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The impact of soil salinity on the chemical properties of soil at Hatiya Upazila, a remote area of Noakhali, Bangladesh

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Abstract

Soil salinity influences soil quality and other essential plant nutrients, reducing productivity and soil fertility in the Hatiya Upazila (Upazila is the second lowest tier of regional administration in Bangladesh), a coastal district of Noakhali, which is the soil saline vulnerable region of Bangladesh. This study determined the area's soil salinity level, current crop production condition, and related soil salinity level of Hatiya Upazila. This research aimed to evaluate the effect of soil salinity on soil nutrients and other soil characteristics. To conduct this study, we randomly collected 78 soil samples from the 26 villages with three replicable samples from each sampling location and nine chemical characteristics of the soil samples evaluated. We mapped the soil salinity and other soil properties using the inverse distance weighting (IDW) interpolation techniques in ArcGIS software (version 10.8) environment. Also, we used Pearson's correlation coefficient and linear regression models to evaluate the impact of soil salinity on the chemical properties of the soil. Results show that 38% of the study area has mild salinity, while 8% of the study area is affected by moderate salinity. In addition, around 4% of the study area is affected by high salinity. The reverse relation occurs when soil salinity is high and phosphorus, total nitrogen, organic matter, and carbon levels are low. According to statistical analysis, soil salinity (EC) is closely related to Na and K ($r=0.422$). Soil salinity (EC) negatively affects OM, TN, P, and OC. The pH or sulphur content (EC) had no effect on the salinity of the soil. Among OCs, OM and TN have a favourable and strong relationship among themselves. These findings will benefit many stakeholders from the public and private sectors and local leaders in taking appropriate action to decrease the impact of soil salinity on agricultural production.

Highlights

1. To estimate the soil salinity level in current crop production and impact on soil components and nutrients.
2. OC and OM positively strongly correlated with each other ($r=0.90$), and OM and TN also follow a positive strongly correlation ($r=0.877$).
3. Organic carbon, organic matter, TN, and P showed a moderate negative correlation with ECe.

Keywords Soil salinity · Chemical properties · Correlation · Coastal areas · GIS · Bangladesh

Introduction

Global environmental pollution, increasing soil and water salinity levels, and scarcity of water resources have been observed at the beginning of the 21st century. The alarming growth of the human population and the inadequacy of land for cultivation are two major threats to agricultural sustainability and food security (Shahbaz and Ashraf 2013). Many environmental stresses, such as droughts, extreme temperatures, cyclone, soil salinity, and floods, have affected the cultivation and production of crops. Soil salinity is one of the major stressors among them. It is the most damaging environmental stress, producing significant losses in crop yield, crop quality, and cultivated land area (Yamaguchi and Blumwald 2005; Shahbaz and Ashraf 2013).

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Soil salinity is a global problem affecting approximately 20% of cultivated land and significantly diminishes crop yields (Qadir et al. 2014; Chen and Mueller 2018; Majeed and Muhammad 2019; Pessarakli and Szabolcs 2019). At the confluence of the Ganges, Brahmaputra, and Meghna river systems, a low-lying flat delta (Southern coast of Bangladesh) has been formed. The country's southern coast is 710 km long and runs parallel to the Bay of Bengal, passing through 19 districts and 151 sub-districts (MoWR 2005). Various environmental Issues have been witnessed in this area, which affects the coastal livelihood. One of the most significant issues in this coastal area is salinity, which is expected to intensify because of climate change and sea-level rise, endangering agricultural production (Hossain et al. 2015; Majeed and Muhammad 2019; Ahmed et al. 2019; EL Sabagh et al. 2020; Mojid 2020). Bangladesh's southern region has been designated as an agro-ecologically disadvantaged area. In Bangladesh's south coastal area, soil salt, salt water and water-logging are critical threats to better agricultural output (MoA 2013). In coastal areas, however, significant salinity arises because of the intrusion of saline water into the land (Mondal et al. 2001; Ravindran et al. 2007). Saline soil has electrical conductivity (EC) of the saturation extract (ECe) at the root zone of over 4 dS/m. The growth of the most agricultural plants is slowed at this ECe, and also, many crops' growth is slowed at lower ECes (Munns 2005; Jamil et al. 2011). According to Ministry of Agriculture, Bangladesh, the salinity-affected region in Bangladesh grew from 8,330 km^2 in 1973 to 10,560 km^2 in 2009 (MoA 2010).

Hatiya Island, is the one of the coastal Upazila, is located in the Noakhali district and has a total land size of 1508 square kilometers. This upazila comprises 11 unions (smallest rural administrative units) and 1 pouroshova (municipality) with 452,463 people (BBS 2011). It includes the Lower Meghna estuarine floodplain areas. The South Hatiya channel, the West Hatiya canal, and the East Shahbazpur Channel encircle Hatiya Island. The area to the east of Shahbazpur is home to a flood channel, whereas the area to the southwest of Hatiya is home to an ebb channel. In Bangladesh, Hatiya is known as the "route" of cyclones. Hatiya is well-known for being devastated by the cyclones of 1970, 1985, and 1991. Due to the fact that the ground level in Hatiya is 10 m higher than the mean sea level, the coastal population there has been negatively affected by seasonal tidal flooding and subsequent saline incursions, particularly during the dry season when the flow of river water is reduced (Faisal and Parveen 2004; Miah et al. 2020; Nguyen et al. 2020; Waheduzzaman and Mizauzzaman 2021). Therefore, the livelihood of the study area residents has been highly affected by these events, and they will be very susceptible to future sea-level rise. Agricultural activity in the study area depends on monsoon for production (MoA 2018). Because of salinity in groundwater, people do not use this for agricultural activities. In Hatiya Sub-district, high land comprises 640 ha with 0.6%; medium high land comprises 28,315 ha with 24.4% and others (home, pond, river, forest land, and new char land) (MoA 2018). Based on these facts, we selected Hatiya Upazila as a case study for this research.

The coastal area of Bangladesh covers almost 20% and over 30% of the entire land and cultivable land of Bangladesh, respectively. Furthermore, the intrusion of salinity into groundwater, surface water, and soil is considered one of the main threats for in the coastal Bangladesh (Hasan et al. 2019). Besides, most of the people in coastal areas are dependent on agriculture, but salinization of water have been affecting agricultural production for long-times (MOEF 2006; Rahman and Bhattacharya 2006; Alam et al. 2017). Also, Dasgupta et al. (2015) and Nicholls et al. (2018) reported that saline water intrusion could make climate change effects like rising sea levels, storm surges, and a trend toward more salty water in coastal areas worse. A study conducted by Nicholls et al. (2018) described how the integration of climate change scenarios and human induced activities can predict the future scenario of soil salinity to enhance the salinity management plans for sustainable agriculture practice and food security in the coastal region. In particular, a study done by Hasan et al. (2020) stated that agricultural lands have been decreasing over time in Bagerhat district because of salinity intrusion, and effect of cyclone and storm surges. It is highly important to focus on the issue of salinity intrusion in the coastal areas of Bangladesh to ensure sustainable livelihood, especially agricultural activities, which are also described by Hasan et al. (2020). Based on the analysis of soil intrusion in the coastal areas, the sufficient interventions and adaptation measures should be implemented (Fiorella et al. 2016; Lam et al. 2021) to ensure proper intervention focusing on the issues like soil and water contamination (Baten et al. 2015). Therefore, it is crucial to understand the effects of salinity on chemical properties of soil in coastal areas in Bangladesh.

