Heliyon 6 (2020) e04926

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Assessment of soil salinity in the accreted and non-accreted land and its implication on the agricultural aspects of the Noakhali coastal region, Bangladesh

Razat Suvra Das [a], Mahfuzur Rahman [a], Nur Pasha Sufian [a], Shahriar Md Arifur Rahman [b], Mohammad Abdul Momin Siddique [a,c,*]

[a] Department of Oceanography, Noakhali Science and Technology University, Noakhali, 3814, Bangladesh
[b] Department of Environmental Science and Disaster Management, Noakhali Science and Technology University, Nokhali, 3814, Bangladesh
[c] University of South Bohemia in Ceske Budejovice, Faculty of Fisheries and Protection of Waters, South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses, Research Institute of Fish Culture and Hydrobiology, Zatisi 728/II, 389 25, Vodnany, Czech Republic

ARTICLE INFO

Keywords:
Earth sciences
Soil salinity
Electrical conductivity
Accreted land
Meghna river estuary

ABSTRACT

Soil salinity is a global problem that has adverse effects on both agriculture and aquaculture production. The main objectives of this study were to observe the distribution pattern of soil salinity in the accreted and non-accreted land of the Noakhali district and to determine the intensity of salinity at different depths (1–2 cm, 15–20 cm, and 45–60 cm). Soil samples from 60 sampling sites were analyzed to measure electrical conductivity (EC). The two-way factorial ANOVA model revealed a significant effect of depth ($p < 0.001$) and sampling locations ($p < 0.001$) on soil salinity. After decomposition of this model, one-way ANOVA showed that 45–60 cm of depth contains significantly higher soil salinity ($p < 0.01$) ranging from 0.28 to 4.70 dS/m compared to 1–2 cm (ranging from 0.14 to 2.39 dS/m) and 15–20 cm (ranging from 0.18 to 2.37 dS/m) depth. In the case of accreted lands, surface (1–2 cm) and mid-layer (15–20 cm) soils were found slight to severely saline, while soil at a depth of 45–60 cm was found high to extremely saline. In all cases, salinity increases from the north to southwards and surface to downwards. Our results showed that the accreted land of the Noakhali district contains higher soil salinity compared to the non-accreted land, and soil salinity is positively correlated with depth. Assessment of suitable species and pattern of traditional cropping practices in the study area show conformity with our salinity profile. The study will help stakeholders associated with agricultural development and management in planning and designing the future land use and cropping practices.

1. Introduction

Land salinization is a global issue that has been affected by more than 412 million hectors of the coastal lands in around 100 countries in the world (Jakeman et al., 2016). Salinization in surface soil has adverse effects on both agriculture and aquaculture production. The accumulation of salt in the soil root zone adversely affects crop production by altering the nutritional balance of plants and causes toxicity in plants by excessive ions (Corwin and Yemoto, 2017). Salinity affects other significant soil degradation phenomena such as soil dispersion, increased soil erosion, and engineering problems (Metternicht and Zinck, 2003). Because of the strong detrimental effect of high salinity in the soil, it is becoming diametrically essential to measure and monitor soil salinity of salinity affected coastal areas.

The 710 km long coastal belt of Bangladesh is very dynamic, which is covering 19 districts in the southern part of the country. This coastal belt covers 32% of the country and accommodates more than 35 million people in Bangladesh (Haque, 2006; Alam et al., 2017). Erosion, accretion is a regular phenomenon in this coastal belt. A series of erosion and accretion phenomena that happened in the present study area has been noted in previous studies (Alam et al., 2017; Allison, 1998). Accretion occurs in the Southern part of the Noakhali coast as every year, 1060 million tons of suspended solids, and more than 173 million tons of total dissolved load transported to the Bay of Bengal through the Ganges-Brahmaputra, and Meghna Rivers (GBM) (Milliman et al., 1995).

* Corresponding author.
E-mail addresses: tigermomin@yahoo.com, siddique.ocn@nstu.edu.bd (M.A.M. Siddique).

https://doi.org/10.1016/j.heliyon.2020.e04926
Received 11 April 2020; Received in revised form 20 June 2020; Accepted 9 September 2020

Allison (1998) has estimated that the annual net gains of land are 14.8 km^2 from 1792 to 1840 and of 4.4 km^2 from 1840 to 1984 in Bangladesh. These newly accredited lands are primarily low lying and affected by high tide, and the tidal water causes salinity intrusion to these coastal lands. In both accreted and non-accreted lands, the salinity of the uppermost layer of soils is less compared to the lower layers due to the leaching effects.

From an economic point of view, salt-induced degradation of land has an intense effect on socioeconomic aspects. On average, 20% of the world's irrigated areas are affected by salts, while ≥30% of the irrigated lands are affected in Egypt, Iran, and Argentina (Ghassemi et al., 1995). Bangladesh is an agriculture-oriented country where a plurality of Bangladeshis earns their living from agriculture. Agricultural production has contributed 21% of the national GDP of Bangladesh (DOE, 2009). When soil salinization of an agriculture-oriented country is assessed in economic terms, reasons to be concerned about it become more apparent for the local farmers as well as for the government. For instance, the economic damage caused by secondary salinization was estimated at 750 million USD per year for the Colorado River Basin in the USA, and 208 million USD per year for the Murray–Darling Basin in Australia (Ghassemi et al., 1995). Salinity intrusion causes a hostile environment for crop production in the coastal belt of Bangladesh (Alam et al., 2017). Salinity affected land in our coastal belt was recorded 102 million hectares, which were increased to 105.6 million hectares in 2009 (SRDI , 2010). Over the last 35 years, salinity has increased by around 26% in the coastal region of Bangladesh (Mahmuduzzaman et al., 2014). However, remedial actions require reliable information to help set priorities and land management actions that are most appropriate in each case. Monitoring is needed to understand the changes in the salinity level and their distribution pattern. So that proper and timely decisions can be made to modify the management practices (Metternicht and Zinck, 2003). Therefore, the main objectives of this study were to observe the distribution pattern of soil salinity in the accreted and non-accreted land of the highly vulnerable coastal district Noakhali in Bangladesh at different depths (1–2 cm, 15–20 cm, and 45–60 cm) for crop selection and agricultural land use.

