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Research Article

Soil Characteristics of Indian Sundarbans: The Designated World Heritage site -

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Abstract

Soil profile in the mangrove dominated lower Gangetic delta plays a crucial role in regulating floral and faunal distribution. Soil organic carbon, pH and salinity were monitored in mangrove ecosystem of Indian Sundarbans in five successive years (2011 – 2015). Samplings were carried out at 14 stations at four different depths (0.01-0.10 m, 0.10-0.20 m, 0.20-0.30 m and 0.30-0.40 m) through three seasons (pre-monsoon, monsoon and post-monsoon). High organic Carbon load was observed at the stations in Western Indian Sundarbans (mean = 1.04%) which is near to the highly urbanized city of Kolkata. The Central and Eastern sectors under the protected forest area showed comparatively less soil organic Carbon (mean = 0.61%). Soil pH exhibited a lower value in the reserve forest zones (Central and Eastern sectors) compared to the Western sector. The soil salinity increased with depth, while organic carbon and pH decreased with depth in all the stations. A complete mapping of spatio-temporal variations of soil parameters is needed to sustain healthy mangrove vegetation in the lower Gangetic delta.

INTRODUCTION

In mangrove ecosystem, organic carbon usually originates *via* the riverine introduction of pollutants, including industrial and domestic wastes, agricultural, aquacultural and mining runoff, accidental spillages and decomposition debris from marine organisms. However, different factors may control the partitioning and also the bioavailability of the hydrophobic organic compounds within the benthic ecosystem. These factors include sediment characteristics, such as grain size distribution, mineral composition and organic content [1-3]. Surface sediments may be resuspended and redistributed by the action of waves and currents [4]. As these phenomena trigger the process of erosion and accretion, therefore the top most layers of the sediments contain recently deposited organic matter. Total organic carbon has a major influence on both chemical and biological processes that take place in sediments. The amount of organic carbon has a direct role in determining the redox potential and pH in sediment, thus regulating the behavior of other chemical species such as metals [5,6] Natural processes and human activities have resulted in elevated content of total organic carbon in mangrove soils and adjacent estuaries and creeks. These include diverse input through fall, stream flow, inappropriate animal waste applications and disposals, forest clearance, agricultural practices, and changes in land uses [7]. Also mangrove litter fall and decomposition of organisms regulate the organic carbon budget in the intertidal mudflats [8]. The mangrove ecosystem of Indian Sundarbans, at the apex of Bay of Bengal covers an area of about 4266.6 sq. km [9]. On the basis of satellite imagery, the Forest Survey of India (1999) [10] estimated the area of Indian Sundarbans as 2125 sq. km, excluding the anastomising network of creeks and backwaters, which are part and parcel of mangrove ecosystem. Mangrove communities often exhibit distinct patterns of species distribution [11-13]. Since the mangrove habitat is basically saline, several studies have attempted to correlate salinity with the standing crop of vegetation and productivity [14-18]. Local patterns of tidal inundation further influence soil characteristics that control the zonation of species in mangrove wetlands [19,20]. The distribution of mangrove species, in many cases, can be explained primarily by salinity gradients [21]. The pH of soil significantly affects plant growth, as essential elements such as phosphorus (P), as well as non-essential elements such as aluminium (A1) can be toxic to plants at elevated concentrations [22]. The importance of both soil salinity and pH for the growth of mangroves has been emphasized by Wakushimaet al (1994 a,b). Sundarbans shelters one of the most important mangrove communities of the world. A few published works deal with the community structure of this forest [23,24]. However, very few reports are available on the organic carbon profile of mangrove soil [8] that can reflect the status on this unique ecosystem in terms of natural [25] or anthropogenic influences [26-28]. In this paper, we report our unpublished data of soil organic carbon, pH and salinity to evaluate their depth-wise variation in the intertidal mudflats of Indian Sundarbans through seasons. The aim of this paper is to determine what role the anthropogenic and natural factors have on mangrove soil.

