 to 2016, farmers still use excess fertilizer dosages for crop production. A percentage of excess and unused fertilizers from agricultural regions may find their way into the Bay of Bengal through the coastal rivers.

Agriculture, together with air deposition, power plants, industry, motor vehicles, and distant sources, may deliver roughly 40% N to coastal water, according to Rahman et al. Shrimp production is widespread in Bangladesh's coastal zones, and agriculturists rely on nutrients and large amounts of nutrients to produce them. Nutrient stacking and eutrophication in coastal areas are caused by these methods. Furthermore, some cattle dung and poultry wastes are used in rice fields and for producing fish, while the rest is disposed of in open water and on land.

On Bangladesh's shore, there are more than 8,542 industries (BOBLME, 2011). Industries are concentrated at their highest levels around Dhaka, Narayanganj, Ghorashal, and Tongi, contaminating the Turag and Suitalayakha Rivers. Those tainted waters are on their way to the Bay of Bengal via the Meghna River. In addition, Khulna district has 165 industries in the upstream. These industries' wastes flow into the Bhairab-Rupsha waterway system, finally making their way to the Bay of Bengal via the Sundarbans. Polychlorinated biphenyls are discharged at Sitakunda, Chittagong, at a rate of 22.5 t yr^{-1} (M. R., Islam, 2004). Unrefined waste from tanneries, 35.0 t day^{-1} China clay from the Karnaphuli Paper Process, and 4.0 t day^{-1} fibers from the Karnaphuli Rayon Process are all dumped directly into waterways and so end up in coastal and marine water. Mongla harbour also adds to pollution by releasing waste oil and spilling it, as well as sewage and garbage. Around 50000 t yr^{-1} of oil, refinery waste is discharged, with significant amounts entering coastal waters (M. M., Rahman,2006). Industrial wastes contain excessive metals that have accumulated in the bodies of oceanic life above acceptable levels (H. Tamanna, and M.M. Hossain, 2010).

The majority of crude sewage that enters the ocean and sea water comes from developing countries like Bangladesh and India. Pollutants from India, Nepal, and China travel to the Bay of Bengal via the Padma, Jamuna, and Brahmaputra rivers, where they settle in Bangladesh's coastal soils. The amount of municipal garbage entering the Pasur stream from Khulna and Mongla harbors is estimated to be 2.2 tons of BOD per day (Wahid et al., 2006). Textile companies emit roughly 40,000 m^3 of wastewater per day, with a pollution burden of 26,000 kg per day(S. Dey, and A. Islam, 2015).

Because of rising sea levels and less freshwater input from upstream, Bangladesh's saline zone is spreading. Such an increase in salinity alters the ionic balance in soil and water, impeding the development of fragile organisms. Changes in the ionic predominant order disrupt crop nutrient uptake patterns and make it difficult to be productive in a few zones.

As much as 75 billion tons of soils containing unique natural matter and other nutrients were reallocated due to land erosion (A. Haque, Sumaiya, and M. Rahman, 2016). The water of the Ganges-Brahmaputra-Meghna Stream system carries around one billion tons of sediment and other harmful components each year, with the majority of it ending up in the Bay of Bengal. In Bangladesh, deforestation is widespread due to fuel shortages, brick furnaces, human habitation, salt production, shrimp farming, and other factors. The Bay of Bengal's waterways conveys increasing amounts of nutrients from land to sea (Seitzinger et al. 2010).

In the Bay of Bengal, nutrient loads exported by rivers to coastal waters have grown in recent decades (Sattar et al. 2014), resulting in nutrient stoichiometry alterations (Islam et al. 2004; Tripathy et al. 2005) and damaging non-siliceous algal blooms (Garnier et al. 2010).

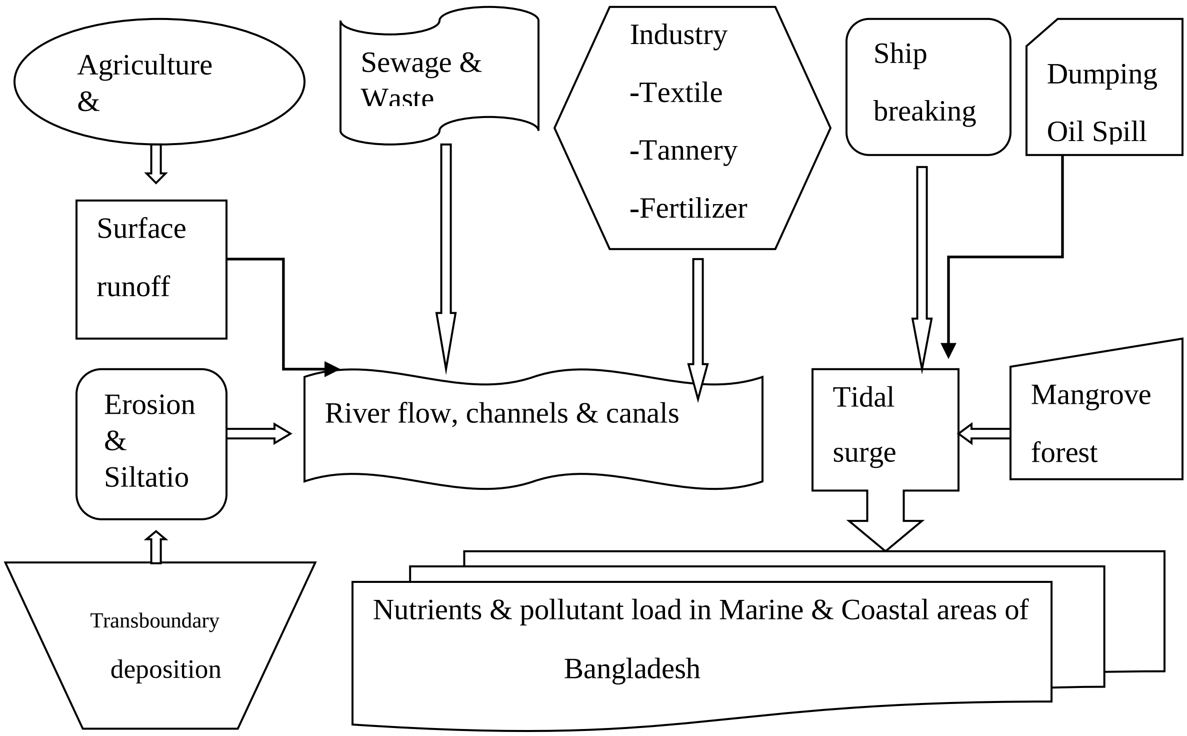

Fig 2.1: Flow diagram showing possible movements of nutrients and pollutants toward coastal zones of Bangladesh.

2.3 The distribution of nutrients along Bangladesh's coast

The land-use framework in Bangladesh's coastal areas is agriculture, which is characterized by rice cultivation with regular rabi crops. Continuous saline water interruption owing to sea-level rise and increasing shrimp production is causing nutritional imbalances in Bangladesh's coastal zones, which was negatively impacted coastal agricultural productivity on a large scale. Soil is a crucial source of nutrients for crop production and plant growth (Ashman and Puri, 2013). Nitrogen (N) is the most important elemental nutrient for crop development (Cao et al., 2018), and N deficiency results in crop leaves turning yellow.

The bioavailability of soil nutrients is affected by soil properties such as pH, salinity, and nutrient. Soil salinity is acknowledged as a major issue in land development (El-Ramady et al., 2018). Hasanuzzaman et al. (2013) claimed that soil salinity has substantial abiotic stress that significantly reduces crop production. Additionally, excessive salinity worsens the hydrological situation and, as a result, lowers conventional crop production year-round (Haque, 2006).

The Sundarbans are one of the world's most productive mangrove ecosystems (Ali, 1998; Das and Siddiqi, 1985; Rahman, 2003). It's a region where the Ganges' freshwater and the Bay of Bengal's saltwater meet. The rivers Rupsha, Pasur, Shibsha, Baleswar, Bhola, Arpangashia, and Kholpetua open into the Bay of Bengal via the Sundarbans reserve forest, transporting substantial amounts of nutrients that fluctuate with the tides and seasons, boosting the region's production (Rahaman et al. 2013). Additionally, these areas are crucial for the movement of nutrients from land to sea (Eyre and Twigg 1997). Sundarbans mangrove habitats provide surrounding coastal ecosystems with a substantial amount of organic nitrogen, phosphorus, and other nutrients. The availability of nutrients is one of the most significant factors influencing the composition and productivity of mangrove forests (Reef et al., 2010). However, Tidal, seasonal, and climate variables all influence the distribution and behavior of nutrients. Flooding deposits suspended sediments in mangroves and improves mangrove soil and water. The nitrogen cycle and nutrient fluctuation by the rivers that pass through the mangrove forest directly affect the organisms.

2.4 Seasonal variations of water quality parameters in the coastal zone of Bangladesh

2.4.1 pH

According to Hoq et al. (2006), the pH of Sundarbans River water is slightly alkaline and remains neutral to alkaline (7.4–8.1) throughout the year. Due to much less rainfall and an influx from upstream rivers during the post-monsoon and winter seasons, overland run-off, river flow, and water level generally decline. As a result, pH levels increased above those of the pre-monsoon and monsoon seasons (Rahman et al., 2013). Rahman et al. (2003) found a pH range of 7.0 to 8.4 in the Pasur-Sibsa river system. According to Geetha et al. (2009), the pH ranges from 7.3 to 8.9 in the mangrove ecosystem along Kerala's southwest coast, with the pre-monsoon period having the highest value and the monsoon and post-monsoon periods seeing the lowest. The pH value during the pre-monsoon was high because of enhanced photosynthetic activity, which causes under-saturation with regard to carbon dioxide, the pH value during the pre-monsoon was high. The pH range of the Cochin estuary was 7.02 to 7.88 on average (Joseph & Ouseph ,2010) due to greater freshwater influx during the monsoon season. Rahaman et al. (2014a) observed that the pH fluctuated between 7.73 and 7.97 during the post-monsoon and between 7.22 and 7.89 during the dry winter in the Rupsha-Pasur River system. Higher pH levels are caused by a variety of causes during dry seasons, including the removal of CO_2 by photosynthesis through the degradation of bicarbonate, dilution of saltwater by freshwater input, changes in salinity and temperature, and the breakdown of organic waste. Rahaman et al. (2014b) recorded the pH ranged from 7.31 to 7.82 in the Kholpetua-Arpangashia river system, during the dry season.

According to Billah et al. (2016), the Miri mangrove river estuary in East Malaysia had a pH ranging from 6.34, which is slightly acidic, to 7.15, which is slightly alkaline. The pH value was within the range that the World Health Organization advises (6.50–9.20; WHO, 2004). The presence of CO_3-, Ca^{2+}, and Mg^{2+} is indicated by alkalinity, whereas the acidity may be caused by the photosynthetic process and the oxidation of organic molecules. Moreover, Masoud et al. (2019) found a mangrove environment in Egypt with a pH value in the range of 7.83 to 8.39.

2.4.2 Salinity

The salinity of the estuary's water grows from upstream to downstream (Ji, 2008). Due to the entrance of highly saline water and the absence of freshwater outflow, the estuary's salinity increases (Liu et al., 2005; Robins et al., 2018). During the high tide, seawater reaches the estuary area, which rises the salinity. However, during low tide, freshwater discharge from upstream rivers reduces the estuary's salinity (Mukhopadhyay et al., 2006). Local runoff, freshwater discharge from the Gorai River, and, to a much greater extent, the volume of the regional discharge all affect salinity variance in this area (Rahaman et al., 2013a).

According to Hoq et al. (2006), the water salinity of the Sundarbans mangrove forest progressively increases, reaches a peak in March following the monsoon season, and then begins to fall from June to a minimum from July to September throughout the monsoon season. Earlier studies discovered a greater salinity in the estuary mouth because saltwater entered directly and was diluted by freshwater from upstream (Qasim & Gupta, 1981; Perumal et al., 2009). Fatema et al. (2014) evaluated the regional variation of water quality indicators in Merbok River, a mangrove estuary in wet, tropical Peninsular Malaysia, and discovered that the surface water salinity ranged between 13.31 and 24.22 ppt. The salinity of the stations upstream was lower than that of the stations downstream because freshwater was released upstream. The water salinity varies from 4% to 28% in April and May in the northern Sundarbans (eastern and central subsystems), and from 1% to 9% in the post-monsoon. The salinity of the water increased three to eight times from September to May, but the salinity of the soil increased two to five times.

2.4.3. Ammonia-N

Ammonia is a dissolved inorganic form of nitrogen; frequently the primary form of dissolved nitrogen in an aquatic environment and the main kind of nitrogen needed for algal development. Total ammonia includes unionized NH_3 and ammonium ions (NH_4^+). The preferred form of nitrogen for algal development is NH_4^+, and its concentration is frequently much greater than that of NH_3. Nitrite and nitrate are used by algae to thrive when the amount of NH_4^+ lowers. The primary form of ammonia used by plants is inorganic ammonia, which is produced when organic waste and animal dung are decomposed by bacteria. In the sediments of the mangrove swamp, inorganic nitrogen is easily chemically transformed. Microorganisms produce the ammonium ion after the organisms degrade in the sediment, and subsequently, aerobic nitrification processes generate nitrate and nitrite (Giridharan et al., 2008). According to Mwashote et al. (2005)'s investigation of the spatial and temporal distribution of dissolved inorganic nutrients in Mida mangrove water, Kenya, ammonia concentrations ranged from 0.002 to 5.45 M, with higher values in the dry season and lower values in the wet season. The much lower NH^{4+} concentrations during the rainy season compared to the dry season are most likely caused by the dilution impact, refractory terrigenous material, and turbidity brought on by large runoff episodes. According to Wahid et al. (2007), the ammonia concentration in the Sundarbans mangrove river system in Bangladesh ranged from 0.040 to 6.74 mg/L with an average concentration of 2.218 mg/L. A very small amount of non-ionized ammonia (NH_3-N) was also detected, pointing to the high caliber of the river's water. In addition, according to Chauhan & Ramanathan (2008), during the post-monsoon dry season, the ammonium concentration in the Bhitarkanika mangrove system on the east coast of India varied between 0.16 and 0.22 mg/L. But, According to Essien et al. (2008), the ammonia-nitrogen concentration ranged from 1.3 to

1.8 mg/L in the wet season and from 1.7 to 2.1 mg/L in the dry season in the brackish Qua Iboe mangrove estuary in Nigeria. A higher ammonia level during the dry season may be due to an increased rate of organic matter breakdown. Gandaseca et al. (2011) investigated that the ammonia-nitrogen concentration was extremely low, ranging between 0.1 and 0.31 mg/L, at the Wildlife Sanctuary Sibuti mangrove forest, Sarawak, Malaysia. This could be a result of the overuse of ammonia, which is chemically eliminated by the oxidation of NO_2^- and NO_3^-.

Increased ammonia levels during the monsoon season may be brought on by wastewater runoff, deteriorating soils, river runoff from inland areas with a variety of agriculture and aquaculture enterprises, and more. There are no notable variations in ammonia concentrations throughout the dry or post-monsoon seasons. The western portion of the mangrove forest, which is more salinity-rich year-round than the remainder of the Sundarbans, has particularly high ammonia levels during the monsoon. Within the western Sundarbans, there are extensive agricultural and aquaculture enterprises, which might lead to a considerable amount of washed-out inorganic fertilizers adding to the high ammonia level during the rainy season (Rahaman et al. 2013).

2.4.4 Nitrite (NO_2^-)

Nitrite is generated in water either by the nitrification process as a result of the biological oxidation of ammonium or denitrification via nitrate reduction (Dvir et al., 1999). By using bacteria, ammonium salts are transformed into nitrites, which are subsequently converted to nitrates by nitrification. Ammonia is quickly nitrified by nitrifying bacteria into nitrite, which is then transformed into nitrate, and eventually nitrate.

According to Srilatha et al. (2013), nitrite concentrations range from 0.060 to 2.082 g/L in the Muthupettai mangrove along India's southeast coast. The researcher observed the monsoon season had the greatest value, 2.082, and summer had the lowest, 0.06. The decomposition of phytoplankton, nitrate reduction and ammonia oxidation all had an impact on the amount of nitrite in the environment. However, according to Dattatreya et al investigation, in the mangrove zone on the Krishnapatnam Coast of India, the concentration of nitrite fluctuated between 0.36-3.52 g/L, with the greatest values in the rainy season and minimum values in the dry season. Because of the influxes of organic load, including nitrogenous compounds, and subsequent breakdown, nitrite develops during the rainy season.

2.4.5 Nitrate (NO_3^-)

Nitrate is the primary nitrogen species that enters the estuary. However, nitrate concentrations in the estuary may change due to downstream nitrification of ammonium, consumption by primary and secondary producers, and denitrification in the water column or in the sediment (Pein et al., 2019). Anthropogenic input, land runoff, and the oxidation of ammonia to nitrite and then to nitrate are the main sources of nitrate in the aquatic environment (Saifullah et al., 2014a).

According to Essien et al. (2008), the nitrate content in the surface water of Nigeria's brackish Qua Iboe mangrove estuary fluctuated between 1.5 and 2.1 mg/L during the rainy season and between 0.78 and 1.21 mg/L during the dry season. The researchers claimed the reasons behind this are the rising nutrient loadings from upstream agricultural croplands and aquaculture operations. Rahaman et al. (2014a) found that the nitrate levels in Bangladesh's Rupsha-Pasur River system were highest in the winter and lowest in the monsoon at Karamjal Station. The researchers noted a seasonal tendency of lower levels during the monsoon and greater values during the dry winter and the post-monsoon in the Sundarbans River system.

2.4.6 Phosphate (PO_4^{3-})

When phosphorus compounds are present in the water, algae and other photosynthetic primary producers grow faster. The main contributors to the addition of phosphorus in the aquatic system are household sewage and runoff from agricultural regions, urban sources notably detergent, and industrial waste. Orthophosphate that has been dissolved from low-concentration water sources is easily absorbed by phosphorus-deficient cells. The productivity of coastal waters is frequently limited by the levels of nitrogen compounds (Skinner & Turekian, 1973).

According to Qasim and Gupta (1981), high salinity in estuaries combined with low PO_4^{3-} levels suggest that PO_4^{3-} is primarily obtained from freshwater sources and land runoff, while the contribution of saltwater to PO_4^{3-} is insignificant and relatively consistent throughout the year. Moreover, Al-Badaii et al. (2013) found Phosphate levels in Malaysian rivers varied from 0.08 to 0.95 mg/L during the wet season and from 0.62 to 1.9 mg/L during the dry season, which is a substantially higher concentration. High phosphate concentrations are indicators of eutrophication-related pollution which is caused by urban runoff from neighboring industrial wastewater and household effluents like detergents and fertilizers.

Billah et al. (2016), showed the phosphate concentrations in the Miri estuary, Malaysia, varied from 0.02 to 0.14 mg/L, with the lowest concentration occurring in the dry season at 0.02 mg/L and the highest during the wet season at 0.14 mg/L. The levels of phosphate indicate a considerably lower eutrophic condition. Nevertheless, the concentrations were below the 0.2 mg/L limits established by the national water quality standard (NWQS) for Malaysian rivers. The decrease in freshwater discharge, which led to a decline in the urban and industrial runoff, was the cause of the reduced phosphate during the dry season.

Phosphorus concentrations were somewhat higher during the monsoon season than they were during the post-monsoon and dry seasons in most Sundarbans locations. The use of farming in riverine regions in the Sundarbans mangroves could be a feasible solution to the high levels of phosphate from monsoon run-off (Kumar et al. 2014).

2.5 Previous studies on nutrients in the coastal zone of Bangladesh

In Bangladesh, several studies have been carried out regarding nutrient assessment in coastal rivers. CEGIS (2020) conducted research at Pasur River on some selected points in the monsoon season in their 25th water quarterly monitoring program. They revealed that pH values ranged from 6.9 to 7.8. They found the lowest pH value in the middle of the Pasur River; the pH value was almost 7.2 near the power plant areas and around 7.4 inside the deep forests. The reason for higher values in the deep Sundarbans was the high tidal influence in that area. The salinity was found to be between 0.2 and 4.0 ppt. In the study period, salinity was 0.2-0.5 ppt near the power plant and 2.0-4.0 ppt in the deep forest area. They found total hardness in the range of 1,040–3,800 mg/L in the Pasur River and 2,555 mg/L in the Sundarbans Forest. They found the highest nitrate (NO_3^-) concentration near powerplants (4.0 mg/L) and in the Sundarbans Forest (avg. 3.3 mg/L) and the reason for the high nitrate concentration was surface run-off, agricultural run-off, atmospheric deposition, and domestic waste dumping together with industrial pollution from upstream. They also found PO_4^{3-} concentration within the range of 0.2-0.4 during February 2020.

They showed that upstream anthropogenic activities are probably the reason for that kind of trend for phosphate.

M.S., Hoq, et al., (2020), performed research on seasonal and tidal dynamics of nutrients and chlorophyll concentration in the water of the Pasur river and Koromjol canal in the Sundarbans mangrove ecosystems from March 2018 to February 2019. They collected samples from five sampling stations during March, August, and November, when these months were considered pre-monsoon, monsoon, and post-monsoon seasons, respectively. The nutrients NH_3-N, NO_3^--N, PO_4^{3-}-P, SO_4^{2-}, and chlorophyll-a concentration are found at 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 much higher than the suitable limit during both tides in the monsoon and post-monsoon seasons. The PO_4^{3-}-P is found moderately high during both tides at all stations. The SO_4^{2-} 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, which are much higher than water quality standards. The results show that the Pasur river and the Koromjol canal fluctuate seasonally and tidally to some magnitude, and their variations can alter the water quality as well as the density and distribution of living organisms.