2. Materials and methods

2.1. Study area

The mainland of the Noakhali district is in the south-central coastal part of Bangladesh, bounded between latitudes 22.4534° N to 23.1327° N and longitudes 90.8925° E to 91.3782° E (Figure 1). Being a part of the Ganges, Brahmaputra, and Meghna (GBM) Delta, this district is characterized by extensively flat topography, which is affected by the diurnal tidal pattern of the Bay of Bengal at the south resulting in the regular inundation of lowlands by tidal waters. This area experienced a series of erosion and accretion phenomena due to the Meghna river estuary. A vast amount of sediments is depositing in this region from the Meghna River, resulting in an accretion trend of the landmass in recent year, which is expanding southward.

2.2. Sampling design

A total of 180 soil samples were collected from 60 stations at three different depths viz: 1–2 cm, 15–20 cm, and 45–60 cm using a hand auger. These stations were distributed in ten segments (each segment is approximately 6 km wide) from north to south. Every segment was consisting of 6 sampling stations. There is a trank road along the north-south through the centre of the Noakhali district. Sampling stations have been distributed on the east and west sides of the trunk road to

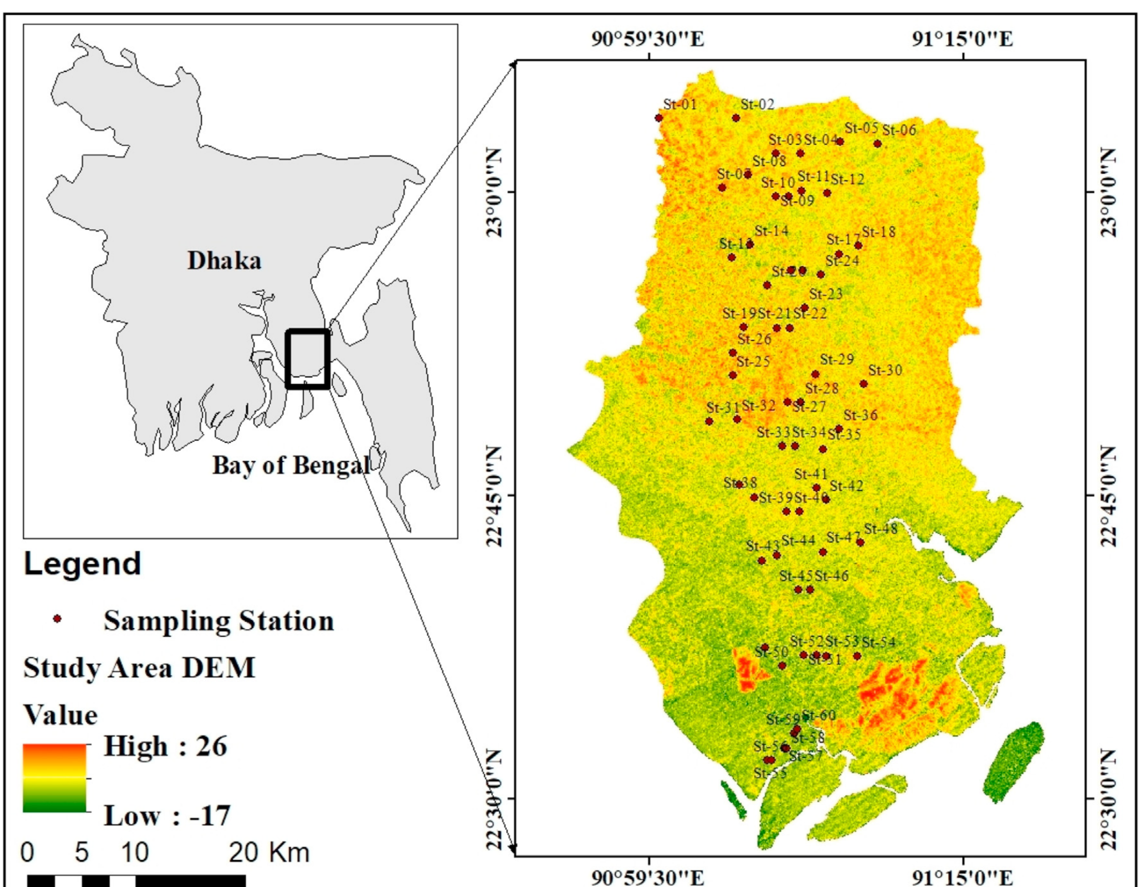

Figure 1. Study area and sampling location. Three samples were collected from each station at 0–2 cm, 15–20 cm, and 45–60 cm depth.

cover the entire Noakhali district. However, the sampling stations could not be extended far along this road from east to west because of the weak communication system. However, the sampling design was enough stretched to represent the whole area. Soil sampling was carried out from March to May 2019, which is considered as pre-monsoon hot summer season. The average rainfall of the pre-monsoon period in Bangladesh is 400–450 mm (Shahid, 2010). Although rainfall has a significant effect on the salinity of the upper layer of soil and seasonal variations were not checked, and the present study has described the vertical change of soil salinity where leaching has a significant effect. The soil sample was collected when the moisture content of the soil was not too high nor too dry (approximately 10–20%), and rainy days were also avoided.

2.3. Measuring soil salinity

Measuring soil salinity at a high sampling density is rather costly and time-consuming. Fortunately, it is possible to use a quick in-situ method of electrical conductivity (EC) to evaluate soil salinity. The relationship between EC and soil salinity is a bit complicated because some other factors such as soil texture, water content, and bulk density can influence measuring EC (Rhoades et al., 1976; Banton et al., 1997). In the present study, we measured EC in the laboratory to understand the salinity of the selected soil samples.

