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Biophysical and Chemical Properties of Soil in the Mangrove Habitat of the Hypersaline Tracts: An Assessment in the Henry Island of Southwestern Sundarban, India

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Abstract: *Mangrove ecosystems are among the most vital ecosystems in terms of fragility, productivity and biodiversity. The Sundarban, which contains some of the largest mangrove forests in the world, is also an endangered ecosystem. It is of importance to investigate the characteristics of soil in the mangrove habitats of the Sundarban, how they change over the seasons, and their association with the quality of the mangroves. Towards this, the Henry Island situated in south-western Sundarban is selected, and soil samples are collected from different locations in hypersaline tracts based on elevation throughout the three seasons, pre-monsoon, monsoon and post-monsoon, over several years. The zonation of the mangroves is estimated from field survey and remote sensing techniques. Main objectives of this investigation are (i) to study the changes in the physical and chemical properties of soil over different seasons within the same habitat, (ii) to investigate the relationship among the soil parameters through statistical analysis and to assess the impact of the soil characteristics on mangroves. Comparative boxplots and an analysis of variance are used to investigate seasonal changes in the soil characteristics. Correlation plots are employed to study the relationships among the soil variables and the effect of the seasons over them. Results show considerable seasonal changes in the distributions of sand, silt and clay contents, organic carbon, organic matter, salinity and electrical conductivity of soil in the saltpan areas. The relationship between the quality of the mangroves and the soil variables over time is studied using regression analysis. It is found that electrical conductivity and salinity have considerable effects on the growth of mangroves.*

Introduction

Mangrove ecosystems are found within specific physiographic settings and coastal configurations (Thom, 1967, 1982; Bouillon *et al.*, 2009; Taylor *et al.*, 2003) and areas of sediment supply into the coastal zones under definite geological settings (Paul, 2002). The Sundarban, which contains the largest contiguous mangrove forest, is one of the most dynamic geomorphic units on the earth surface, covering approximately 10,000 km^2, of which 62% lies in Bangladesh and 38% lies in India. Morphologically, this region is the product of successive depositions of Ganga, Brahmaputra and Meghna rivers. Once it was a marshy forested immature low land, but later on, it has evolved as a unique hydro-geomorphic unit with distinctive hydrological characters. The Sundarban is a macrotidal estuary (tidal range is greater than 4 m). The seasonal tidal regime here reaches the inland area up to 1 m to 6 m elevation, and inundates low lying areas frequently. The mangrove ecosystem here acts as an active buffer against all-natural calamities and shoreline erosion of the intertidal region (Hazra and Samanta, 2016).

A World Heritage Site, the Sundarban is endowed with high biodiversity of aquatic and terrestrial flora and fauna (Barik and Chowdhury, 2014). Major habitats of this region are mudflats, coastal dunes, sandy beaches, mangrove swamps and estuarine network and narrow creeks. The structures of mangrove ecosystems are controlled by many environmental factors including climate, geomorphology, hydrodynamics and soil characteristics. Physicochemical properties of the soil, availability of nutrients, dissolved and particulate nutrient pools affect the halophytic plants of Sundarban (Tam and Wong, 1998), while the soil characteristics are themselves influenced by seasonal variation in the weather (Gupta and Rorison, 1975; Clarke, 1985). So, it is imperative to investigate the soil characteristics in the mangrove regions in the Sundarban, how they change over the seasons, and how they affect in turn the mangroves (Jackson, 2005). Aspects of the soil characteristics of mangroves in several other regions are studied in the literature (Holmer *et al.*, 1994; Lacerda *et al.*, 1995; Moreno and Calderon, 2011; Rambok *et al.*, 2010). The interplay of soil characteristics and mangrove vegetation was studied by several authors (Nazrul-Islam, 2003; Kathiresan *et al.*, 1996; Sah *et al.*, 1989).

In this study, overall assessment has been made on the issues of soil physical and chemical parameters and their temporal and spatial changes, and their effects on the growth of mangroves. For the collection of soil samples and the investigation of mangrove characteristics, the Henry Island situated in south-western Sundarban is chosen owing to its suitable geomorphological features, which are described in the next section. The characteristics of soil, like moisture content, electrical conductivity, pH, organic matter, salinity and nutrient present have a major effect on the mangrove ecosystem. So, these soil variables are analysed from the collected samples from the Henry Island.

Study area

The Henry Island has unique geomorphological features and mature development of hypersaline patches within the island. This island is located between Saptamukhi river in the east and Bakkhali river in the west (Fig. 1). The sedimentary environment, active coastal process and topography produce unique physiographic setting in which mangroves grow in response to the hydro-geomorphic character of the coast (Paul, 2002). Several physiographic settings are identified in the island, among which the following five are the most prominent: (i) tidal flat with planated mud banks, (ii) mangrove restoration tracks, (iii) salt flat with thin vegetation cover, (iv) planted vegetation on tidal flats, and (v) overwash fan lobes (Fig. 5). Mangrove patches of low, moderate and high density are present in the island. Mangroves of the coastal region adapt themselves with changing climate and sea level rise through physiological processes. Soil, pore water salinity, hot and humid climate, tidal inundation and storm surges play influential roles in the distribution of mangroves in the Henry Island. Micro-topographic variations in surface elevation of the island help to accumulate storm water, tidal water and rain water, which play significant roles to spread the wetlands towards the inland of the island. The region is characterised by tropical climate with a dry season between November and April, with annual precipitation amounting to 1500 mm–2000 mm occurs chiefly during the monsoon season (May–July) and scanty rainfall in the post-monsoon season.

