

Assessment of Shoreline Changes and the Groundwater Quality along the Coast of Kuakata, Patuakhali, Bangladesh

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ABSTRACT

Shoreline changes and groundwater quality monitoring have become pressing issues for the coastal region of Bangladesh. This study investigated the shoreline changes from 2000 to 2020 and evaluated the groundwater quality, as well as SWI in the Kuakata coastal area. While analyzing satellite images, the temporal shoreline changes were assessed through the Digital Shoreline Analysis System (DSAS) in ArcGIS 10.4.1. Higher erosion rates (>2 m/year) were found in the southernmost part and the SE part of the studied area. Twenty-five groundwater samples were collected, and the physicochemical parameters were measured to assess the groundwater quality. The geographic information system (GIS) was used to assess the spatial variation of the EC, pH, and Cl⁻ contents through the inverse distance weighted (IDW) interpolation method. The EC, Cl⁻, and pH values of the studied groundwater ranged from (1.2 mS/cm to 19.5 mS/cm), (79.88 mg/L to 11241.67 mg/L), and (7.9 to 8.7), respectively. The analysis revealed that the majority of the groundwater samples were unsuitable for drinking purpose due to higher EC and Cl⁻ values. Saline water intrusion (SWI) was determined by using the alternative EC vs Cl⁻ method in the southern part of the Kuakata beach area, which was closest to the sea.

Keywords: saline water intrusion, hydrogeochemical analysis, digital shoreline analysis system, salinity.

INTRODUCTION

The coastal region of Bangladesh covering almost 29,000 sq. km, is one of the vulnerable places on this planet due to sea-level rise, saline water intrusion (SWI), erosion, accretion, frequent occurrence of paleo-saline in aquifers, and periodic inundation of saline water by the Sidr, Aila, and Mahasen super cyclone (MoWR, 2005; Woobaidullah et al., 2006; Brammer, 2014; Islam et al., 2015; Khalil et al., 2016; Islam et al., 2017). Over the past few decades, the quality of groundwater and sustainability of coastal aquifers in Bangladesh have been affected by SWI (Sarwar and Woodroffe, 2013; World Bank, 2014; Mahmuduzzaman et

al., 2014). SWI in coastal areas of Bangladesh is maximum during March–April and minimum during the monsoon because the interface between saline water and freshwater movement directly depends on groundwater recharge (Mahmuduzzaman et al., 2014; Hussain et al., 2019). The majority population in coastal areas are dependent on groundwater resource for domestic and agricultural purposes as the surface water is highly saline, as a result of frequent cyclonic storm surge, sea-level rise, and reduction in upstream flow (BBS, 2011; Khalil et al., 2016; Rahman and Islam, 2019; Shammi et al., 2019). In most places of the coastal region, shallow groundwater (below 150 m) is contaminated with high arsenic, iron, nitrate, and even

elevated boron and manganese are also found in some locations (Rahman et al., 2021; Rahman et al., 2022). Hence, the deep groundwater (over 150 m) serves as the conceivable elective source for drinking water supply within the coastal locale of Bangladesh. Moreover, the excessive abstraction of groundwater poses a threat to the accessibility of freshwater for potable and agricultural purposes. Large-scale extraction has not been encouraged in the coastal areas due to the possibility of seawater intrusion or leakage from the upper aquifer (Aggarwal et al., 2000; Zahid et al., 2011).

It is essential to monitor the quality and sustainability of the groundwater resources of coastal aquifers as the decline of groundwater quality will have serious impacts on sustainable development (Elango et al., 2007; Singh et al., 2015; Rahman and Islam, 2019; Shammi et al., 2019). The intrusion of saline water in the coastal areas of Bangladesh is exaggerated by rapid erosion, accretion, sea-level rise, and other natural calamities that bring saline water to the inland area (Shibly and Takewaka, 2012; Brahmamar, 2014). Erosion and accretion denote the changes in offshore islands and shorelines which can be measured by analyzing time-series

satellite images (Chand and Acharya, 2010; Patra et al., 2018). Erosion, and accretion are prominent phenomena in the southern part of the country (Ghosh et al., 2015; Salauddin et al., 2018). When erosion occurs, the shoreline shifts towards the mainland, and saline water inundate the area that was once dry land. The inundation situation becomes worse when there is a rapid sea-level rise. Due to sea-level rise, the southern part of the coastal districts of Bangladesh was found extremely fragile, while the coastal sections of the Sundarbans were found quite vulnerable (UNDP, 2019). Greater erosion activity with sea-level rise implies flooding of coastal lands and more saline water intrusion.