Collected soil samples (3 replicates per site) were first air-dried for 72 h, exposing to sunlight, and then crushed well. In the laboratory, soil salinity was measured by electrical conductivity (EC) of a 1:5 soil and distilled water suspension (1:5 weight-to-volume method). The EC was measured 3 h of settling after mixing, followed using DPIRD (DPIRD, 2019). Salinity classes for loam texture soil according to DPIRD, govt. of Western Australia is presented in Table 1. As the EC reading increases by approximately 2% with the rise in per degree Celsius temperature from 25 °C and vice versa, so the reading was corrected at 25 °C temperature. EC was measured in dS/m and then compared to the salinity class of the Department of Primary Industries and Regional Development (DPIRD), Govt. of Western Australia (DPIRD, 2019). Soil salinity distribution of the Noakhali district was then shown in three separate maps of every depth.

2.4. Data analysis

All data were analyzed using Statistica version 10 (Statsoft Inc., Tulsa, OK, USA) and PAST 4.01 version. Residuals were tested for normality (Shapiro-Wilk test) and homogeneity of variance. Alpha was set at 0.05 for main effects and interactions. A posteriori analysis was performed using Tukey's multiple comparisons procedures. The mean value of soil salinity (as dependent variable) concerning different depths (1–2 cm, 15–20 cm, and 45–60 cm) and position (accreted and non-accreted land) were analyzed using a two-way factorial ANOVA model. Then, the model was decomposed into a series of lower-order statistical models. Salinity distribution map across the study area was shown with ArcGIS 10.2 Software using the geo-statistical analyzing tool in the ordinary kriging method. A scatter plot was prepared to represent the salinity vs depth profile along the north to south of the study area.

3. Results

The salinity distribution pattern of three different depths of soil is presented in Figures 2, 3, and 4. The accreted land of the Noakhali district, especially from the Chairman ghat (Southern part of the mainland) to Sonapur (around 22.8° E), exhibited a higher amount of soil salinity in terms of EC (in dS/m) compared to the non-accreted land.

A significant variation of soil salinity was observed among three different depths (1–2 cm, 15–20 cm, and 45–60 cm) of the non-accreted (northern) and accreted (southern) lands, which is bounded by the latitude 22.8° E (Figure 5). In all cases, salinity increases from the north to southwards and surface to downwards. In the non-accreted lands, the soil is slightly saline or no saline in some places at 1–2 cm depth (ranging from 0.14 to 0.28 dS/m), but slight to moderate salinity was observed at a depth of 15–20 cm (ranging from 0.18 to 0.89 dS/m) and 45–60 cm (ranging from 0.28 to 1.20 dS/m), respectively. In the case of accreted lands, surface (1–2 cm) and mid-layer (15–20 cm) soils were found slight to severely saline (Figures 2 and 3). At a depth of 45–60 cm, the accreted lands were found mostly high to extremely saline (ranging from 1.35 to 4.70 dS/m) (Figure 4).

The two-way factorial ANOVA model revealed a significant effect of depth ($p < 0.001$) and sampling locations ($p < 0.001$) on soil salinity. Therefore, the model was decomposed into a series of lower-order statistical models. After decomposition of this model, a one-way ANOVA was performed to determine the effects of different depth (Figure 5) and the sampling position on the soil salinity (Figure 5). After decomposition of this model, one-way ANOVA showed that 45–60 cm of depth contains significantly higher soil salinity ($p < 0.01$) ranging from 0.28 to 4.70 dS/m compared to 1–2 cm (ranging from 0.14 to 2.39 dS/m) and 15–20 cm (ranging from 0.18 to 2.37 dS/m) depth (Figure 6). Similarly, a significant effect was also detected ($p < 0.01$) between accreted and non-accreted land. To execute a hierarchical cluster dendrogram, a Single-Linkage method was employed with Euclidean distance, which resulted in three distinct clusters (Figure 7). Most of the sampling stations from the non-accreted land were found in cluster 1, which has distinctly separated $9 + 9 = 18$ sampling stations from the newly accreted lands comprising cluster 2 and cluster 3, respectively.

4. Discussion

The Ganges, Brahmaputra, and Meghna (GBM), these three central river systems of Bangladesh carry about more than a billion tons of sediments per year from the upstream into the Bay of Bengal. This vast amount of deposit interacts with the dynamic processes in the eastern Bengal shelf, the coasts of Bangladesh, particularly the Noakhali coast (Paul and Rashid, 2016; Goodbred et al., 2003). Noakhali coast is characterized by continuous geomorphological changes such as erosion, accretion, land subsidence, etc. (Davies et al., 2003; Paul and Rashid, 2016). A massive erosion was started in the offshore islands as well as along the shoreline of the Meghna estuary from 1910 AD and continued till 1935 AD. During this period, about 40 km of coastal lands were eroded in the south to the northern direction. Several thousands of people became homeless and migrated to other cities. In the late 1950s, several cross-dams were constructed in the eastern branch of the Meghna River to accelerate the land reclamation process (Paul and Rashid, 2016). Consequently, the natural accretion process gave rise to several new chars (bars or islands), and over 1,000 square kilometers of the land area is added to the Noakhali mainland by mid-1960s (Alam and Uddin, 2013).

These accreted lands in the Noakhali coast are mainly the result of continuous sediment accumulation that is carried out from the upstream freshwater river systems. Tide- and storm-driven processes distribute sediments to major depositional areas on the inner shelf of the Bay of Bengal near the Meghna estuary (Paul and Rashid, 2016). Additionally, some sediments were transported by the undercurrents into the deeper Bay of Bengal, wave actions, high astronomical tides, tropical cyclones, and associated storm surges, etc. Therefore, extensive muddy tidal flats

Table 1. Salinity classes for loam texture soil according to DPIRD, govt. of Western Australia.