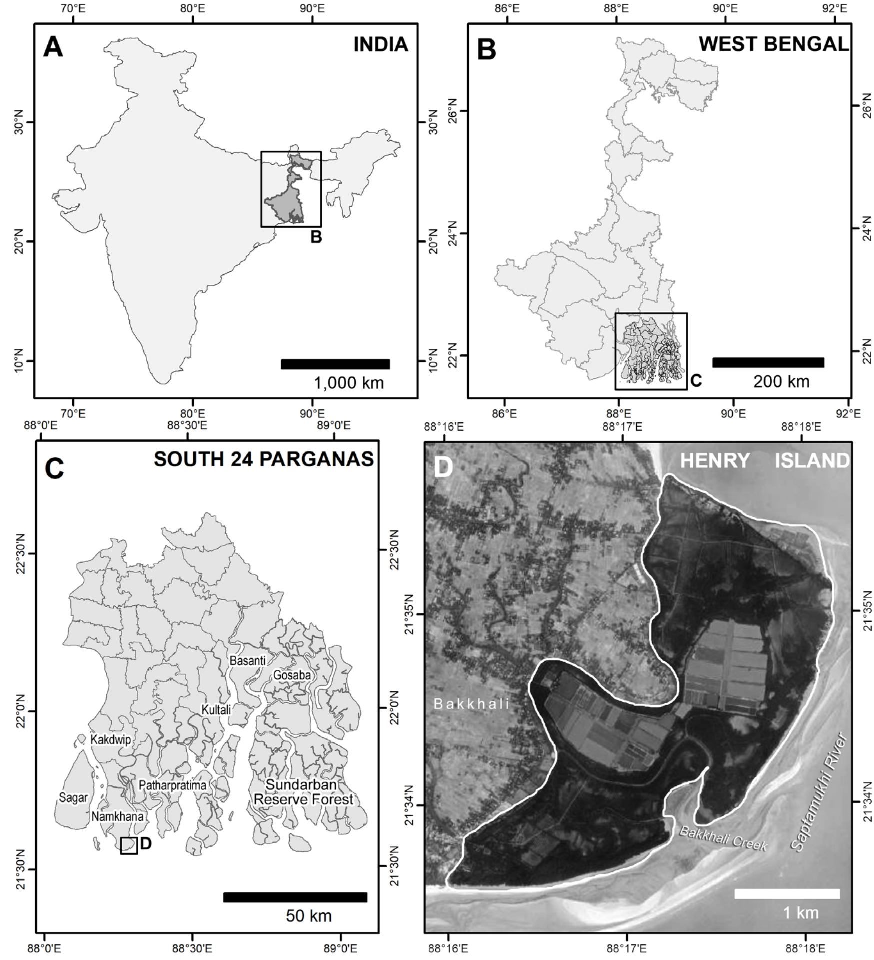


Figure 1. Location map of the study area.

Increasing temperature, extreme evaporation rate, tidal drainage loss, high intensity cyclones, sea level rise and high frequency of coastal flooding are causing changes in the pattern of mangrove species in the Henry Island. Cumulative effects of changing weather patterns, subsidence of low-lying areas, reduction of low saline areas, and development of salt patches within mangrove swampy zone create an imbalance of fresh water and saline water in the island. This indirectly changes the soil character and retards the growth of mangroves in various ways. The densest mangrove forests are seen along the shoreline which is a result of plantation to protect from natural hazards. Density of the mangroves is decreasing in the inland areas because of over-exploitation of the mangroves, expansion of tourism, aquaculture activities and fishing. Development of saline patches within mangrove swamps is noteworthy. Blocking of tidal creeks, hyper-saline conditions, topographic depressions are major reasons behind the development of saline patches. Seasonal changes in soil character occur mainly due to infrequent rainfall, high temperature, changes in relative humidity, extreme evaporation rate, etc.

Among the topographic features in

the Henry Island, the saline blanks are particularly notable. The saline blanks are the salt encrusted areas formed in the topographic depressions within the island having bare surface and minimal vegetation cover along its margin. Ecologically these areas support the highest variation in mangrove density. From barren patches to dense mangroves — all forms of canopy covers are present in and around these saline blanks. For the collection of soil samples, three saline blanks were selected, which are termed as Saline Blank-I, Saline Blank-II and Saline Blank-III. The sampling sites were chosen in and around these three saline blanks in view of the diversity in vegetation and topographic character.

Objectives

The main objectives of this research work are to identify the physical and chemical properties of the soils of the major salt patches located in the central part of the Henry Island, the seasonal changes of these characteristics and the temporal changes of the mangrove forest cover in the island. The paper also aims to investigate the relationship among these soil properties and their impact on the spatial distribution of mangroves in the island.

Materials and methods

The present work is based on data collected through field survey and satellite images (Paul *et al.*, 2014). Soil samples are collected in pre-monsoon, monsoon and post-monsoon season from 15 locations between 2015 and 2019. Monitoring of mangrove diversity from shoreline to inland area has been made by direct field observations. GPS and total station are used in the saline blank for contour planning and identification of locations. Normalised Difference Vegetation Index (NDVI) was determined from Landsat images acquired from USGS platform (Fig. 3) (Gandhi *et al.*, 2015). TNT MIPS and QGIS software are used for mapping purpose. Ranges of NDVI vary in this area, from below 0.1 to above 0.3. It helps to identify

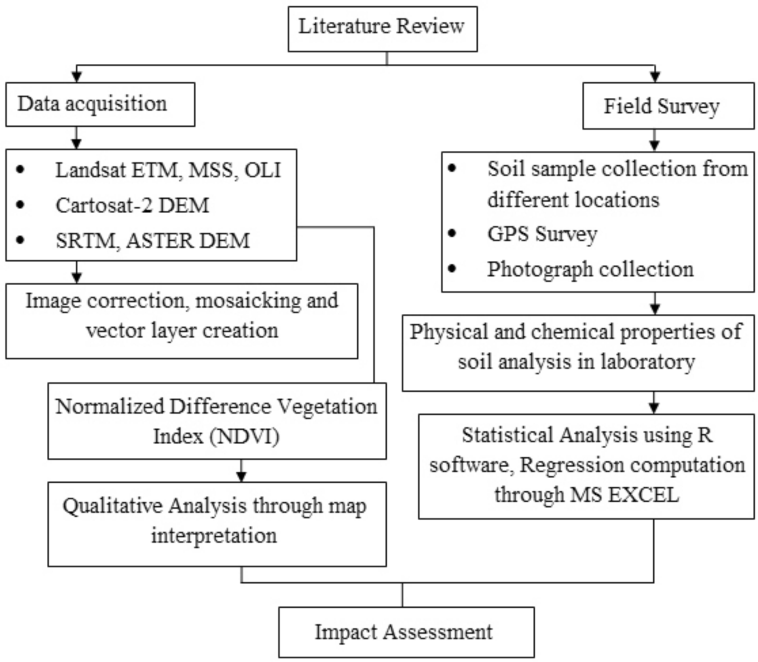


Figure 2. Methodology of the present work

the spectral variability and the changes in the vegetation growth of this area. Cartosat 2 Digital Elevation Model (DEM) is collected from NRSC for preparing the micro-relief zonation map for the whole island.