Shefat et al. (2019) conducted a study on the assessment of Physico-chemical properties of the Pasur river estuarine water connected to the Sundarbans mangrove ecosystem at fifteen sampling stations along the main axis of the estuary in March 2018, April 2018, January 2019, and March 2019 during the dry season to examine the ecosystem health. The study shows pH from 7.1 to 7.9 with the highest value of 7.86 in January 2019 and the lowest value of 7.11 in March 2018, and salinity from 8.5 to 16.2 PSU with the highest salinity of 16.2 PSU in April 2018 and the lowest salinity of 8.3 PSU in January 2019, dissolved oxygen (DO) from 5.9 to 8.4 mg/L with the maximum value of 8.43 mg/L in January 2019 and the minimum value of 5.97 mg/L in April 2018. Nitrate concentrations (NO_3^-) in the Pasur River were extremely low and vary between 0.01 and 0.08 mg/L, with the highest concentration in March 2019 and the lowest in January 2019. The maximum concentration of nitrate was found upstream, and the minimum was found at the seaward station. A relatively higher amount of nitrate in the upper region of the estuary might be attributed to agricultural runoff and shrimp farms. Ammonium-nitrogen (NH_4^+) from

0.11 to 2.11 mg/L during the dry season, with the highest mean value of 1.3 mg/L in March 2018 and the lowest mean of 0.5 mg/L in March 2019. The concentration of ammonium varied non-significantly between sampling stations but significantly between sampling months. The higher NH_4^+ concentration in the water column was mostly attributed to the release by tidal wash-out of the interstitial waters of the surficial mangrove sediments. Dissolved inorganic nitrogen concentrations also varied insignificantly among the sampling stations but vary significantly among the sampling months. In contrast, the phosphate concentration varied from 0.07 to 5.8 mg/L. The study results show a lower concentration of phosphate at the sampling stations, ranging from 0.07 to 5.82 mg/L during the dry season, with the highest mean value of 1.29 mg/L in March 2019 and the lowest mean value of 0.19 mg/L in January 2019. Phosphate concentrations in the study area varied insignificantly across sampling stations, but significantly across sampling months.

Chowdhury AH (2017) conducted research to find out the environmental impact of the coal-based power plant in Rampal on the Sundarbans and surrounding areas. The research was conducted from August 2011 to July 2013 in 10 permanent stations in each of the three study areas (Rampal, Mongla, and the Sundarbans). This study showed that most of the impacts of coal-fired power plants are negative and irreversible, which means they can't be mitigated in any way. It stated that the coal-fired power plant would have a long-term impact on the climate, topography, land use pattern, air, and water quality, floral and faunal diversity, aquatic ecosystems, catch fisheries, and tourism in the Sundarbans and surrounding areas. The study found that during the study period, the different water parameters in Rampal, Mongla, and Sundarbans were as follows: electric conductivity of 4-16.5 ms/cm; 7.78-14.1 ms/cm; pH 7.1-8.7; 7.3-8.9; CO_3^{2-} alkalinity 4-18 mg/L; total hardness 660-1022 mg/L; phosphate 1.53-1.87 mg/L; 1.65-1.78 mg/L.

Rahaman et al. (2015) carried out research on the spatial and seasonal patterns of water quality in the Sundarbans River System of Bangladesh. For that research, they selected fifteen experimental sites: five stations of Rupsha-Pasur RS, namely Karamjol, Karamjol Canal, Joymoni, Harbaria, and Harbaria Canal; and four stations of Baleswar-Bhola RS, namely Bogi, Sharankhola, Supati, and Supati Canal for the collection of water samples under different tidal conditions. According to the study, the mean pH in the Rupsha-Pasur River ranged from 7.29 in the monsoon to 7.87 in the post-monsoon, whereas in the Baleswar-Bhola River it ranged from 6.70 in the post-monsoon to 7.53 in the monsoon. This paper also revealed that mean salinity in Rupsha-Pasur ranged between 4.5 and 10.5 ppt, while in Baleswar-Bhola, mean salinity was 4.0 ppt both during the post-monsoon and monsoon periods and 9.5 ppt during the dry winter. Significant tidal variations in water salinity over the three sampling seasons are regulated by the discharge of fresh water from upstream. The salinity distribution pattern in the study area showed a significant decrease from the northwest (Kholpetua-Arpangashia) to the northeast (Baleswar-Bhola) as inland freshwater input gradually increased into the river systems. During that study period, mean nitrate (NO_3^-) was recorded from 0.317-0.21 to 0.627-0.42 mg/L and 0.425-0.48 to 0.603-0.73 mg/L in Rupsha-Pasur and Baleswar-Bhola, respectively. The highest concentration (.1 mg/L) was observed in Baleswar-Bhola during the post-monsoon. The highest nitrate concentration was measured in Rupsha-Pasur RS at Karamjol Canal in winter and the lowest at Karamjol Station in the monsoon. The highest and lowest concentrations for Baleswar-Bhola RS were identified at Bogi in summer and Supati station in the monsoon, respectively. The annual mean phosphate (PO_4^{3}-) for Rupsha-Pasur and Baleswar-Bhola is 0.168 - 0.12 to 0.449 - 0.26 mg/L and 0.011 - 0.005 to 0.029 - 0.011 mg/L, respectively, according to the study results. The highest and lowest concentrations of Rupsha-Pasur RS were observed at Karamjol in the post-monsoon and Harbaria in the monsoon, respectively. In Baleswar-Bhola RS, the highest concentration was found at Sharankhola during the monsoon and the lowest at Supati during winter. RS ranged from 0.052 to 0.026 mg/L, while Baleswar-Bhola RS ranged from 0.038 to 0.018 to 0.041 mg/L. Rupsha-Pasur RS shows the highest concentration at Joymoni in winter and the lowest at Karamjol in the monsoon. In Rupsha-Pasur and Baleswar-Bhola RS, NH_4^+ values were lower in the monsoon and higher in the winter and post-monsoon. This study revealed that with the onset of monsoon as well as post-monsoon, these rivers experienced the greatest reduction in organic substance levels but experienced an increase with the beginning of dry winter.

Rahaman et al. (2014) conducted research to find out the seasonal nutrient distribution in the Rupsha-Pasur tidal river system of the Sundarban mangrove forests. This paper showed the pH of Rupsha-Pasur ranged between 7.19 to 7.54 and 7.23 to 7.59 at high and low tide, respectively. During that study period, salinity fluctuated between 6 to 10 ppt and 7 to 10 ppt at high and low tide, respectively, in the post-monsoon season. During the dry winter, water salinity varied from

10 to 13 ppt at high tide and from 10 to 11 ppt at low tide, while monsoon data indicated 4 to 7 ppt and 4 to 6 ppt water salinity at rising and falling tide, respectively. They discovered in their study that ammonia (NH_3-N) concentrations increased from monsoon (0.013 to 0.019 mg/L) to dry winter (0.0703 to 0.0803 mg/L), but the tide had no effect on ammonia concentrations. They found lower SO_4^{2-} content (7.301 to 37.508 mg/L) at all the sampling stations during post-monsoon and winter, while in the monsoon period, most of the stations showed higher concentrations up to 126.92 mg/L. In contrast to the post-monsoon season, which had higher PO_4^{3-}P values (0.314 to 1.347 mg/L), the Rupsha-Pasur River had low phosphate concentrations (0.045 to 0.5 mg/L) during the winter and monsoon seasons. Most of the study sites showed considerable tidal changes in phosphate value during the post-monsoon and monsoon seasons. The NO_3^-N concentration fluctuated between 0.083 and 1.233 mg/L with no distinct seasonal distribution pattern.

Rahaman et al. (2013) conducted an investigation on nutrient dynamics in the Sundarbans mangrove estuarine system of Bangladesh under different weather and tidal cycles. This study provides considerable advances in understanding the seasonality of nutrient distribution with possible tidal influence. The key point of this paper is that nutrient concentrations are influenced by seasonal changes. Mean nutrient levels during post-monsoon, winter, and monsoon seasons, respectively, are in the following ranges: nitrate (0.06–0.40, 0.06–0.46, and 0.08–0.46 mg/L); phosphate (0.09–0.18, 0.05–0.42 and 0.10–0.16 mg/L); sulfate (58.71–86.14, 68.68–119.01 and 78.15–136.47 mg/L) and ammonia (0.02–0.08, 0.02–0.04 and 0.26–0.38 mg/L). They showed increased levels of phosphate, sulfate, and ammonia and lower DO and salinity during the monsoon period. Most of the experimental sites showed higher nitrate content during the monsoon, whereas few elevated concentrations are observed during the post-monsoon and winter periods. High and low tidal waters contained mean nutrient levels in the following ranges: nitrate (0.05–0.46 and 0.04–0.40 mg/L), phosphate (0.05–0.42 and 0.07–0.18 mg/L), sulfate (63.63–125.36 and 58.71–136.47 mg/L), and ammonia (0.02–0.38 and 0.02–0.37 mg/L) without following any distinct fluctuation patterns. Rahaman et al. (2013a) recorded NH_3–N concentrations between 0.02 and 0.38 mg/L with an average of 0.14 mg/L with significantly higher concentrations ranging from 0.26 to 0.38 mg/L during the monsoon season and relatively lower amounts ranging from 0.02 to 0.08 mg/L during the post-monsoon and winter periods. Wahid et al. (2007) reported an average ammonia concentration of 0.054 mg/L, whereas previous studies reported an average ammonia concentration ranging from 0.001 to 0.33 mg/L (IWM, 2003). The western part of the Sundarbans receives less freshwater input during the monsoon season than other areas of the ecosystem, which reduces the variability of nutrient levels and water quality components. Rahaman et al. (2013a) also observed lower phosphate concentrations ranging from 0.05 to 0.42 mg/L with an average of 0.12 mg/L in the Rupsha-Pasur River system. The average phosphate value of 0.323 mg/L was recorded in this study and is higher than that of 0.115 mg/L, as has been reported by Wahid et al. (2007). IWM (2003) also recorded an average phosphate concentration of 0.115 mg/L in the Sundarbans mangrove estuarine. The addition of phosphorus to the aquatic ecosystem is derived mainly from domestic sewage and the runoff from agricultural areas. A study conducted by Rahaman et al. (2013a) indicates a comparatively higher phosphate value of 0.314 to 1.347 mg/L in the post-monsoon season than in the winter and monsoon periods (0.045-0.5 mg/L) in the Rupsha-Pasur River system.

Jashim et al. (2010) carried out a study on water chemistry in and around the Sundarban mangrove forests. The study presented the spatial and temporal patterns of river water chemistry at 25 sites in and around the Sundarbans. Conductivity, TDS, major cations, major anions, alkalinity, pH, and hardness were determined from September 2008 to July 2009 in four seasons at Sarankhola, Chandpai, Nalian, and Burigualiny from Bhola, Pasur, Sipsa, and Khulpatua rivers, respectively. There is a wide temporal variation in conductivity (from 201 μS/cm to 43.7 mS/cm) and TDS (0.13 to 31.2 g/L) from the eastern to western Sundarbans, suggesting a low flow of fresh water into the western Sundarbans. Ammonium (0.04 to 6.74 mg/L), nitrate (0.1 to 1.4 mg/L) and phosphate (0.026 to 0.252 mg/L) were present in sufficient quantity for aquatic life to survive. Heavy metal concentrations are exceeded in some areas. The study revealed that the water chemistry of the Sundarbans Mangrove Forest is approaching critical value for the survival of organisms.

There has never been any significant work done to measure the nutrient variation caused by tidal impact in the Pasur and Baleswar river estuaries. The findings from the present study will contribute to a greater understanding of the influence of tides on nutrient availability in the tidal freshwater segments of the Pasur and Baleswar rivers and their role in nutrient transport to the lower (saline) estuary. The Pasur River estuary is the largest and most important estuary that experiences upstream saltwater intrusion during the dry season (Shaha and Cho, 2016), as well as supports the world’s largest mangrove forest biodiversity by carrying freshwater from upstream. Therefore, any change in the physical, chemical, or even biological interests could lead to a serious impact on this biological hot spot.

The primary objective of this project is descriptive: to examine how nutrient concentrations change during an incoming versus an outgoing tide. This project work was conducted as part of the requirements for a Post Graduate Diploma degree under IWFM, BUET.

CHAPTER 3
STUDY AREA

3.1 Introduction

This chapter contains an overview of the study area. It provides a general description of different important features like geographical location, demographic features, land type, major river systems, and climatic conditions of the study area.

3.2 Geographic Location

The study area is located in the Bagerhat district of the South-West region of Bangladesh. Field observation was conducted at two stations, namely Sarankhola on the Baleshwar river and Mongla on the Pasur river. The sampled areas are characterized by semidiurnal tides and strong currents. Comprehensive field measurements were made in winter (December 2021[*1]) and at different tidal cycles. Mongla Upazila (Bagerhat district) has an area of 1461.22 sq.km. and is located between 21°49'N and 22°33'N latitudes and between 89°32'E and 89°44'E longitudes. It has 27,192 units of housing and a total area of 1461.22 km^2. Sarankhola Upazila (Bagerhat district) has an area of 756.61 sq.km. and is located between 22°13'N and 22°24'N latitudes and between 89°46'E and 89°54'E longitudes. It has 19,588 units of housing (Banglapedia, 2012)

3.3 River System:

A number of rivers run through the Bagerhat district, like Baleshwar, Bhairab, Panguchi, Pasur, and Madhumati. Most of the rivers are tidal. The Pasur River is in southwesternn Bangladesh and is a distributary of the Ganges. It continues to the Rupsa River. All its distributaries are tidal. It meets the Shibsa River within the Sundarbans, and near the sea, the river becomes the Kunga River. It is the deepest river in Bangladesh (Wikipedia, 2021). The Baleshwar River is located in Bangladesh, forming part of the eastern border of Bagerhat district and the western border of Barguna District. It is bounded on the east by the world's largest mangrove forest, the Ganges-Brahmaputra delta, the Bangladesh portion of which is designated as the Sundarbans reserve forest. The Baleshwar River flows south into the Haringhata River, which flows into the Bay of Bengal.

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[1] As per the suggestions of the Exam Committee Members resampling was done during December 2021. First sampling was done in December 2020, but the data was erroneous.

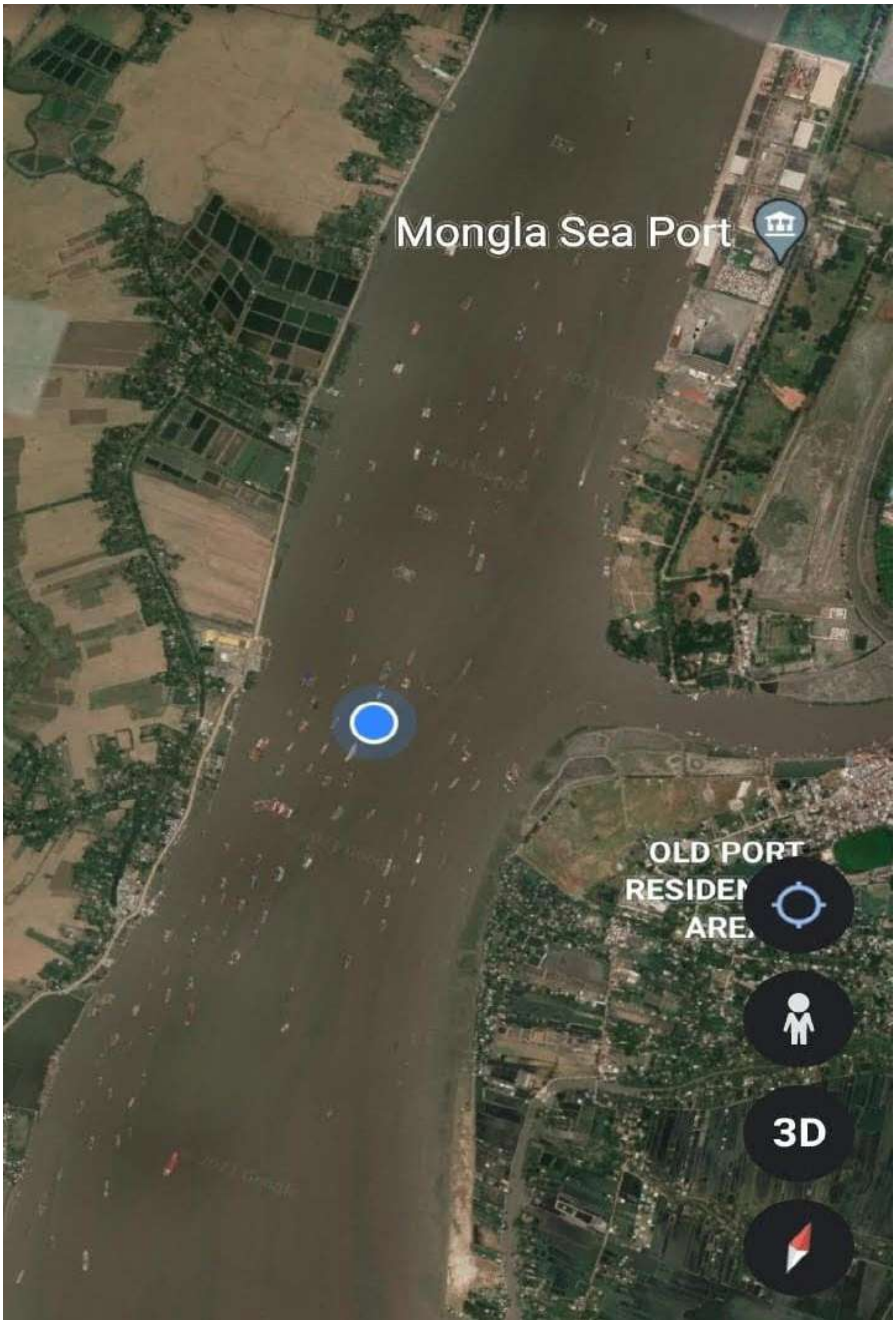

Fig-3.1: Location of the sampling point at Mongla Station of Pasur River.

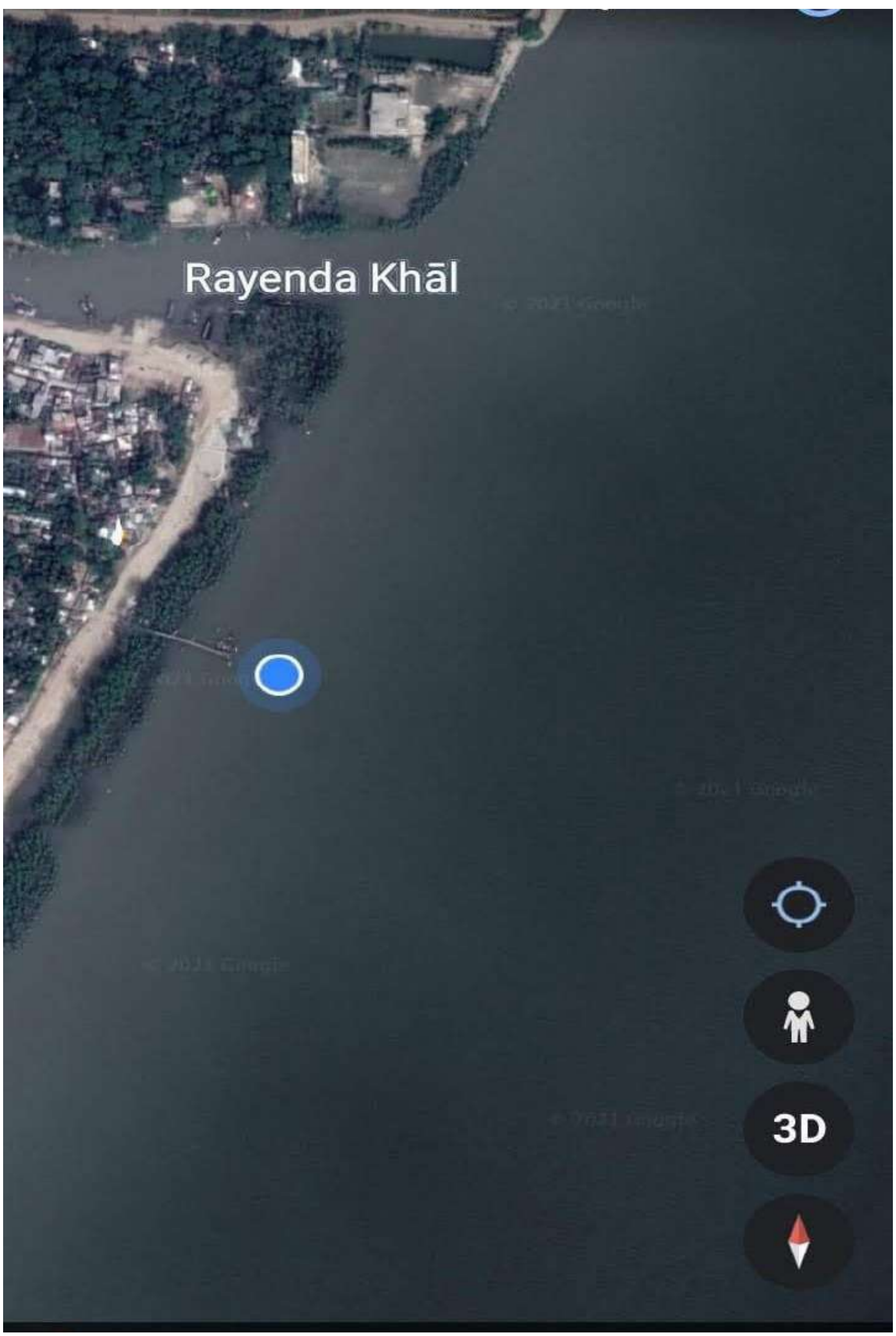

Fig-3.2: Location of the sampling point at Rayenda station of Baleshwar River.

3.4 Climate of the study area:

Climatically coastal areas of Bangladesh enjoy tropical monsoon climates like other parts of Bangladesh. The average annual maximum temperature of the Bagerhat district is 33.5^0 C whereas the average minimum temperature is 12.5^0 C with an annual average annual rainfall of 1710mm. Figures 3.3 shows the cimatic condition of Bagerhat District and Figure 3.4 shows the Mongla and Sharankhola Upazilas in Bagerhat District along with Pasur and Baleshwar Rivers.