The impact of climate change is speeding up the salinity scenario in coastal areas of Bangladesh (Hasnat et al. 2020). Therefore, several studies have already been done on different aspects salinity intrusions, like climate change and soil salinity (Dasgupta et al. 2015), effects on salinity intrusion on health (Shammi et al. 2019), reasons of salinity intrusion in coastal Bangladesh, and land-use change and salinity intrusion (Mahmuduzzaman et al. 2014; Hasan et al. 2020b). In contrast, very rare studies have been conducted on the impact of salinity on the chemical properties of soil. Following this research gap, we conducted this study to quantify and map the soil salinity level with other properties of soil of the Hatiya island of Bangladesh. Also, this study was done to determine the effects of soil salinity on soil nutrients and other soil properties.

Materials and methodology

Study area

Hatiya is one of the coastal Upazila of the Noakhali district (Fig. 1). There are 11 unions and one Pouroshova (municipality) (BBS 2011). In this sub-district, we selected 26 villages purposefully for conducting this study. We selected these sites to determine the soil salinity and its effects on crop production. Geographically, it is located at 22°22′N 91°7.5′E coordinates. The average annual temperature is 25.8°C, with an average annual rainfall of 3215 mm. January is the coldest month, with an average temperature of 14 °C, and only 5 mm of rain occurs, while May is the hottest month of the year, with an average temperature of 32.2 °C. July is the wettest month, with an average rainfall of 742 mm.

Also, the estuarine flood plain occurs mainly in this area, and this coastal saline area lies under the mean sea level (MoA 2018). These areas are prone to flooding throughout the monsoon season, while sections of the basin experience waterlogging during the dry season. The influence of the tides is observed in the rising and dropping of the water level regularly in the study area. The torrent repeatedly floods the soils, impregnating them with soluble salts, resulting in salinity issues. Silt loams and clay loams are the soil types found in this coastal zone (MoA 2018).

Soil sample collection

This study mainly used soil samples from the agricultural lands of the study area. We collected 78 soil samples from the selected 26 villages, where three replicable samples were taken from each sampling point. We collected the topsoil from a depth of 0–15 cm with the help of a scoop with

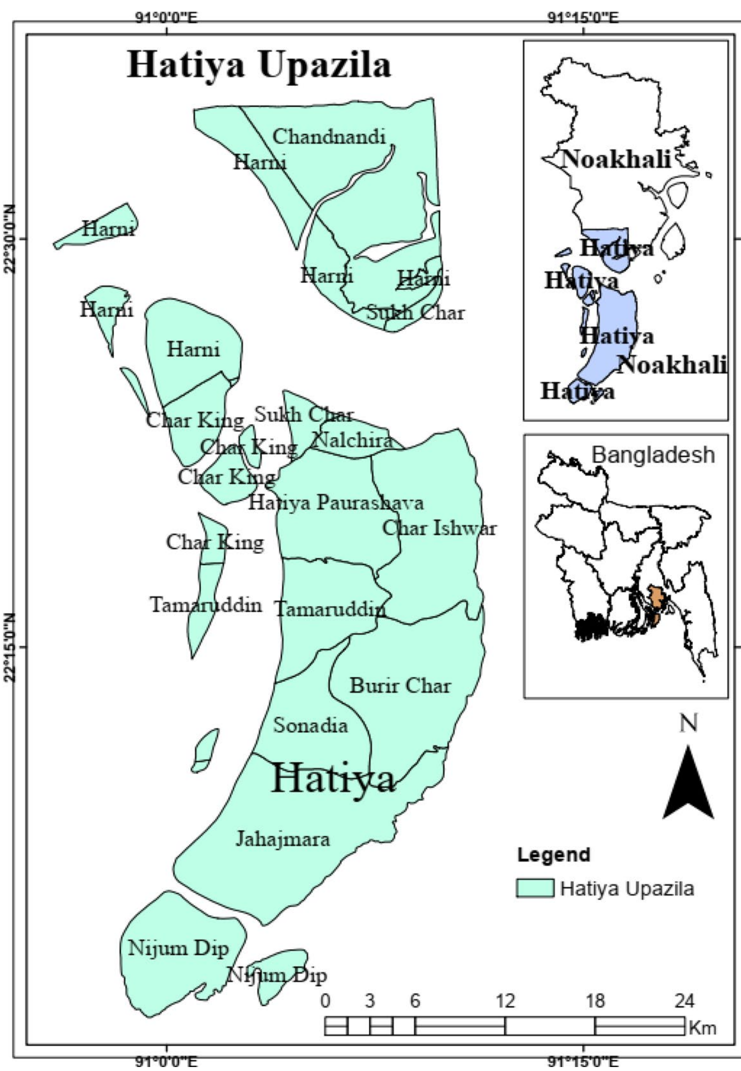

Fig. 1 Location of Hatiya Upazila (study area map)