From each soil sample, 12 physicochemical characteristics have been measured — soil pH, electrical conductivity, soil moisture, sand, silt, clay, salinity, soil organic matter, soil organic carbon, soil nitrogen, phosphorous and potassium. Statistical analysis of the soil variables is carried out using comparative box plots, analysis of variance and correlation plots. Comparative box plot analysis is carried out to visually present the median levels, the spread and the skewness of the soil variables and their changes across the seasons. To ascertain whether the differences in the average levels of the soil variables over the seasons are statistically significant or not, analysis of variance (ANOVA) in the datasets are carried out. Next, the pair-wise association of the soil variables is analysed using the Pearson product-moment correlation coefficient (Casella and Berger, 2002) and its test of significance. Let (X_1, Y_1), ..., (X_n, Y_n) be a paired sample, and let

$\bar{X} = n^{-1} \sum_{i=1}^{n} X_i$ and $\bar{Y} = n^{-1} \sum_{i=1}^{n} Y_i$

The Pearson product-moment correlation coefficient is expressed as:

$$\rho_{X,Y} = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} .$$

Table 1: NDVI values of mangrove in Henry Island (km²).

Mangrove Status	2005	2010	2015	2019
Dense	1.166	1.718	1.964	1.749
Moderate	0.921	0.967	1.168	1.22
Low	1.349	1.737	2.011	1.654
Very Low	2.168	1.907	1.281	1.804

$\rho_{X,Y}$ lies between 1 and –1, and it measures the strength of linear association between the variables. $\rho_{X,Y}$ is 1 when there is a perfect positive linear association between X_i s and Y_i s, and $\rho_{X,Y}$ is –1 when there is a perfect negative linear association between X_i s and Y_i s. Next, the relationship between the density and the extent of the mangroves in the Henry Island and the soil variables is investigated. For this, the mangrove-covered area in Henry Island, over several years has been used, which is divided into three parts based on the density of the mangroves — dense, moderate and low. The corresponding yearly averages of all the soil variables are calculated. Then, linear regression analysis has been carried out for all possible pairs consisting of the yearly average of one soil variable as the covariate and one mangrove variable as the response (viz. areas of dense mangrove, moderate mangrove and low mangrove). Here, the result of the regressions involving the soil electrical conductivity, pH, salinity and soil organic matter are presented.

Results and discussion

The NDVI maps are presented in Fig. 3, depicting the dense, moderately dense, low and very low concentration of mangroves. The higher density of vegetation is seen along the higher elevation zones, e.g., along the sand dunes of the shore fringes. Moderately dense mangroves are found in the central part of the island, especially in northern section. Zones of mangroves with low and very low density are found within saltpans and beside the aquaculture plots.

In Table 1, one can notice significant increase in dense vegetations in 2010. According to local people, the reason for this increase was plantation and afforestation by the forest department. To combat the problem of mangrove degradation in 2009 after the

Aila cyclone, NGOs, local people along with the forest department took initiatives to replenish the incurred losses by planting the second lowest zone lies in the eastern and the northern fringes. Average height of the island is 1.50 m. The highest elevation above

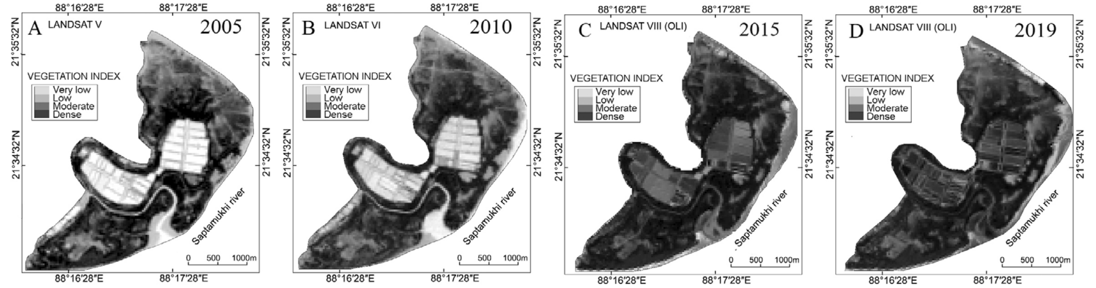


Figure 3. NDVI maps of the Henry Island for the years (A) 2005, (B) 2010, (C) 2015, and (D) 2019, prepared from Landsat, USGS.

trees. But in 2019, the area under mangroves decreased due to over exploitation of coastal vegetation, expansion of fisheries and devastations caused by the cyclones Fani and Bulbul.

The micro relief variation map (Fig. 4) prepared on Cartosat-2 DEM of 2 m spatial resolution is clearly showing the elevation zones from 0.90 m to 2.40 m in different 2.40 m is found along the shoreline due to the position of sand dunes (Fig. 5).

There are several major physiographic settings (Fig. 5) like dense mangrove in the eastern part along the shoreline, moderately dense or mangrove swamp in the inland areas, planted vegetation on tidal flats, sand dunes, fish drying platforms, wash over lobes, salt flats with thin vegetation cover, etc.