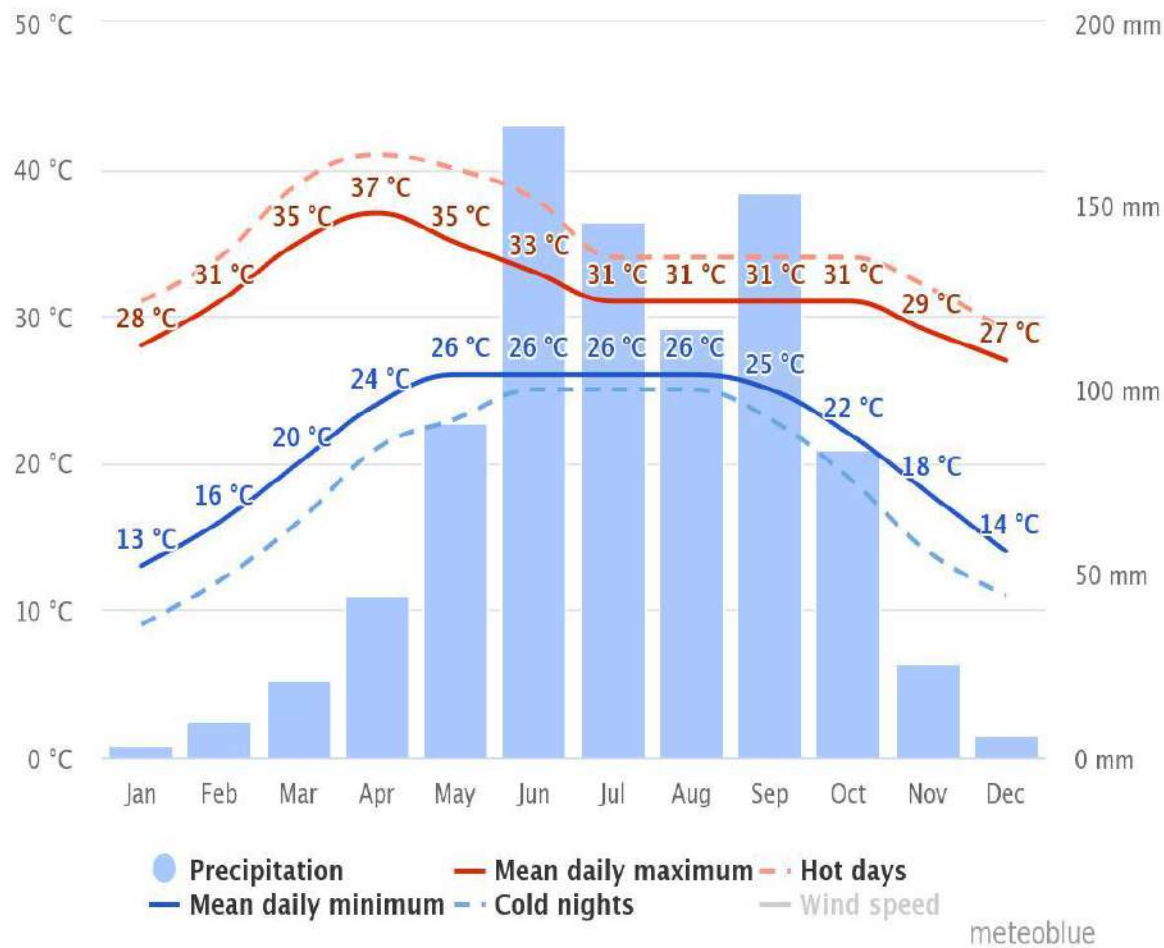

Fig-3.3: Climatic condition of Bagerhat District (Source: worldweatheronline.com)

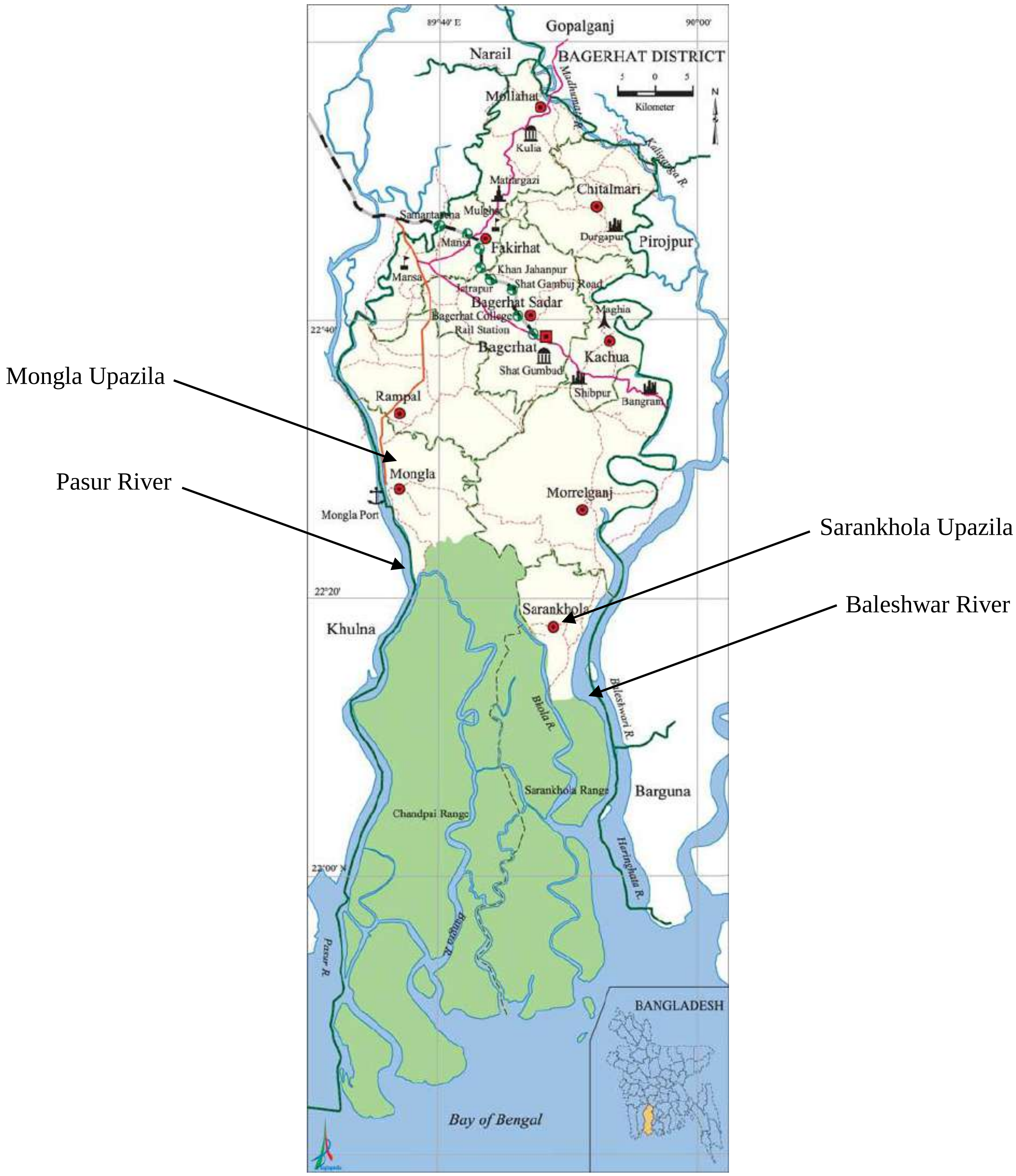

Fig 3.4: Map of Bagerhat district along with locations of Mongla and Sarankhola Upazilas and Pasur and Baleshwar Rivers

3.5 Soil nutrients status of the study area

Different areas of the Bagerhat district fall into three different agro-ecological zones, namely the Low Ganges River Floodplain (AEZ-12), Ganges Tidal Floodplain (AEZ-13), and the Gopalganj-Khulna Bills (AEZ-14). The land elevations of these three agro-ecological zones are highland (above normal flood level), medium highland (flooded up to 90cm), medium lowland (flooded between 90-180cm), lowland (flooded between 180-300cm) and very lowland (flooded above 300cm) (SRDI, 2001; BARC, 2012). The soil of the Bagerhat district are floodplain soils. In general, the coastal areas of Bangladesh are categorized as less fertile land (Moseleh Uddin et. al., 2013). Topsoil pH was strongly alkaline to slightly alkaline (8.02–7.85) in both pre-monsoon and post-monsoon with a significant variation. Seasonal organic matter status was below the optimum level (3.4). The mean salinity status was very slightly saline in both seasons. Total nitrogen status was low in different lands in both seasons. In the post-monsoon, phosphorus status was very low (0.06 g/g) for upland and wetland crops. Sulfur status was very high (> 45.0 g/g) in both seasons for upland and wetland crops. The seasonal mean status of B, Ca, and Mg was very high in different lands. Zinc status was medium in both seasons, with some lands having a deficiency (9.0 g/g) (Khalid Hassan Real1, Md. Younus Mia, Utpol Kumar2, and Natasha Khanam1, 2018). Multivariate analysis showed that lowlands were rich in salinity, OM, K, Ca, total nitrogen, and S compared with medium lowlands and medium highlands (LL>MLL>MHL). Figures 3.5 and 3.6 show the land use maps for Mongla and Sarankhola Upazilas.

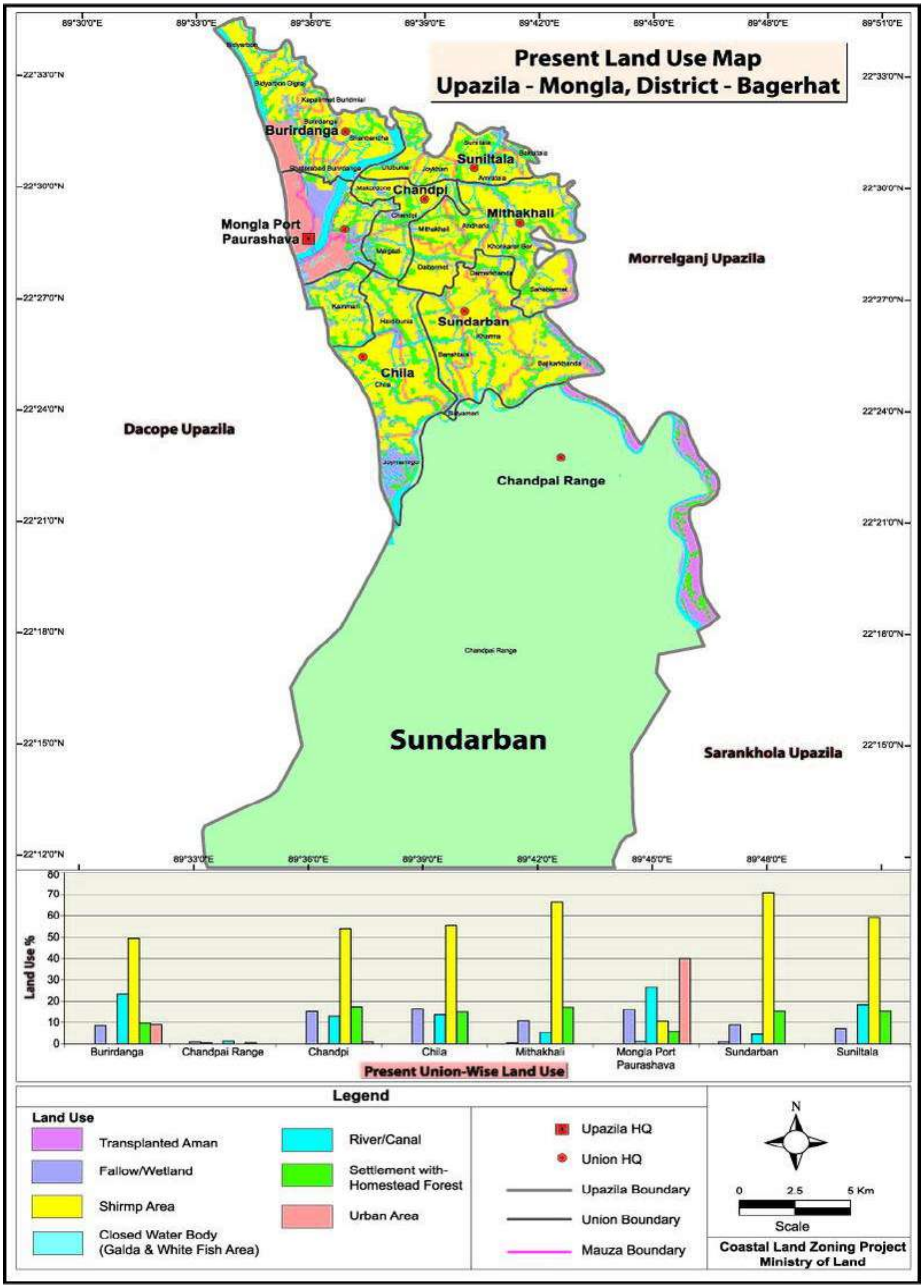

Fig 3.5: Land use map of Mongla Upazilla

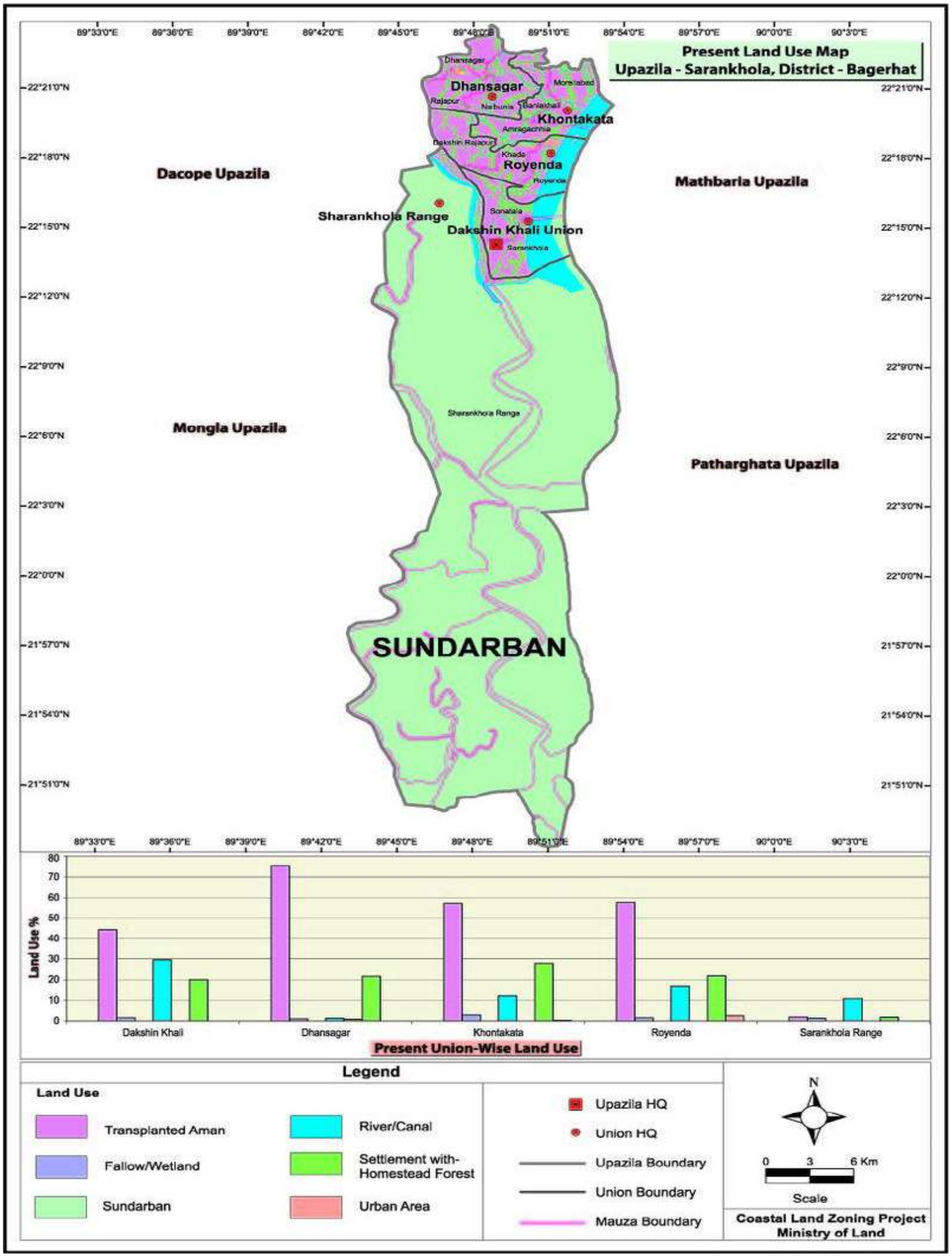

Fig 3.6: Land use map of Sarankhola Upazilla

3.6 Land use of the study area

3.6.1 Agricultural land use

The land in the coastal area is mainly used for agriculture. The gross area of the coastal zone is 4.72 mha, of which the net cultivable area is 1.95 mha. At present, coastal regions are contributing about 16% of the total rice production of the country. In coastal districts, Aman is the dominant crop, covering about 70% of the total rice-cropped area, while Aus covers 16% and Boro 14%. Farmers cultivate both local and HYV Aman rice in the Kharif-II season. During the Kharif-I and Rabi seasons, when most farmers grow vegetables for their own consumption, the salinity intensity increases. Table 3.1 shows the cultivable land use in Mongla and Sarankhola Upazilas and Table 3.2 shows the landcover classification of Sarankhola Upazila.

Table 3.1: Cultivable land use of the study area

Upazilla	Land use	Area (hectares)
Mongla	Total Cultivable Land	12565.76
	Single crop land	99.03 %
	Double crop land	0.86 %
	Treble crop land	0.11 %
	Fallow land	611.79
Sarankhola	Arable land	11616
	Single crop land	53.02%
	Double crop land	26.67%
	Treble crop land	20.31%
	Fallow land	819

Source: bagerhatinfo.com

Table 3.2: Land-cover classification statistics of Sarankhola Upazilla

Land cover types	2010	
	Area (km2)	**%**
Rural Settlements	68.99	9.09
Water	128.68	16.89
Sundarbans	475.56	62.68
Agricultural Lands	14.22	1.87
Vegetation	19.13	2.52
Vacant Land	52.60	6.93

Total	758.68	100

Source: Bangladesh Institute of Planners (2016)

The land use of Sharankhola is changing day by day. From table 3.2, it is found that 22% of rural settlement has increased and 20% of agricultural land has decreased between 1989 and 2010 and that in the year 2025, the maximum portion of the agricultural land will be lost. Land-covered types of agricultural land and vegetation are converted into areas of rural settlements and vacant land. Land-cover types of agricultural land and vegetation are demolished for the faster growth of the population for their accommodation. Vacant land is increasing because this land will be used in the future for mixed agricultural uses (e.g., shrimp farming) and rural settlements.

3.6.2 Shrimp Culture

At present, tiger shrimp (Bagda) is being cultivated in about 145,000 ha and Galda shrimp is being grown in about 35,000 ha of coastal and tidal lands in Ghers and ponds (in 25–30 thousand farms) at Satkhira, Khulna, Bagerhat, and Cox's Bazar (including Chakoria and Teknaf) areas under both monoculture, polyculture, and integrated with paddy in the Khulna area. Bagerhat district is one of the areas where tiger shrimp farming has been extensively practiced in Rampal, Mongla, and a portion of Fakirhat Thana (Khanom, 1999). According to Islam (1999), the total cultivable area of prawns is estimated at 6,000 hectares, of which 3,261 hectares are located in the Bagerhat district, and 1,429 hectares in Fakirhat Thana. Commercial prawn farming has recently taken place in the Bagerhat area in Ghers. The practice of shrimp culture needs saline water as an input to the shrimp pond. As a result, salinity intrusion increases with the expansion of shrimp culture. The extent of salinity in groundwater is also increasing because of continuous shrimp cultivation in fresh agricultural land. Table 3.3 shows the livestock, fisheries, and other industries of the study area, while Table 3.4 shows the use of chemical fertilizer (in metric tons) in the Bagerhat district. Table 3.5 Occurrence of river erosion during the year 2008-2011, while Table 3.6 shows the number of Growth Centres, Hat/Bazar, Poultry farms, Dairy farms, Nurseries, and Brick kilns in Bagerhat.

Some salient features of the study area are presented in figures 3.7: Saline soil at Mongla beside Pasur River during ebb tide; 3.8: Vegetation near Pasur River at Mongla; 3.9: Shrimp culture at Mongla of Bagerhat district; 3.10: Land erosion alongside Pasur River at Mongla; 3.11: Riverbank beside Baleshwar River of Sarankhola; 3.12: Eutrophication at Sarankhola of

Baleshwar River; 3.13: Industries besides the Pasur River of Mongla and 3.14: Ebb tide stage of Pasur River.

Table 3.3 Livestock, fisheries, and other industries of the study area

Upazilla	Livestock, fisheries, and industries	Number
Mongla	Power plant	2
	Oil refinery	5
	Shrimp fishery	760
	Poultries	60
	Frozen fish processing	1
	Cement Factories	2
	LP gas industry	1
Sarankhola	Shrimp fishery	-
	Poultries	23
	Welding factory	5
	Ice factory	3
	Brickfield	>10

Source: bagerhatinfo.com

Table 3.4 Use of chemical fertilizer (in metric tons) in Bagerhat district (BBS 2010-11)

Upazilla	UREA	TSP	MP	DAP	Others
Bagerhat Sadar	2876	789	367	441	167
Kachua	1975	390	275	260	95
Rampal	790	1551	0	26	0
Sarankhola	1520	490	285	25	20
Chitalmari	2956	690	710	185	0
Morrelganj	3500	1800	810	0	345
Mongla	638	60	2	0	0
Mollarhat	2465	667	468	775	110
Fakirhat	3046	1183	262	300	2200
Total	19766	7620	3179	2012	2937

Table 3.5 Occurrence of river erosion during the year 2008-2011 (Yes/No)

Upazila	2008	2009	2010	2011
Bagerhat Sadar	No	No	No	No
Kachua	No	No	No	No
Rampal	No	No	No	No
Sarankhola	Yes	Yes	Yes	Yes

Chitalmari	Yes	Yes	Yes	Yes
Morrelganj	No	Yes	No	No
Mongla	Yes	No	No	No
Mollarhat	No	No	No	No
Fakirhat	No	No	No	No

Table 3.6 Number of Growth Centres, Hat/Bazar, Poultry farms, Dairy farms, Nurseries and Brick kilns in Bagerhat (BBS: 2011)

Upazila	Growth Centre	Hat/Bazar	Poultry farm	Dairy farm	Nursery	Brick kiln
Bagerhat Sadar	8	35	157	176	16	2
Kachua	3	19	45	37	61	7
Rampal	5	23	105	57	21	0
Sarankhola	2	14	276	5	8	1
Chitalmari	5	17	383	216	4	1
Morrelganj	6	37	123	34	58	11
Mongla	5	19	228	5	4	0
Mollarhat	8	19	49	37	4	4
Fakirhat	4	12	253	46	0	5
Total	46	195	1619	613	176	31

Fig: 3.7: Saline soil at Mongla beside Pasur River during ebb tide

Fig-3.8: Vegetation near Pasur River at Mongla

Fig-3.9: Shrimp culture at Mongla of Bagerhat district

Fig-3.10: Land erosion alongside Pasur River at Mongla

Fig 3.11: Riverbank beside Baleshwar River of Sarankhola

Fig- 3.12: Eutrophication at Sarankhola of Baleshwar River

Fig 3.13: Industries near the Pasur River of Mongla

Fig 3.14: Ebb tide stage of Pasur River

CHAPTER 4
METHODOLOGY

4.1 Introduction

This chapter elaborates on the methodology that was adopted for achieving the objectives of the research. This study was designed based on sample collection from the Pasur and Baleshwar rivers in the southwest coastal areas of Bangladesh. Information was gathered from scientific literature, several visits to the study area, and relevant organizations.