Very few works have been done highlighting the shoreline changes and saline water intrusion in the groundwater of the Kuakata beach area. The prime goals of this study were to explore the transient changes of shoreline over two decades and groundwater quality in the Kuakata coastal region. In addition, this study also focused on the potential of groundwater as a drinking water supply. For long-term groundwater utilization and management, an assessment of coastal erosion and its implications on groundwater quality is essential.

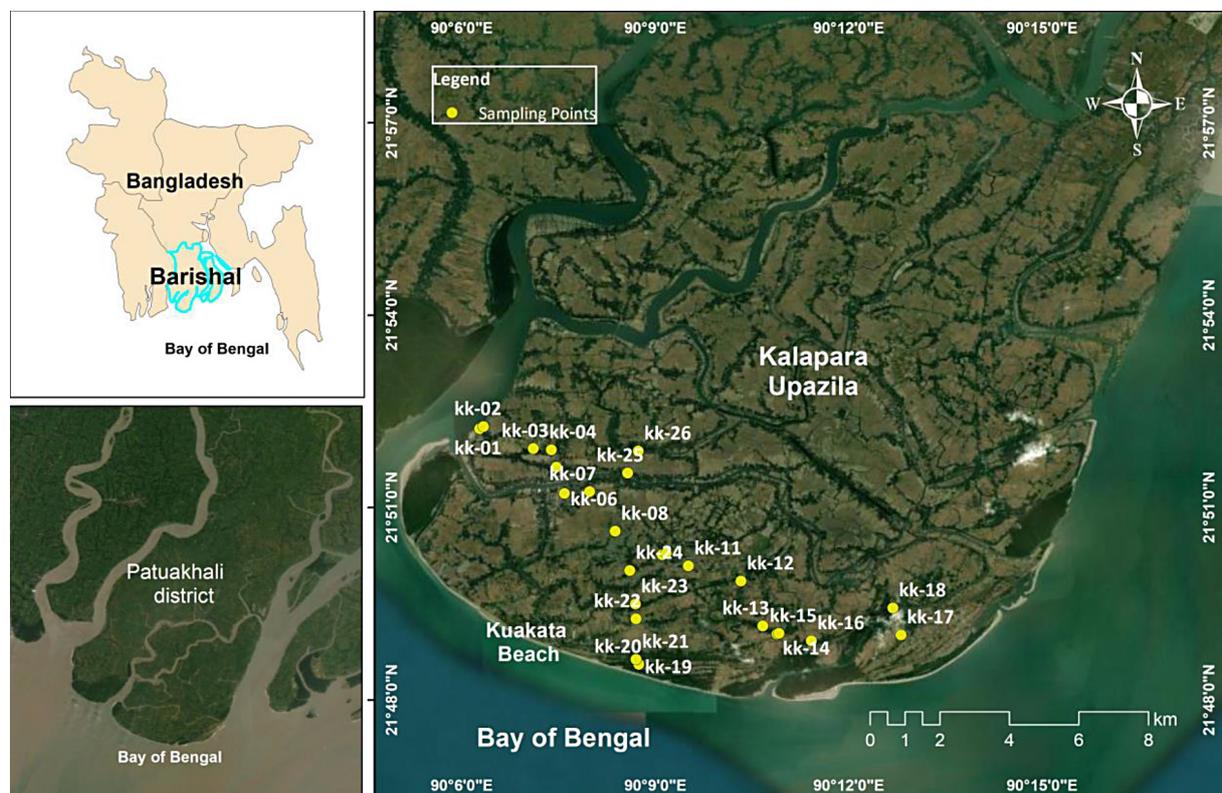


Figure 1. Location map of the study area prepared by Arc GIS 10.4.1. Yellow dots show the sampling locations

MATERIALS AND METHODS

Study area

The study area lies in the Kuakata sea beach area, at Kalapara Upazila in the Patuakhali district. It covers from 21° 48' 33.23" N to 21° 52' 16.03" N latitude and 90° 6' 16.45" E to 90° 12' 48.46" E longitudes (Fig. 1). Kuakata is situated in Latachapli union Parishad, and the Kalapara Upazila town is located to the north, a panoramic sea beach is found to the south, eastern and western parts are bounded by the confluence of two rivers namely Andharmanik in the east and the Galachipa river in the west. The Kuakata area accommodates 2,065 households with a 9,077 population (BBS, 2011). The study area lies within the moist tropical monsoon and experienced moderate rainfall. In addition, the area experiences the highest temperature in January (25.1°C) and 33.8°C in April (BMD, 2020), with a mean annual rainfall of 2580 mm/year. The period from June to September receives 90% of precipitation of the year (BBS, 2011). Tropical cyclone strikes the study area in the month from May to November causing tidal surges (Ahmed, 2006; Subhani and Ahmad, 2019).

