

Present status of soil nutrient and tree stands density of Sundarbans mangrove forest of Bangladesh

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ABSTRACT: The study was conducted in Khulna and Satkhira ranges of western Forest Division to determine the present nutrient status in soils and tree stand density of Sundarbans mangrove forest of Bangladesh during February to May 2016. Sampling was carried out at 46 sites from two locations viz. 23 sampling sites were from Khulna forest range and 23 sites from Satkhira range. The soil samples were collected at two depths viz. surface (0 to 15 cm) and sub-surface (15 to 30 cm) layers of soil. Tree-related data like name of the species, a number of trees/plots were recorded for all the natural trees having a diameter at breast height (dbh) ≥ 10 cm to calculate the stand density in the study area marked 10 m \times 10 m quadrat sample plots randomly. The collected soil samples were analyzed in a laboratory to determine the nutrient status. The result revealed that the soils of Sundarbans mangrove forest in Bangladesh were neutral to saline and the pH values (7.6) of surface soils were higher compared to sub-surface soils. The results also indicate that organic matter, total N, available P, Ca, Mg, S, Fe, B and Zn were observed comparatively higher (1.65%, 0.09%, 19.26 ppm, 9.11 meq/ml, 2.92 meq/ml, 169.59 ppm, 22.72 μ g/ml, 0.66 μ g/ml and 4.22 μ g/ml, respectively) in surface soils except for exchangeable K which was higher (1.55 meq/100g) in sub-surface soils. However, the tree stands density in Sundarbans mangrove forest was recorded as 525 trees/ha and 569 trees/ha in Khulna and Satkhira forest ranges, respectively. Therefore, the information of this study would be helped to the researcher and policymaker for better understanding and management of Sundarbans.

Keywords: Mangrove forest, surface and sub-surface soils, soil nutrient status, tree stand density.

INTRODUCTION

Bangladesh is a South Asian developing country with an area of 147,57, 000ha. However, the agricultural land covers about 65%, forest lands account for almost 17% and 18% for others from the total area of Bangladesh. But practically, Bangladesh has only 9.5% of forest coverage though it requires at least 25% for ecological balance (BFD, 2017). The Sundarbans is the largest tidal halophytic mangrove forest in the world which covers 23.8% of the total forest area of Bangladesh (BFD, 2017). The Sundarbans is very rich in biodiversity supports versatile interactions and correlations and relationships among its vertebrates and invertebrates, flora, fauna, aquatic organisms, marine lives, wildlife, fishes, birds, natural habitats (Awal, 2007). Sundari (*Heritiera fomes*) is the main tree species which covers about 60% of the total area (BFD, 2017). The Sundarbans is one of the valuable

natural assets of Bangladesh which provides economic, social and ecological benefits. But presently, this forest is losing its soil fertility and biodiversity day by day for both natural and man-made reasons like illegal cutting, shrimp culture and climate change as well as environmental pollution, all of which have a great impact on the forest ecosystem. For the sustainability of existing forest coverage, increasing soil nutrient content and maintenance of the site, it is utmost necessary to maintain the stand density of the forest. Within a forest stand, nutrients exist in many forms and distinct pools and are cycled between soils and plants. The most important nutrients in forests are the macronutrients which are needed directly for plant growth. Micronutrients are also required by plants, but are usually abundant in soils and rarely limit plant growth (Binkley, 1986). Plants uptake

nutrients from the soil solution and incorporate them into biomass, which is then returned to the soil through litter fall, root turnover, and tree mortality. This biomass or organic matter is then decomposed by soil organisms such as bacteria and fungi that excrete enzymes to break down organic molecules into smaller units, liberating nutrients and making them available to plants again (Chapin et al., 2002). So, forest soils influence the composition of the forest stand and ground cover, rate of tree growth, vigor of natural reproduction and other silviculturally important factors. Several studies on the physical and chemical status of mangrove and coastal soils have been investigated throughout the world and Indian sub-continent by various researchers (Ramamurthy et al., 2012; Arianto et al., 2015; Barik et al., 2018). But in Bangladesh, only a few worked were conducted on Sundarbans forest soils which are not sufficient (Muhibullah et al., 2005; Rashid et al., 2007; Hossain et al., 2012; Hossain and Bhuiyan, 2015). Therefore, the study was undertaken to analyze the present status of soil nutrient and account of tree stand density of Sundarbans mangrove forest of Bangladesh. For answering the preceding objective, the study set forth a hypothesis tested with data gathered on the present status of soil nutrient and tree stand density of Sundarbans mangrove forest was unknown.