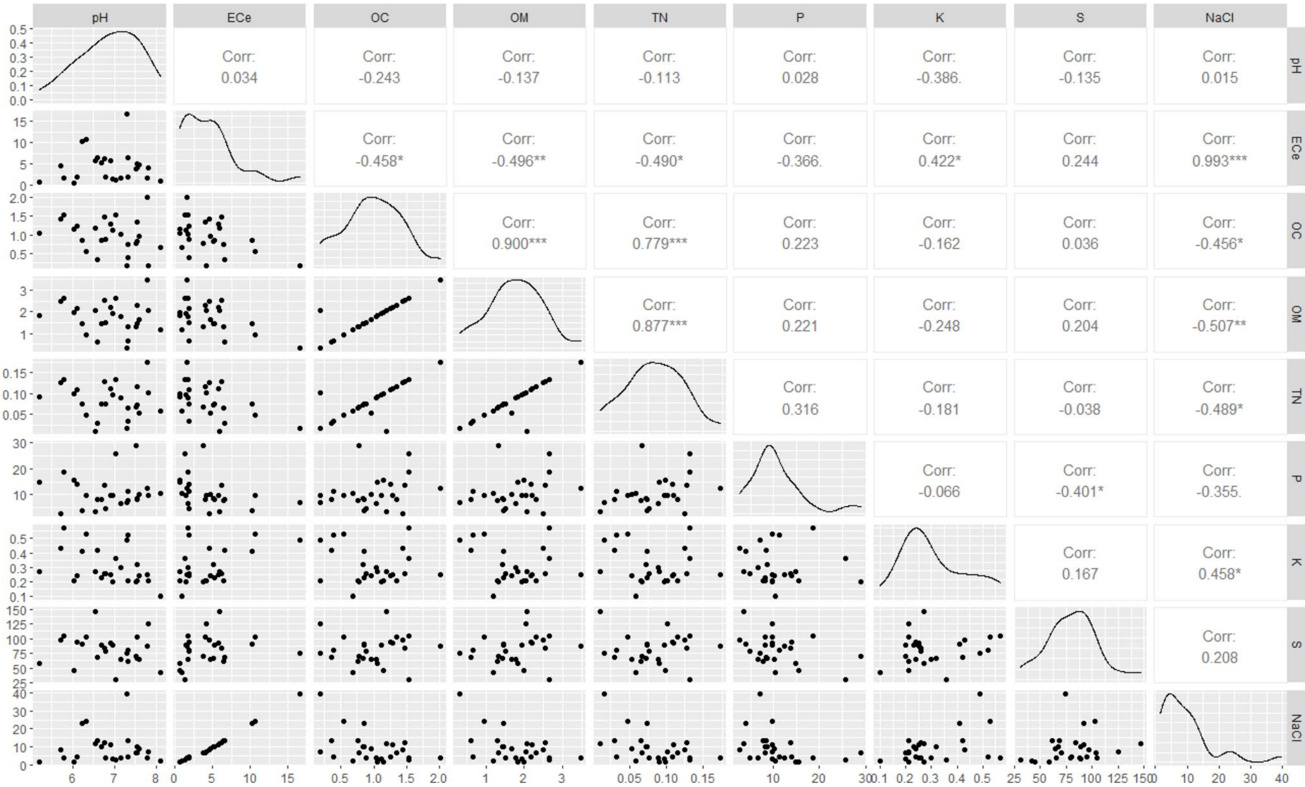

Fig. 2 Correlation Scatter matrix among ECe, pH, NaCl, OC, OM, TN, P, K, and S

a "V" shaped soil hole and kept these soil samples in polyethylene bags. After that, we did sample replication to complete the procedure. Meanwhile, each soil sample weighed 500 g. All soil samples were grass, plant roots, and dirt-free.

The collected soil samples were tightly sealed by labeling polythene bags to avoid exposure to the air. Sampling numbers, dates, and locations were marked on the bags, and soil samples were brought to the laboratory. With wet soil samples, drying in the air was performed before the laboratory test. The Soil Resource Development Institute (SRDI), Regional Laboratory, Noakhali, analyzed soil samples. The chemical properties, such as pH, ECe (Salinity), OC (Organic Carbon), OM (Organic Matter), Na-Cl (Sodium Chloride), TN (Total Nitrogen), P (Phosphorus), K (potassium), and S (Sulfur) were analyzed by the standard methods.

Soil analysis

A glass electrode pH meter was used to determine the pH of the soil, and the soil-water ratio was kept at 1:2.5, as shown by (Jackson 1958. We measured the pH using an ADWA AD 1000 H/mV temperate pH meter. The electrical resistance of a 1:5 soil: water suspension is measured with a conductivity cell to determine electrical conductivity (ECe). The wet oxidation technique measured the volume of organic carbon (OC) in soil samples (Walkley and Black 1934). By multiplying the value of organic carbon by the Van Bemmelen factor, 1.724, the amount of soil organic matter (OM) was estimated (Piper 1950). The soil's total nitrogen (TN) was calculated by digesting the soil sample at 390 °C in a digestion tube with 5 ml of 98% conc. H_2SO_4 and 1.0 g of catalyst combination (K2SO4: CuSO4.5H2O = 10:1) by a digestion unit. Distillation with 33% NaOH was added to nitrogen to the digest, followed by titration of the distillate trapped in 0.05 M HCl with 0.05 M NaOH (Page AL 1982). Two methods were used to determine the amount of phosphorus (P) in the soil, such as (i) P was extracted with 0.5 M NaHCO3 when the soil pH was more significant than seven as described by Olsen (1954); and (ii) when the soil pH was seven, P was extracted with 0.03 M NH4F, 0.025 M HCL extracting solution method as defined by Bray and Kurtz (1945). A Spectrophotometer with an 890 nm wavelength was used to determine the amount of phosphorus in the soil. The amount of exchangeable potassium (K) in soil was evaluated by extracting it with 1 N ammonium acetate (CH_3COONH_4 (pH 7.0) and measuring it with a flame photometer (CA. 1965). By extracting the soil using a sulfur extraction solution, the accessible sulfur (S) level was calculated. The extractable sulfur concentration was evaluated by adding acid seed solution and turbidimetric reagent to create turbidity. A spectrophotometer with a 535 nm wavelength was used to measure the turbidity intensity. We used the turbidity extraction technique described by Fox et al. (1964).

Anomaly calculation

Anomalies better represent soil quality data variability over more significant regions seen with their sampling site or number, and they provide a frame of reference that allows for more meaningful comparisons between places and more accurate data trend estimates.

The actual data value is subtracted to calculate the anomalies from the average value for each parameter. The remaining value is the "anomaly," the difference between the actual data and the average value of accurate data. The general formula is,

$$A_N = A_V - R_V \tag{1}$$

where, A_N =Anomaly; A_V =Average Data value; R_V =Real Data Value.

Excel 2019 was used to finish this computation, and a graph was created, shown in the result and discussion section of this paper.

Statistical analysis

In the present study, we employed Pearson's correlation coefficient technique to explore the relationship among the chemical properties of soil. Also, we applied linear regression model to investigate the effect of the soil salinity on the other chemical properties of the soil. Furthermore, we applied it to see how the chemical properties of soil and saline soil have been changed over the sample's location.

IDW Interpolation

Inverse distance weighted (IDW) is the most often used interpolation method nowadays. IDW interpolation detects values/things that are near together as being comparable to those that are further away. The IDW approach may find values from the surroundings to forecast a value for any unmeasured site. The measured values closer to the forecast location will have a more significant impact on the expected value than those further away (ESRI 2001; Shi et al. 2007). It can give the following equation.

$$Z^*(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \tag{2}$$

Here, Z*(s0) is the value we're trying to forecast for the position of s0, and N is the number of measured sample points that will be utilized to make the prediction. The weights allocated to each measured location that we will utilize are denoted by i. With time, these weights will decrease. The observed value at the position si is Z(si). The formula to determine the weights is the following:

$$\lambda_i = d_{i0}^{-p} / \sum_{i=1}^{N} d_{i0}^{-p} \sum_{i=1}^{N} \lambda_i = 1 \tag{3}$$

In this research, the IDW approach is utilized to interpolate the soil parameter testing results to acquire approximately values of the surrounding site in Hatiya Upazilas to gain a clear outset for the surrounding place. This interpolation is completed using ArcGIS 10.5 software.

Result and discussion

Determination of chemical properties of soil

The mineral balance in the soil provides the foundation for balanced soil chemistry. The presence of nutrients, soil pH, salt content, or EC, and organic matter content all have a role in soil fertility. Plant growth is restricted in agricultural land because of salinity stress. Salinity-induced nutritional deficiencies could harm crop production. The chemical characteristics of soils from paddy fields in Hatiya Upazila, Noakhali, Bangladesh are summarized in the Table 1.