MATERIALS AND METHODS

Sampling sites

The Sundarban mangrove ecosystem, covering about one million ha in the deltaic complex of the Rivers Ganga, Brahmaputra and Meghna, is shared between Bangladesh (62 %) and India (38 %) and is the world's largest coastal wetland. Enormous load of sediments carried by the rivers contribute to its expansion and dynamics. The Indian Sundarbans (between 21°13' N and 22°40' N latitude and 88°03' E and 89°07' E longitude) is bordered by Bangladesh in the east, the Hooghly River (a continuation of the River Ganga) in the west, the Dampier and Hodges line in the north, and the Bay of Bengal in the south. The important morphotypes of deltaic Sundarbans include beaches, mudflats, coastal dunes, sand flats, estuaries, creeks, inlets and mangrove swamps [29]. The temperature is moderate due to its proximity to the Bay of Bengal in the south. Average annual maximum temperature is around 35°C. The summer (premonsoon) extends from the middle of March to mid-June, and the winter (postmonsoon) from mid-November to February. The monsoon usually sets in around the middle of June and lasts up to the middle of October. Rough weather with frequent cyclonic depressions occurs during mid-March to mid-September. Average annual rainfall is 1920 mm. Average humidity is about 82 % and is more or less uniform throughout the year. 34 true mangrove species and some 62 mangrove associate species have been documented in Indian Sundarbans [27]. This unique ecosystem is also the home ground of Royal Bengal tigers (*Panthera tigris*). The deltaic complex sustains 102 islands, only 48 of which are inhabited. The ecosystem is extremely prone to erosion, accretion, tidal surges and several natural disasters, which directly affect the top soil of the intertidal mudflats encircling the islands. The average tidal amplitude is around 3.0 m. Some sea facing islands experience high tidal amplitude (~5.0 m). We conducted survey at 14 stations in the Indian Sundarbans region during three seasons viz. premonsoon (May), monsoon (September) and postmonsoon (December) from 2011 to 2015. Station selection was primarily based on anthropogenic activities, salinity, mangrove floral richness and biomass. Because of rapid industrialization, urbanization, unplanned tourism, navigational and shrimp culture activities, the western Indian Sundarbans is a stressed zone (stations 1 to 7). On the contrary stations 8 to 14 are within the reserve forest areas with luxuriant mangrove vegetation and diversity and have been considered as control zone in this study. The major activities influencing the nature of soil in the selected stations are highlighted in table 1.

Sampling and analysis

Table 1 and Figure 1 represent our study site in which sampling plots of 10 m × 5 m were considered for each station. Care was taken to collect the samples within the same distance from the estuarine edge, tidal creeks and the same micro-topography. Under such conditions, spatial variability of external parameters such as tidal amplitude and frequency of inundation [30], inputs of material from the adjacent bay/estuary and soil granulometry and salinity [31] are minimal. 10 cores were collected from the selected plots in each station by inserting PVC core of known volume into the soil to a maximum depth of 0.40 m during low tide condition. Each core was sliced in 0.10-m layers up to 0.40 m depth. The uppermost 0.01 m, which frequently includes debris and freshly fallen litter, was not

Table 1: Major activities influencing the organic carbon pool in Indian Sundarbans.