Salinity class	EC 1:5 range for loams (dS/m)
Non-saline	0–0.18
Slightly saline	0.19–0.36
Moderately saline	0.37–0.72
Highly saline	0.73–1.45
Severely saline	1.46–2.90
Extremely saline	>2.90

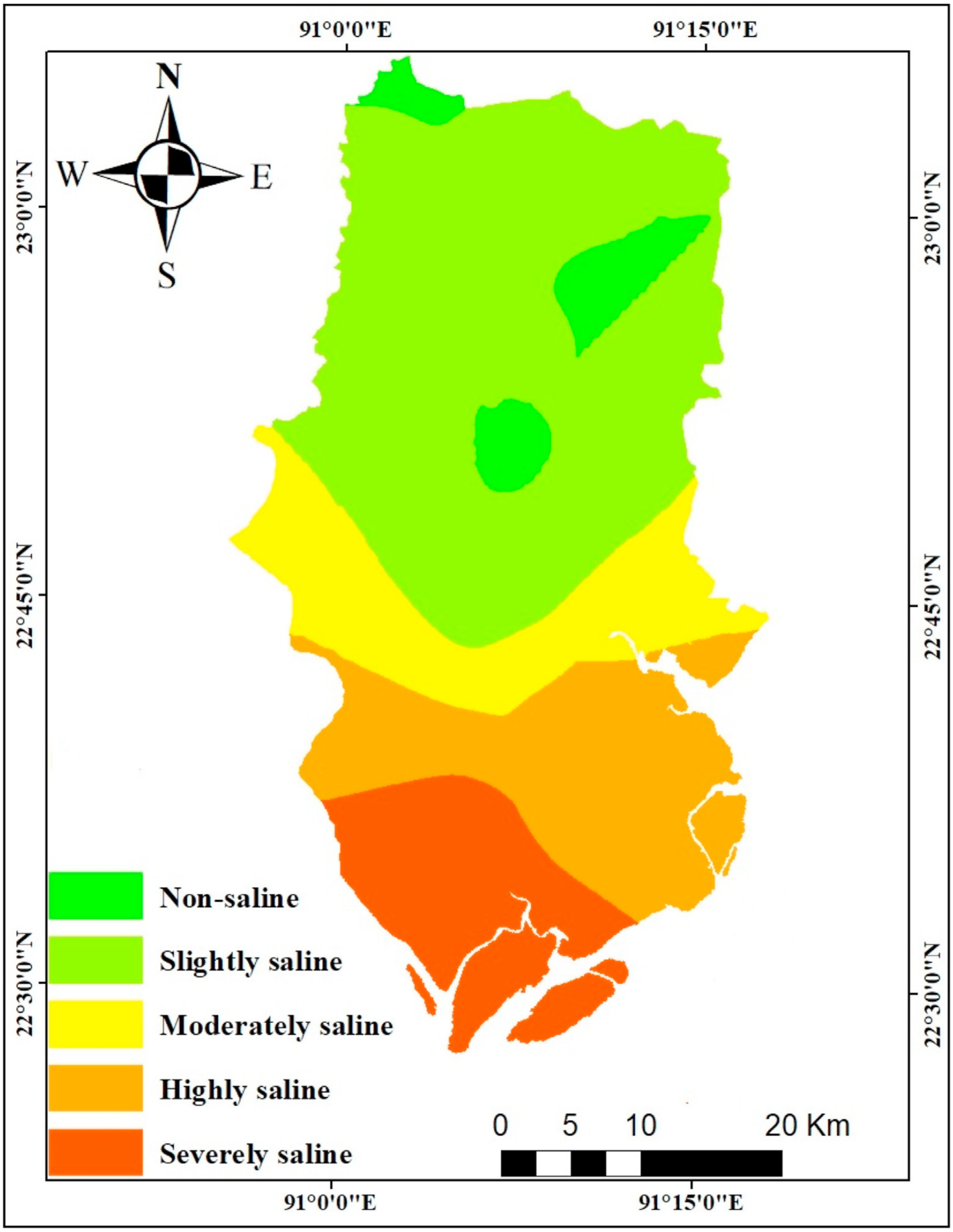

Figure 2. Salinity distribution pattern of accreted and non-accreted land at a depth of 1–2 cm of surficial soil.

are developed along the shoreline (Michels et al., 2003). Both processes occur simultaneously. During the deposition, the freshwater sediment carried out from the upstream rivers creates non-saline sandbars and ridges while the ocean depositions bring about saline soil in the accreted lands. Throughout the deposition process, a vast amount of saline water gets trapped into the ground. Besides, numerous cyclonic storms occur in the area when saline water enters the mainland through different canals and channels. These are possibly the primary reasons behind the higher and non-uniform concentration of salts in the accreted soils as compared to the non-accreted soils of the study area. The salt concentration decreases as we move coast to land inward (south to northward). The groundwater of the Noakhali district is moderate to highly saline (Mahmud et al., 2016; Anjum et al., 2017) and has been regularly used for domestic and irrigation purposes. Therefore, the use of saline groundwater for irrigation purposes can be responsible for the secondary soil salinization in Noakhali.