Concentration of pH

The pH of the soil expresses the acidic or alkaline state of a solution. One of the most significant aspects of soil is its pH. According to the Guide (2012), the optimal pH range

Table 1 Descriptive statistics of physiochemical properties of soil from paddy fields

Physiochemical Properties	pH	ECe (dS/m)	Nacl (%)	OC (%)	OM (%)	TN (%)	*P* (µg/m)	K (Meq/100 g)	S (µg/g)
Min	5.2	0.63	1.5	0.18	0.32	0.01	2.74	0.1	30.65
Max	8.1	16.63	39.5	2.01	3.46	0.17	28.95	0.57	146.66
Mean	6.9	4.45	9.4	0.99	1.77	0.08	10.616	0.306	81.26
SD	0.7	3.69	8.5	0.44	0.72	0.04	6.282	0.122	25.18

Note The soil analysis is a mean of three replications and here, Min = Minimum, Max = Maximum, SD = Standard Deviation

Table 2 Classification of soil pH of the sample according to the standard of MoA (2010)

Class	Range	Number of soil samples and location
Extremely acidic	< 4.5	0
Highly acidic	4.5-5.0	0
Moderately acidic	5.1–6.8	12 (Burirchar, Rehania, Purba Bardeil, Paschim Bardeil, Aladigram, Nijhumdwip Namarbazar, Daspara Charking, Tamaraddi, Bangla Bazer, Purba Gamchakhali, Purbo gamchakhali 2, Choumuhoni)
Neutral	6.9-7.0	4 (Sagoria, Nijhumdwip Choyakhali, Sonadia, Kazirbazer)
Moderately basic	7.2–7.9	9 (Char makparsonsan, Nijhumdwip ghat, Brizbazar, Purba Lakshmidia, Uttar Rajerhala, Char Iswar, Paschim Gamchakhali, Ochkhali Pouroshova, Ochkhali,
Highly basic	8.0–9.0	1 (Khasherhat).
Extremely basic	> 9.0	0

Table 3 Classification of soil EC of the sample according to the standard of MoA (2010), BARC, (2005) and Chowdhury, Khairun, Salequzzaman, & Rahman, (2011)

Salinity classification	Range(dS/m)	Number of soil samples and location
Non-saline	< 2	11 (Paschim Bardeil, Paschim Bardeil, Nijhumdwip, Choyakhali, Brizbazar, Daspara, Charking, Tamaraddi, Kazirbazer, Bangla Bazer, Purba Gamchakhali, Khasherhat, Ochkhali).
Very slightly saline	2–4	2 (PurbaLakshmidia, Uttar Rajerhala,)
Slightly saline	4–8	10 (Burirchar, Purba Bardeil, Aladigram, Char makparson, Sonadia, Char Iswar, Paschim Gamchakhali, Purbo gamchakhali 2, Ochkhali Pouroshova, Choumuhoni).
Medium saline	8–12	2 (Rehania, Nijhumdwip Namarbazar).
Highly saline	12–15	0
Extremely saline	> 15	1 (Nijhumdwip ghat)

for sufficient nutrient availability in the soil is 6.0-7.5. In the research region, the minimum pH content was 5.21, and the maximum was 8.10 (mean = 6.9) (Table 1). The pH of the soil in the research region ranged from moderately acidic to fairly basic (Table 2). The lowest pH value was discovered in Bangla Bazar, while the highest value was discovered in Khaserhat. The soil pH was extremely acidic in areas along the shore and in the acidic saline zone. However, it steadily grew (basic) as it got further away from the coast. These places have moderately basic soil and are located far from the shore, such as Char Mekparson, Khaserhat, Ochkhali, and Chariswar.

Concentration of soil electric conductivity (EC)

The soil's apparent electrical conductivity (EC) is used to measure its salinity (Friedman 2005). Salt content causes coastal soil salinity in the soil, a naturally occurring mineral in soil and water, affecting plant development and vitality . Soil salinity is the amount of soluble salt that has accumulated in the soil layer above a particular level (MoA 2010).

As a measure of soil salinity, electric conductivity (ECe) is used. According to Table 1, the EC values in the research region varied from 0.63 to 16.63 dS/m. The most significant values were discovered in Nijhum Dwip ghat, Namar Bazar, and Rehania (16.63, 10.70, and 10.22 dS/m), near the coast (Meghna estuary Floodplain). In contrast, the lowest values were found in Sagoria, Daspara, Tamaraddi, Ochkhali, Khaserhat, and Banglabazar (1.52, 0.63, 1.69, 1.65, and 0.90), which are far from the coast, except Daspara and Banglabazar. Despite their proximity to the coast, Daspara and Banglabazar are classified as medium-high terrain by the map unit and are naturally non-saline regions (MoA 2010). The average soil salinity reported in Hatiya Sub-district is 4.451 dS/m (Table 1), showing that the soil is saline (Table 3). Hatiya is a Meghna River-surrounded coastal island. Most of the sub-district's areas are along the river. These regions are flooded with saline water to depths of over 90 cm (MoA 2010). During the dry season, a water stagnation issue has been observed in the study area, which increases soil salinity and affects the soil fertility.

Concentration of salt concentration (NaCl %)

The proportion of sodium chloride in the soil indicates salt in the soil. According to the current study, the most significant percentage values of NaCl were discovered in Nijhum Dwip ghat, Rehania, Nijhum Dwip, Namar Bazar, and Danardol. At Daspara, Bangla Bazar, and Khaserht had the lowest NaCl percentage concentration (1%, 1%, and 2%, respectively). The Nijhum Dwip ghat, which covered 39.5% of the area and was extremely close to the coast, had the greatest concentration of NaCl.

Concentration of organic carbon

Soil organic carbon is a significant regulator of soil quality and agricultural production in the tropics, particularly in dry and semi-arid regions. In Hatiya Sub-district, the average OC concentration is 0.99% (Table 1) in agricultural land, with topsoil thickness ranging from 0 to 15 cm. The lowest amount, 0.18%, was discovered in Nijhum Dwip ghat. Conversely, places with less salinity, such as Ochkhali, have the most significant proportion of organic carbon, 2.01%. According to Islam (2004), organic carbon concentration is inversely proportional to soil salinity. Losses of SOC occur because of salinity, sodicity, and solubilization of SOM (Wong et al. 2005).

Concentration of organic matter

Decomposed plant and animal leftovers, cells, and tissues of soil organisms, besides well-decomposed compounds, make up soil organic matter (SOM) (Brady and Weil 1999). Organic matter is a "storehouse of plant nutrients" and a "soil's life force." Good soil requires at least 2.5% organic matter. However, most of Bangladesh's soil contains less than 1.5%, and some soil contains less than 1% organic matter (BARC 2005; MoA 2010). Paddy requires a minimum of 3–5% OM content in the soil (MARDI 2000).

In the study area, soil OM content was low, ranging from 0.32 to 3.46%. Nijhum Dwip ghat and Purbo Bardeil have the lowest organic matter (0.32% and 0.60%, respectively) in the topsoil (0–15 cm), with soil salinity of 16.63 ds/m and 6.57 ds/m, respectively. The most significant percentage of organic matter (%) was discovered in Ochkhali (3.46%), where salt soil was less affected. Hatiya sub-district's organic matter content is 1.77% (Table 1), showing very low fertility (Table 4). Patcharapreecha et al. (1989) reported the presence of saline soils with 0.07–0.74% of soil organic matter in the coastal areas, while Haque (2006) discovered that soil OM concentration in coastal saline soils is relatively low (1.0–1.5%).