Geological and hydrogeological settings

Patuakhali, one of the coastal districts in Bangladesh, is located in the Bengal Foredeep Basin of the late Holocene age which is influenced by

little or no tectonic movements (Uddin and Kaudstaal, 2003; Adhikari et al., 2006; Ahmed, 2006; Mahmuduzzaman et al., 2014). The hydrogeology of the coastal aquifers in Bangladesh is very complex, with the alteration of aquifer-aquitard as well as the grain size of aquitards is highly variable within a short distance (BGS and DPHE, 2001; BWDB, 2013; Shamsudduha et al., 2019). The aquifers seem to be hydraulically connected down to a depth of 350 m, and intensive pumping causes recharge during the monsoon season in several regions (BGS and DPHE, 2001; BWDB, 2013). There are two aquifers systems one at shallow depth with a maximum thickness of 143 m which is characterized by very fine sand and another at greater depth extends below 350 m which is characterized by fine sand (Khalil et al., 2020).

The upper shallow aquifers of the coastal regions are usually recharged by the rainwater and flowing surface water bodies (Bahar and Reza, 2010). Figure 2 shows the hydrogeological cross-section along N-S across Bangladesh. The direction of the regional flow pattern is mainly from north to south during the dry period since the aquifers are at or exposed above the ground surface (BGS and DPHE, 2001).

Satellite image analysis

Satellite images were used for investigating the temporal shoreline changes from 2000 to 2020 in ten years intervals (Table 1). A digital

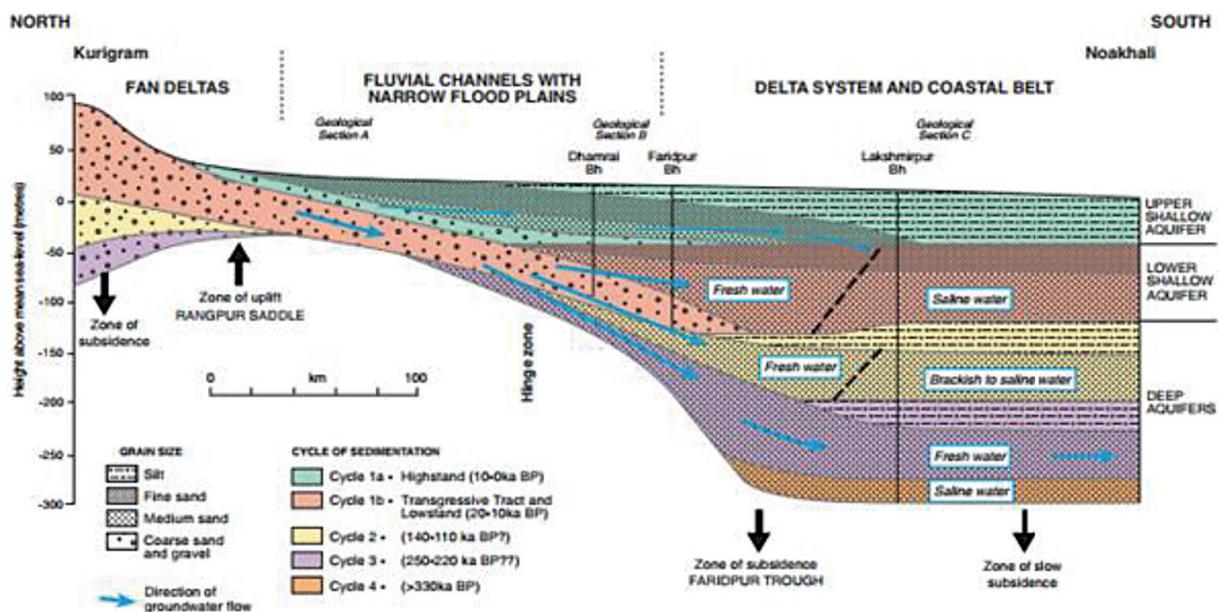


Figure 2. A hydrogeological cross-section across Bangladesh shows aquifer materials and the occurrence of fresh water and saline water in the study area (BGS and DPHE, 2001)

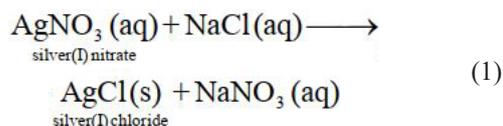
Table 1. Information about satellite images used for investigating the shoreline changes

Satellite	Spatial resolution (m)	Sensor	Row/path	Date of acquisition	Radiometric resolution	Number of bands
Landsat 8	30	OLI/TIRS	45/137	27/12/2020	16 bit	11
Landsat 5	30	TM	45/137	30/01/2010	8 bit	7
Landsat 5	30	TM	45/137	19/01/2000	8 bit	7

shoreline analysis system (DSAS) was used in Arc GIS 10.4 to evaluate the shoreline changes which could be estimated by the shoreline and a baseline using transects (Thieler et al., 2009; Chand and Acharya, 2010). The shoreline was classified into stable, erosional, and accretional, using 1052 transects created by the Arc GIS 10.4 DSAS module.