Soil salinity might not be so devastating as environmental hazards such as earthquakes, volcanic eruptions, or large-scale landslides etc. However, it is undoubtedly a frequent and severe environmental hazard (Metternicht and Zinck, 2003), especially in the coastal areas concerning crop cultivation and ecological restoration. Therefore, the soil salinity has attracted increasing attention among the farmers, relevant government departments, and environmental scientists. Our result showed that the soil salinity in the depth of 45–60 cm was higher than that in topsoil (1–2 cm and 15–20 cm) in the study area. The current distribution of soil salinity is the result of the overall effects of natural processes such as rainfall and anthropogenic activities such as cropping practices, irrigation water quality, drainage condition, application of chemical and organic fertilizers, adoption of techniques to influence capillary rise, etc. Leaching of saline water resulting from rainfall and irrigation can significantly affect the salt content of the soil by flushing the salt from the surface to the lower layers (Cuevas et al., 2019). This can explain the

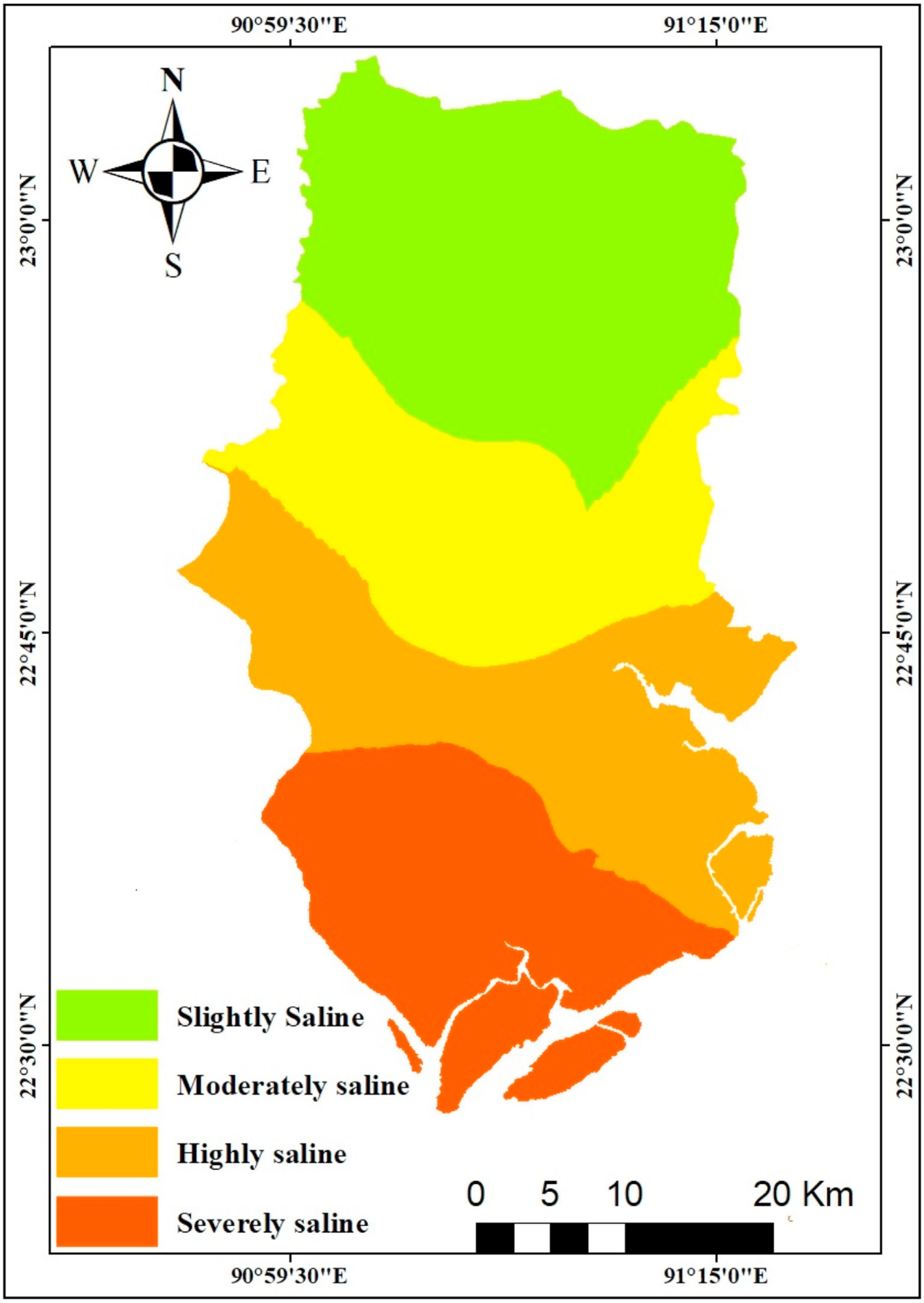

Figure 3. Salinity distribution pattern of accreted and non-accreted land at a depth of 15–20 cm of soil.

higher soil salinity in the lower layer than the upper layers for our study area.

The land use pattern in the non-accreted land in our study area shows suburban set up with a lower number of croplands. In contrast, the accreted land contains a significant number of farmlands producing crops in three different seasons, namely Kharif-1 (mid-March to mid-July) and Kharif- 2 (mid-July to mid-November) as the wet season, and Rabi (mid-November to mid-March) as the dry season. The Kharif-1 crops include Jute, Aus rice, summer vegetables, cotton, sesame, pigeon pea etc.; the Kharif-2 includes *T. Aman*, *B. Aman,* soybean, groundnut, late-summer vegetables etc. and rabi crops include wheat, potato, mustard, *Roro rice*, winger vegetables, lentil, tobacco, soybean, and cabbage etc. There are several ways how the farmers cope up with the salinity of the soil through chemical remediation, different crop management practices, soil management practices, planting procedures. Salinity level below 4.0 dS/m are generally not stressful for most of the plants, and beyond this level, the yield gets significantly lower as found by Dasgupta et al. (2014, 2018). Our study showed that the newly accreted land of the Noakhali district is much higher than that tolerance range of salinity for most crops.

In the accreted region of Noakhali, the soil salinity shows a pronounced seasonal cycle that influences cropping practices of the farmers (Sattar and Mutsaers, 2004). Dasgupta et al. (2015), in their study on the soil salinity over nine years, found that the maximum seasonal salinity decreases from the dry season (Rabi) to the wet season (Kharif) by ~ 1.5 dS/m for both accreted and non-accreted regions of the Noakhali district.