Concentration of soil nutrient content (%) in different paddy field soils

For improved crop growth and production, proper nutrition is required. N, P, K, Ca, Mg, and S are the essential nutritional elements. Because N, P, and K are all necessary nutrients, N is the most important to plants, followed by phosphorus (P) and potassium (K) (Leye Samuel and Omotayo Ebenezer 2014). The following table shows the soil nutrient contents (N, P, K, and S) in various paddy field soils in the research region.

Table 4 Classification of soil Organic Matter (OM) according to the standard of MoA (2010)

Fertility status of organic matter into the soil	
Organic matter status	Range of %
Very low	< 1.0
Low	1.0-1.7
Medium	1.7–3.4
High	3.4–5.5
Very high	> 5.5

Concentration of total nitrogen

Nitrogen is the most abundant necessary nutrient required by plants, and almost all plants use it for growth and development (Leye Samuel and Omotayo Ebenezer 2014). Total nitrogen concentrations in the study area ranged from 0.01 to 0.17%. Ochkhali had the highest score of 0.17%, while Nijhum Dwip ghat and Aladigram had the lowest value of 0.01. According to MoA (2010), the research area's soil nitrogen concentration was deficient. According to the findings, the high nitrogen concentration discovered in Ochkhali is a mainland location (non-saline) distant from the coast. Nijhum Dwip Ghat and Aladigram have low nitrogen levels since they are both close to the coast and have a high salty environment. Hatiya Upazila has an average nitrogen content of 0.081% (Table 1). According to MoA (2010), the optimal nitrogen value for soil fertility is 2.27%. The shows that nitrogen levels in Hatiya Sub-district soils are lower than the national average (Table 5). On N-deficient soils, most salinity and N interaction studies were done (Grattan and Grieve 1999). Adding nitrogen to cowpea, tomato, clover, millet (Papadopoulos and Rendig 1983), and wheat increased growth and output where salinity was not severe (Soliman et al. 1994). In a study of saline soils, Patcharapreecha et al. (1989) discovered that total nitrogen levels (0.005–0.043%) were severely low in all of them. Due to increased osmotic pressure in the plant-soil system Bhumbla, salt reduces N absorption by crops and does not promote plant development despite adequate nutrient levels in the soil (Al-Rawahy et al. 1992).

Phosphorus concentration

Phosphorus (P) is a mineral that is required for plant growth. P is necessary for various activities, including energy storage and transmission, photosynthesis, enzyme control, and

Table 5 Classification of Soil Nutrient level (Total Nitrogen, Phosphorus, Potassium, and Sulfur) based on MoA (2010)

Elements	Very low	Low	Medium	Optimum	High	Very high	Critical limits
TN (%)	≤ 0.09	0.09–0.18	0.181–0.27	0.27–0.36	0.36–0.45	> 0.45	0.12
P ($\mu g\ g^{-1}$) B &K	≤ 3.75	3.76–7.50	7.60-11.25	11.26-15.0	15.1-18.75	> 18.75	5.00
K (meq/100 g)	≤ 0.08	0.08–0.15	0.15–0.23	0.23–0.30	0.31–0.38	> 0.375	0.12
S ($\mu g\ g^{-1}$)	≤ 7.50	7.51-15.0	15.1–22.5	22.51-30.0	30.1–37.5	> 37.5	10.00

carbohydrate transport. The total P concentration of soils in the study region ranged from 2.74 g/g to 28.95 g/g. Soil salinity may alter phosphorus levels. The most significant phosphorus levels have been observed in Uttar Rajerhaola and Nijhum Dwip, Choya Khali, where the salinity of the soil appears to be relatively low, at 28.95 g/g and 25.65 g/g, respectively. High saline regions such as Burirchar, Rehania, Aladigram, and Nijhum Dwip ghat have the lowest Phosphorus levels of 2.74, 3.89, 3.6, and 7.17. According to the (MoA 2010) categorization of the status of phosphorus in the soil, the average quantity of phosphorus discovered in the soil of the Hatiya Sub-district is 10.94 g/g (Table 1), showing that a medium level (Table 5) of phosphorus exists in the soil of Hatiya Sub-district.

Potassium concentration

Potassium (K) is an essential nutrient for soil fertility and is directly linked to plant growth. The lowest K concentration (0.10 meq/100 g) was observed in Khaserhat, where the soil was non-saline. Tamaraddi, a non-saline region, has the highest potassium concentration (0.57 meq/100 g). The average potassium value discovered in Hatiya Sub-district is 0.306meq/100 g (Table 1), showing that the area's soil is potassium-rich (Table 5). Compared to nitrogen and phosphorus fluctuation in the research region, potassium variation in soil with soil salinity is less severe. Khaserhat is a highland region. Therefore, salinity is not an issue. Farmers in this area do not use potash fertilizer (SRDI), but they should instead use MOP fertilizer to increase potassium levels in their crops. Salt limits potassium concentration in soils on a rare occasion (Maliwal, G. L., & Somani 2010).

Sulfur concentration

Sulfur is a secondary macronutrient that is required for life. Sulfur is mainly found as sulfides, sulfates, and organic components linked to nitrogen and carbon. Sulfur accumulation is caused by sulfate, preferred in soils with high salt content, such as salty coastal soil. The soil's total sulfur content and the soil's sulfate sulfur content have a strong positive connection (Das and Das 2004). In Nijhum Dwip, Choya Khali, and Khaser hat, the minimal sulfur concentration was 30.6 g/g and 41.75 g/g, respectively. In Aladigram, the highest sulfur concentration was determined to be 146.66 g/g. In the study area, the sulfur concentration in soil is relatively high (> 37.5 g/g,) as seen in Table 5. The average sulfur value in the research region was around 81.25 g/g (Table 1), showing that the soil of the Hatiya Sub-district is sulfur-rich.

Statistical analysis between soil salinity (ECe) and chemical properties of soil

In the present study, we performed some statistical techniques, such as correlation coefficient and linear regression to investigate the relationship between soil salinity and chemical properties of soil (See Fig. 2). Table 6 shows the values of correlation and regression between salinity (ECe) and chemical characteristics of soils in the Hatiya Upazila.

Table 6 shows that soil salinity (EC) is substantially associated with sodium chloride concentration ($r = 0.993$), as well as exchangeable K ($r = 0.422$). Soil salinity (EC) has a negative relationship with soil OM (r = -0.496), total N (r = -0.490), total P content (r = -0.338), and soil OC (-0.458). Soil salinity was not substantially related to pH or S concentration (EC). OC and OM, for example, have a positive strong connection ($r = 0.90$), OC and TN have a positive strong correlation ($r = 0.788$), and OM and TN have a comparable positive strong correlation ($r = 0.877$).