Groundwater sample collection and analysis

Then fieldwork was carried out to assess the current scenario of groundwater quality. Electric conductivity (EC), temperature, and pH data were taken along a North-South and East-West transect from twenty-five tubewells using a multiparameter probe during the fieldwork, and the tubewells were chosen using a simple random sampling procedure. An alternative graphical method Cl^- versus EC was employed to study the SWI. The determination of the salt content of seawater is an important area of research because the salt content affects ocean currents and global climate. The chloride content of salt waters was measured using chloride titration. A precipitation reaction between the silver nitrate and sodium chloride was used to determine the chloride content in salt water.



Cl^- concentration was measured using the following formula:

$$Cl(\text{ppm}) = \frac{[35.5 * \text{normality of AgNO}_3 * (T - B) \text{ml} * 100 * 10^4]}{1000 * \text{volume of sample}} \quad (2)$$

where: normality of AgNO_3 is 0.05 N;

T – amount of AgNO_3 in ml required in titration of the sample;

B – amount of AgNO_3 in ml required in titration of the blank which is measured 0.2 ml.

RESULTS AND DISCUSSION

Estimation of the shoreline changes

The shoreline change investigation in the study area identified frequent movement within the last 20 years from 2000 to 2020 (Fig. 3). The total length of the analyzed shoreline was 55.07 km in 2000 whereas it decreased in 2020 to 54.64 km. Not only erosion worked in this area, but it also experienced some accretionary processes. The total shoreline was categorized into six classes according to erosion and accretion rate. Six categories correspond to the areas of very high erosion (>2 m/year), high erosion (2 to 1 m/year), moderate erosion (0.99 to 0 m/year), Stable (>0 to 1 m/year), high accretion (>1 to 2 m/year), and very high accretion (>2 m/year).

The southern, southwestern, and southeastern portions of the Kuakata beach area showed higher erosion rate (>2 m/year) and progression rate (>2 m/year) at the confluence of two rivers with the sea. This high erosion may be due to the newly exposed loose bank sediments, steep slopes, and high tidal pressure. On the other hand, a higher rate of accretion is found in the areas of gentle slopes because of the recent sediments deposited by rivers.

The total number of transects drawn is 1052 using Arc GIS 10.4 DSAS extension and among them, 786 of those are erosional transects, 263 of those show accretionary characteristics and four of those are stable. The eroding transects indicate the landward direction of shoreline movement and the average movement rate is 3.65 m/year toward land.

The comparison of erosional patterns throughout the study area was illustrated in Figure 4. The polygons A, B, and C are located at different positions in the study area where sampling points meet the water body. The red and yellow lines indicate the shorelines of 2000 and 2020 respectively. In every aspect, there is an evident indication of an erosive shoreline. Because of the shoreline changes, this shifting is consistent with the

higher EC values of the analyzed samples near the shoreline. The EC value of KK-14, and KK-01 is 19.50 mS/cm and 8.70 mS/cm, respectively and both points are very near to seawater and

close to the selected area C and A where shoreline retreat is in progress. This landward movement of the shoreline greatly influences the advancing freshwater-saline water interface.