4.2 Primary data

For the water and sediment sampling, two stations (one from each river) at the upper estuary of the Pasur and Baleshwar rivers were selected. At every site, water and suspended sediment samples were collected for one tidal cycle (12 hr 25 min) at a 2 hr interval during the post-monsoon/winter period of 2021. Each site was visited twice at an interval of seven days to capture the spring and neap tidal impacts. Table 4.1 shows the sampling schedule.

Table 4.1 Field Visit Schedule:

Field Visit	Date	Location Name	Sampling Place	Latitude	Longitude
1st visit	13-12-2021	Mongla	Mongla Sea Port	22.46122	89.594839
2nd visit	14-12-2021	Sarankhola	Rayenda Pheri Ghat	22.312019	89.858052
3rd visit	21-12-2021	Mongla	Mongla Sea Port	22.46122	89.594839
4th visit	22-12-2021	Sarankhola	Rayenda Pheri Ghat	22.312019	89.858052

4.3 Secondary data collection

To confirm the tidal phase at the sampling stations, water level data at the nearest tidal station during the study period were collected from the Bangladesh Water Development Board (BWDB). The influence of any precipitation in the study area was neglected as there was no rain during the sampling period which is usually during the winter season in Bangladesh.

Table 4.2: Water Level data of BWDB during the observation period

Station ID	Station	River	Latitude	Longitude	Date	Time	Water Level (m)
SW244	Mongla	Rupsa-Pasur	22.48066^0	89.60798^0	13/12/2021	06:00 am 08:00 am 09:00 am 12:00 pm 03:00 pm 06:00 pm	1.65 2.12 1.95 0.61 -0.37 1.04
SW244	Mongla	Rupsa-Pasur	22.48066^0	89.60798^0	21/12/2021	06:00 am 08:30 am 09:00 am 12:00 pm 02:00 pm 03:00 pm 06:00 pm	0.40 -0.76 0.73 1.51 2.15 2.03 0.20

Station ID	Station	River	Latitude	Longitude	Date	Time	Water Level (m)
SW107.2	Rayenda	Gorai-Madhumati-Haringhata-Baleswar	22.3134^0	89.8600^0	14/12/2021	06:00 am 07:15 am 09:00 am 12:00 pm 12:45 pm 03:00 pm 06:00 pm	2.22 2.62 1.88 1.54 0.60 1.84 2.12
SW107.2	Rayenda	Gorai-Madhumati-Haringhata-Baleswar	22.3134^0	89.8600^0	22/12/2021	06:00 am 09:15 am 12:00 pm 02:45 pm 03:00 pm 06:00 pm	1.76 0.68 2.12 2.64 2.72 2.22

4.4 Primary data collection from the sampling site

Water samples were collected for each 2-hour interval during an incoming and outgoing tide at Mongla station on the 13th and 21st of December while at Sarankhola station on the 14th and 22nd of December of 2021. Water samples were collected at a distance of 200 m away from the riverbank and at a depth of 1 ft below the water surface during low tides and high tides. The non-acidified sampling bottles were rinsed with respective water samples before sampling. These samples were preserved in plastic bottles and transported to the lab to analyze pH, alkalinity, nutrients, and salinity using standard procedures. These samples were used to assess tidal effects on nutrient concentration.

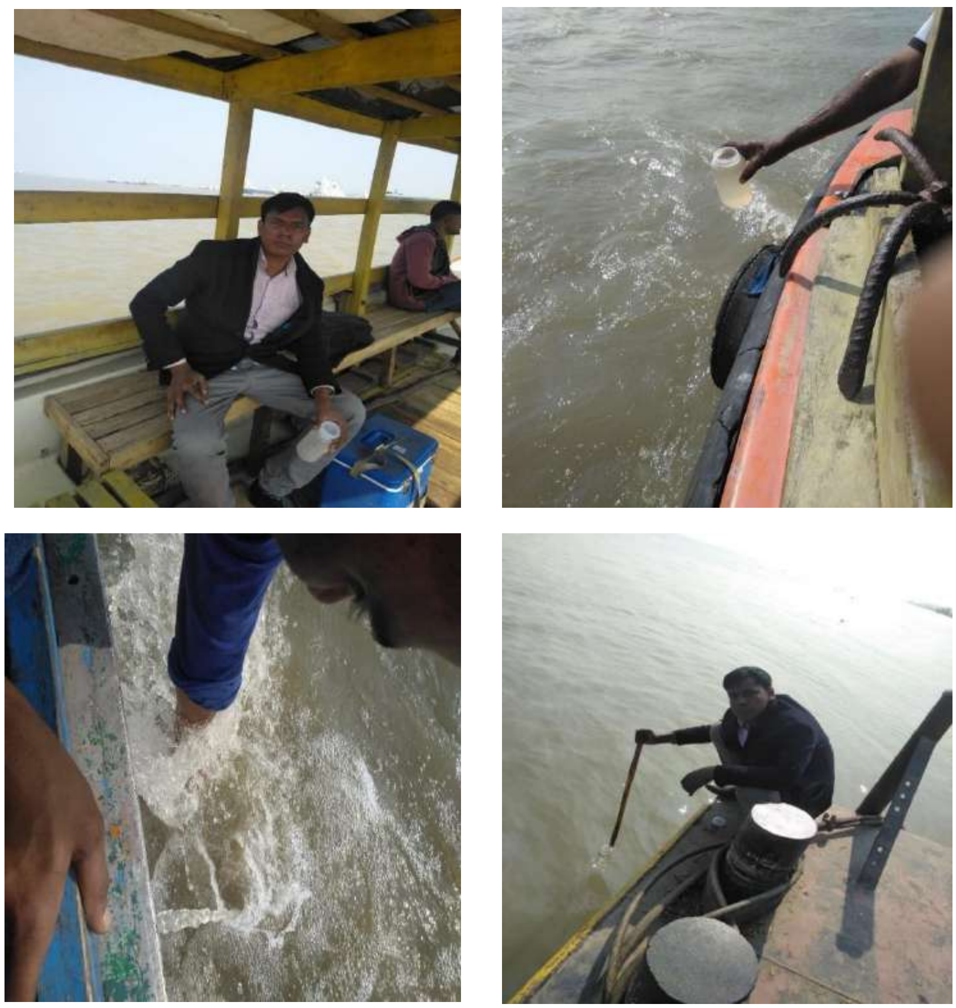

Fig 4.1 River water sample collection

Fig 4:2: Collected samples from Baleshwar (Left) and Pasur (Right) Rivers are preserved in the icebox

4.5 Water sample analysis in the laboratory

For laboratory analysis, water samples were taken into 250 ml plastic bottles, immediately preserved in an icebox, and later carried out to the laboratory for nutrient analysis. Nutrient parameters were analyzed in the soil and water testing laboratory of IWFM, BUET.

During the analysis of nutrient concentration, the Molybdovanadate method was used for phosphate. Nessler and the cadmium reduction method were used for ammonia and nitrate, respectively. The diazotization method was used for nitrite. A highly equipped HACH visual spectrophotometer was used for estimating the concentration of water nutrients. Table 4.3 shows the methods for the determination of different water quality parameters, while Fig-4.3 shows nutrients and salinity testing in the IWFM laboratory.

Table 4.3: Methods for the determination of different parameters of water

Serial No.	Parameters	Unit	Methods	References
1	pH		pH Meter	
2	Electrical Conductivity	µS/cm	EC Meter	HACH, Model HQ40D
3	Nitrate-Nitrogen	mg/L	Spectrophotometric method- Cadmium reduction method	HACH method 8039
4	Nitrite-Nitrogen	mg/L	Spectrophotometric method- USEPA Diazotization method	HACH method 8507
5	Ammonia-Nitrogen	mg/L	Spectrophotometric method- Nessler Method	HACH, Method 8038
6	Phosphate-Phosphorous	mg/L	Spectrophotometric method- Molybdovanadate Method	HACH Method 8114
7	Alkalinity	mg/L as CaCO3	Phenolphthalein and Total method	HACH method 8203

Fig 4.3: Nutrients and Salinity testing in the laboratory

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

In this chapter, water level, pH, alkalinity, salinity, and nutrient analysis results for the water samples collected from the Pasur River and Baleshwar River are presented. As already mentioned, from each site, samples were collected during spring tide and neap tide periods during the winter season: December 2021 at an interval of one week. Tidal water level data from the nearest water level measuring station of BWDB was analysed to ensure the timing of sample collection.

5.2 Water level and nutrients during Neap tide at Pasur River

Table 5.1: Tidal water level, salinity, pH, alkalinity, and nutrient concentrations at different tidal phases at Mongla sampling station on the Pasur River on December 13th, 2021 (Neap)

Sample No	Sampling time	Water level(m)	pH	EC (µS/cm)	Nitrite -N (mg/L)	Nitrate-N (mg/L)	NH_3-N (mg/L)	PO_4^{3-} -P (mg/L)	Alkalinity (mg/L as CaCO3)
01	8:00 am	2.12	8.05	559	0.02	2.8	0.29	0.2	125
02	10:00 am	1.28	7.9	548	0.027	3.1	0.26	0.3	115
03	12:00 am	0.61	7.88	540	0.025	3.7	0.19	0.4	115
04	2:00 am	-0.32	7.77	533	0.032	4.3	0.14	0.5	110
05	4:00 am	0.3	7.84	541	0.028	4.1	0.14	0.5	115
06	6:00 am	1.04	8.1	552	0.02	3.3	0.21	0.3	120

From Table 5.1, it is evident that during neap tide in the Pasur River, water level varied from-0.32 m to 2.12 m, the tidal range being 2.44 m, while pH fluctuated from 7.77 to 8.1, and salinity varied from 533 µS/cm to 559 µS/cm. The concentrations of nitrate fluctuated between 2.8 mg/l to 4.3 mg/l; ammonia between 0.14 and 0.29 mg/l; nitrite between 0.02 and 0.032 mg/l; and phosphate between 0.2 and 0.5 mg/l.

5.3 Water level and nutrients during Spring tide at Pasur River

Table 5.2: Tidal water level, pH, alkalinity, salinity, and nutrient concentrations at different tidal phases at Mongla sampling station on the Pasur River on December 21st, 2021 (Spring)

Sample No	Sampling time	Water level(m)	pH	EC (µS/cm)	Nitrite -N (mg/L)	Nitrate-N (mg/L)	NH_3-N (mg/L)	PO_4^{3-} -P (mg/L)	Alkalinity (mg/L as CaCO3)
01	8:30 am	-0.76	7.7	516	0.03	4.4	0.18	0.5	110
02	10:30 am	0.98	7.91	555	0.011	3.8	0.27	0.4	115
03	12:30 am	1.82	8.07	567	0.017	3	0.3	0.4	125
04	2:30 am	2.15	8.11	573	0.019	2.8	0.28	0.3	125
05	4:30 am	1.21	7.98	552	0.02	3.2	0.19	0.4	120
06	6:30 am	0.16	7.85	526	0.023	4.8	0.14	0.5	110

From Table 5.2, it is evident that during spring tide in the Pasur River, water level varied from-0.76 m to 2.15 m, the tidal range being 2.91 m, while pH fluctuated from 7.7 to 8.11 and salinity varied from 516 µS/cm to 567 µS/cm. The concentrations of nitrate fluctuated between 2.8 mg/l to 4.8 mg/l; ammonia between 0.14 and 0.30 mg/l; nitrite between 0.02 and 0.03 mg/l; and phosphate between 0.3 and 0.5 mg/l.

5.4 Water level and nutrients during Neap tide at Baleshwar River

Table 5.3: Tidal water level, salinity, and nutrient concentrations at different tidal phases at the Sarankhola sampling station of the Baleshwar River on December 14th, 2021 (Neap)

Sample No	Sampling time	Water level(m)	pH	EC (µS/cm)	Nitrite -N (mg/L)	Nitrate-N (mg/L)	NH_3-N (mg/L)	PO_4^{3-} -P (mg/L)	Alkalinity (mg/L as CaCO3)
01	7:15 am	2.62	8.17	427	0.01	2.8	0.31	0.2	130
02	9:15 am	1.78	8.07	395	0.016	3.3	0.25	0.3	120
03	11:15 am	0.97	8.02	398	0.02	3.5	0.21	0.5	110
04	1:15 am	0.68	7.98	392	0.022	4.6	0.19	0.6	105
05	3:15 am	1.41	8.01	424	0.019	4	0.13	0.4	115
06	5:15 am	2.01	8.05	430	0.018	2.6	0.16	0.3	120

According to Table 5.3, during neap tide in the Baleshwar River, water level varied from 0.68 m to 2.62 m, with a tidal range of 1.94 m, pH varying from 7.98 to 8.17, and salinity varying from 395 µS/cm to 43 µS/cm. The concentrations of nitrate fluctuated between 2.8 mg/l to 4.6 mg/l, ammonia between 0.13 to 0.31 mg/l, nitrite between 0.01 to 0.022 mg/l, and phosphate between 0.2 to 0.6 mg/l.

5.5 Water level and nutrients during Spring tide at Baleshwar River

Table 5.4: Tidal water level, salinity, pH, alkalinity, and nutrient concentrations at different tidal phases at Sarankhola sampling station on the Baleshwar River on December 22nd, 2021(Spring)

Sample No	Sampling time	Water level(m)	pH	EC (µS/cm)	Nitrite -N (mg/L)	Nitrate-N (mg/L)	NH_3-N (mg/L)	PO_4^{3-} - P (mg/L)	Alkalinity (mg/L as CaCO3)
01	7:00 am	1.81	8.16	421	0.017	3.9	0.24	0.5	120
02	9:00 am	0.54	7.99	396	0.021	5.4	0.15	0.7	105
03	11:00 am	1.12	8.01	413	0.019	4.3	0.18	0.6	105
04	1:00 am	1.64	8.08	411	0.016	2.9	0.23	0.4	110
05	3:00 am	2.72	8.19	433	0.011	2.7	0.28	0.2	120
06	5:00 am	2.32	8.03	419	0.015	2.1	0.22	0.3	120

According to Table 5.4, during spring tide in the Baleshwar River, water level varied from 0.54 m to 2.72 m, with a tidal range of 2.18 m, pH varying from 7.99 to 8.19, and salinity varying from 396 µS/cm to 433 µS/cm. The concentrations of nitrate fluctuated between 2.1 mg/l and 5.4 mg/l; ammonia between 0.15 and 0.28 mg/l; nitrite between 0.011 and 0.021 mg/l; and phosphate between 0.2 and 0.7 mg/l.