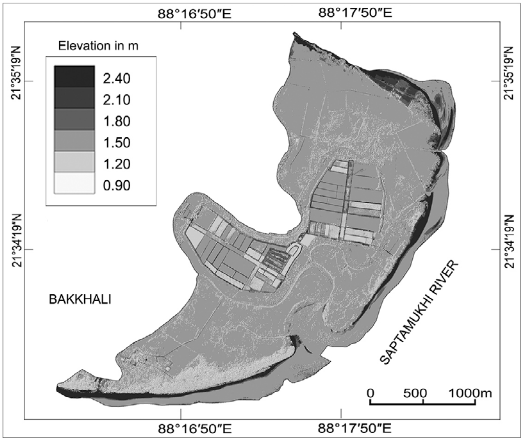


Figure 4. Micro relief variation map of the Henry Island based on Cartosat-2 DEM (2019)

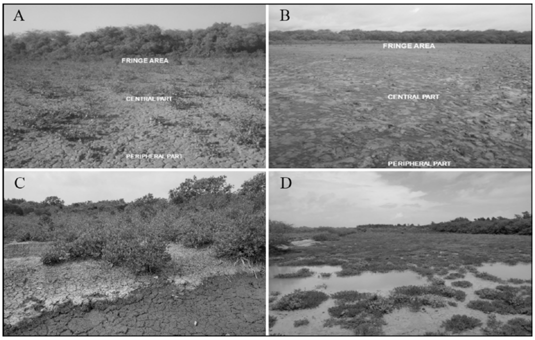


Plate 1. Seasonal changes of soil and mangrove characteristics within saline blanks: (A) Die-back of mangroves in December 2019 (S-I), (B) Algal encrustation in July 2019 (S-I), (C) Dwarf mangroves in November 2019 (S-II), (D) Standing pool of water in July 2019 (S-III).

physiographic units. Considering elevations values, the island is divided into six elevation zones. The lowest elevation zone (0.90 m) is found in the central part of the island whereas

Soil samples were collected on the basis of these physiographic settings in different seasons to observe the changes in soil character and how they influence the

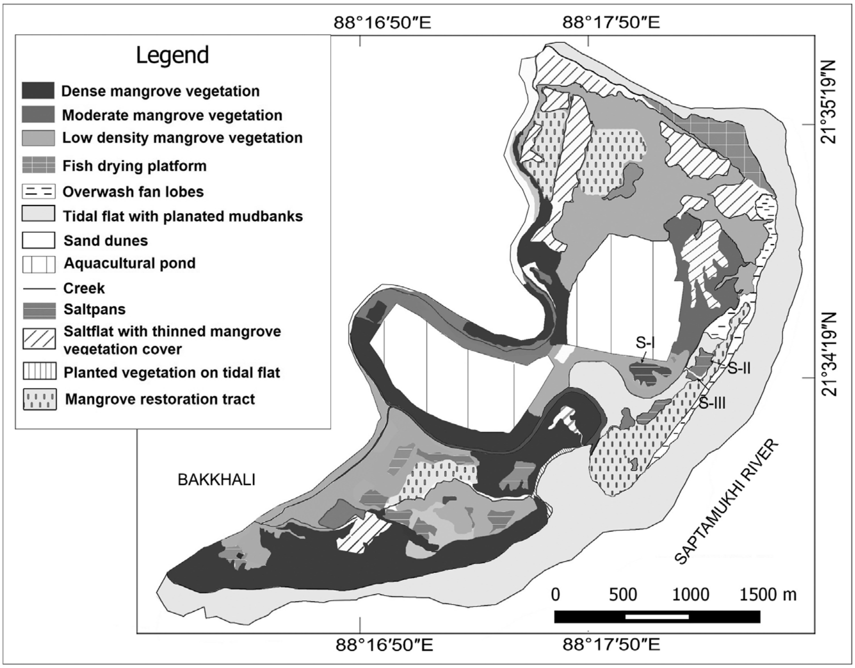


Figure 5. Geomorphological settings of the Henry Island showing location of saline blanks.

mangrove distribution. For this investigation, eight soil sampling sites in saline blank S-I were selected. The location of S-I, S-II and S-III are Saline Blank-I, Saline Blank-II and Saline Blank-III.

The saline blanks are selected on the basis of size and mangrove zonation. They are named as S-I, S-II and S-III. Saline blanks are low depressions within mangrove swamps having distinct characters of soil in different seasons (Plate 1). To get an idea about the surface expression of saltpans, total station was used for contouring. The contour map of the saltpan indicates a depression in the central part, which is a bare surface having high salinity level, whereas the peripheral region has comparatively high elevation and is rich in organic carbon and organic matter. Density of mangroves tends to increase in periphery with low salinity level (Plate 1B). The soil characteristics in the saline blanks are found to be changing seasonally. Physicochemical properties of S-I are different from S-II and S-III (Plate 1). Zonation and density of mangroves are also different within the saltpan areas and the island.

Identification of physicochemical properties of soil in different seasons

Physical and chemical properties of soil in the saline blanks are presented in Table 2. Among twelve parameters, salinity, electrical conductivity, pH and organic matter play dominant roles in all regions. Sample locations were selected from eastern fringe, western fringe, middle-eastern fringe upper and lower parts, southern fringe, southeastern fringe, central part, and southern-middle part of saline blank S-I. In Fig. 7A, variations of pH, electrical conductivity (EC) and soil moisture are depicted, which indicate that EC level is very low in western fringe and maximum in southern fringe.