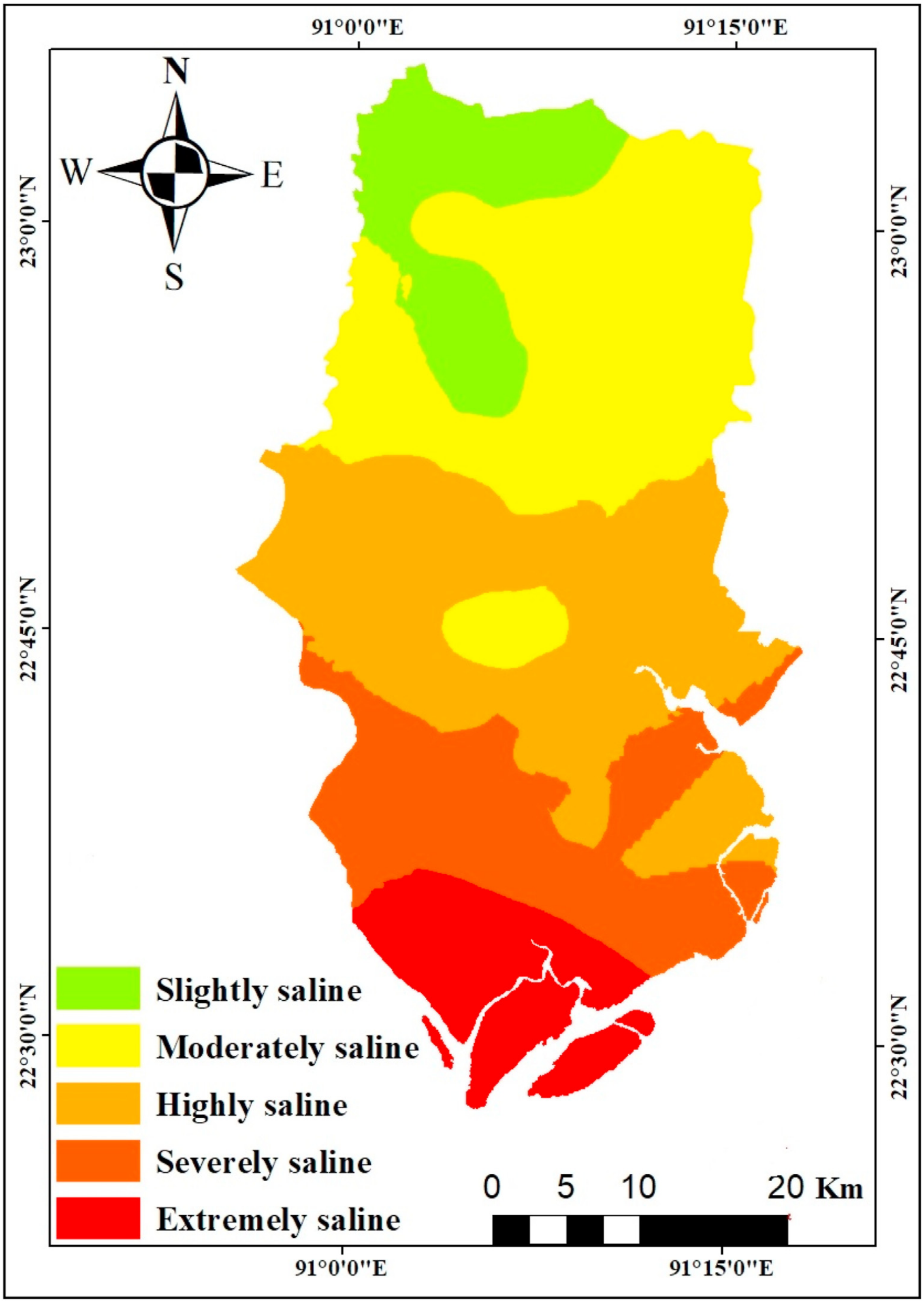

Figure 4. Salinity distribution pattern of accreted and non-accreted land at a depth of 45–60 cm of soil.

They indicated that the influence of rainfall provides a dilution effect on the soil and reduces the salinity. Due to climate change, the rainfall does not show a particular pattern in terms of intensity and duration. Consequently, the soil salinity does not follow a particular direction over the years.

During the monsoon, rainwater infiltrates into the dry soil, pushes in the salts down, and produces a lower-saline top layer where paddy can be grown easily. After the season, the ground dries up, and the capillary rise of groundwater desalinizes the upper layer. Farmers sow *Aus* paddy, as a Kharif-1 crop, with the first rains just after soil salinity has the highest value. Since *Aus* is sensitive to salinity, the extent of *Aus* growing in an area is a good indicator of the salinity conditions. Kharif-2 crops do not show higher yield in the char lands in the *Aman* season due to higher salinity. Among the Rabi season crops, sweet potato, green gram, linseed, groundnut, millet, etc. and for vegetable batisak, chili, spinach, kangkong, garlic, etc. show higher tolerance level (Sattar and Mutsaers, 2004).

Our study was carried out in March–May, which coincides with the Kharif-1 season. This season is characterized by elevated temperature and lower rainfall during the crop establishment stage. During this period, crops often suffer from drought at the early stage and may get submerged at the later stage, particularly in low-lying areas. Such unreliable climatic conditions made this season having the least productive potential. Although several crops are grown nowadays in this season under irrigated conditions in some coastal areas, only *Aus* rice and a few summer vegetables are grown in Noakhali (Sattar and Mutsaers, 2004).

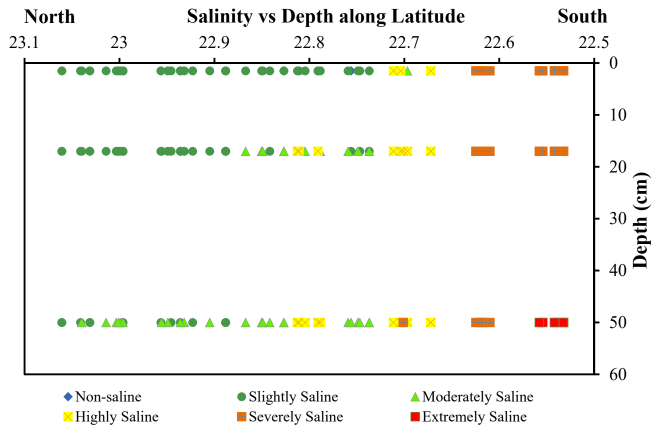

Figure 5. Mean concentrations of salinity vs. depth along the latitudes of accreted and non-accreted land in the Noakhali district.