According to the results of a simple regression study of ECe and other parameters, soil salinity (ECe) showed no significant contribution to soil pH (=0.034, t=0.166, $p > 0.05$), showing that a 1-unit increase in soil salinity (ECe) raises 0.034 unit in soil pH. Also, theoretically, the soil salinity does not have any significant influence of the pH. The coefficient of determination (R^2) suggests that soil salinity (ECe) can account for around 0.1% of the variance in soil pH. Such a finding is because of the somewhat acidic soil in most of the chosen regions. Figure 3 further shows

Table 6 Correlations between soil salinity (ECe) and other chemical properties of soil

	ECe	pH	NaCl	OC	OM	TN	*P*	K	S
ECe	1								
pH	0.034	1							
NaCl	0.993**	0.015	1						
OC	−0.458*	−0.243	−0.456*	1					
OM	−0.496**	−0.137	−0.507**	0.900**	1				
TN	−0.490*	−0.113	−0.489*	0.778**	0.877**	1			
P	−0.338	0.008	−0.326	0.222	0.196	0.285	1		
K	0.422*	−0.386	0.458*	−0.162	−0.248	−0.181	−0.023	1	
S	0.244	−0.135	0.208	0.036	0.204	−0.038	−0.427*	0.167	1

Here, **. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed)

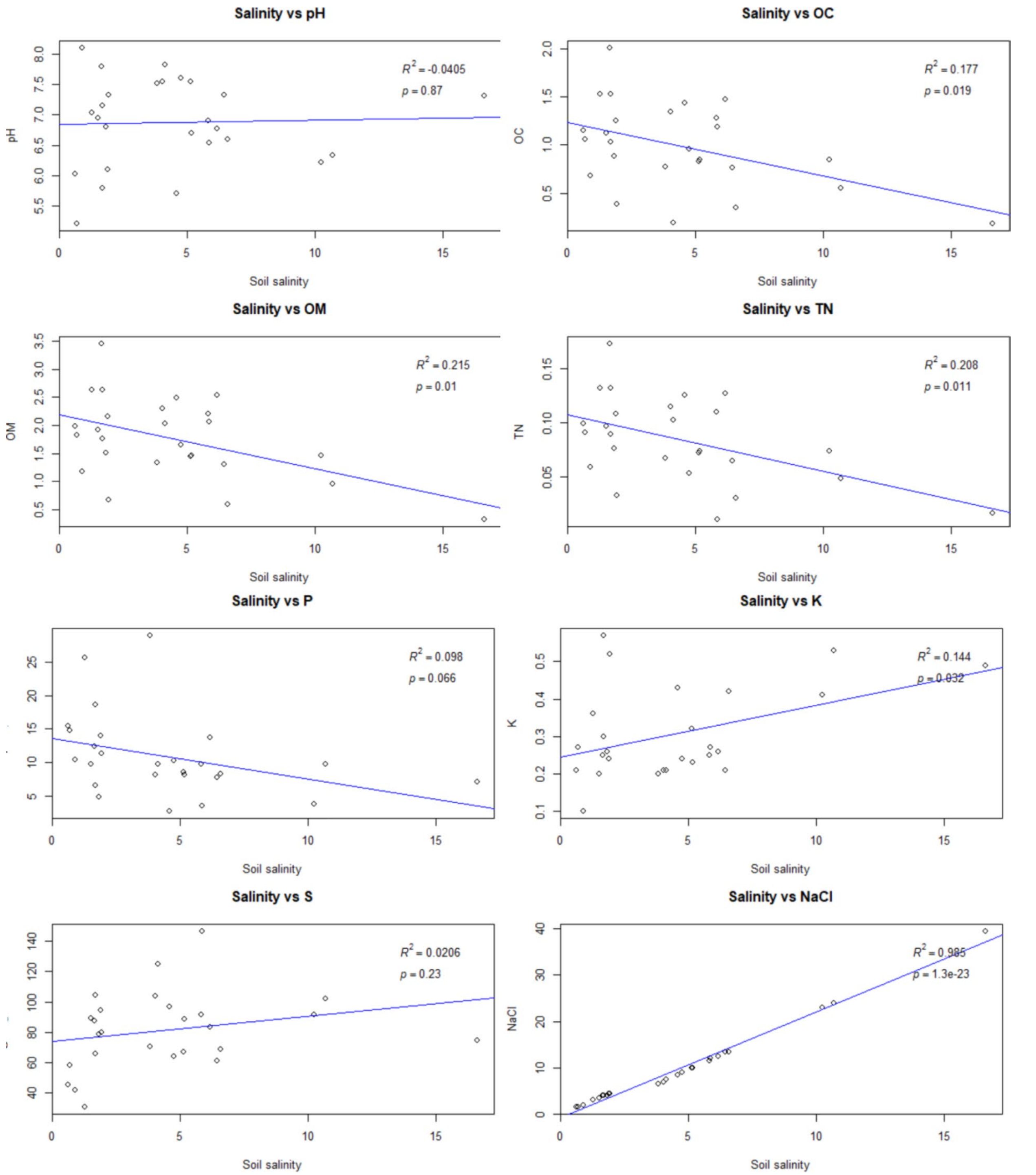

Fig. 3 Relationship modeling between ECe, and other soil chemical properties (pH, NaCl, OC, OM, TN, P, K, and S) using linear regression modeling

that soil salinity (ECe) has a significant predictor variable of NaCl (=0.993, t=40.458, p=<0.05), showing that a 1-unit increase in soil salinity (EC) raises 0.993 units in soil NaCl and accounts for nearly 99% of soil NaCl variability. Soil salinity (ECe) affects (β = -0.458, t = -2.527, p=<0.05), OM (β = -0.496, t = -2.799, p=<0.05), TN (β = -0.490, t= -2.752, p=<0.05), P (β = -0.338, t = -1.757, p=<0 0.05), revealing that a 1-unit increase in soil salinity (ECe) reduces 0.458, 0.496, 0.490, and 0.338 units of OC, OM, TN, and P, respectively. Changes in soil salinity caused variations in OC, OM, TN, and P of 21%, 24.6%, 24%, and 11.4%, respectively (ECe). Again, the effects of soil salinity on K

Table 7 Effects of soil salinity (ECe) on soil pH, NaCl, OC, OM, TN, P, K, and S

Dependent variable	Beta (β)	R^2	F	t	Sig.	Independent variable
ECe	0.034	0.001	0.028	0.166	0.869	pH
	0.993	0.986	1636.882	40.458	0.000	NaCl
	-0.458	0.210	6.384	-2.527	0.019	OC
	-0.496	0.246	7.834	-2.799	0.010	OM
	-0.490	0.240	7.573	-2.752	0.011	TN
	-0.338	0.114	3.087	-1.757	0.092	P
	0.422	0.178	5.151	2.278	0.032	K
	0.244	0.060	1.525	1.235	0.229	S