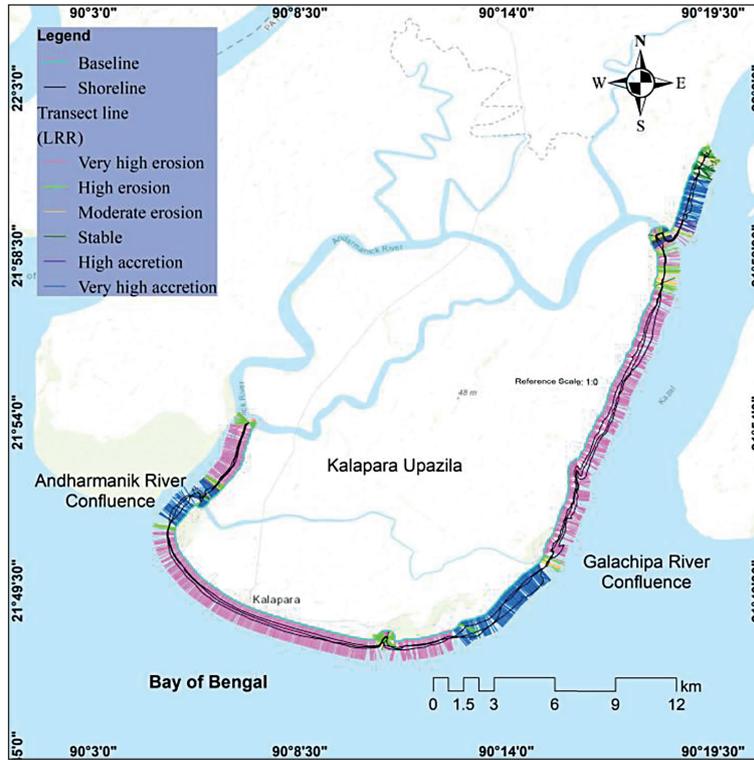


Figure 3. Transects using the DSAS method show shoreline changes from the year 2000 to 2020

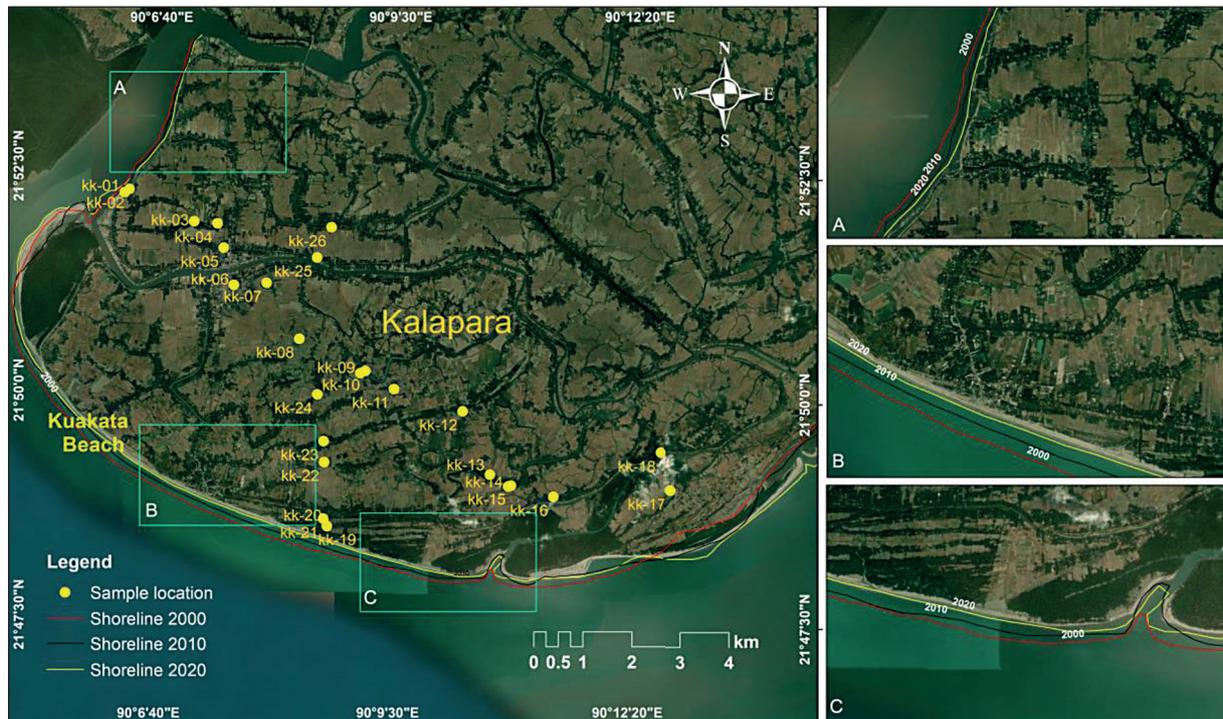


Figure 4. The Spatial pattern of shoreline movement: A, B, and C indicate three different parts of the study area and compare movement patterns

The spatial variation of EC

EC varies with temperature and is the direct measurement of salinity providing the degree of SWI in aquifers (Hem, 1991; Sreekesh et al., 2018). The variation of conductivity gives important information on groundwater chemistry. It rises in response to the changes in temperature and total dissolved salts (Detay and Carpenter, 1997). The EC of groundwater ranges from 1.2 mS/cm to 19.5 mS/cm with a mean of 10.35 mS/cm. The feasibility of the collected samples based on EC is shown in Table 2. About 80% of the analyzed samples were unsuitable for drinking and about 12% are hazardous for use in this area.