5.6. pH fluctuations with respect to tidal water level

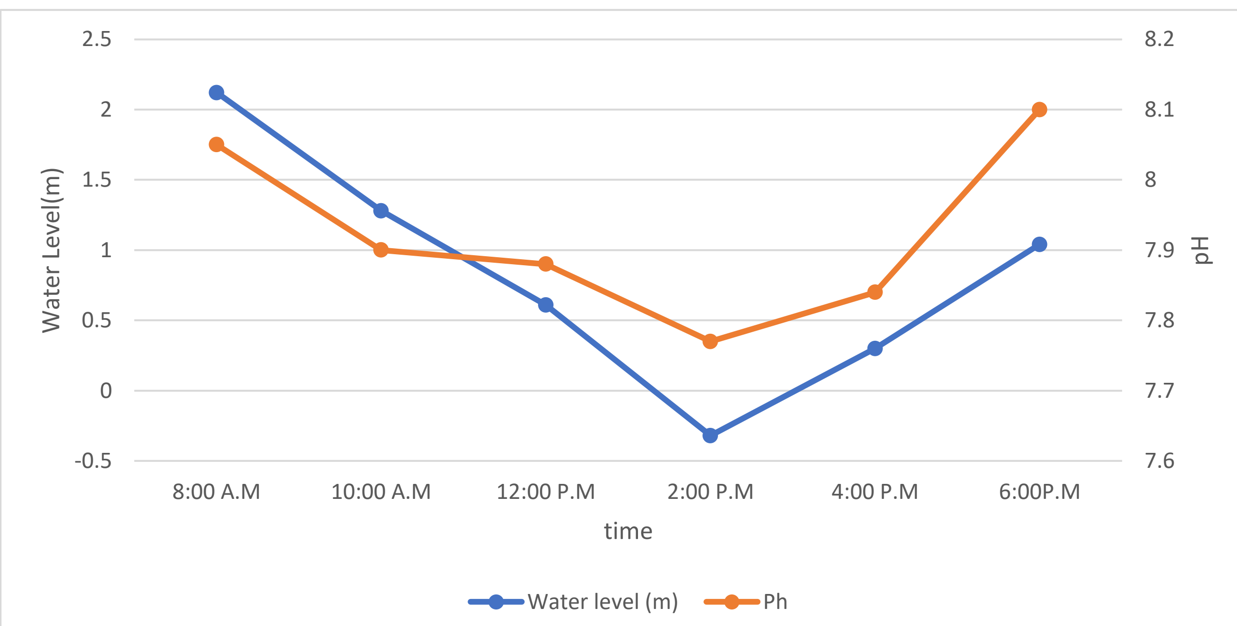

Fig 5.1a: Water level vs. pH of Pasur River on December 13^{th}, 2021

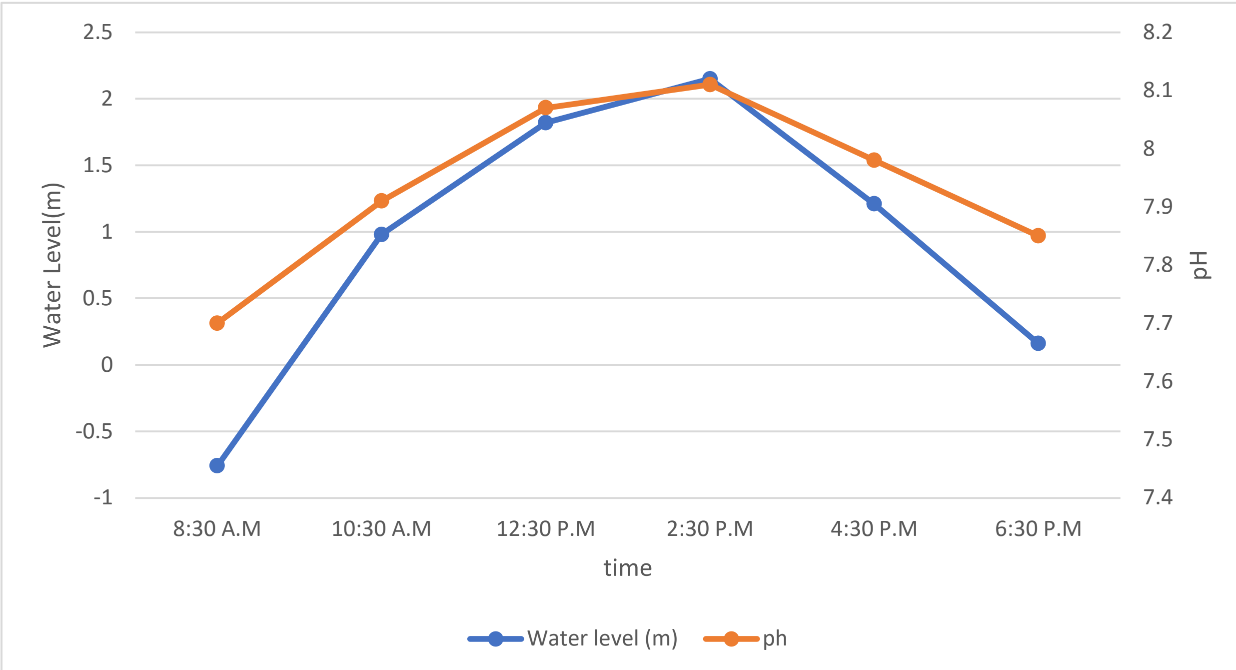

Fig 5.1b: Water level vs. pH of Pasur River on December 21st, 2021

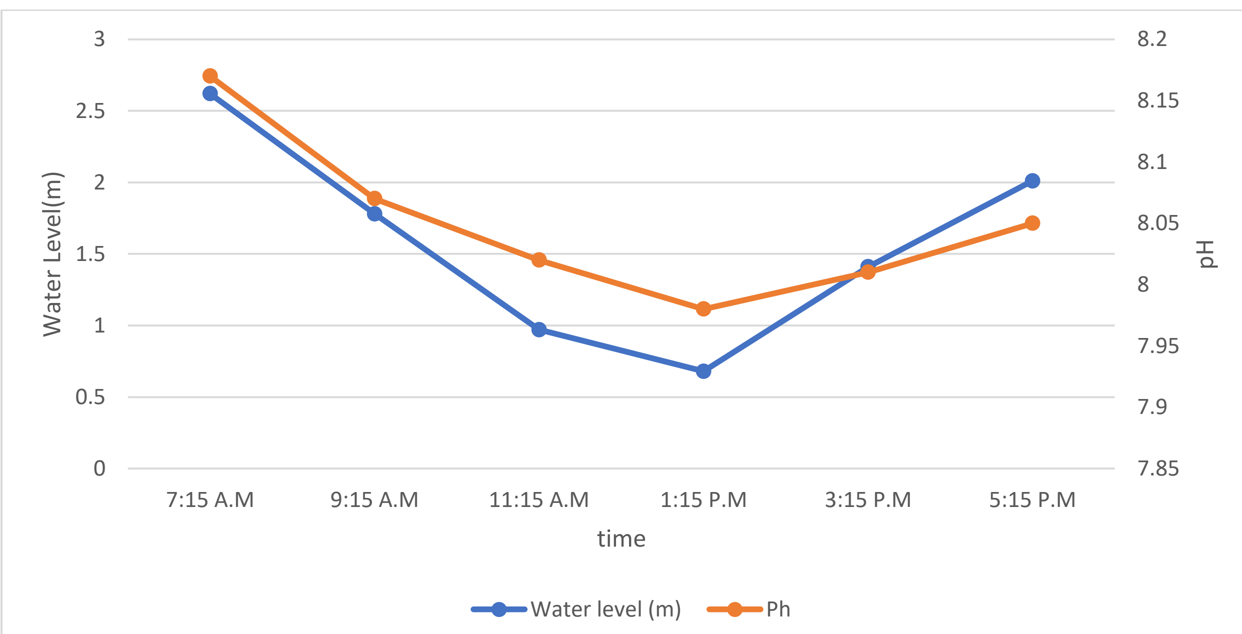

Fig 5.1c: Water level vs. pH of Baleshwar River on December 14th, 2021

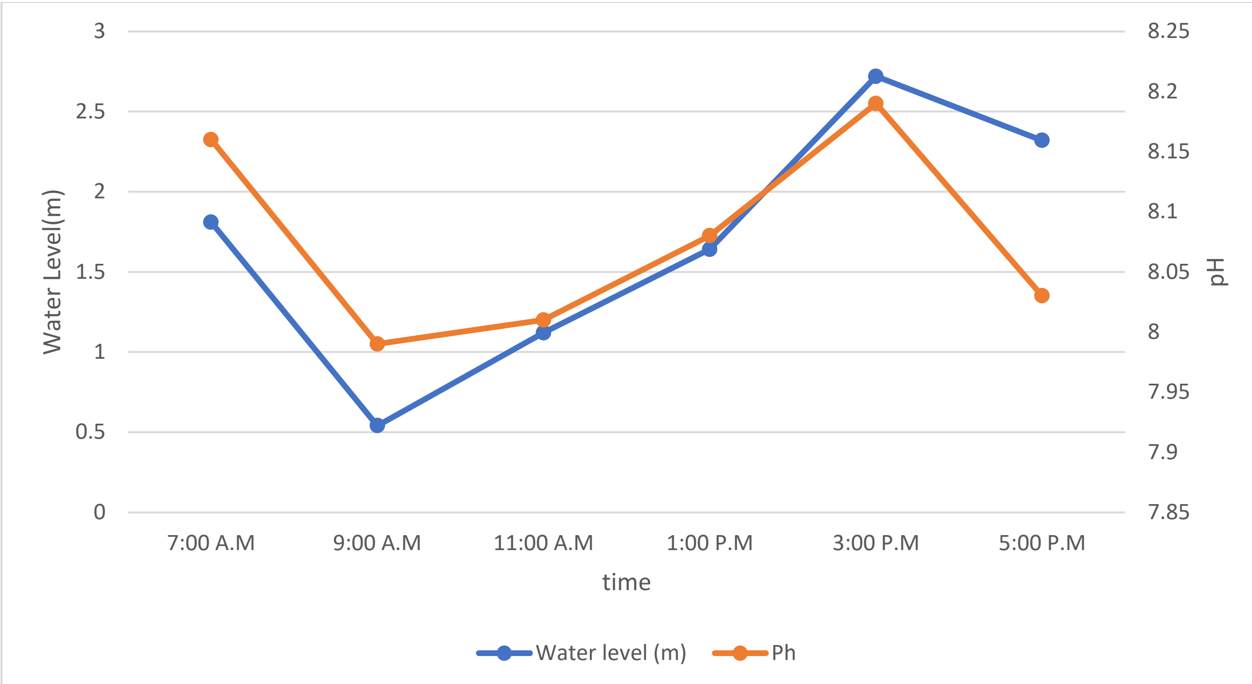

Fig 5.1d: Water level vs. pH of Baleshwar River on December 22nd, 2021

The pH was clearly modulated by the tidal cycle, indicating a clear difference between the neap and spring tidal events studied. The pH of the Pasur River ranged between 7.77 and 8.05 during neap tide and 7.7 and 8.11 during spring tide (Fig 5.1a and 5.1b). Again, pH varied between 7.98 and 8.17 during neap tide and between 7.99 and 8.19 during spring tide (Fig 5.1c and 5.1d) of the Baleshwar River during the sampling period. The pH increases with the incoming tide and decreases on the outgoing tide, but only within a very narrow range for each site. The correlation coefficients for both neap and spring tides showed a strong positive relationship with tides. This relationship seemed to be more significant during spring conditions. Deviations in pH are similar for both tidal conditions; however, temporal variations are more regular with a spring tide and specify strong positive correlations with water depth. So, it was found from the study that pH fluctuates with the tidal cycle for neap and spring tide conditions. The highest values are measured at high tide and the lowest values at low tide (Fig. 5.1a, 5.1b, 5.1c, and 5.1d).

5.7 Salinity fluctuations with respect to tidal water level

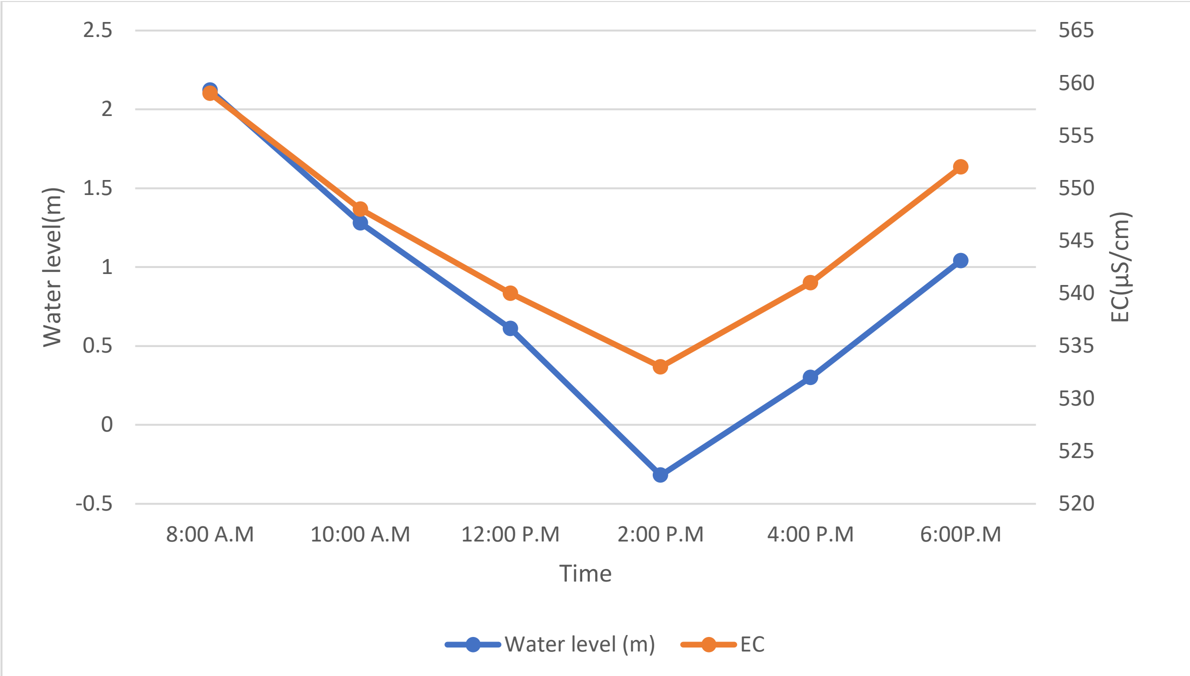

Fig 5.2a: Water level vs. EC of Pasur River on December 13th, 2021

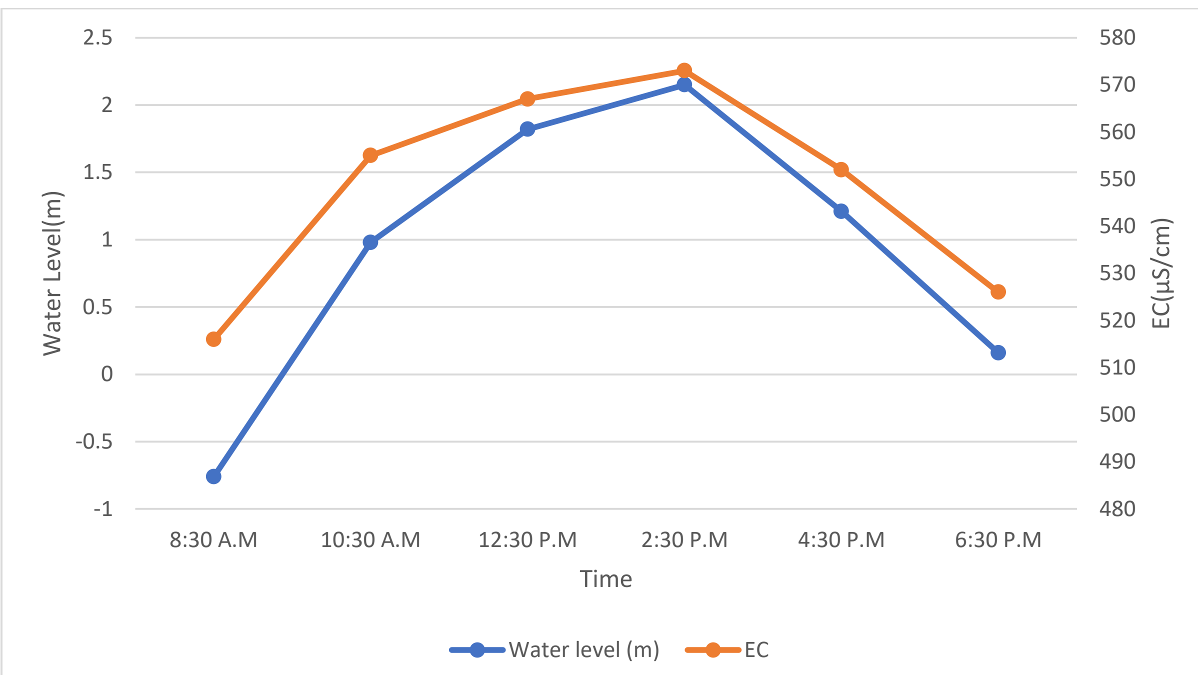

Fig 5.2b: Water level vs. EC of Pasur River on December 21st, 2021

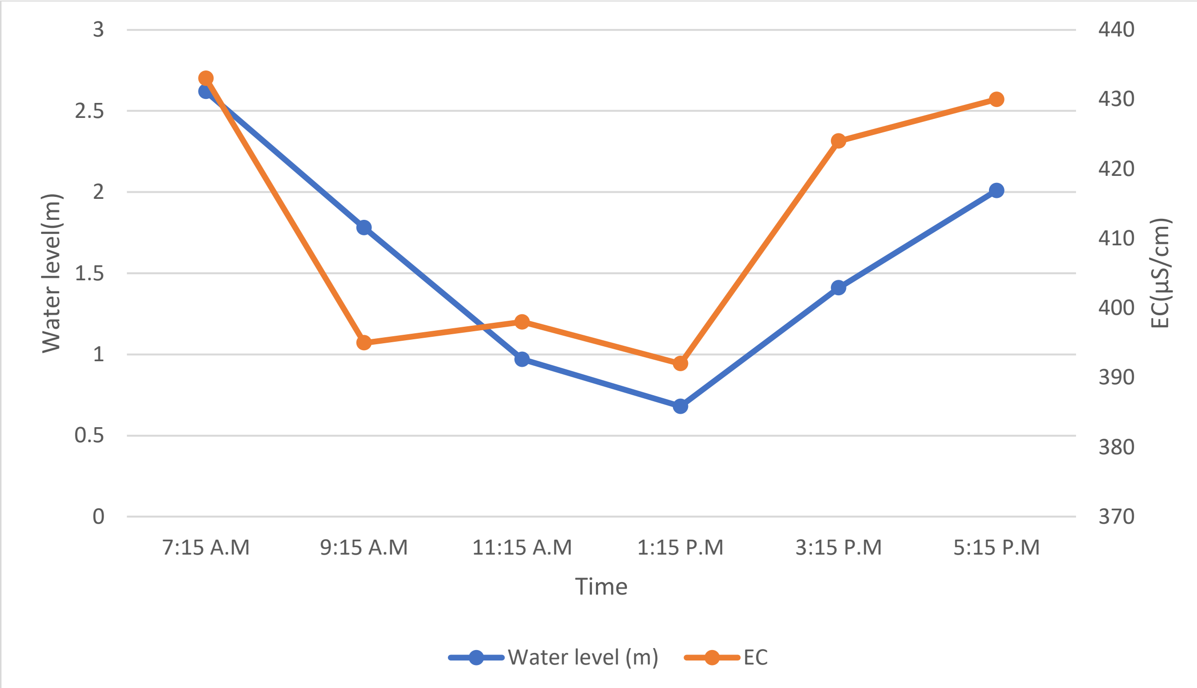

Fig 5.2c: Water level vs. EC of Baleshwar River on December 14th, 2021

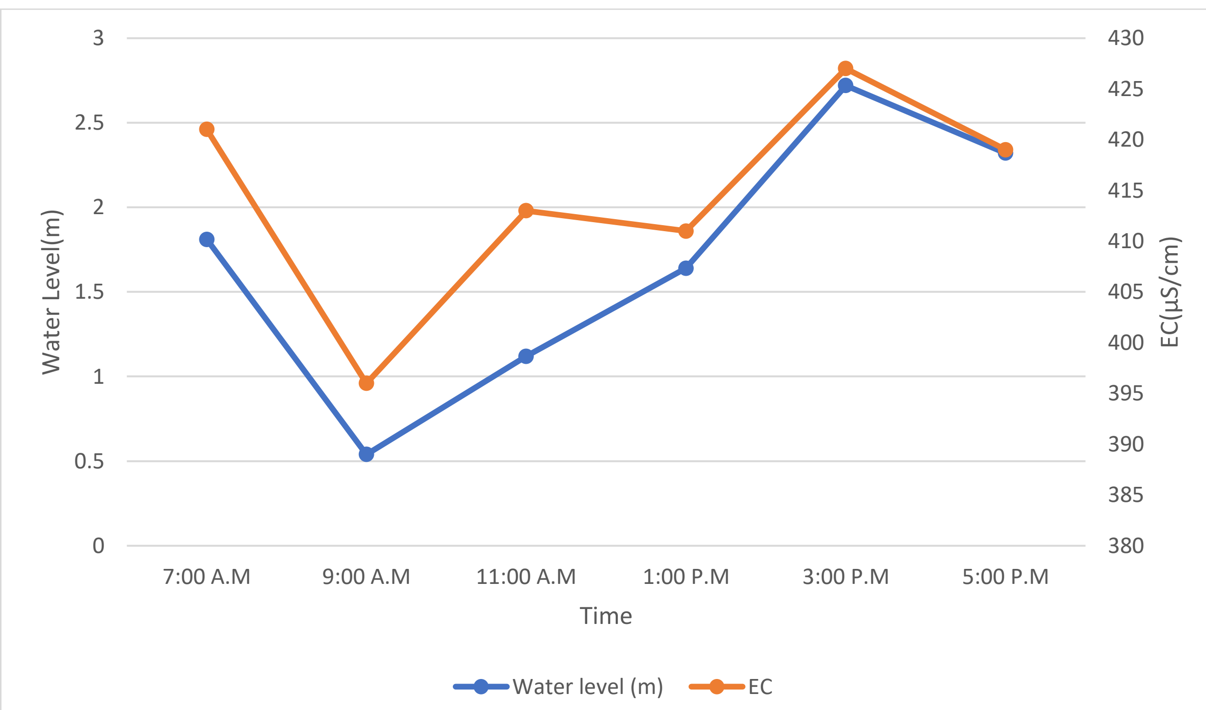

Fig 5.2d: Water level vs. EC of Baleshwar River on December 22nd, 2021

Figures 5.2a, 5.2b, 5.2c, and 5.2d show the expected pattern for salinity variation with tidal water level fluctuation in the Pasur and Baleshwar Rivers during a tidal cycle. Changes in electrical conductivity (EC) show a clear tidal pattern. EC in the Pasur River ranged from 533 to 559 µS/cm during neap tide and from 516 to 573 µS/cm during a spring tide (Figs. 5.2a and 5.2b).EC in the Baleshwar River ranged between 395 and 427 µS/cm during neap tide and between 396 and 433 µS/cm during a spring tide (Fig 5.2c and 5.2d).

At neap tide, changes in EC are reasonably consistent with the modulation of each tide. At spring tide, variations of EC appear to follow tidal cycle variations more strongly for both rivers. EC was observed to rise with incoming tides, with peaks at the top of the incoming tide.

5.8 Nitrate-N fluctuations with respect to tidal water level

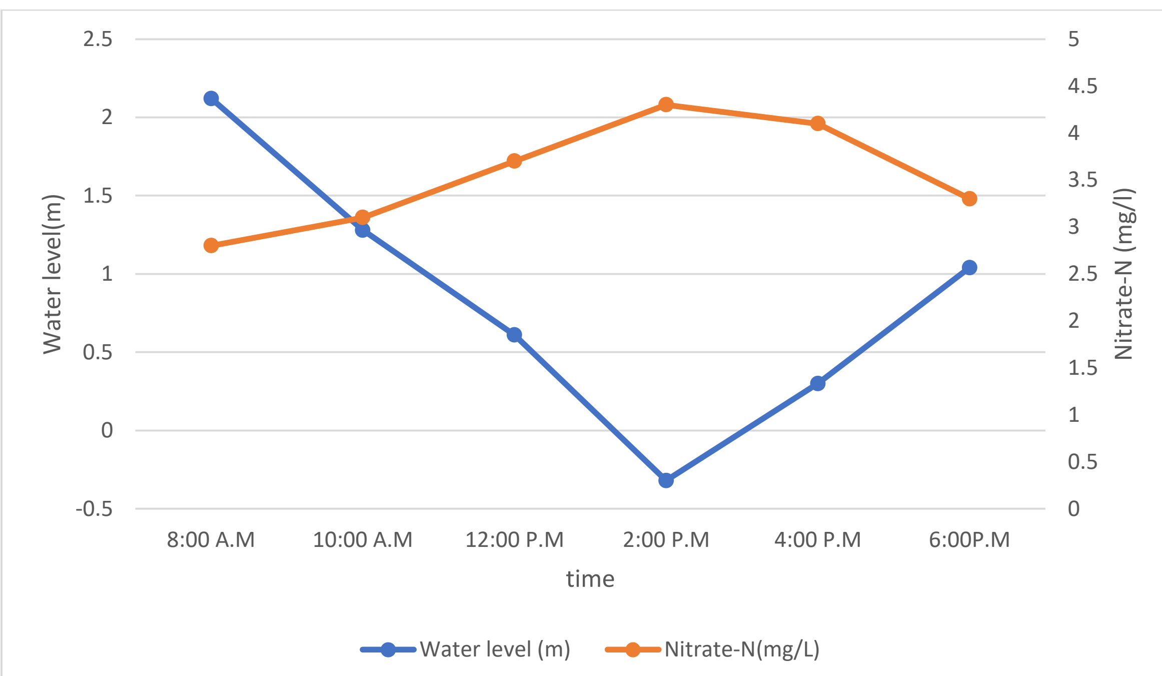

Fig 5.3a: Water level vs. Nitrate-N of Pasur River on December 13th, 2021

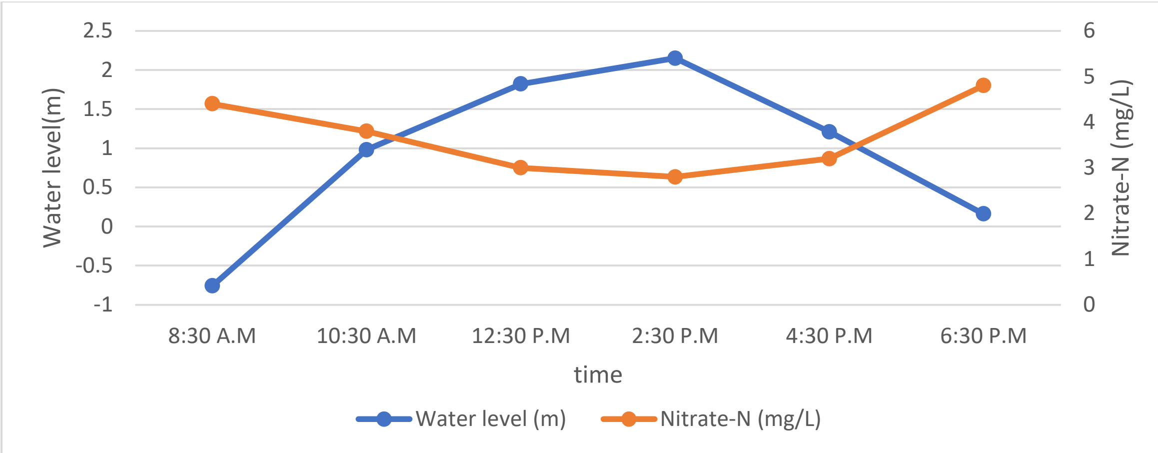

Fig 5.3b: Water level vs. Nitrate-N of Pasur River on December 21st, 2021

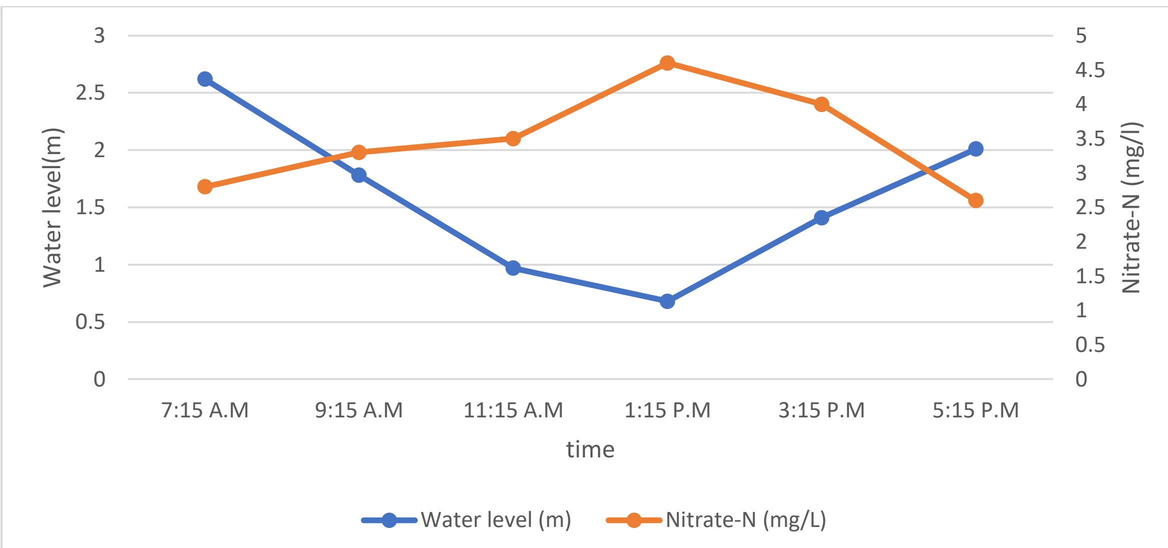

Fig 5.3c: Water level vs. Nitrate-N of Baleshwar River on December 14th, 2021

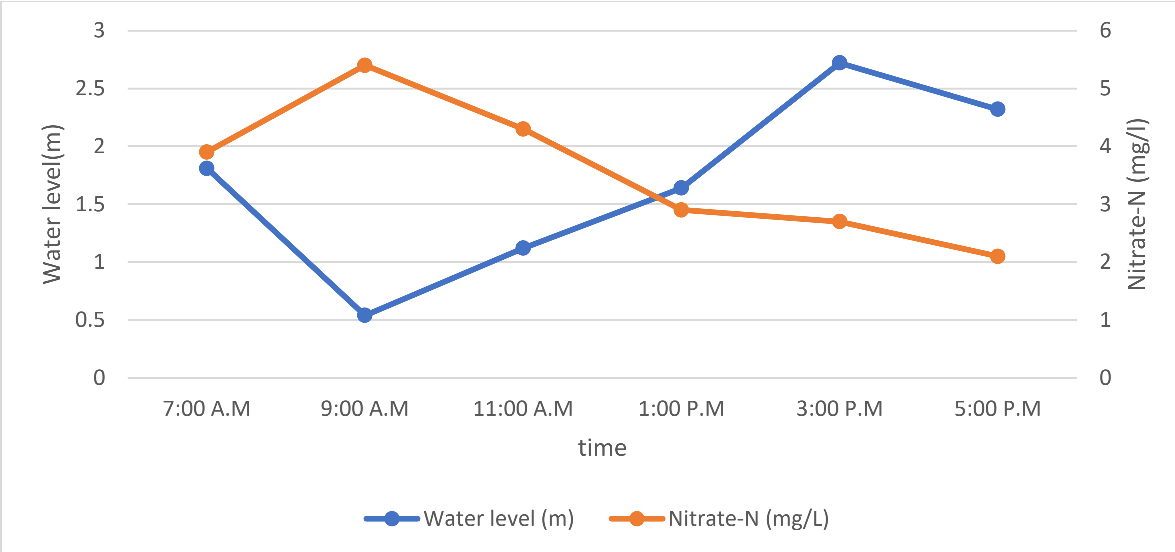

Fig 5.3d: Water level vs. Nitrate-N of Baleshwar River on December 22nd, 2021

From the above graph, it is evident that nitrate-N fluctuated between 2.8 and 4.3 mg/L during the neap tide and between 2.8 and 4.8 mg/L during spring tide conditions in the Pasur River (Fig 5.3a and 5.3b). Again, nitrate-N fluctuated between 2.6 and 4.6 mg/L during the neap tide and between 2.1 and 5.4 mg/L during spring tide conditions in the Baleshwar River (Fig 5.3c and 5.3d). During both tidal cycles, the highest values of Nitrate-N were recorded during low tides and the lowest values during high tides for both rivers during the sampling period. Nitrate-N decreases on incoming tides and increases on outgoing tides. In both rivers, the highest levels of nitrate-N are found near low tide and the lowest levels near high tide.