That means nutrient is higher in southern part compared to western fringe. Moisture content is also higher in southern area compared to eastern and western fringes. Soil

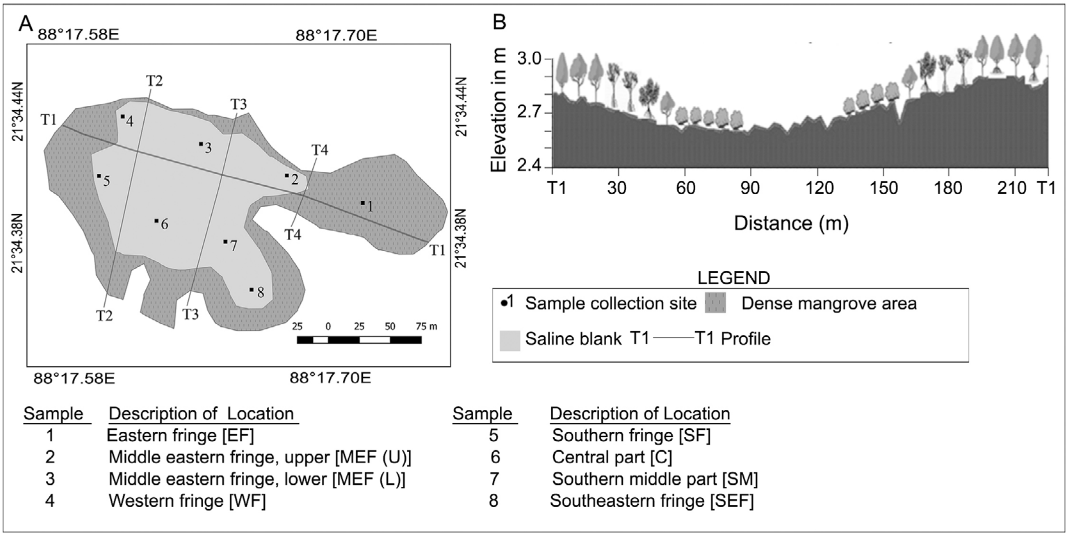


Figure 6. (A) Soil sampling sites of Saline Blank-I, **(B)** Saline blank profile along transect T1.

Table 2: Seasonal variation of soil properties at selected sample locations in saline blank S-I (Refer Fig. 6A for sampling locations).

Samples	Season	pH (1:5)	EC (µmhos cm-1)	Moisture (%)	Sand (%)	Silt (%)	Clay (%)	Salinity (ppt.)	Organic Carbon (gkg–1)	Organic matter (%)	N (mg kg–1)	P (mg kg–1)	K (mg g–1)
1	Pre-monsoon	8.42	9746.91	16.70	33.40	48.62	19.65	11.13	0.18	0.69	137.64	55.34	579.98
	Monsoon	7.71	7493.61	18.89	38.59	40.18	23.81	7.85	0.39	1.80	171.18	22.11	601.01
	Post-monsoon	8.93	7366.86	15.37	36.38	38.84	26.98	8.25	0.06	1.02	129.75	29.00	600.29
2	Pre-monsoon	7.36	8297.74	15.15	32.97	36.59	25.11	9.60	0.25	0.68	132.85	32.63	595.69
	Monsoon	6.65	6044.44	17.34	38.16	28.15	29.27	6.31	0.82	1.79	166.39	0.60	616.71
	Post-monsoon	7.87	5917.69	13.81	35.95	26.81	32.44	6.71	0.36	1.01	124.96	6.29	615.99
3	Pre-monsoon	6.64	9269.06	18.38	36.27	36.04	27.74	11.40	0.66	0.78	147.58	40.83	598.91
	Monsoon	5.93	7015.76	20.57	41.46	27.6	31.90	8.12	1.23	1.89	181.11	7.61	619.93
	Post-monsoon	7.15	6889.01	17.04	39.25	26.27	35.07	8.52	0.78	1.11	139.68	14.49	619.21
4	Pre-monsoon	7.67	10607.58	17.26	37.54	37.95	26.75	10.95	0.59	0.98	171.81	43.77	691.65
	Monsoon	6.96	8354.28	19.45	42.72	29.51	30.91	7.67	1.16	2.09	205.35	10.55	712.68
	Post-monsoon	8.17	8227.53	15.92	40.00	28.17	34.08	8.07	0.70	1.31	163.91	17.43	711.95
5	Pre-monsoon	6.45	12292.74	17.16	32.35	37.77	17.01	13.17	0.38	0.55	138.00	94.15	474.23
	Monsoon	5.74	10039.44	19.35	37.54	29.33	21.17	9.88	0.95	1.66	171.53	60.93	495.25
	Post-monsoon	6.95	9912.69	15.82	35.33	27.99	24.34	10.28	0.50	0.88	130.10	67.81	494.53

moisture plays a vital role for the growth of mangroves. Soil pH level remains high in monsoon season than pre- and post-monsoon throughout the saline blanks. Salinity level is high in post-monsoon times in the western fringe, but it tends to decrease towards periphery (Fig. 7C). Salt tolerant dwarf mangrove species (Plate 1C) are seen in the central part. Mangrove colonisation is dense at the periphery of saline blank. Organic carbon is also high at periphery in the monsoon. But it is low in pre-monsoon due to low intensity of rainfall in pre- and post-monsoon.

In the western fringe, the level of sand is high. The lower layer of middle-eastern fringe has higher clay concentration. This indicates that deposition of sand on the top soil makes this layer infertile, but lower parts of soil horizon show clay-dominant fertile soil (Plate 2).

Levels of organic carbon, nitrogen, phosphorus and potassium are higher in the monsoonal season. The southern fringe has much higher concentration of organic matter and potassium. This zone exhibits denser and luxuriant growth of mangroves compared to western and eastern fringes. Central part of the saline blank is bare without vegetation. Desiccation cracks in pre-monsoon and algal encrustations in monsoon are common features of saltpans (Plate 1B).

Relationship among soil parameters and their impacts on mangroves

The results of the statistical analysis of the soil parameters and the mangrove variables are presented in this section. The plots for comparative box plot analysis of the soil variables over the seasons are presented in Fig. 8. The box plots clearly reflect the changes in the median level as well as the dispersion and the skewness of the soil variables over the seasons.