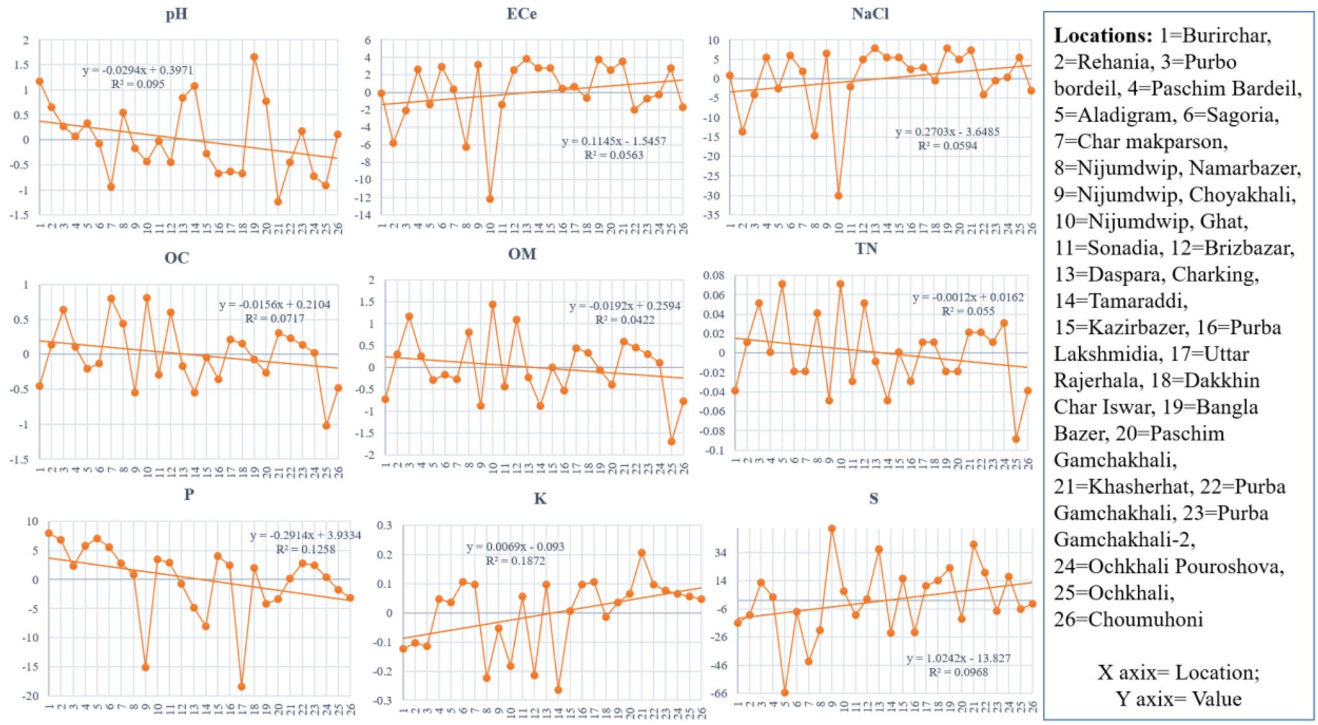

Fig. 4 Anomaly of different parameters: ECe (dS/m), pH, NaCl (%), OC (%), OM (%), TN (%), K (meq/100 g), S (µg g-1) and P (µg g-1)

(β = 0.422, t = 2.278, p = < 0.05) and S (β = 0.244, t = 1.235, p = > 0.05) show that a one-unit increase in soil salinity increases 0.422 and 0.244 units of K and S, respectively. The K and S variables, respectively, explain 17.8% and 6% of the variation in soil salinity (ECe).

Because salt raises salinity or ECe, there was a significant positive association between NaCl and ECe, despite the fact that pH had little to no effect on ECe (Table 7). Carbon, organic matter, nitrogen, and potassium exhibited somewhat negative associations with ECe; K had a slightly positive link with it. As a result of the strong correlation between high soil organic matter, high soil organic carbon, and total nitrogen, it may be concluded that these three variables are intertwined. P is negatively associated with OC, OM, and TN, although OC and TN have no connection to S. However, pH does not affect any other soil quality indicator. There is typically no relationship with other parameters since this is a coastal environment.

Anomaly discussion

Hatiya Island is near the mouth of the Bay of Bangle. Thus, the physicochemical qualities of the soil differ significantly from those found in other regions. It is well suited for some specialized production in this environment, but soil salinity dominates most production (Ece), reducing soil quality and influencing other soil nutrients described by local participants. Figure 4 shows the fluctuation of soil characteristics after their average value has been calculated. The fluctuation varies from – 1.23 to 1.67, -12.17 to 3.82, -30.1 to 7.90, -1.02 to 0.80, -1.6 to 1.44, -0.89 to 0.08, -18.33 to 7.88, -0.26 to 0.20 and – 65.40 to 50.60 for pH, Ece, Nacl, OC, OM, TN, P, K, and S, respectively. Salinity has a detrimental influence on agricultural, pasture, and tree productivity because of nitrogen absorption, lower growth, and plant reproduction. Toxic to plants are specific ions such as