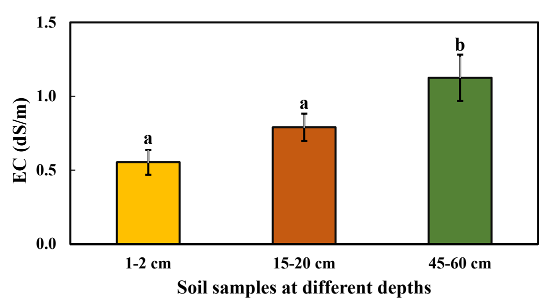

Figure 6. Comparison of the mean concentrations (±SE) of salinity (in terms of EC) at different depths of soil. Different letters on the bar show significant differences ($p < 0.01$).

Due to unfavorable salinity levels and moisture content in the soil, farmers prefer *Aus* to the summer vegetables in the accreted lands. After the dry season, at least 150–200 mm rainfall is required for the land preparation and stand establishment of *Aus* crop. Farmers prepare their lands after one or two showers. Deficiency in optimum rainfall is met by supplemental irrigation. *Aus* seeds are generally sowed in two methods: direct seedings and transplanting methods. The choice of planting method depends on factors such as rainfall patterns, types of variety and agroecological conditions etc. (Sattar and Mutsaers, 2004). In the direct seeding method, farmers sow the seeds by broadcasting or dibbling the seeds directly into the sub-soil layer after the first shower in late March or early April. With an early monsoon, deep dibbling (about 5-cm deep) helps to avoid salt injury. The transplanting method is less popular in the accreted lands of Noakhali due to the scarcity of suitable lands and sufficient irrigation water. HYVs such as BR20 and BR21 over the local varieties are widely cultured by the farmers. However, a significant amount of land in this area is kept fallow in this season between the dry (Rabi) and wet (Kharif-2) season to offset the excessive amount of soil salinity and to prepare the fields for Kharif-2 crops (Shahidullah et al., 2006).

Kharif-2 covers the monsoon season (mid-July to mid-November), which is characterized by the high rainfall and minimum level of salinity. Such conditions are suitable for transplanted *Aman* rice in the coastal region of Noakhali. In this method, seedlings are raised in the exceptionally cared seedbeds, transplanted to fields, and finally harvested from mid-November to December. On the other hand, the Rabi season generally starts in December to mid-January in the coastal areas. During this season, the crops might face constraints such as drought in the establishment phase and a higher level of salinity. With supplemental irrigation, Rabi crops such as vegetables, spices, oil crops, cereals, and pulses etc. can grow easily in the region (Amin et al., 2011).

Bangladesh is an agriculture-based country where types of cultivated crops and vegetables are very diverse. The present study revealed that the salinity of the surficial soil is less saline compared to the deeper soil. The average root depth of our most cultivated crops and vegetables are within ~20 cm. Therefore, the salinity at the topsoil would not exert the devastating effects on the production of crops and vegetables in the non-accreted land and some stations at accreted lands (station 31 to 42). However, this baseline study would be beneficial for the selection of crops and vegetables to develop coastal agriculture in this region.

Declarations

Author contribution statement

R. S. Das: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

M. Rahman: Analyzed and interpreted the data; Wrote the paper.

N. P. Sufian: Performed the experiments; Analyzed and interpreted the data.

S. M. A. Rahman: Analyzed and interpreted the data; Wrote the paper.

M. A. M. Siddique: Conceived and designed the experiments; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

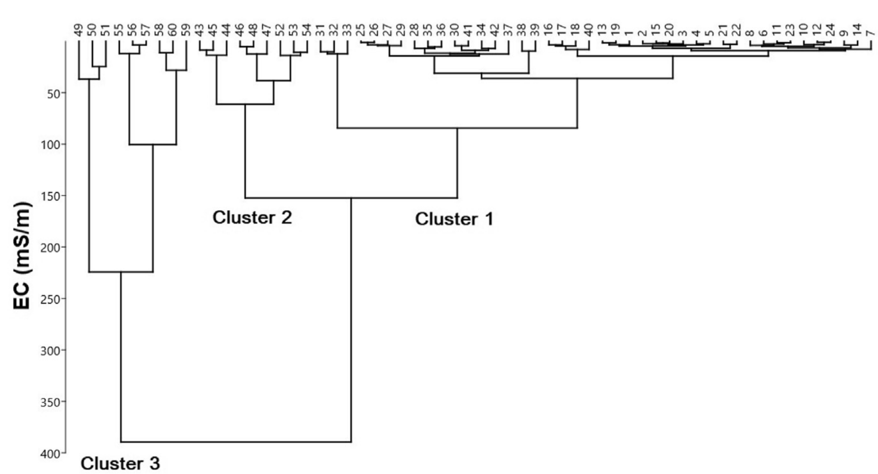

Figure 7. Hierarchical clustering of soil salinity (EC) of different sampling stations ($n = 60$) of accreted and non-accreted land in the Noakhali district.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We would like to thank Md. Ekamat Faruque for his assistance during field sampling.

References

Alam, M.S., Uddin, K., 2013. A study of morphological changes in the coastal areas and offshore islands of Bangladesh using remote sensing. Am. J. Geogr. Inf. Syst. 2 (1), 15–18.