Station name and Stn. No. (as in map)	Geographical Location		Major activity	Magnitude
	Longitude (°E)	Latitude (°N)		
Kachuberia (1)	88°08'04.43"	21°52'26.50"	Navigational channel	+++
			Passenger vessel jetties	+++
			Shrimp culture farms	+
			Market place	++
Harinbari (2)	88°04'52.98"	21°47'01.36"	Mangrove patches (n = 7; AGMB = 89t/ha)	++
			Unorganized fishing activities	+
Sagar South (3)	88°03'06.17"	21°38'54.37"	Pilgrims	+++
			Tourism	+++
			Navigational channel	+++
			Erosion (sea facing)	+++
			Mangrove patches (n = 11; AGMB = 94t/ha)	++
Chemaguri (4)	88°10'07.03"	21°39'58.15"	Fish landing stations	+++
			Tourism	+++
			Mangrove patches (n=17; AGMB=71 t/ha)	++
			Shrimp culture farms	++
Frazergaunge (5)	88°15'15.63"	21°33'11.84"	Shrimp culture farms	++
			Mangrove forest (n = 17; AGMB = 124t/ha)	+++
			Fish landing stations	+
			Market place	++
Prentice Island(6)	88°17'10.04"	21°42'40.97"	Mangrove patches (n = 18; AGMB = 108 t/ha)	+++
Lothian island (7)	88°22'13.99"	21°39'01.58"	Mangrove forest (protected area; n = 31; AGMB = 136 t/ha)	+++
			Navigational channel	+++
			Erosion	+++
			Wave action	+++
Sajnekhali (8)	88°46'0.08"	22°05'13.04"	Mangrove forest (protected area; n = 31; AGMB = 136 t/ha)	+++
			Tourism	++
Amlamethi (9)	88°44'26.07"	22°03'54.02"	Mangrove forest (n = 17; AGMB = 148 t/ha)	+++
			Tourism (occasional)	+
			Shrimp and prawn culture farms.	+
Jharkhali (10)	88°41'47.25"	22°05'52.82"	Mangrove forest and eco-tourism (protected; n = 13; AGMB = 141 t/ha)	+++
Dobanki (11)	88°45'20.06"	21° 59'24.04"	Accretion zone	++
			Mangrove forest (n = 16; AGMB = 112 t/ha)	+++
Netidhopani (12)	88°44'39.4"	21° 55'14.9"	Mangrove forest (n = 16; AGMB = 112 t/ha)	+++
Haldibari (13)	88°46'44.9"	21°43'01.4"	Accretion zone	++
			Mangrove forest (n = 16; AGMB = 112 t/ha)	+++
Burirdabri (14)	89°01'43.6"	22°04'39.2"	Mangrove forest (protected area; n = 21; AGMB = 136 t/ha)	+++

+, **++** and **+++** indicate low, medium and high magnitude respectively for the major activities in the selected stations; n and AGMB represent number of mangrove species and above ground mangrove biomass ($t\ ha^{-1}$) of three dominant species respectively.

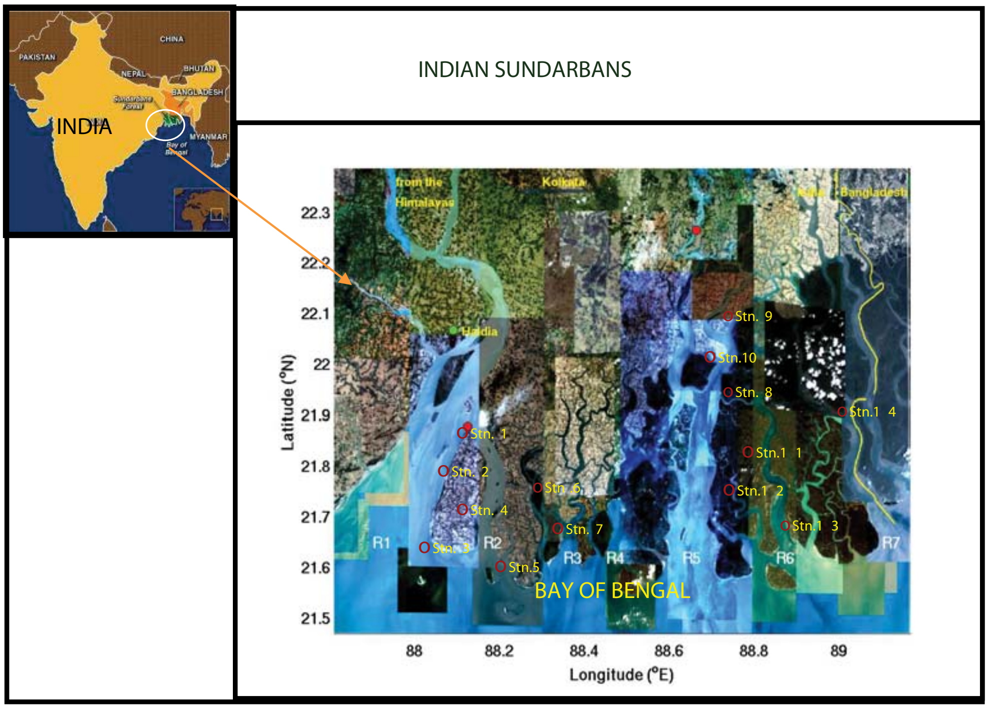

Figure 1: Map of the study region showing the sampling stations. R1 to R7 are the seven rivers of Sundarbans starting from west to east, namely Hooghly, Mooriganga, Saptamukhi, Thakuran, Matla, Gosaba and Harinbhanga.