The dispersion of the soil pH increases from pre-monsoon to post-monsoon through monsoon as reflected in the interquartile spreads in the respective box plots, and its median level also rises gradually. The electrical conductivity is lower in monsoon than in pre-monsoon or post-monsoon, while the moisture content is positively skewed in monsoon. Sand and silt levels rise in monsoon, while the median level of clay remains almost unchanged over the seasons. The dispersions of the sand, the silt and the clay contents vary over the seasons noticeably. The dispersion in soil salinity is lowest in monsoon, and its median level in monsoon is lower than that in pre-monsoon. The soil organic carbon distribution is very positively skewed in monsoon. Soil organic matter and available nitrogen levels rise considerably in monsoon, and the distribution of available nitrogen

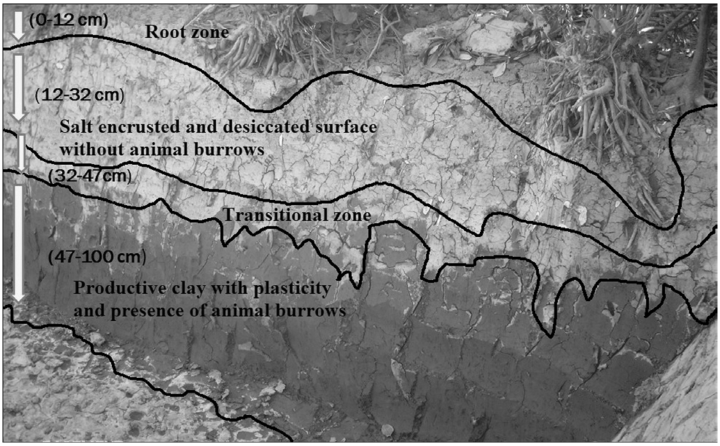


Plate 2. Stratigraphic view of a saline blank and the underlying swampy soil.

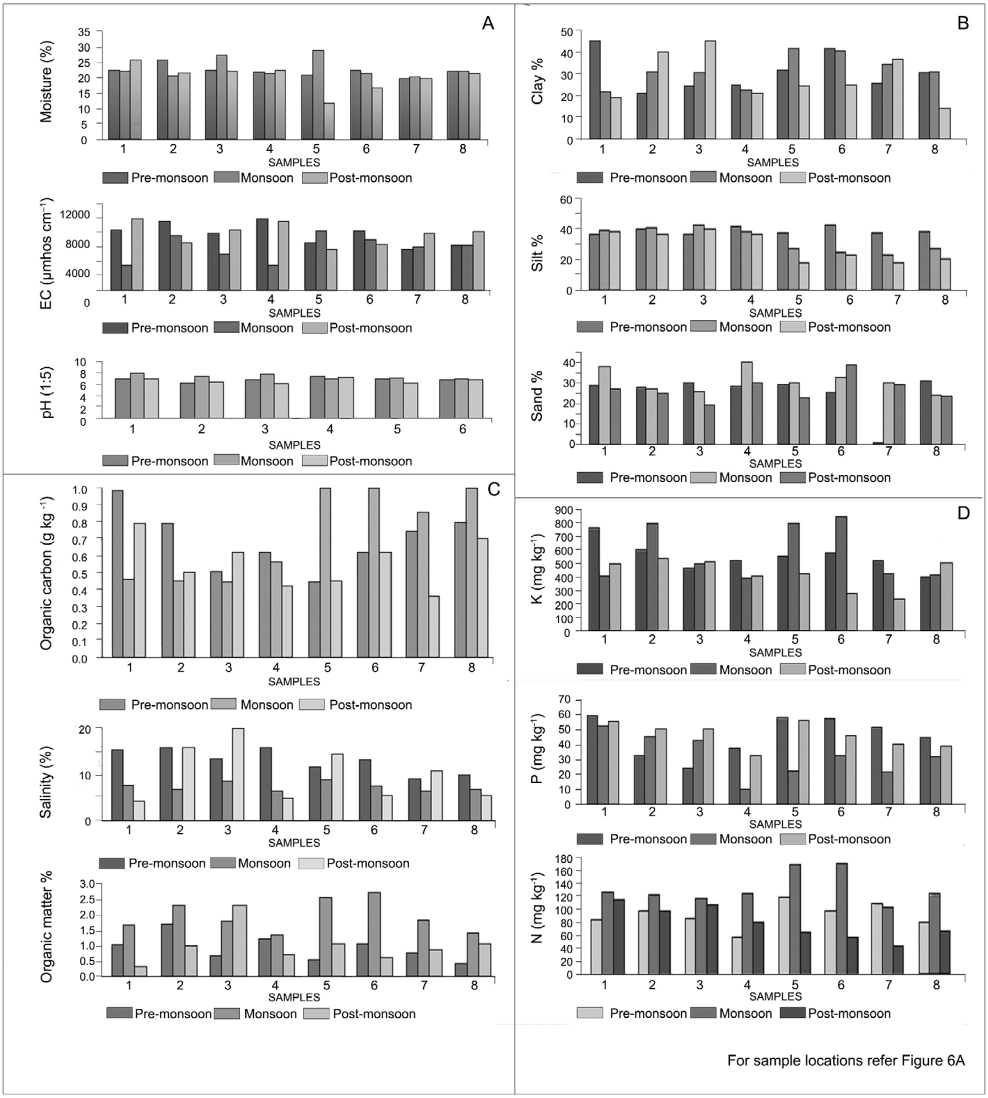


Figure 7. Spatial and seasonal variability of soil parameters within saline blank-I: (A) Variation of pH, electrical conductivity, moisture, (B) Variation of sand, silt, clay, (C) Variation of salinity, organic carbon and organic matter, (D) Variation of potassium, phosphorous and nitrogen.

is also positively skewed in monsoon. The available phosphorus level is lower in monsoon than in pre-monsoon and in post-monsoon. Available potassium level is higher in monsoon and its dispersion is also higher in that season.

Next, to ascertain whether the differences in the average levels of the soil variables over the seasons are statistically significant or not, analysis of variance (ANOVA) is carried out in the datasets. The p-values of the ANOVA test are presented in Table 3.

One can notice that the ANOVA p-values for moisture, silt, organic matter and nitrogen are smaller than 5%. So, it may be stated that there are statistically significant differences at level 5% among the group means for moisture, silt, organic matter and nitrogen across the seasons.