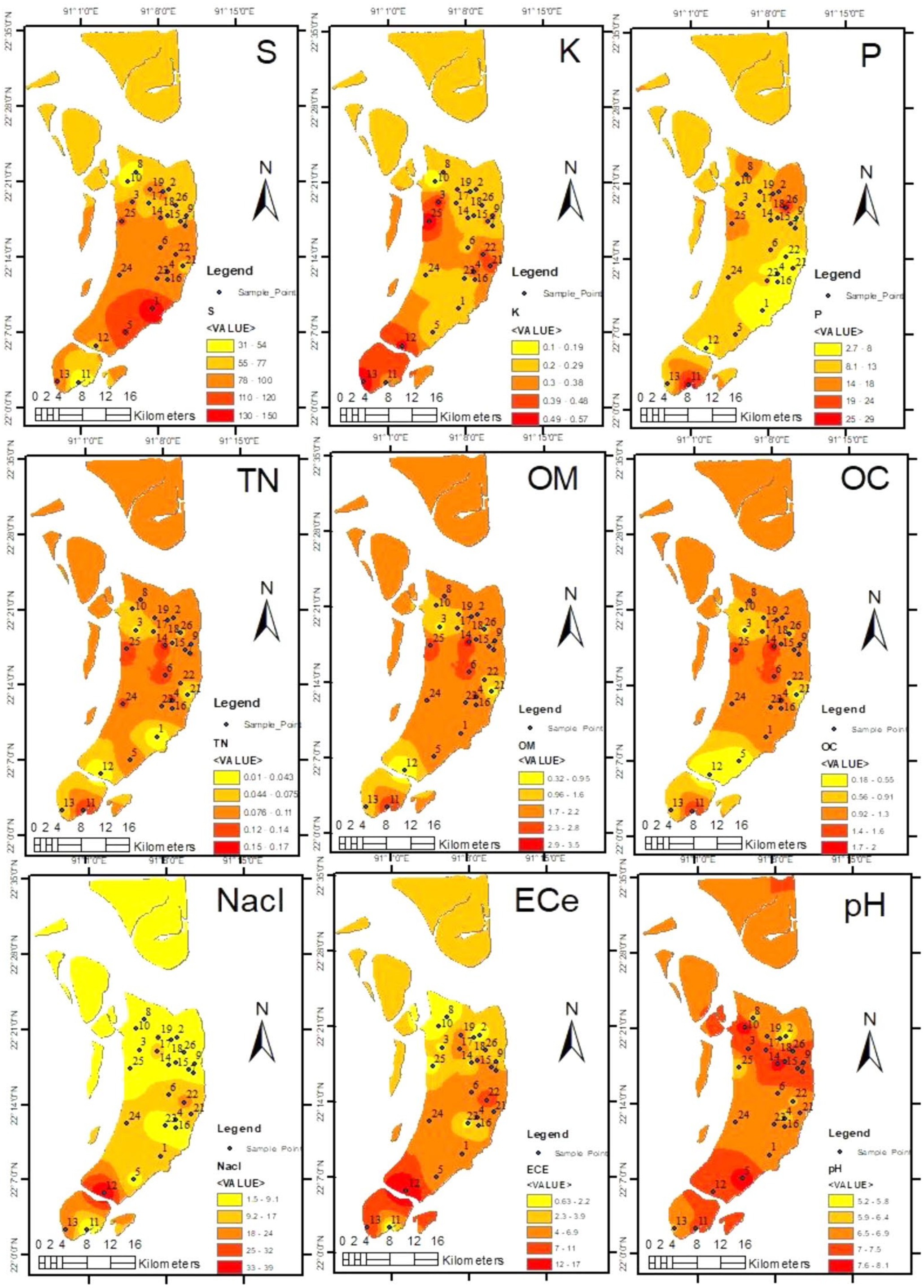

Fig. 5 Spatial distribution of soil quality parameters: ECe (dS/m), pH, OC (%), OM (%), TN (%), K (meq/100 g), and P (μg g-1)

chloride, which may poison and kill them if their concentration increases. In this illustration, the upward trend of ECe (salinity) and NaCl has a detrimental impact on the other essential nutrients for crop production, including OC, OM, TN, and P. We observed that the salinity has increased. We found that the Ockhali area has high salinity and a low TN value. Nijhum Dwip has low salinity but high total nitrogen, organic carbon, and organic matter concentrations.

Spatial analysis of soil parameter

Hatiya Upazila is a full-fledged coastal island, and reaching specific locations to gather samples proved too challenging.

On the other hand, many samples were collected from easily accessible locations. While Hatiya's northern section is lower in concentration, the southern portion is higher in ECe and NaCl, according to the spatial analysis. Again, higher OM, OC, and TN concentrations were found in the northern part of the research region than in the southern half (Fig. 5). The island's construction period is the fundamental cause of this difference. The open channel also affected the concentration rate. People in the north are more densely concentrated than those in the south because of transportation and communication challenges; thus, chemical fertilizer is being used to minimize salinity and make the northern region's soil viable. According to a geographical analysis scenario, the northern half of Hatiya Upazila is more productive for agricultural output than the southern half.

Impact of soil salinity on major nutrients of crops and plants

Agriculture, namely paddy farming with seasonal rabi crops (which are seeded at the end of the monsoon or beginning of winter), is the primary land-use system in the coastal area of Bangladesh. Because of rising sea levels and increasing shrimp farming, the coastal areas of Bangladesh are experiencing a continuous influx of salt water, which is causing the nutrient status to change. This, in turn, significantly influences the amount of coastal agricultural output.

The nutrients that are essential for the growth of plants and the production of crops can be found in the soil (Ashman and Puri 2013). Again, the significance that soil nutrients play in ensuring the long-term viability of soil quality, agricultural productivity, and environmental quality cannot be overstated (Andrews et al. 2004). *Nitrogen* is the essential nutrient required in higher quantities for crop production (Cao et al. 2018). Because of high salinity, nitrogen deficits cause crop leaves to become yellow and limit the tillering of cereal crops. In the present, we observed that salinity is negatively correlated with N and also, influenced nagatively. In addition to nitrogen, phosphorus (P) is an essential nutrient for plant growth and productivity. Because of the increasing soil salinity, the P nutrient has been reduced in the soil. While P regulates cell division, enzyme activity, and carbohydrate production processes (Malhotra et al. 2018). In addition, phosphorus is essential for cellular activities since it handles forming high-energy molecules, maintaining membrane structures, and synthesizing biomolecules (Malhotra et al. 2018). Therefore, soil salinity can negatively affect crop production by reducing the amount of P in the soil. Our findings also show that soil salinity negatively influences the P nutrient as well as the S nutrient. Furthermore, sulfur (S) helps the synthesis of coenzyme A and vitamins during plant metabolism (Lucheta and Lambais 2012), and potassium (K) increases the water-holding capacity of soils (Zörb et al. 2014). These nutrients are also negatively correlated. If the presence of saline water increases in the soil, these nutrients will be removed from the soil. It, in turn, negatively affects the plants' metabolism and water-holding capacity. Therefore, despite this, the coastal regions of Bangladesh are vulnerable in terms of soil fertility since they are in floodplain areas. This is despite over 30% of the country's cultivable land being covered by coastal lands (Haque 2006). Dasgupta et al. (2015) found that there wasn't enough phosphorus in the soils of Chittagong, Barguna, Satkhira, and Patuakhali because of soil salinity.

Soil qualities include pH, salinity, and nutrient biogeochemical and physicochemical processes regulating soil nutrient bioavailability. It is well acknowledged that soil salinity presents a significant obstacle for agricultural land (El-Ramady et al. 2018). According to Hasanuzzaman et al. (2013), salt in the soil acts as a significant abiotic stress, which results in a significant reduction in crop output. Also, soil salinization makes one or more of the functions of soil less effective. This is a major environmental problem that makes agriculture less sustainable and threatens food security (Cuevas et al. 2019).

Soil salt levels in coastal areas fluctuate considerably, making it difficult to grow crops. The hydrological condition is also harmed, and it even restricted regular agricultural production when salt is abundant in the soil (Haque 2006). Therefore, the management of soil salinity should be implemented in the coastal Bangladesh in order to improve the situation of food security and sustainable agriculture practice under the huge population pressure.

Conclusion

Bangladesh's coastal districts are experiencing an increase in soil salinity, significantly affecting health and agricultural output. According to this study, the land of Hatiya has high acidic to basic chemical characteristics, with soil salinity (EC) and NaCl ranging from high to low. We found organic carbon and organic matter to be lower than in excellent agricultural soil. P, K, and S concentrations in the soils of the Hatiya Sub-district are assessed to be medium, high, and extremely high, respectively. EC has a positive correlation with NaCl and exchangeable K, whereas it negatively correlates with organic matter, organic carbon, N, and P. Balanced soil qualities are required for long-term agricultural output. This research could not address soil salinity and physicochemical qualities concerning crop productivity, which may be done. This research will assist many stakeholders, such as scientists and policymakers, in making reasonable efforts to promote sustainable soil management in Bangladesh's coastal regions.

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Author contributions Sujit Kumar Roy design the study, analysis the data with visualization and interpretation of outcome, and develop the writeup of the whole study. Trisna Das and Tanuja Barua Collect the field data, make the laboratory work and complete the methodology part. Arif Chowdhury, Swapon Talukder and Naif Mana Almakayeel develop the write up of this research incorporating their suggestion. Javed Mallick and Atiqur Rahman make the critical review including their suggestion and comment.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

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Consent to publish Not applicable.

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