used in this study. Each core section was placed in aluminium foil and packed in ice for transport. In the laboratory, the collected samples were carefully sieved and homogenized to remove roots and other plant and animal debris prior to oven-drying to constant weight at 105°C. Total organic carbon was analyzed by standard method. Measurement of soil pH was done with fresh samples in the field with glass – calomel electrode (sensitivity = ± 0.01) to avoid oxidation of iron pyrites (a common constituent of mangrove soils) to sulphuric acid [32]. Soil salinity was determined in supernatant of 1:5 soil-water mixtures using a refractometer.

RESULTS

Soil organic carbon

The soil organic carbon differed significantly between stations and years considering the mean values of all four depths. We observed relatively higher values of organic carbon in the stations of anthropogenically stressed western sector (Stn. 1 to 7) compared to those in the central (Stn. 8 to 11) and eastern sectors (Stn. 12 to 14) of Indian Sundarbans that encompass mainly the reserve forest with almost no human intrusion. The mean value of soil organic carbon in the western sector (stressed zone) is 1.04%. In the central and eastern sectors (control zone) the value was 0.61%. In all the selected stations, the soil organic carbon content decreased with depth. We also observed significant seasonal variations of soil organic carbon considering the average of all stations in the present study area. The gradual increase of organic carbon (composite figure of four depths) through years in all the stations clearly reflected the efficacy of Sundarban mangrove as potential sink of carbon dioxide. In western Indian Sundarbans the rate of increase was 0.035% yr^{-1}, whereas in the stations of central and eastern sectors that were mostly within the reserve forest, the value was 0.022% yr^{-1}.

Soil pH

Soil pH decreased significantly at those sites which fringe the salt marsh grass (*Porteresia coarctata*) bed and sustain rich mangrove vegetation particularly in the reserved forest area (Stn. 8 to 14). The average soil pH in this zone (considering all depths and years) was 7.29. In western sector of Indian Sundarbans (Stn. 1 to 7) comparatively higher soil pH was observed (average pH value of all four depths considering five successive years = 7.40). We also observed a decreasing trend in soil pH with depth in all the stations. The uppermost layers were alkaline and slightly acidic soil was observed within the depth of 0.20 to 0.40 m mainly in the stations 8 to 14. Significant seasonal (premonsoon>postmonsoon> monsoon) and yearly variations of soil pH was observed in the present study area. In both the sectors a decreasing trend in soil pH was observed through time. In stations 1 to 7 the values are 7.48, 7.44, 7.40, 7.36 and 7.32 in 2011, 2012, 2013, 2014 and 2015 respectively. In stations 8 to 14 the values were 7.41, 7.35, 7.26, 7.26 and 7.22 in 2011, 2012, 2013, 2014 and 2015 respectively.

Soil salinity

The soil salinity exhibited a unique spatial trend. In western Indian Sundarbans (Stn. 1 to 7), the values were relatively lower (mean value of all depths and years = 9.76 psu). The values were higher in stations 8 to 11 adjacent to Matla River in the central sector of Indian Sundarbans (mean value of all depths and years = 13.88 psu). Interestingly, in stations 12 to 14 (the stations adjacent to Bangladesh Sundarbans), the soil salinity again decreased significantly (mean value considering all depths and years = 7.01 psu). An apparent increase in soil salinity with depth was observed in all the stations. Considering the average values of 14 selected stations, we observed significant seasonal variation ($p < 0.0001$) with highest values during premonsoon followed by postmonsoon and monsoon. It was observed that the soil salinity exhibited a decreasing trend with years in stations 1 to 7 (10.91 psu, 10.15 psu, 9.81 psu, 9.18 psu and 8.72 psu in 2011, 2012, 2013, 2014 and 2015 respectively) and stations 12 to 14 (7.72 psu, 7.38 psu, 7.08 psu, 6.64 psu and 6.19 psu in 2011, 2012, 2013, 2014 and 2015 respectively), but the values increased in stations 8 to 11 (13.35 psu, 13.55 psu, 13.65 psu, 14.27 psu and 14.50 psu in 2011, 2012, 2013, 2014 and 2015 respectively).