Proceeding to investigate the

interrelationship of the soil variables and the effect of the seasons over it, the correlation plots of the soil variables are presented in Fig. 9A, 9B and 9C for pre-monsoon, monsoon and post-monsoon, respectively. The correlation values, which are found to be statistically significantly different from 0 at level 5%, have a background colour of either blue (for positive correlation) or red (for negative correlation). From the statistically significant correlation values in Fig. 9A, one can see that in pre-monsoon, soil pH has negative correlation with salinity and positive correlation with available nitrogen, while electrical conductivity has positive correlation with salinity. Clay has positive correlation with moisture but negative correlation with sand and silt percentages. Silt in turn has negative correlation with nitrogen in soil. Salinity also has negative correlation with nitrogen and phosphorus content. Finally, soil organic carbon and soil organic matter are positively correlated. In Fig. 9B, one finds considerable number of statistically significant correlations among the soil variables in monsoon. There, electrical conductivity has positive correlation with clay, organic matter and potassium, but negative correlation with phosphorus. Moisture is positively correlated with only salinity. Silt is negatively correlated with organic carbon and nitrogen in soil. Clay in turn is positively correlated with organic matter, organic carbon, nitrogen and potassium, but negatively correlated with phosphorus. Soil organic carbon is also positively correlated with nitrogen but negatively correlated with phosphorus. Soil organic matter is negatively correlated with phosphorus but positively correlated with potassium. Phosphorus is negatively correlated with nitrogen and potassium. In Fig. 9C, one finds relatively few statistically significant correlations among soil variables in post-monsoon.

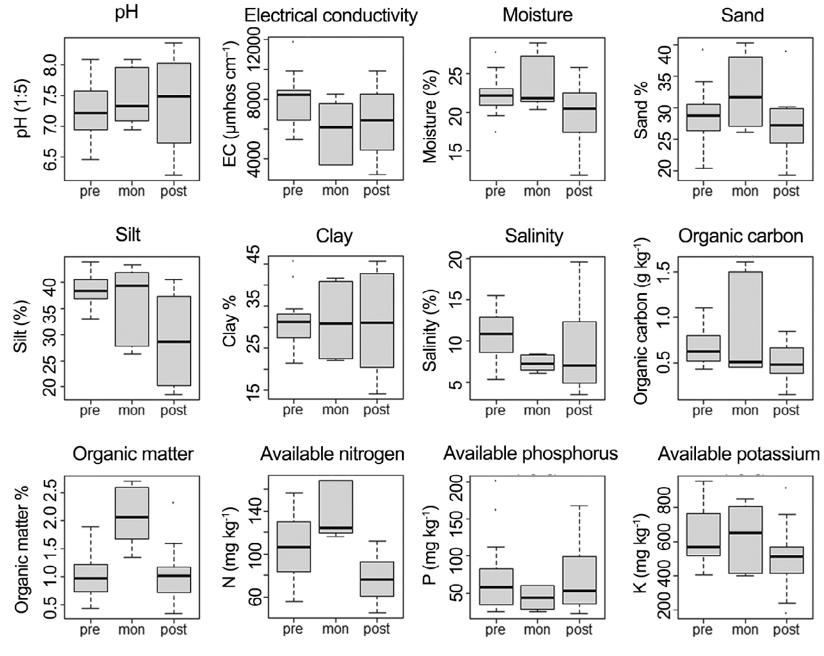
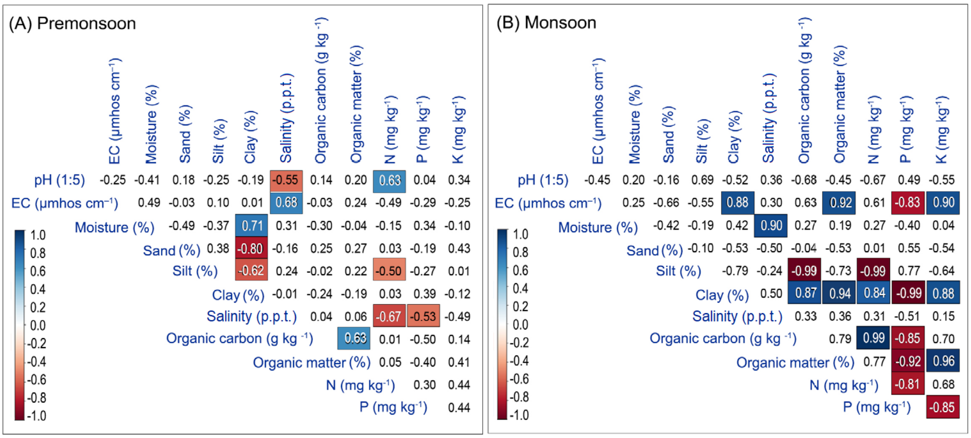


Figure 8. Comparative box plots across seasons for the soil variables (pre: pre-monsoon, mon: monsoon, post: post-monsoon). The black horizontal lines represent the median value, the lower and upper boundaries of the box are the 1st and the 3rd quartiles, respectively. The whiskers are at the distance of 1.5 times the interquartile range from the respective boxes.



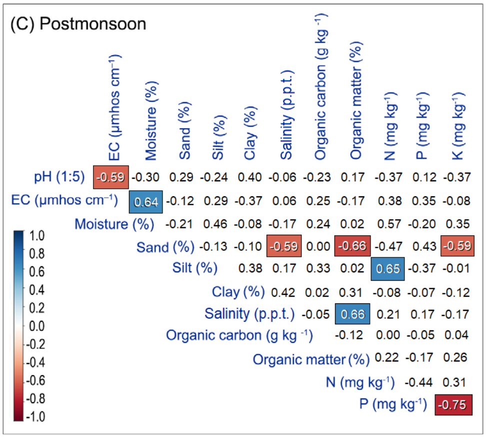


Table 3: ANOVA p-values of soil variables.