5.9 Phosphate-P fluctuations with respect to tidal water level

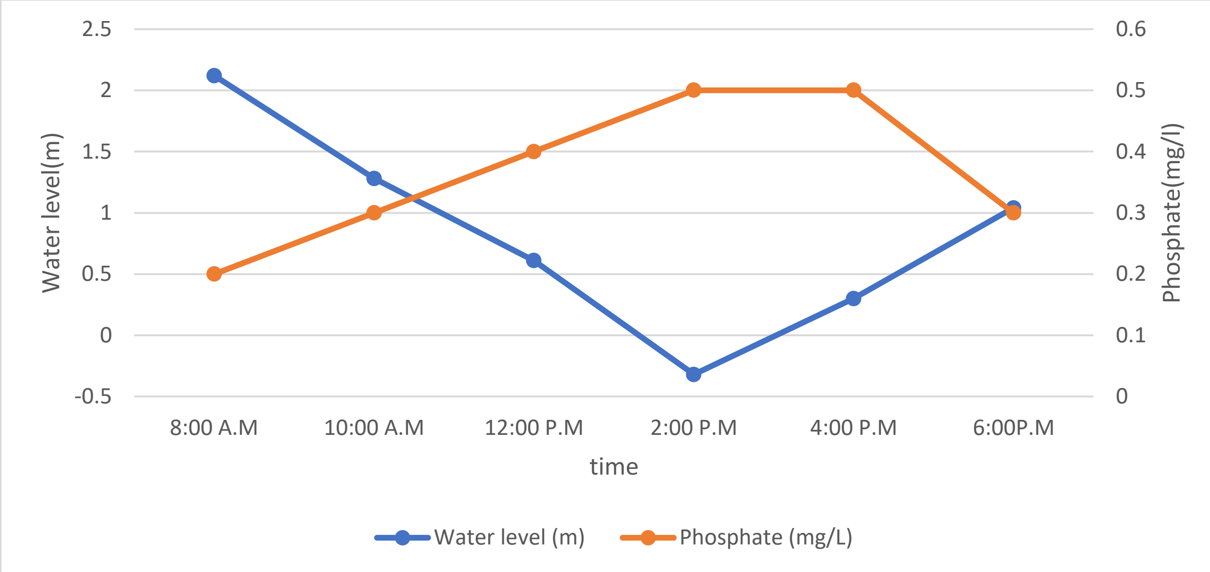

Fig 5.4a: Water level vs. Phosphate of Pasur River on December 13th, 2021

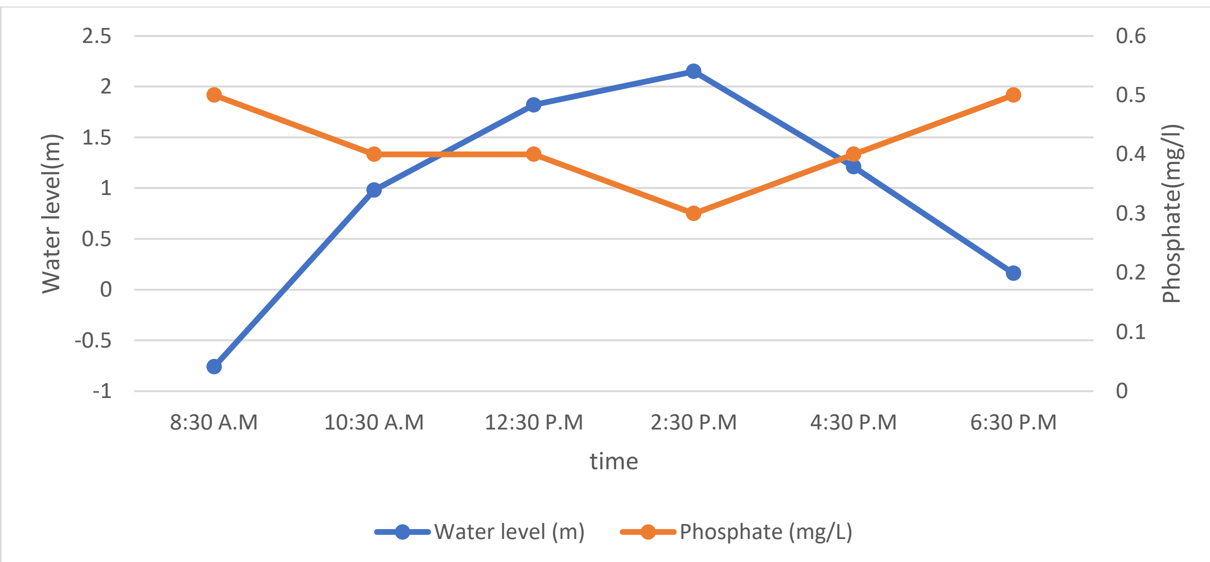

Fig 5.4b: Water level vs. Phosphate of Pasur River on December 21st, 2021

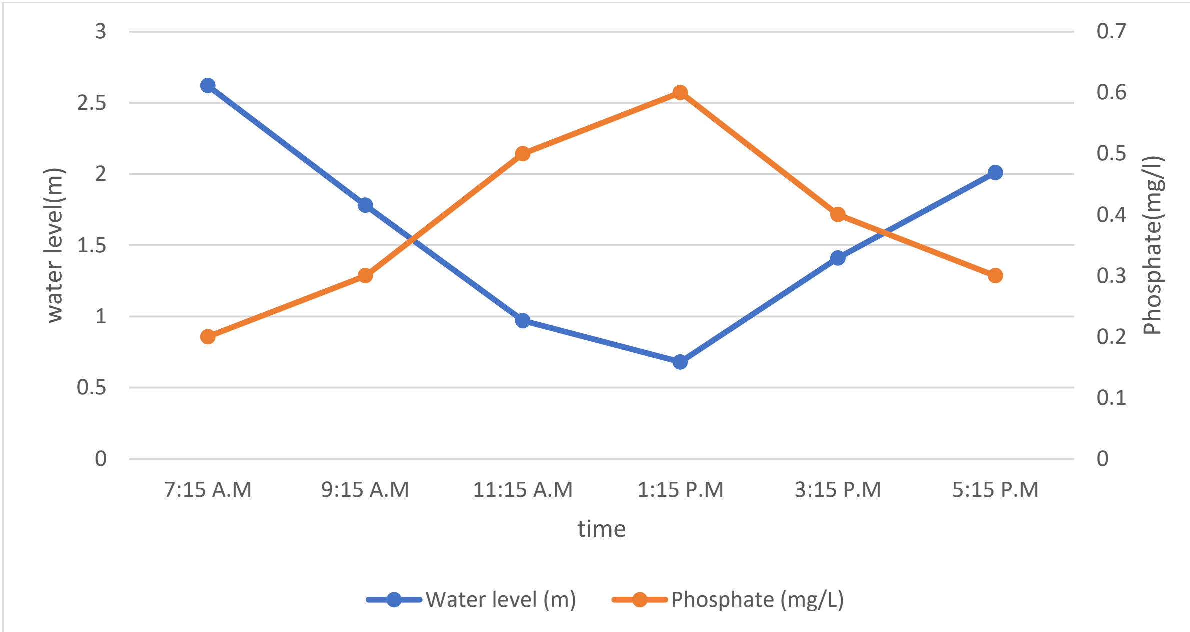

Fig 5.4c: Water level vs. Phosphate of Baleshwar River on December 14th, 2021

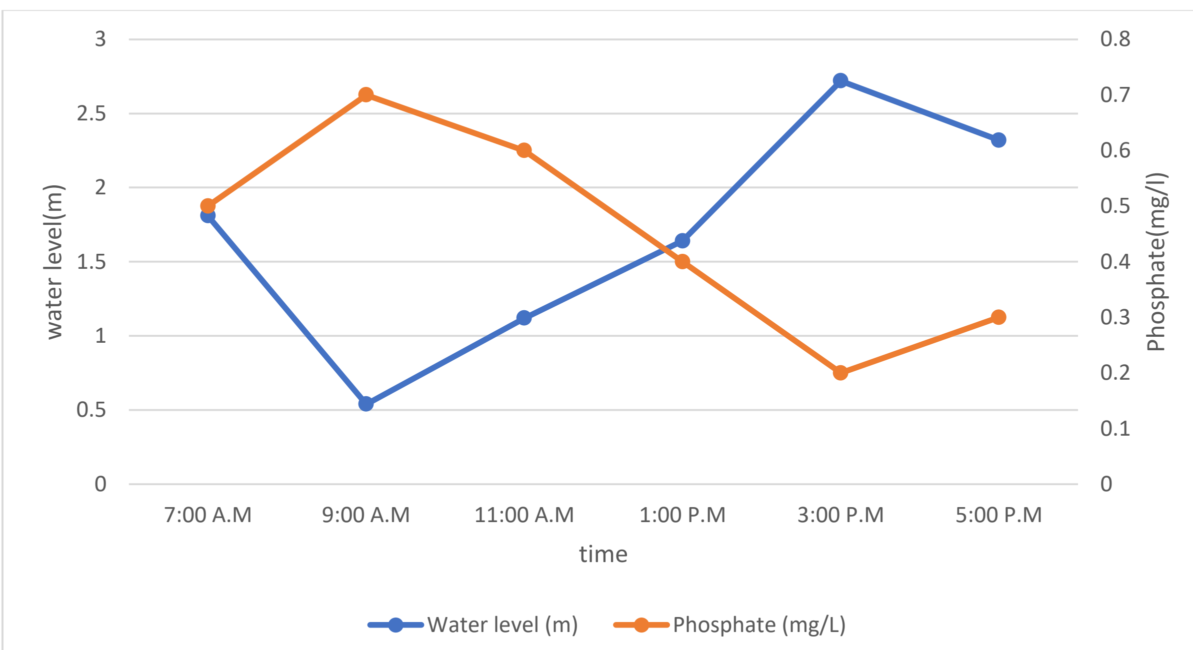

Fig 5.4d: Water level vs. Phosphate of Baleshwar River on December 22nd, 2021

Phosphate-P varied between 0.2 and 0.5 mg/L during the neap tide and between 0.3 and 0.5 mg/L during spring tide conditions in the Pasur River (Fig 5.4a and 5.4b). Phosphate-P levels in the Baleswar River ranged between 0.2 and 0.6 mg/L during neap tide and between 0.3 and 0.7 mg/L during spring tide (Fig 5.4c and 5.4d). During both tidal cycles, the highest values of phosphate were recorded during low tides and the lowest values during high tides for both rivers during the sampling period.

5.10 Ammonia-N fluctuations with respect to tidal water level

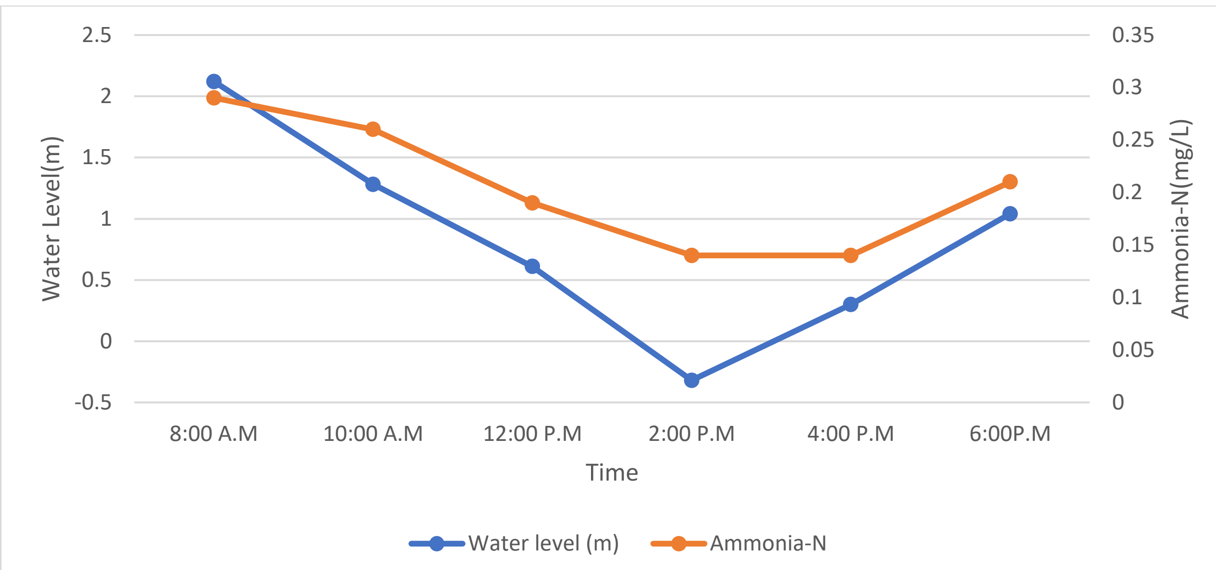

Fig 5.5a: Water level vs. Ammonia-N of Pasur River on December 13th, 2021

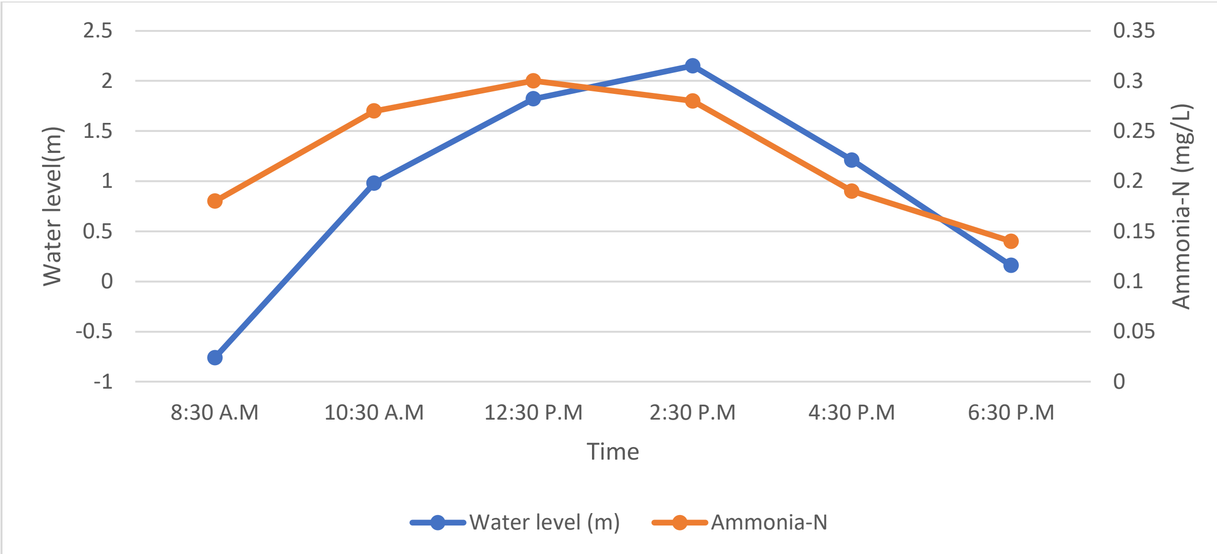

Fig 5.5b: Water level vs. Ammonia-N of Pasur River on December 21st, 2021

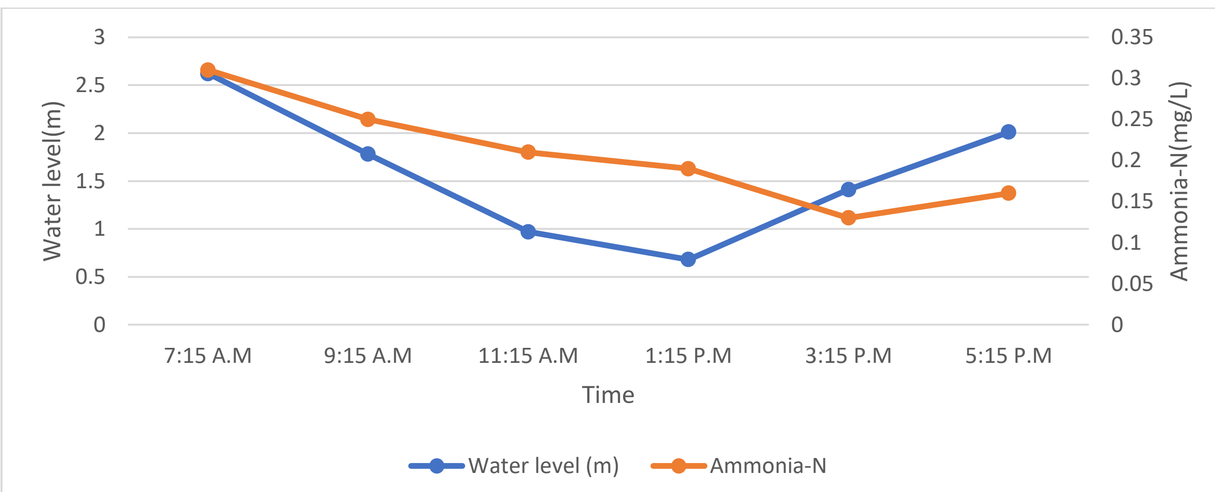

Fig 5.5c: Water level vs. Ammonia-N of Baleshwar River on December 14th, 2021

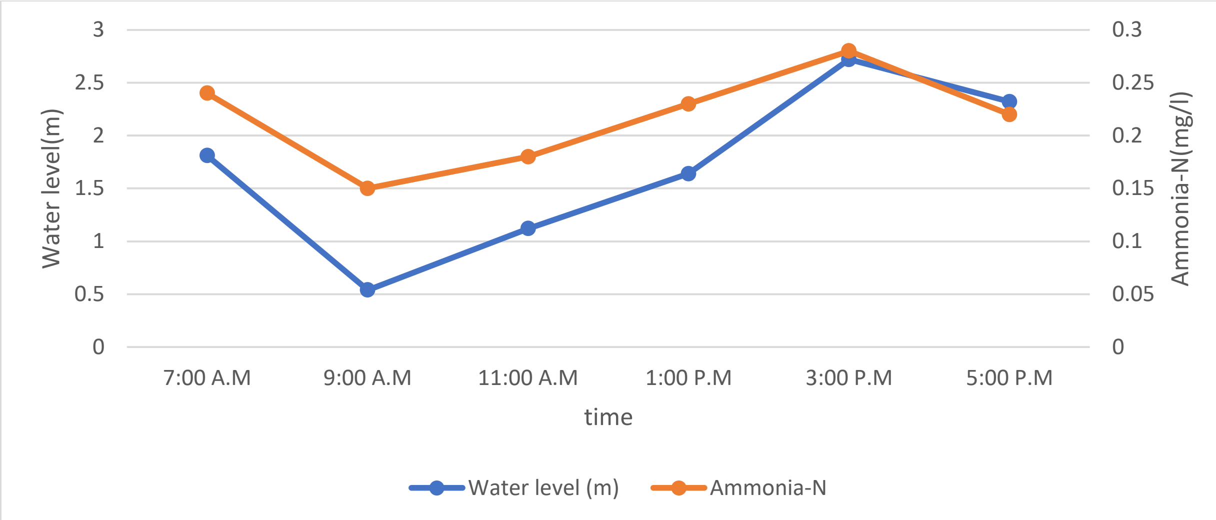

Fig 5.5d: Water level vs. Ammonia-N of Baleshwar River on December 22nd, 2021

The ammonia-N concentration varied between 0.14 and 0.29 mg/L during the neap period and 0.14 and 0.3 mg/L during the spring period in the Pasur river (Fig 5.5a and Fig 5.5b), while the ammonia-N concentration varied between 0.13 and 0.0.31 mg/L during the neap period and 0.15 and 0.0.28 mg/L during the spring period in the Baleshwar River (Fig 5.5c and Fig 5.5d). The concentration of ammonia increases with the rise of the tidal water level. So, it appears that constituents of nitrate, nitrite, and phosphate are supplied from the upstream side of the Pasur River to the sampling site at Mongla while ammonia is pushed through tidal forcing from the seaside towards the sampling site during high tide. But comparison of peak values of ammonia concentration between Pasur and Baleshwar Rivers does not show any significant difference which could be related to the impact of Sundarbans Mangrove forest at the downstream side of Pasur river. So, it may be concluded that probably the sampling locations were too far from the mangrove forest and were not appropriate to make any concrete conclusions in this respect.