DISCUSSION

Soil organic carbon

The significant variation ($p < 0.0001$) of soil organic carbon between anthropogenically stressed western zone and non-disturbed central and eastern zones may be attributed to a large extent by human activities, mangrove floral richness, and physical factors like accretion and erosion. Anthropogenic activities like fish landing, tourism and unplanned urban development and shrimp farms contribute appreciable amount of organic load in stations like Kachuberia (Stn. 1) and Frazergaunge (Stn. 5). The presence of shrimp farms at Chemaguri (Stn. 6) along with 12 years old mangrove vegetation (17 species) may be attributed to highest organic carbon level in the soil core. The western Indian Sundarbans (encompassing stations 1 to 7) is under severe stress due to intense industrialization, rapid urbanization and unplanned tourism and aquaculture activities [41,26,18] which contribute appreciable organic carbon in the soil. The relatively low organic carbon at Sagar South (Stn. 3) is due to its location at sea front where wave action and tidal amplitude is maximum (range 3.0 m to 5.0 m and mean = 3.5 m). Continuous erosion of this island may be the reason behind minimum retention of organic matter in the intertidal zone. The low organic carbon at stations 8 to 14 confirms the anthropogenic origin of organic load, which is almost absent in these stations (control zone). Being located within the reserve forest area, stations 8 to 14 receive complete legal protection and hence the major source of organic carbon in this zone is primarily the mangrove detritus. The variation of organic carbon in the Indian Sundarbans is thus regulated through an intricate interaction of biological, physical and anthropogenic activities (Table 1). The decrease in soil organic carbon with increased depth ($p < 0.0001$) is in accordance with the findings of Lacerda et al (1995) [33], where the organic carbon levels under *Rhizophora mangle* soil were 2.80%, 2.70% and 2.70% in the 0.01 - 0.05 m, 0.05 - 0.10 m and 0.10 - 0.15 m depth respectively. Similar trend was also observed under *Avicennia* soil [33]. Report of decreasing mangrove soil organic carbon below 1 m is presented by Donato et al (2011) [34]. The factors governing variation of below-ground carbon storage in mangrove soils is difficult to pinpoint [35,36] as it is not a simple function of measured flux rates, but also integrates thousands of years of variable deposition, transformation, and erosion dynamics associated with fluctuating sea levels and episodic disturbances [37]. Significant seasonal variation of soil organic carbon ($p < 0.0001$) is attributable to the climatic conditions that influence the physical processes like waves, tidal amplitude and current pattern. Heavy rainfall in monsoon (80% during July to September) coupled with high tidal amplitude (4.8 to 5.2 m during spring tide and 2.1 to 2.8 m during neap tide) erode the top soil and wash away the deposited organic matter and mangrove litter to the adjacent aquatic system due to which minimum value is observed in monsoon in all the stations. The present study is significant from the point that the area has not yet witnessed the light of documentation of soil carbon content although AGMB and carbon storage have been studied by several workers [38,18,34] quantified whole-ecosystem C storage in mangroves across a broad tract of the Indo-Pacific region, the geographic core of mangrove area (40% globally) and diversity and the study sites comprised wide variation in stand composition and stature spanning 30^0 of latitude (8°S - 22°N), 73° of longitude (90° - 163°E), and including eastern Micronesia (Kosrae); western Micronesia (Yap and Palau); Sulawesi, Java, Borneo (Indonesia); and the Sundarbans (Ganges-Brahmaputra Delta, Bangladesh). The study did not cover the lower Gangetic soil sustaining 38 % of the total Sundarbans in the Indian part. The present approach is thus an attempt to fill this gap area and establish a continuous five year baseline data of soil carbon in the mangrove dominated Indian part of Sundarbans.