Soil properties	p-value
pH (1:5)	0.79
Electrical conductivity (μmhos cm^{-1})	0.08
Moisture (%)	0.04
Sand (%)	0.13
Silt (%)	0.0
Clay (%)	1.0
Salinity (p.p.t.)	0.14
Soil organic carbon (g kg^{-1})	0.08
Soil organic matter (%)	0.0
Available nitrogen (mg kg^{-1})	0.0
Available phosphorus (mg kg^{-1})	0.41
Available potassium (mg kg^{-1})	0.23

Figure 9. Correlation plots of soil variables in (A) pre-monsoon, (B) monsoon, and (C) post-monsoon conditions.

There, electrical conductivity is negatively correlated with soil pH but positively correlated with moisture. Sand is negatively correlated with salinity, organic matter and potassium. Silt is positively correlated with nitrogen. Salinity and organic matter also have positive correlation. Finally, phosphorus and potassium are negatively correlated.

From the three correlation plots in Fig. 9 (A, B, C), one notices the strong effect of the seasons over the inter-relationships among the soil variables, such that the correlation of not a single pair remains both similar and statistically significant over the seasons.

Subsequently, the results of the regressions involving the soil variables and the mangrove variables are presented. In Fig. 10, the regression plots involving the mangrove variables and soil electrical conductivity, pH, salinity and organic matter are presented. One notes that there is a positive association between electrical conductivity and dense or moderate mangrove, which means that as electrical conductivity increases, the areas under dense mangrove and moderate mangrove tend to increase. However, the association between electrical conductivity and low mangrove is negative, which means as electrical conductivity increases, the area under low mangrove tends to decrease. Putting these three observations together, one can conclude that as electrical conductivity increases, the density of the mangroves tends to increase, and sparse mangrove covered regions tend to change to moderate or dense mangrove covered regions. Also, one notices that as pH increases, the areas under dense mangrove and moderate mangrove tend to decrease, while the area under low mangrove increases. This indicates that an increase of soil pH has a detrimental effect on the mangroves, and the density of mangroves decreases with it. One can notice that as salinity increases, the areas under dense and moderate mangroves tend to increase, while the area under low mangrove tends to decrease. The rate of increase is higher in the case of moderate mangrove compared to dense mangrove. This indicates that an increment of salinity is associated with an increase in the density of the mangroves. One also notices that the association with soil organic matter and the density of mangroves is very weak.

mangrove severely. Topography of the hyper-saline patches also influence the surface soil character. Depressions exhibit high salinity levels due to long-time inundation of the surface. In those areas, salt-tolerant species like *Avicennia marina*, *Sueda fruticosa* and *Excoecaria agallocha* are mostly found. Less salt tolerant species like *Bruguiera gymnorhiza*, *Nypa fruticans*, etc. are seen along the peripheral areas.

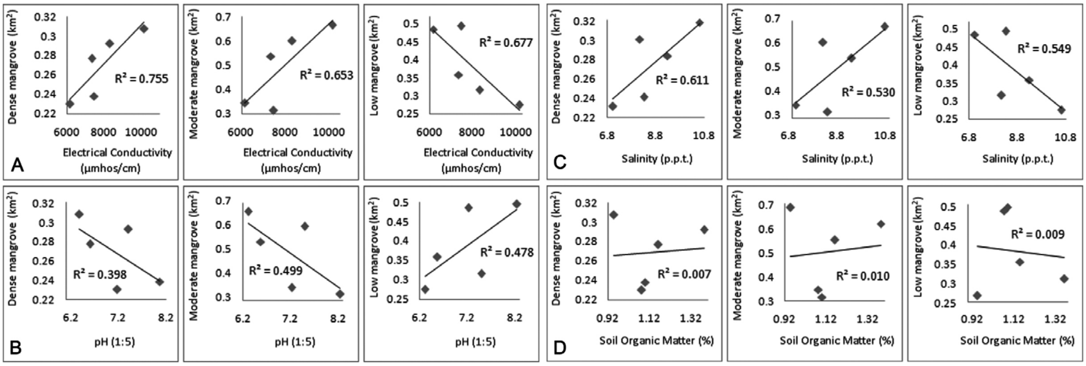


Figure 10. Regression plot of mangrove variables (dense, moderate density, low density) over soil electrical conductivity (A), soil pH (B), soil salinity (C) and soil organic matter (D). The data points correspond to the 5 years of soil sample collection. The areas under dense mangroves, mangroves of moderate density and mangroves of low density are obtained from the NDVI maps of the corresponding years.

Conclusion

In this work, the temporal changes in mangrove vegetation cover, soil characteristics and their inter-relationships are investigated in a coastal mangrove covered island of southwestern Sundarban. NDVI maps depict the temporal changes of vegetation cover in the island, especially after Aila. It is observed that development of salt patches, deforestation and other natural factors affect succession of

In the statistical analysis of soil characteristics, it is found that organic matter and nitrogen in soil significantly increase during the monsoon season. Of course, soil moisture also increases in monsoon. It is also found that the silt content of soil considerably decreases in post-monsoon, while its average levels are similar in monsoon and pre-monsoon. The changes in these four soil variables over seasons are found to be statistically significant in the ANOVA procedure also. However, through visual inspection in the comparative box plots, marginal changes in several other variables are noticeable. One can notice that soil pH gradually increases from pre-monsoon to monsoon and from monsoon to post-monsoon. Electrical conductivity of soil is marginally lower in monsoon, while sand content is marginally higher in monsoon. The average levels of clay, soil organic carbon and phosphorus content remain nearly same throughout the seasons, though their other distributional characteristics, e.g. spread and skewness vary over the seasons. The potassium content in soil is marginally higher in monsoon than in pre-monsoon and post-monsoon. The correlation among the soil variables is very much affected by the seasons, and strong correlation within any pair of soil variables, which remains similar across the seasons, is not observed. Finally, it is observed that electrical conductivity has a strong association with the density and extent of the mangroves, which is intriguing. Soil pH has a negative association with the density and extent of the mangroves, while salinity has positive association. It is also found that soil organic matter does not significantly affect mangrove quality.

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