5.11 Nitrite-N fluctuations with respect to tidal water level

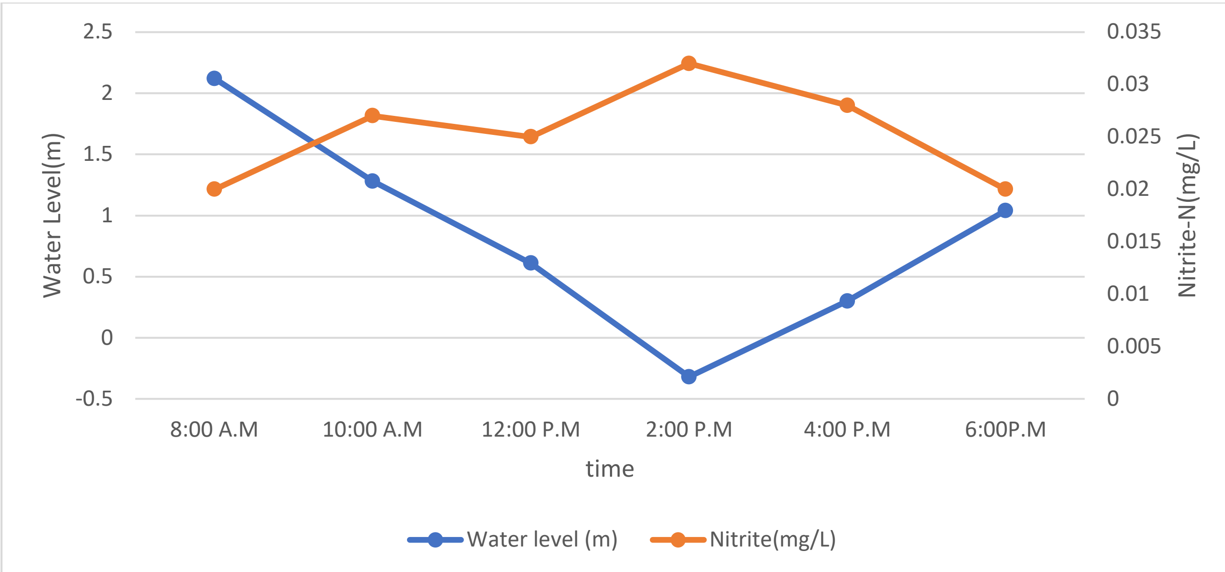

Fig 5.6a: Water level vs. Nitrite-N of Pasur River on December 13th, 2021

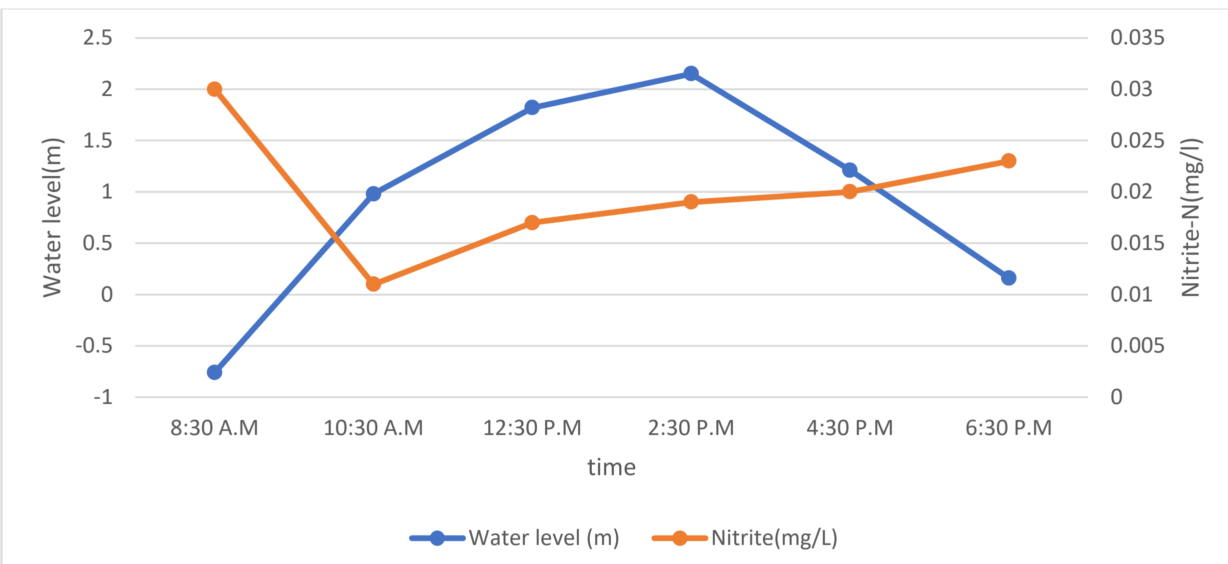

Fig 5.6b: Water level vs. Nitrite-N of Pasur River on December 21st, 2021

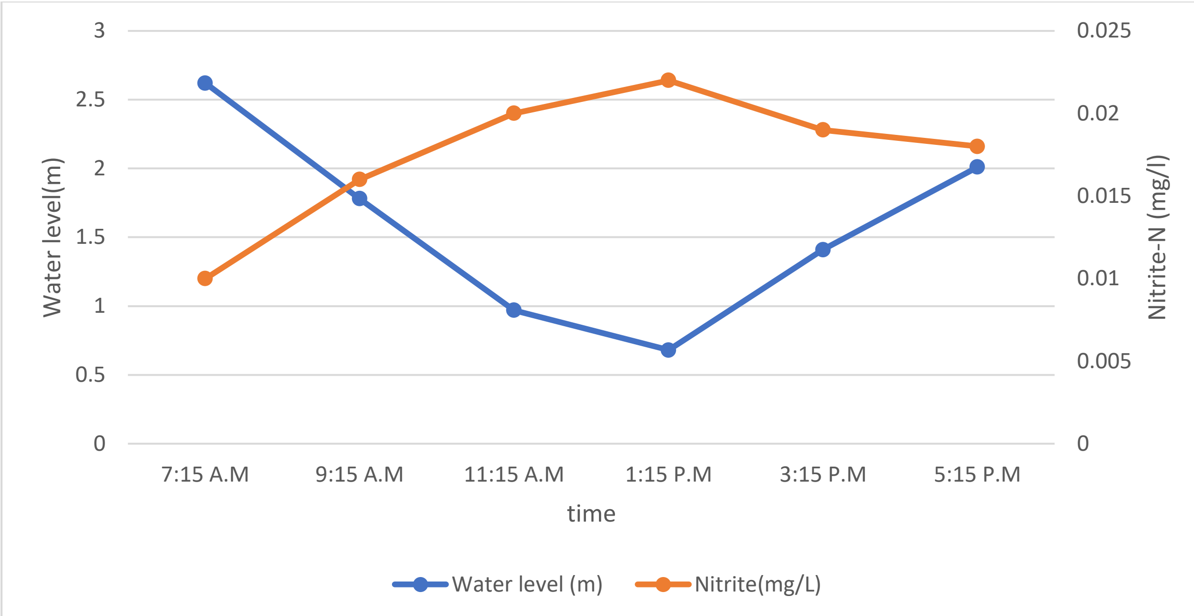

Fig 5.6c: Water level vs. Nitrite-N of Baleshwar River on December 14th, 2021

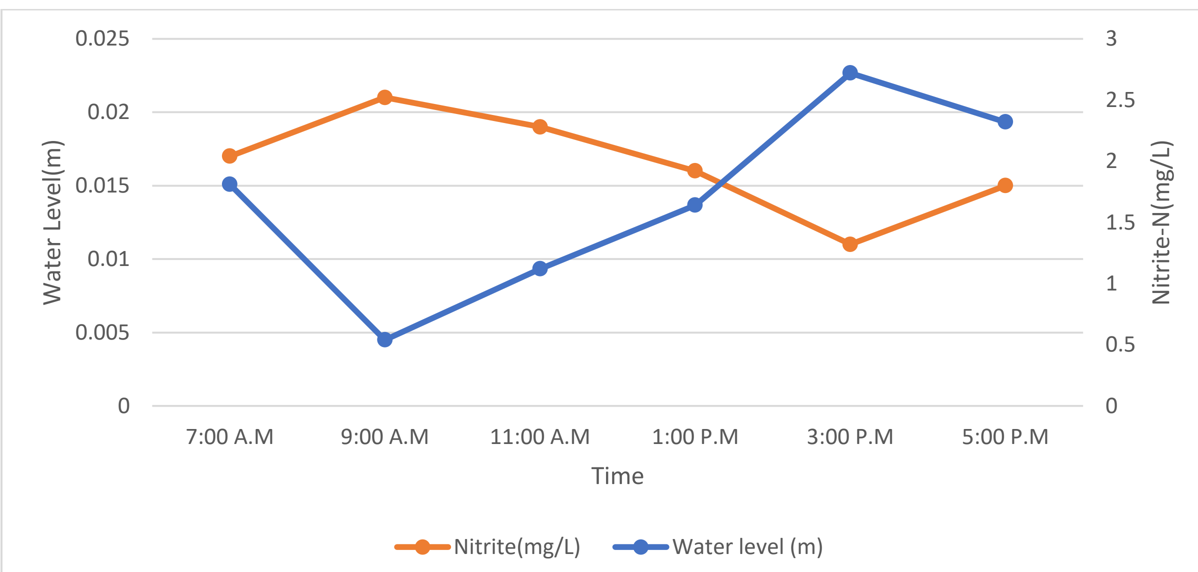

Fig 5.6d: Water level vs. Nitrite-N of Baleshwar River on December 22nd, 2021

Nitrite-N fluctuated between 0.02 and 0.032 mg/L during the neap tide and between 0.02 and 0.03 mg/L during spring tide conditions in the Pasur River (Fig 5.6a and 5.6b). (See Figures 5.6c and 5.6d.) During both tidal cycles, the highest values of Nitrite-N were recorded during low tides and the lowest values during high tides for both rivers during the sampling period.

5.12 Alkalinity fluctuations with respect to tidal water level during the spring and neap tide

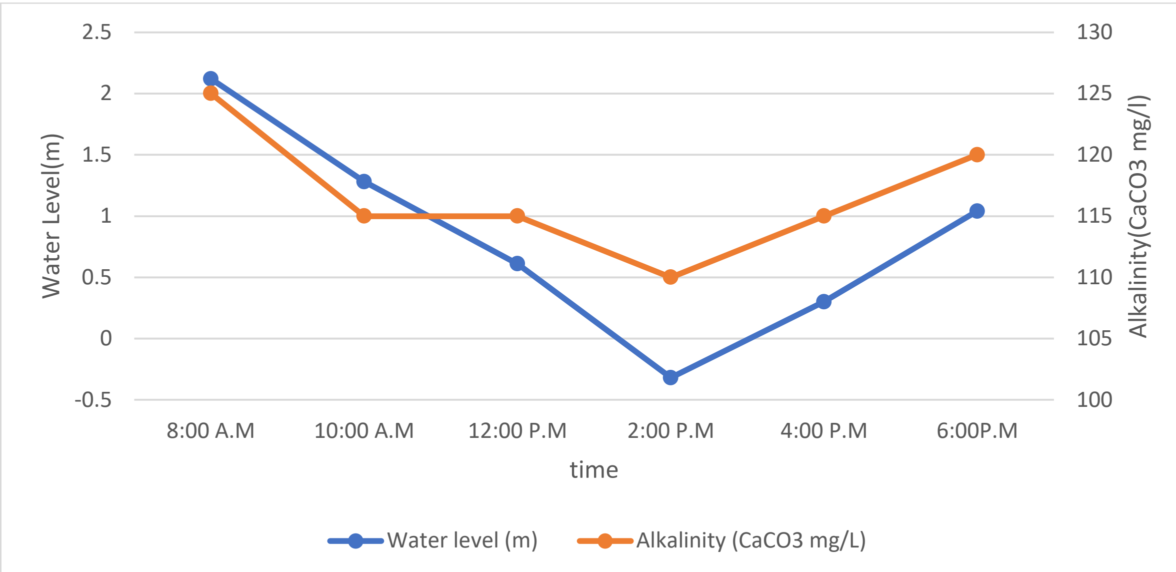

Fig 5.7a: Water level vs. Alkalinity of Pasur River on December 13th, 2021

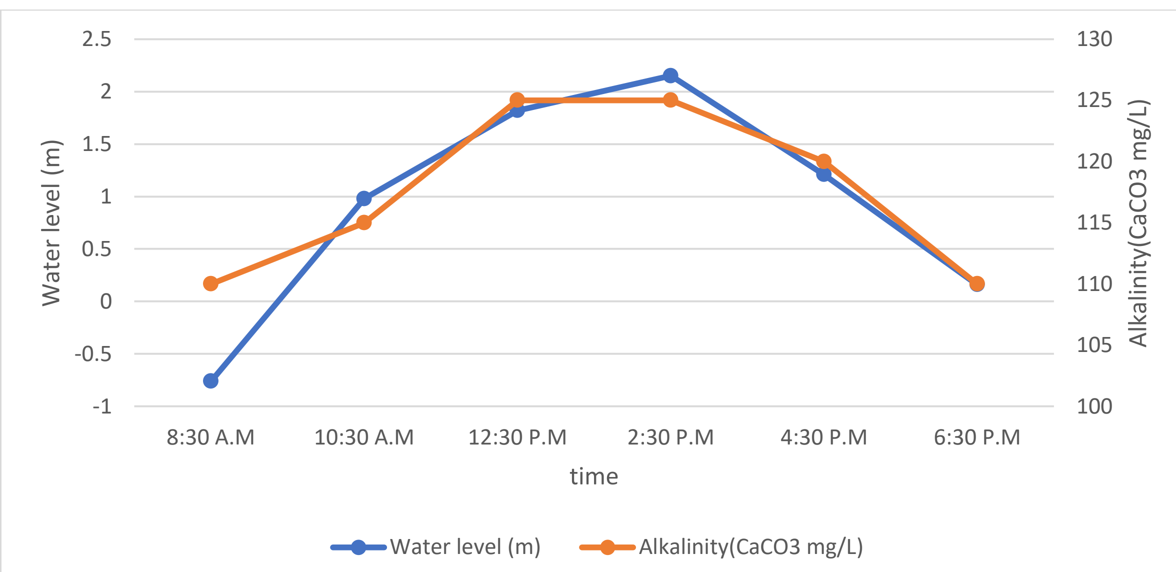

Fig 5.7b: Water level vs. Alkalinity of Pasur River on December 21st, 2021

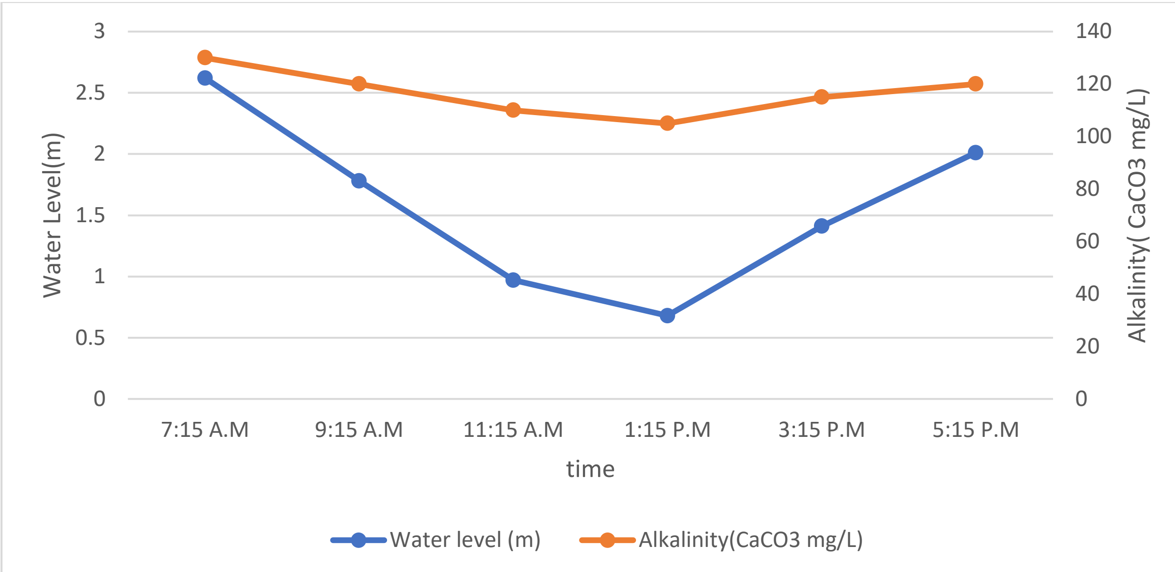

Fig 5.7c: Water level vs. Alkalinity of Baleshwar River on December 14th, 2021

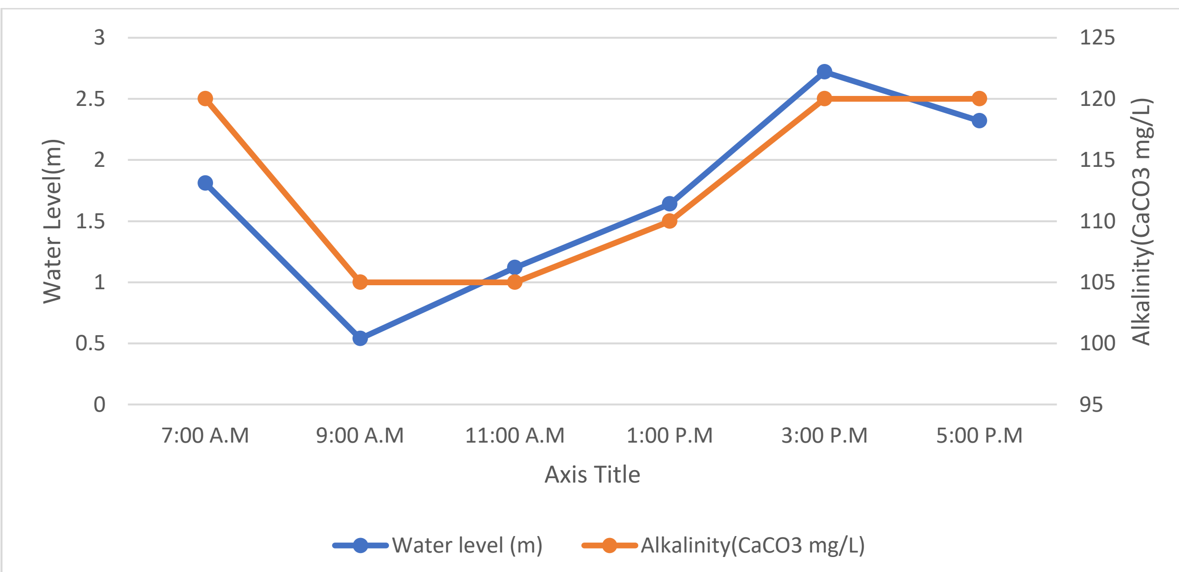

Fig 5.7d: Water level vs. Alkalinity of Baleshwar River on December 22nd, 2021

Alkalinity varied between 110 and 125 mg/L as CaCO3 during the neap period and 110 and 125 mg/L as CaCO3 during the spring period in the Pasur river (Fig 5.7a and Fig 5.7b), while alkalinity varied between 105 and 130 mg/L as CaCO3 during the neap period and 105 and 120 mg/L as CaCO3 during the spring period in the Baleshwar River (Fig 5.7c and Fig 5.7d).

From the above figures, it was found that there is a positive relationship between pH and seawater height. Julia et al. (2015) reported a significant positive correlation between pH and tide height. The highest pH values are measured at high tide and the lowest pH values at low tide. The relationship between salinity and nitrate content is often negative (Saifullah et al., 2014a). There was a negative correlation observed among pH, nitrate, nitrite, and phosphate, whereas a positive correlation was found between pH and ammonium concentration.

5.14 Discussion on results

The main finding from the water quality data was that water fluxes in the segments of the Pasur and Baleshwar rivers were largely driven by tides. These results suggest a strong tidal exchange influences water quality conditions in these tide-dominated river segments. The spring and nap periods were identified before a field visit to the study area. For the Pasur River, the observed tidal water level data confirmed the lunar phase, but for the Baleshwar River, the tidal range appears higher during neap periods.

The lack of carbon dioxide caused by algae photosynthesis during the winter could be the cause of the high pH value. During high tide, water from the Bay of Bengal enters the present estuarine zone, contributing to the increasing salinity. However, during low tide, the effect of freshwater discharge from the upstream rivers lowers the salinity of the study area. Several previous studies (NEERI, 1976) found similar variations in salinity with the tide. Observations of an increase in nutrients with a decrease in salinity have been reported in Indian estuaries by various studies (e.g., Janardanan et al., 2015; Devore, 2016). The estuary's salinity rises due to the entrance of extremely salty water and a lack of freshwater discharge (Liu et al., 2005; Robins et al., 2018). When the tide is high, seawater enters the estuary area, which increases salinity. However, during low tide, freshwater discharge from upstream rivers reduces the estuary's salinity (Mukhopadhyay et al., 2006).

The considerable nutrient load in the present study area may be attributed to: (i) increased industrialization and urbanization; (ii) unplanned expansion of shrimp culture units; (iii) large-scale use of fertilizers (urea, super-phosphate etc.) for boosting crop production in mono-cropping areas of the islands of the Sundarbans; (iv) mushrooming of tourism units; (v) a considerable number of unorganized fish landing sites with no provision for proper sewage and garbage disposal; (vi) increased number of fishing vessels and trawlers [12]; (vii) erosion of embankments and mudflats due to wave action; and (ix) contribution of litter and mangrove detritus from the adjacent landmasses.

Senthil Kumar et al. (2008) conducted an experiment on seasonal and tidal dynamics of nutrients in a mangrove estuary along the southeast coast of India In a 24-h diurnal survey in both dry and wet seasons. They found that the distribution of nutrients is influenced by the tidal cycle, as indicated by changes in tidal height. Rahaman et al. (2013), who made field observations in the Sundarbans intertidal mangrove forest to analyze spatial and temporal variations in phytoplankton abundance and species diversity, reported that spatial and temporal variations in water quality conditions of the river system indicate the influence of various climatic and local forcing functions.

At the study sites, during the flood tide, high-salinity water caused a significant drop in nitrate and nitrite nitrogen and phosphorus concentrations at all stations because river nutrient concentrations were lowered by mixing with seawater. On the other hand, during the ebb tide, riverine input of nitrite, nitrate, and phosphate significantly increased their concentrations in the estuary. The significant tidal variations of nutrients are the net effect of freshwater flow from upstream regions that bring contributions from industries, shrimp farms, tourism units, fish landing stations, and agricultural lands. The variations in nutrients were not significant between the two tidal conditions. The variation of nutrient concentrations between the Pasur and Baleshwar rivers was significant for nitrate and ammonia, particularly during spring periods. The higher nitrate and phosphate levels in and around Mongla and Sarankhola stations are the result of anthropogenic activities. The considerable nutrient load around the sampling station could be a result of eroded soil (Hazra et al., 2002).