Soil pH

The acidity of the soil influences the chemical transformation of most nutrients and their availability to plants. Most mangrove soils are well buffered, having a pH in the range of 6 to 7, but some have a pH as low as 5 [39]. In this study soil pH is lower in the reserved forest area (Stn. 8 to 14) that sustains rich mangrove and several associate floral species. The organic acids released from these vegetations may drive the pH of soil to lower values. The spatial variation of soil pH was highly significant ($p < 0.0001$). A significant decrease in soil pH with depth at all locations ($p < 0.0001$) may indicate the production of organic acids and carbon dioxide by actively metabolizing mangrove roots. The surface soils are usually neutral to slightly acid in mangrove ecosystem due to the influence of alkaline estuary water [39] and in the present system the value ranges from 7.90 to 8.30 depending on season [28]. Soil pH in all the stations exhibited significant seasonal and yearly variations ($p < 0.0001$), which may be attributed to climatic factors that regulate the ambient aquatic pH through precipitation, run-off and biological phenomenon like mangrove litter fall and their subsequent decomposition in the soil of intertidal mudflats.

Soil salinity

Soil salinity reflects the geophysical features of the ecosystem. It is also an indicator of dilution caused by run-off, stream discharge, barrage discharge and other anthropogenic activities. The relatively low soil salinity in the stations at western sector (stations 1 to 7) is the effect of Farakka discharge that release fresh water through the main Hooghly channel. Five-year surveys (1999 to 2003) on water discharge from Farakka barrage revealed an average discharge of $(3.4 \pm 1.2) \times 10^3\ m^3s^{-1}$. Higher discharge values were observed during the monsoon with an average of $(3.2 \pm 1.2) \times 10^3\ m^3s^{-1}$, and the maximum of the order 4200 m^3s^{-1} during freshet (September). Considerably lower discharge values were recorded during premonsoon with an average of $(1.2 \pm 0.09) \times 10^3\ m^3s^{-1}$, and the minimum of the order 860m^3s^{-1} during May. During postmonsoon discharge values were moderate with an average of $(2.1 \pm 0.98) \times 10^3\ m^3s^{-1}$. The lower Gangetic deltaic lobe also receives considerable rainfall (~ 1900 mm average rainfall) and surface runoff from the 60000 km^2 catchment areas of Ganga-Bhagirathi-Hooghly system and their tributaries. All these factors (dam discharge + precipitation + runoff) cause low soil salinity in this sector. The central region (Stn. 8 to 11), on contrary, does not receive the freshwater input on account of siltation of the Bidyadhari River which may be attributed to high saline mangrove soil [18]. Interestingly stations 12, 13 and 14 exhibit low saline soil profile and also decreasing trend with time. This may the effect of proximity of these stations to Bangladesh Sundarbans that receive the maximum fresh water flow from the Himalayan glacier through the River Padma. The presence of numerous creeks and channels in the eastern most part of Indian Sundarbans may act as conveyer belt of fresh water from the Bangladesh part to the eastern Indian Sundarbans. The increase of soil salinity with depth ($p < 0.0001$) is the effect of percolation during tidal inundation of the intertidal mudflats (twice daily). The bottom layer is not washed away unlike the top soil layer by daily tidal action which results in accumulation of salts in the bottom layer. It is to be noted that increase of salinity in the stations adjacent to the Matla River (Stn. 8 to Stn. 11) may pose serious threat to certain mangrove species like *Heritiera fomes* (locally known as Sundari, from which the name Sundarbans has originated). Symptoms of excess chloride include burning and firing of leaf tips or margins, bronzing, premature yellowing, abscission of leaves and, less frequently chlorosis. Smaller leaves and slower growth also are typical. Symptoms of excess sodium also include necrotic areas on the tips, margins, or inter-veinal areas. Already reports of stunted mangrove growth are available from the central Indian Sundarbans due to high salinity and its increasing trend over time [40,18]. This may have far reaching impact on the aquatic sub-system of central Indian Sundarbans as mangrove litter and detritus, which are the primary source of soil organic carbon may reduce in quantum. This may eventually lead to poor productivity of the adjacent water bodies. Therefore, efforts should be made to develop better understanding of the problem so that appropriate management strategy could be adopted for improved and sustainable management of the central sector of Indian Sundarbans with particular reference to siltation problem that has cut off the fresh water supply in the region.

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