Alam, M.Z., Carpenter-Boggs, L., Mitra, S., Haque, M., Halsey, J., Rokonuzzaman, M., Saha, B., Moniruzzaman, M., 2017. Effect of salinity intrusion on food crops, livestock, and fish species at Kalapara Coastal Belt in Bangladesh. J. Food Qual. 2045157.

Allison, M.A., 1998. Historical changes in the Ganges–Brahmaputra delta front. J. Coastal Res. 14, 1269–1275.

Amin, M., Faisal, A.H.A., Farhada, M., 2011. Crop adaptation in saline soils of Noakhali. I. Crop performance. Bangladesh Agron. J. 14 (1 & 2), 43–52.

Anjum, R., Khan, A.S., Islam, M.Z., Islam, R., Bahadur, N.M., 2017. Chemical and microbial analysis of potable water in public water supply of greater Noakhali, Bangladesh. Int. J. Sci. Eng. Res. 8 (12), 1170–1174.

Banton, O., Cimon, M.A., Seguin, M.K., 1997. Mapping field-scale physical properties of soil with electrical resistivity. Soil Sci. Soc. Amer. J. 61 (4), 1010–1017.

Corwin, D.L., Yemoto, K., 2017. Salinity: electrical conductivity and total dissolved solids. Methods of Soil Analysis. SSSA Book Ser. 5. SSSA, Madison, WI.

Cuevas, J., Daliakopoulos, I.N., del Moral, F., Hueso, J.J., Tsanis, I.K., 2019. A review of soil-improving cropping systems for soil salinization. Agronomy 9 (6), 295.

Dasgupta, S., Hossain, M.M., Huq, M., Wheeler, D., 2014. Climate Change, Soil Salinity, and the Economics of High-Yield rice Production in Coastal Bangladesh. Policy Research Working Paper 7140. Development Research Group Environment and Energy Team. The World Bank.

Dasgupta, S., Hossain, M.M., Huq, M., Wheeler, D., 2015. Climate change and soil salinity: the case of coastal Bangladesh. Ambio 44 (8), 815–826.

Dasgupta, S., Hossain, M.M., Huq, M., Wheeler, D., 2018. Climate change, salinization and high-yield Rice production in coastal Bangladesh. Agric. Resour. Econ. Rev. 47 (1), 66–89.

Davies, C., Best, J., Collier, R., 2003. Sedimentology of the Bengal shelf, Bangladesh: comparison of late Miocene sediments, Sitakund anticline, with the modern, tidally dominated shelf. Sediment. Geol. 155 (3-4), 271–300.

DOE, 2009. Climate Change Adaptation Research: Adaptive Crop Agriculture Including Innovative Farming Practices in the Coastal Zone of Bangladesh, DOE, Climate Change Cell, MOEF, Component 4b, CDMP, MOFDM.

DPIRD, 2019. Measuring Soil Salinity, Agriculture and Food. Department of primary industries and regional development, Government of western Australia. https://www.agric.wa.gov.au/soil-salinity/measuring-soil-salinity. (Accessed 16 March 2020).

Ghassemi, F., Jakeman, A.J., Nix, H.A., 1995. Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies. Canberra, Australia: the Australian National University. CAB International, Wallingford, Oxon, UK.

Goodbred Jr., S.L., Kuehl, S.A., Steckler, M.S., Sarker, M.H., 2003. Controls on facies distribution and stratigraphic preservation in the Ganges–Brahmaputra delta sequence. Sediment. Geol. 155 (3-4), 301–316.

Haque, S.A., 2006. Salinity problems and crop production in coastal regions of Bangladesh. Pakistan J. Bot. 38 (5), 1359–1365.

Jakeman, A.J., Olivier, B., Hunt, R.A., Jean-Daniel, R., Ross, A., 2016. Integrated Groundwater Management: Concepts, Approaches, and Challenges. Springer, Switzerland.

Mahmud, M.T., Mukharjee, S.K., Khalil, M.I., Rahman, M.A., Hossen, F., 2016. Physicochemical and Microbiological analysis of tube-well water from Noakhali district, Bangladesh. World 3 (1), 50–55.

Mahmuduzzaman, M., Ahmed, Z.U., Nuruzzaman, A.K.M., Ahmed, F.R.S., 2014. Causes of salinity intrusion in coastal belt of Bangladesh. Int. J. Plant Res. 4 (4A), 8–13.

Metternicht, G.I., Zinck, J.A., 2003. Remote sensing of soil salinity: potentials and constraints. Remote Sens. Envirn. 85 (1), 1–20.

Michels, K.H., Suckow, A., Breitzke, M., Kudrass, H.R., Kottke, B., 2003. Sediment transport in the self-canyon "swatch of No ground" (Bay of bengal). Deep Sea Res. II 50 (5), 1003–1022.

Milliman, J.D., Rutkowski, C., Meybeck, M., 1995. River Discharge to the Sea: a Global River index (GLORI). NIOZ, Texel, The Netherlands, p. 125.

Paul, B., Rashid, H., 2016. Climatic Hazards in Coastal Bangladesh: Non-structural and Structural Solutions. Butterworth-Heinemann.

Rhoades, J.D., Raats, P.A.C., Prather, R.J., 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soc. Amer. J. 40, 651.

Sattar, S.A., Mutsaers, H.J.W., 2004. Agriculture in southeastern coastal chars of Bangladesh. Experiences and Guidelines (No. 12). Technical Report, 1. CDSP-II, Bangladesh.

Shahid, S., 2010. Rainfall variability and the trends of wet and dry periods in Bangladesh. Int. J. Climatol. 30, 2299–2313.

Shahidullah, S.M., Talukder, M.S.A., Kabir, M.S., Khan, A.H., Elahi, N.E., 2006. Cropping patterns in the south east coastal region of Bangladesh. J. Agric. Rural Dev. 4 (1), 53–60.

SRDI (Soil Resources Development Institute), 2010. Saline Soils of Bangladesh, SRDI. Ministry of Agriculture, Dhaka, Bangladesh.