The Mongla station of the Pasur River showed significantly higher concentrations of 0.3 mg/L of ammonia, and the Sarankhola station of the Baleshwar River also showed significantly higher concentrations of 0.31 mg/L of ammonia during the study period (winter season) on average. The source of NH_3 may be municipal effluent discharges, agricultural runoff, NH_3-based fertilizer applications, shrimp aquaculture's excess feed, soil erosion from riverbanks, bacterial decomposition of organic matter that accumulates in sediment, including plants and animal wastes, and indirect means such as nitrogen fixation and air deposition in both study locations. Sediment microbiota mineralizes organic nitrogen or produces ammonia by dissimilatory nitrate reduction (US EPA). The increased rate of organic matter decomposition may be the cause of the greater ammonia content during the dry season at the study location. River runoff from inland areas, which is characterized by diversified agricultural and aquaculture activities (both practices involve the application of fertilizers and other chemicals) as well as wastewater runoff and eroded soils, may contribute to the higher concentrations of ammonia (Wahid et al., 2007). The anthropogenic sources that significantly contribute to nitrogen in water bodies include sewage treatment plant effluents, agriculture, urban development, paper plants, industrial effluents, and recreation.

Both the Pasur and Baleshwar rivers showed relatively low nitrite concentrations. The unstable oxidation state of nitrite in water may be the cause of the relatively low nitrite concentrations (Zhang et al., 2010a, b). Nitrogen is easily produced from ammonia when nitrifying bacteria and oxygen are present, converting ammonia to nitrite and then nitrate. The environment's nitrite concentration was influenced by the breakdown of phytoplankton, nitrate reduction, and ammonia oxidation.

The phosphate concentrations in the Pasur and Baleswar rivers differ significantly. Compared to the Pasur River, the Baleshwar River has a higher phosphate concentration of 0.7 mg/L. The primary sources of phosphorus addition to the aquatic ecosystem are residential sewage and runoff from agricultural areas (Abel, 1996). High phosphate concentrations indicate eutrophication-related pollution from urban runoff of detergent-and fertilizer-containing household effluents, industrial wastewater, and soil erosion (brick kiln, river dredging) from the surrounding areas. The Baleshwar River's greater phosphate concentrations suggest a comparatively higher eutrophic state. The mangrove system receives very little freshwater discharge into the Pasur River during the dry season, which results in a decreased phosphorus concentration.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following major conclusions can be made from the present study:

a) In this study, five environmentally important physicochemical parameters were measured during the spring and neap tidal phases in the winter season of 2021 at the sampling station in the Mongla for the Pasur River and Sarankhola for the Baleshwar River estuary.

b) Expected patterns for salinity variation with tidal water level fluctuation were observed both at the Pasur River and at the Baleshwar River during the tidal cycles of spring tide and neap tide. During flood tides, the incoming saline seawater increases the river water salinity at the sampling sites, and salinity is reduced during ebb tide with upstream freshwater inflow and outgoing tidal water.

c) At both the sites, salinity was relatively higher during spring periods compared to neap periods: 573 μS/cm during spring tide and 559 μS/cm during neap tide at Pasur River; and an average of 433 μS/cm during spring tide and 430 μS/cm during neap tide at Baleshwar River.

d) The fluctuations of salinity during the tidal phases were found to be very small even during the winter season: 57 μS/cm during the spring period with a 2.91 m tidal range and 26 μS/cm during the neap period with a 2.44 m tidal range in the Pasur River; while it was only 37 μS/cm during the spring period with a 2.18 m tidal range and only 38 μS/cm during the neap period with a 1.94 m tidal range in the Baleshwar River.

e) During neap tide in the Pasur River pH fluctuated from 7.77 to 8.1; nitrate fluctuated between 2.8 to 4.3 mg/l, ammonia 0.14 to 0.29 mg/l, nitrite 0.02 to 0.032 mg/l, phosphate 0.2 to 0.5 mg/l and alkalinity 110 to 125 mg/l. In the same river, during spring tide, pH fluctuated from 7.7 to 8.11, nitrate fluctuated between 2.8 to 4.8 mg/l, ammonia 0.14 to 0.30 mg/l, nitrite 0.02 to 0.03 mg/l, phosphate 0.3 to 0.5 mg/l and alkalinity 110 to 125 mg/l.

f) In the Baleswar River, during the neap tide, pH varied from 7.98 to 8.17, nitrate fluctuated between 2.6 to 4.6 mg/l, ammonia 0.13 to 0.31 mg/l, nitrite 0.01 to 0.022 mg/l, phosphate 0.2 to 0.6 mg/l and alkalinity 105 to 130 mg/l. In the same river, during spring tide, pH ranged from 7.99 to 8.19, nitrate fluctuated between 2.1 to 5.4 mg/l, ammonia 0.15 to 0.28 mg/l, nitrite 0.011 to 0.021 mg/l, phosphate 0.2 to 0.7 mg/l and alkalinity 105 to 120 mg/l.

g) During both the spring and neap periods, nitrate, nitrite, and phosphate concentrations decrease as the tidal water level rises and vice versa. So, it appears that constituents of nitrate, nitrite, and phosphate are supplied from the upstream sides of the Pasur and Baleshwar Rivers to the sampling sites, which can be primarily attributed to the agricultural and municipal runoffs.

h) In the case of ammonia, during both the spring and neap periods, it was found that concentration increased with the rise of tidal water levels and vice versa for both the Pasur and Baleshwar rivers. So, it appears that ammonia was supplied from the seaside towards upstream through both the river systems.

i) Comparison of peak values of ammonia concentration between Pasur and Baleshwar Rivers did not show significant difference which could be related to the impact of Sundarbans Mangrove Forest at the downstream side of Pasur river. So, it was concluded that the sampling locations were too far from the mangrove forest and were not appropriate to make any concrete conclusions on the impact of mangrove forests on the nutrient flux through the selected coastal rivers.

6.2 Recommendations:

There are several recommendations that could be made from the present study:

1. Sediment-associated nutrient loads should be assessed through the collection of suspended sediment samples at different tidal phases.
2. Detailed information about land-use activities, especially agricultural activities, and pesticide applications, should be collected to assess the upstream river water quality.
3. Simultaneous water sampling at multiple sampling sites along each of the tidal rivers is expected to provide a clear picture of salinity and nutrient load propagation through the estuarine systems.

4. To better understand the impact of the Sundarbans mangrove ecosystem on the estuarine river water quality, sampling of river water directly adjacent to the mangrove forest should be performed.

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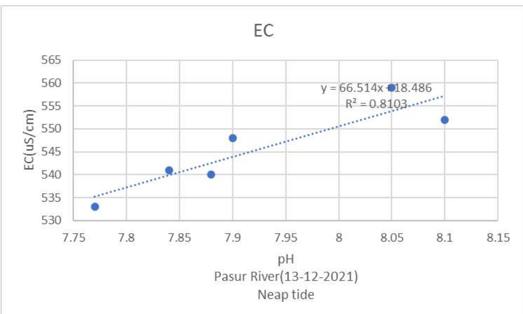
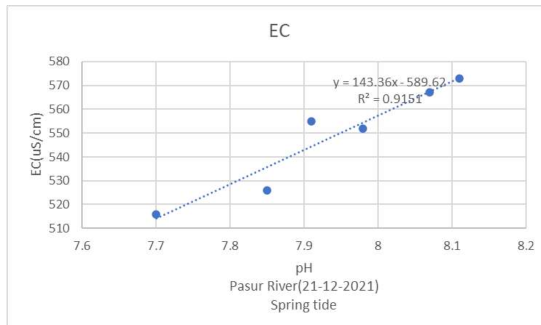
APPENDIX

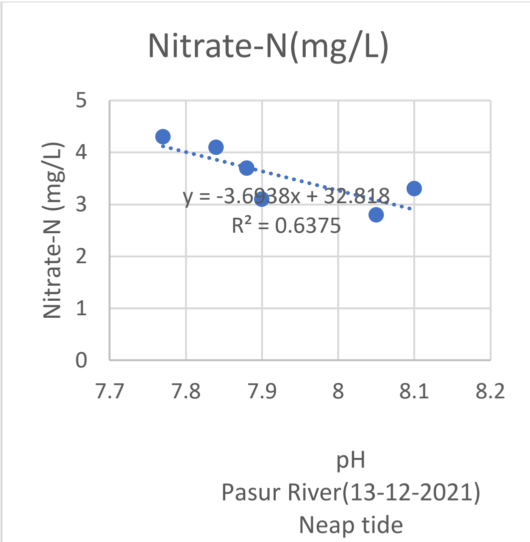
Interlinkage between different water quality parameters

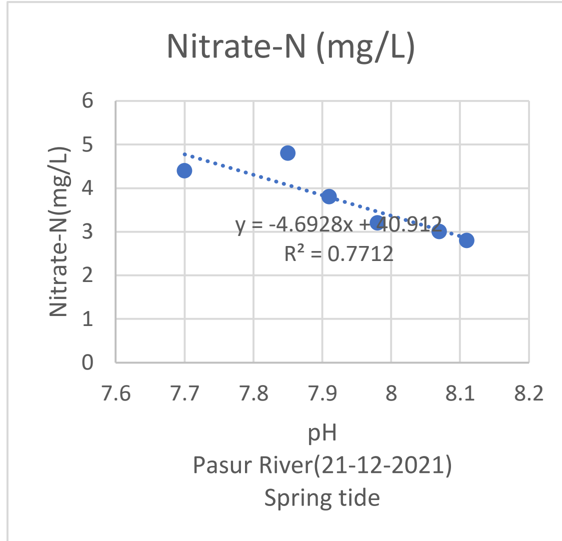
AI. pH vs EC (Pasur River)



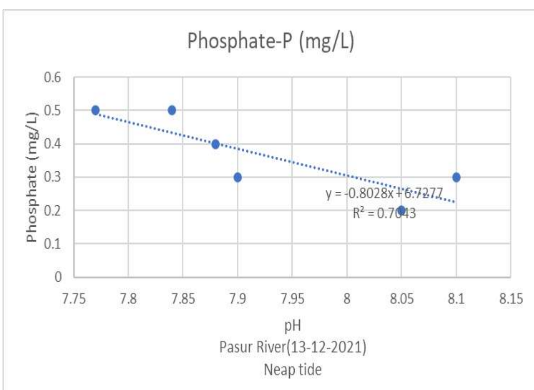


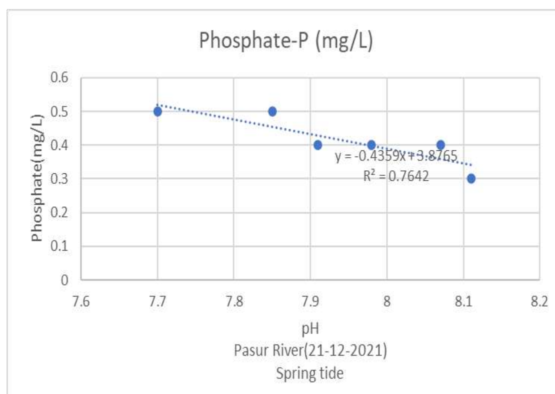
AII. pH vs Nitrate-N (Pasur River)



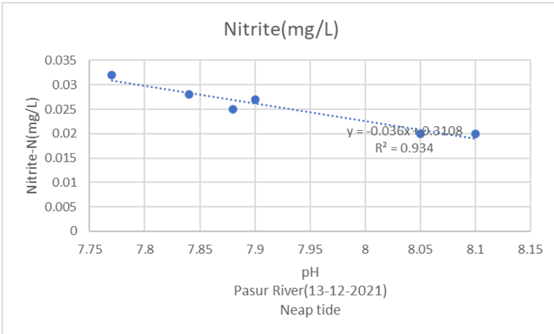


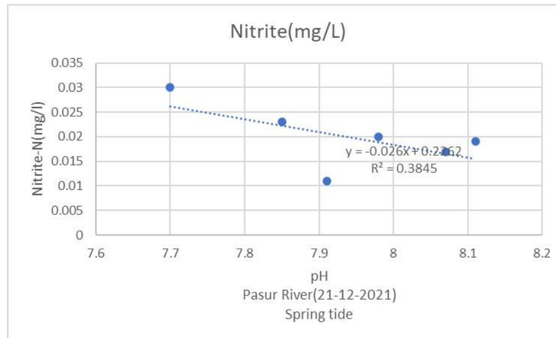
AIII. pH vs Phosphate-P (Pasur River)



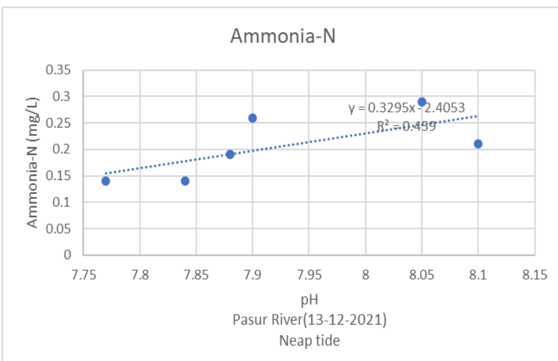


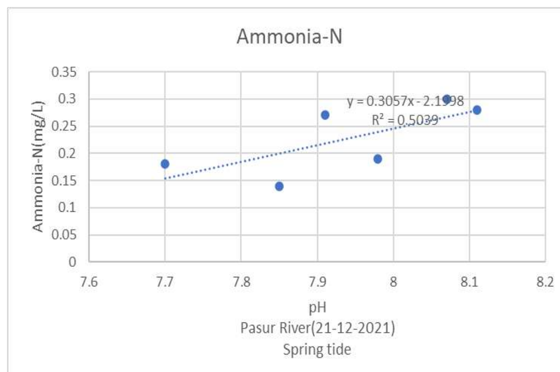
AIV. pH vs Nitrite-N (Pasur River)



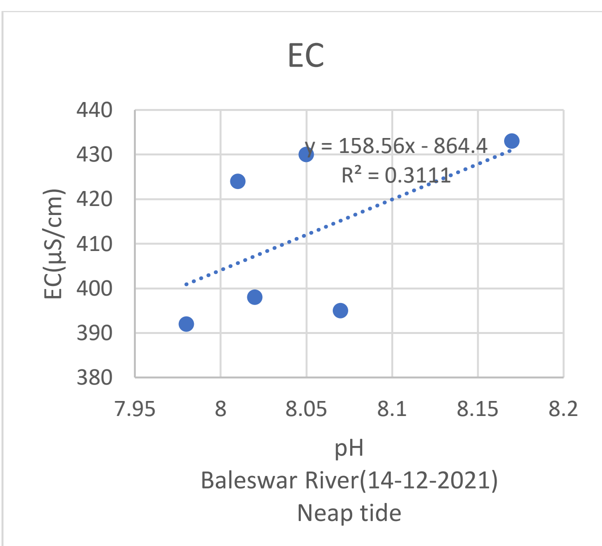


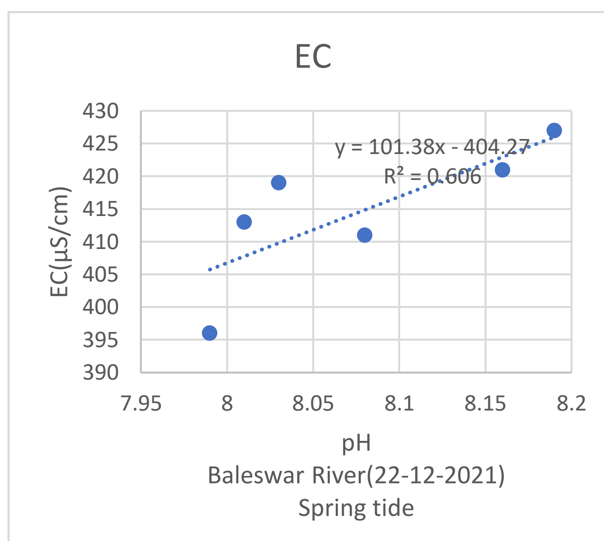
AV. pH vs Ammonia-N (Pasur River)



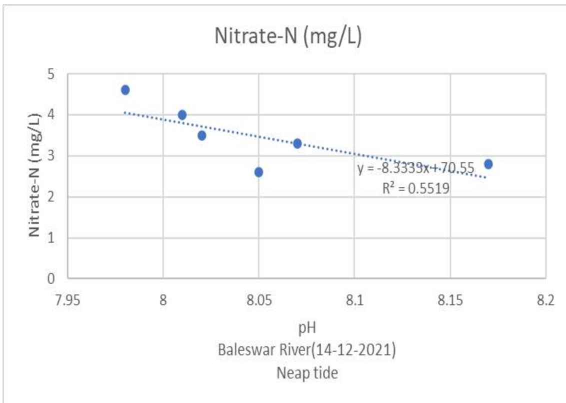


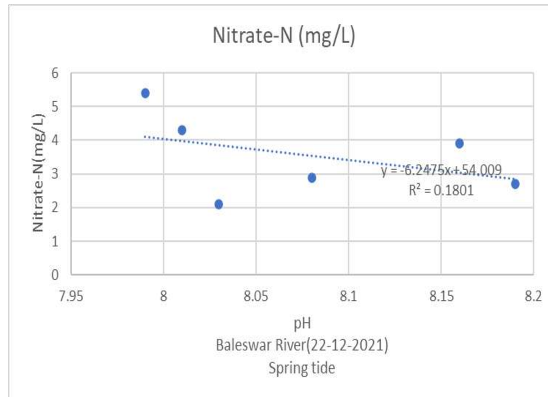
AVI. pH vs EC (Baleshwar River)



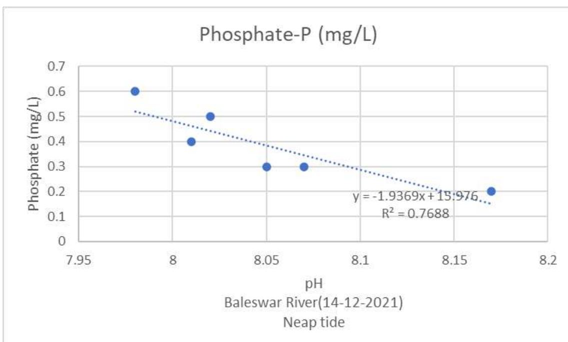


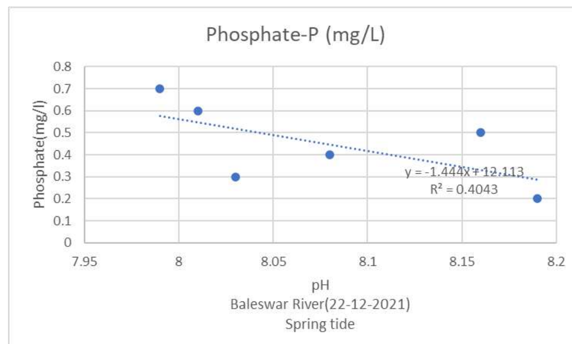
AVII. pH vs Nitrate-N (Baleshwar River)



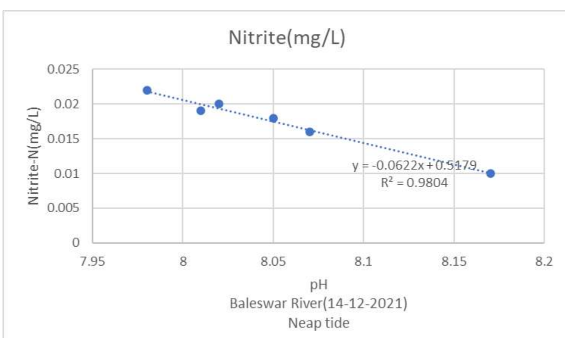


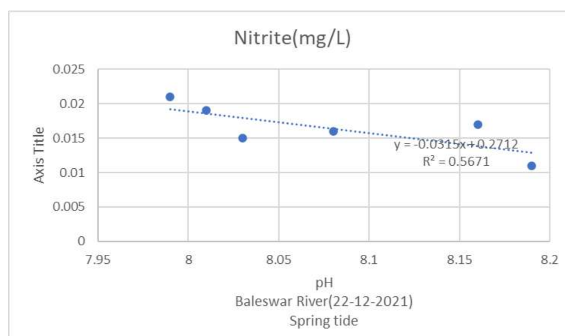
AVIII. pH vs Phosphate-P (Baleshwar River)



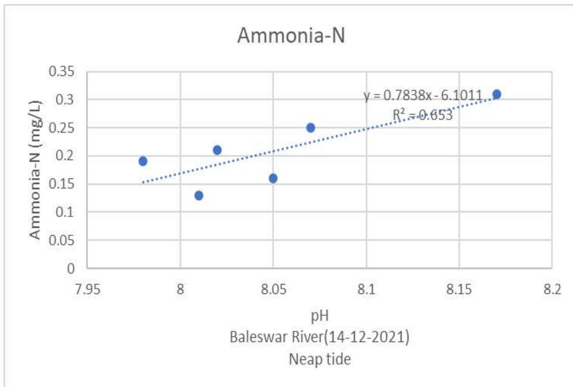


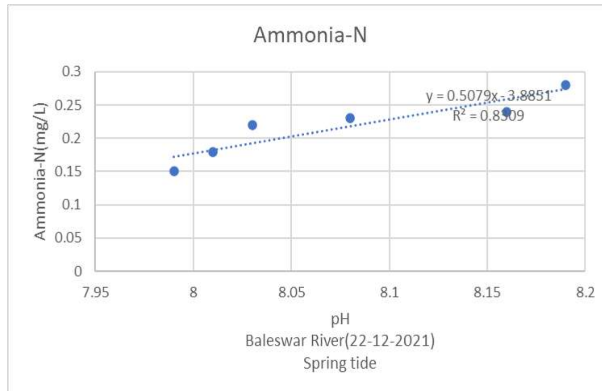
AIX. pH vs Nitrite-N (Baleshwar River)





AX. pH vs Ammonia-N (Baleshwar River)


Ammonia-N
Ammonia-N (mg/L)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
7.95
8
8.05
8.1
8.15
8.2
y = 0.7838x - 6.1011
R^2 = 0.653
pH
Baleswar River(14-12-2021)
Neap tide


Ammonia-N
Ammonia-N(mg/L)
0.3
0.25
0.2
0.15
0.1
0.05
0
7.95
8
8.05
8.1
8.15
8.2
y = 0.5079x - 3.8851
R^2 = 0.8509
pH
Baleswar River(22-12-2021)
Spring tide