The spatial distribution of EC was presented in Figure 5. The southeastern and northwestern parts show higher EC where the shoreline is protruding toward land. The southern and southeastern part is a zone of high erosion, and the rate of

shoreline changes is higher. On the other hand, the northern and southwestern parts which is the middle zone of the two river confluence, showed lower EC than other parts of the study area.

The changing shoreline due to erosion has adverse impact on coastal environments, and EC as well as the salinity in coastal aquifers (Sarwar and Woodroffe, 2013; Lo and Gunasiri, 2014; Sreekesh et al., 2018). Again, the shoreline changes due to sea-level rise (SLR) greatly influence the groundwater quality in coastal aquifers through saline water intrusion (SWI) (Sreekesh et al., 2018). Long-term observations from Hiron point on the western coast of Bangladesh showed that the SLR increased at a rate of 4.46 mm/year from April 1990 to March 2009, which is substantially faster than the global mean (Lee, 2013). In the Barguna-Patuakhali coastal zone, the rate of erosion was found higher than accretion (20 m/year) (Sarwar and Woodroffe, 2013; Salauddin et al., 2018).

Table 2. Classification of collected GW samples shows the suitability of the samples for potable purposes (WHO, 2010)

Range of EC ($\mu\text{S/cm}$)	Classification of GW	Number of samples	Percentages of samples
<750	Desirable	0	0%
750–1500	Permissible	2	8%
1500–3000	Not permissible	20	80%
>3000	Hazardous	3	12%

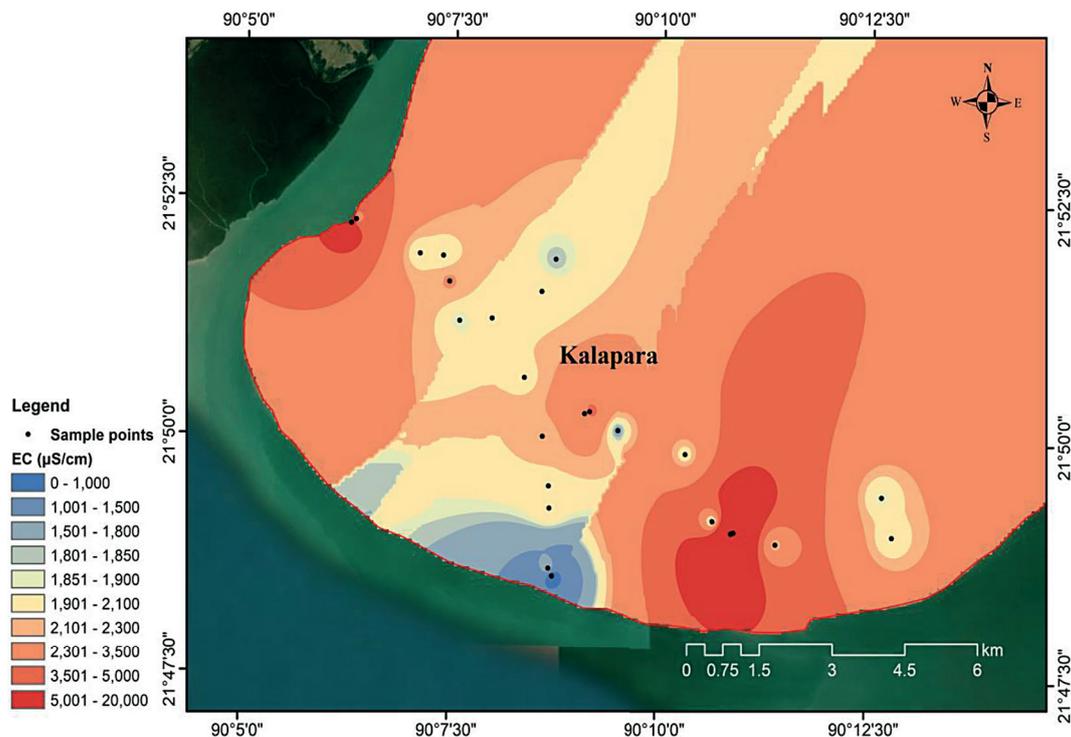


Figure 5. The spatial distribution of EC shows the higher values in the southern, western, and southeastern parts of the study area

The spatial distribution of pH

The pH regulates the chemical characteristics of groundwater as well as the mineral precipitation in it. It varies from 7.9 to 8.7 in the studied area, with a mean of 8.1 in GW, which is within the permissible limit for drinking water (WHO, 1993, 2010). The pH fluctuation in the studied area is shown in Figure 6. Lower pH or slightly acidic water encourage mineral precipitation and

may be soft and corrosive, whereas higher pH values ($\text{pH} > 8.5$) indicate hard water (Preda and Cox, 2000; WHO, 2010). The aquifer is alkaline, as the pH of most water samples ranges from 7.02 to 8.2 (Saxena et al., 2003; Luo et al., 2018).

The spatial distribution of Cl^-

The spatial variation of Cl^- in the groundwater of the research area is depicted below in Figure 7.

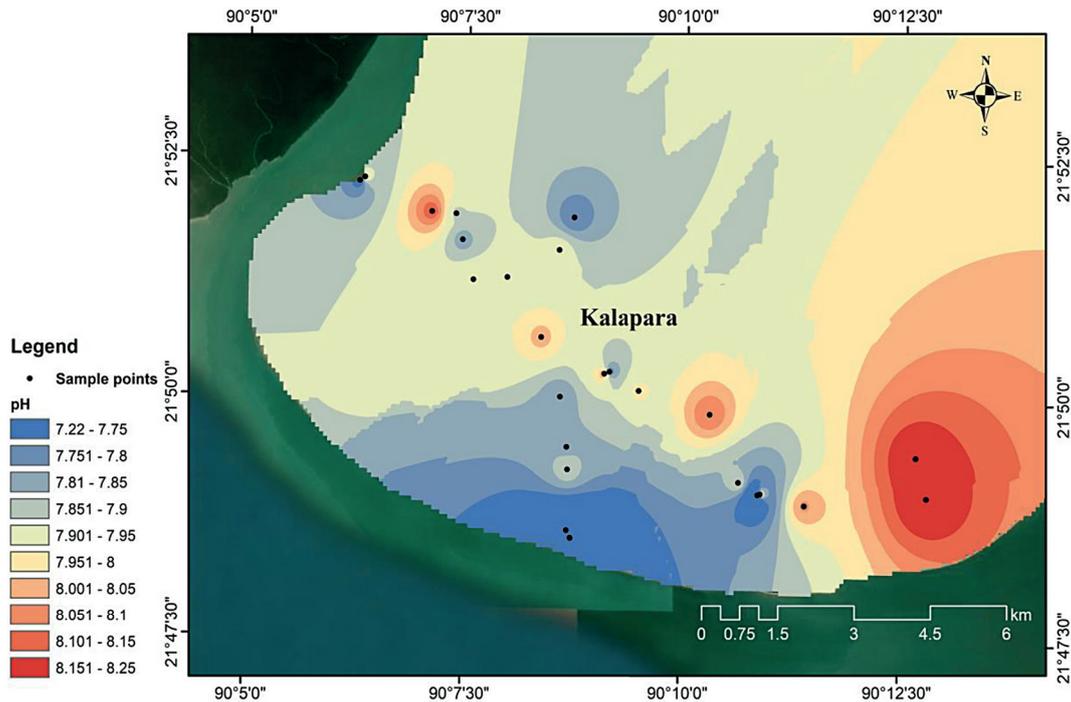


Figure 6. The Spatial distribution of pH in the groundwater of the study area

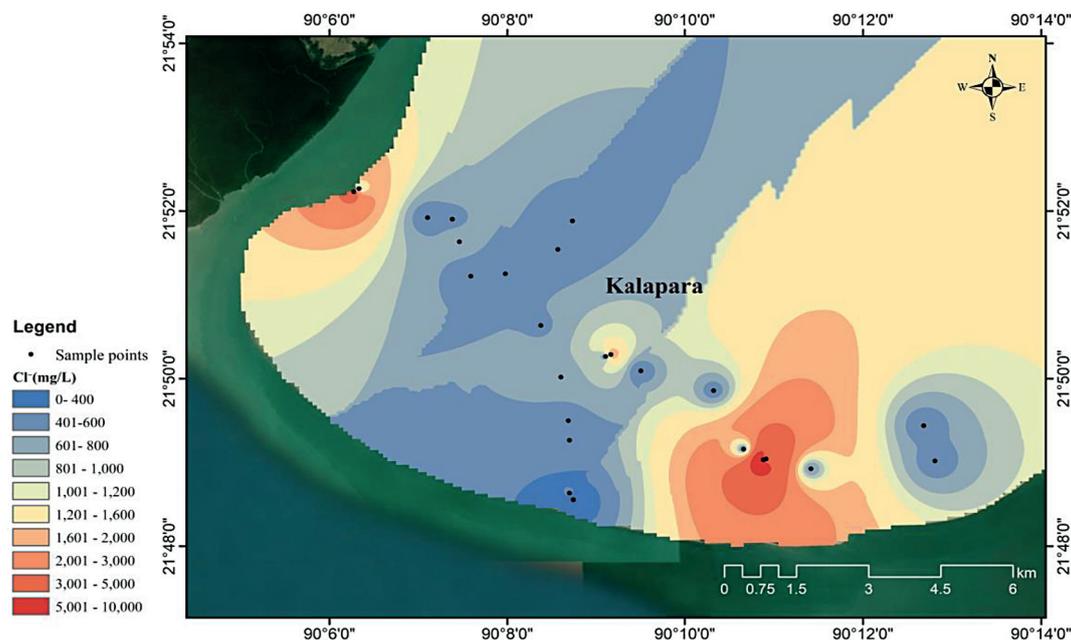


Figure 7. The Spatial distribution of Cl^- in the groundwater of the study area

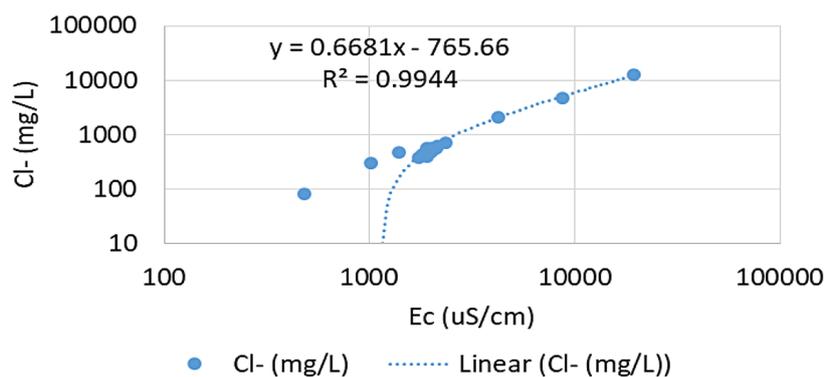


Figure 8. A plot of Cl^- vs. EC depicting the linear relationship of EC with Cl^- ($R^2=0.99$)

It ranges from 79.88 mg/L to 11241.67 mg/L in GW; almost all samples had the values greater than 300 mg/L, indicating high salinity of the groundwater. The southern and south-eastern parts of Kuakata revealed higher Cl^- , resulting from the mixing of freshwater with seawater (Tood, 1980; Mahmduzzaman et al., 2014; Alam et al., 2017; Sarker et al., 2018). Likewise, this section exhibits a significant rate of erosion, showing that the shoreline is moving closer to the land.

An alternative graphical method (Cl^- vs. EC) was used to assess the SWI, which is shown in Figure 8 (The Washington State Department of Ecology, 2005). A close relationship exists between EC and the total dissolved solids (TDS) (Eutech Instruments, 1997). SWI, most likely, influences the groundwater samples with Cl^- exceeding 200 mg/L and EC exceeding $\sim 1000 \mu\text{S}/\text{cm}$. Cl^- between 100–200 mg/L and EC between 600–2000 S/cm reflect a mixture of freshwater and saltwater. The majority of the samples exhibit the Cl^- and EC values greater than 200 mg/L and 1500 $\mu\text{S}/\text{cm}$, indicating SWI.

CONCLUSIONS

The study revealed that the shoreline is changing rapidly in the Kuakata beach area and the total length of the shoreline decreased from 55.07 km to 54.64 km between the years 2000 and 2020. It is moving towards land at about 3.65 m per year. The areas with higher erosion rates and shifting of shoreline have been observed due to steep slopes, newly exposed loose bank materials, and heavy tidal pressure. The EC of groundwater ranged from 1.2 mS/cm to 19.5 mS/cm with a mean of 10.35 mS/cm. The values of Cl^- in groundwater ranged from 79.88 mg/L to 11241.67 mg/L and almost all

samples had the values greater than 300 mg/L indicating high salinity of the groundwater. The analyzed samples demonstrate that the majority of the groundwater is unsafe for drinking purposes. The higher concentrations of EC and Cl^- in most of the groundwater samples along the shore suggest that the studied aquifer was affected by saline water. The spatial distribution maps of physicochemical parameters reveal that the saline water-fresh water interface is migrating towards the north of the study area. Overall, the potential aquifer in the research area appears to be located in the northern section of the area. A well-structured monitoring system for assessing the shoreline changes and SWI in the coastal aquifers should be established for the sustainable groundwater development.

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