MATERIALS AND METHODS

Study area

The study was conducted from February to May 2016 at Sundarbans mangrove forest which is located at the southwest part of Bangladesh (Figure 1). The Sundarbans mangrove forest is situated between 21°30' and 22°30' North latitude and 89° and 90° East longitudes. This forest consists of four different ranges viz. Sarankhola, Chandpai, Khulna and Satkhira. Among the four ranges, Khulna and Satkhira were selected for the study area (Figure 1). The climatic condition of the study areas: the average annual maximum temperature is around 35°C. Average annual rainfall is 1920 mm. The average relative humidity is about 82% and more or less uniform throughout the year (Sadiqul Amin, 2016). The soil of this forest is in general medium textured, sandy loam, silt loam or clay loam. Silt loam is dominant textural class. Organic matter content varies between 4% and 10% in dry soil (Banglapedia, 2012). The soil is saline in nature and it remains wet due to inundation of low-lying areas in two times of every day (Banglapedia, 2012). In this forest, Sundari (*Heritiera fomes*) is the dominant tree species which is distributed over 60% of the reserve. Besides, other species like Gewa (*Excoecaria agallocha*), Keora (*Sonneratia apetala*), Baen (*Avicennia officinalis*), Pasur (*Xylocarpus mekongensis*), Hental (*Phoenix pelludosa*), Golpata (*Nypa fruticans*), Kankra (*Bruguiera gymnorhiza*), Goran (*Ceriops decandra*), Jhana (*Rhizophora mucronata*) etc. are also found (BFD, 2017).

Sampling design and plot measurement

The total 46 sampling sites were selected from the study area where the 23 sites were in Khulna range like S₁ to S₂₃ and 23 sites were in Satkhira range like S₂₄ to S₄₆ (Figure 1 and Table 1). The 10 m×10 m quadrat plot was measured randomly from each sampling site for necessary sample collection and data recording.

Soil sample collection and preparation

Total of 92 soil samples was collected at two depths of soils of 0 to 15 cm (surface) and 15 to 30 cm (sub-surface) from the study sites. From each quadrat plot, five soil cores were taken and mixed to make a composite sample. Then the soil samples were air dried, processed and sieved through 20 mesh sieve and packed with a specific tag for laboratory analysis.

Collection of tree-related data

Tree-related data were recorded from the same plot (10 m×10 m) in the time of soil sampling. Tree species were identified in the spot through visual observation. From each quadrat plot, a number of trees species/plot was recorded which having the diameter at breast height (dbh) ≥10 cm for calculating the trees stands density. Stand density was determined for each species using the estimated number of trees and basal areas of the species per hectare. The estimated number of trees of each species per hectare was obtained by extrapolating the total number of trees enumerated in the respective plots using the formula (Etigale et al., 2013):

$$N = h/a \times c$$

Where: h = one hectare, a = area of the plot in a hectare, c = number of trees counted in the plot and N = estimated number of trees per hectare.

The basal area of each tree was calculated with the basal area function as stated by Avery and Burkhart (2002). The formula is:

$$BA = \frac{\pi D^2}{4(100)}$$

Where: BA = Basal Area (m²), π = Constant (3.142) and D = Diameter at breast height (cm).

Total basal area of each species was obtained by calculating together the basal areas of the individuals of the species. Basal area of each species per hectare was anticipated by extrapolating the total basal area of the species using the formula:

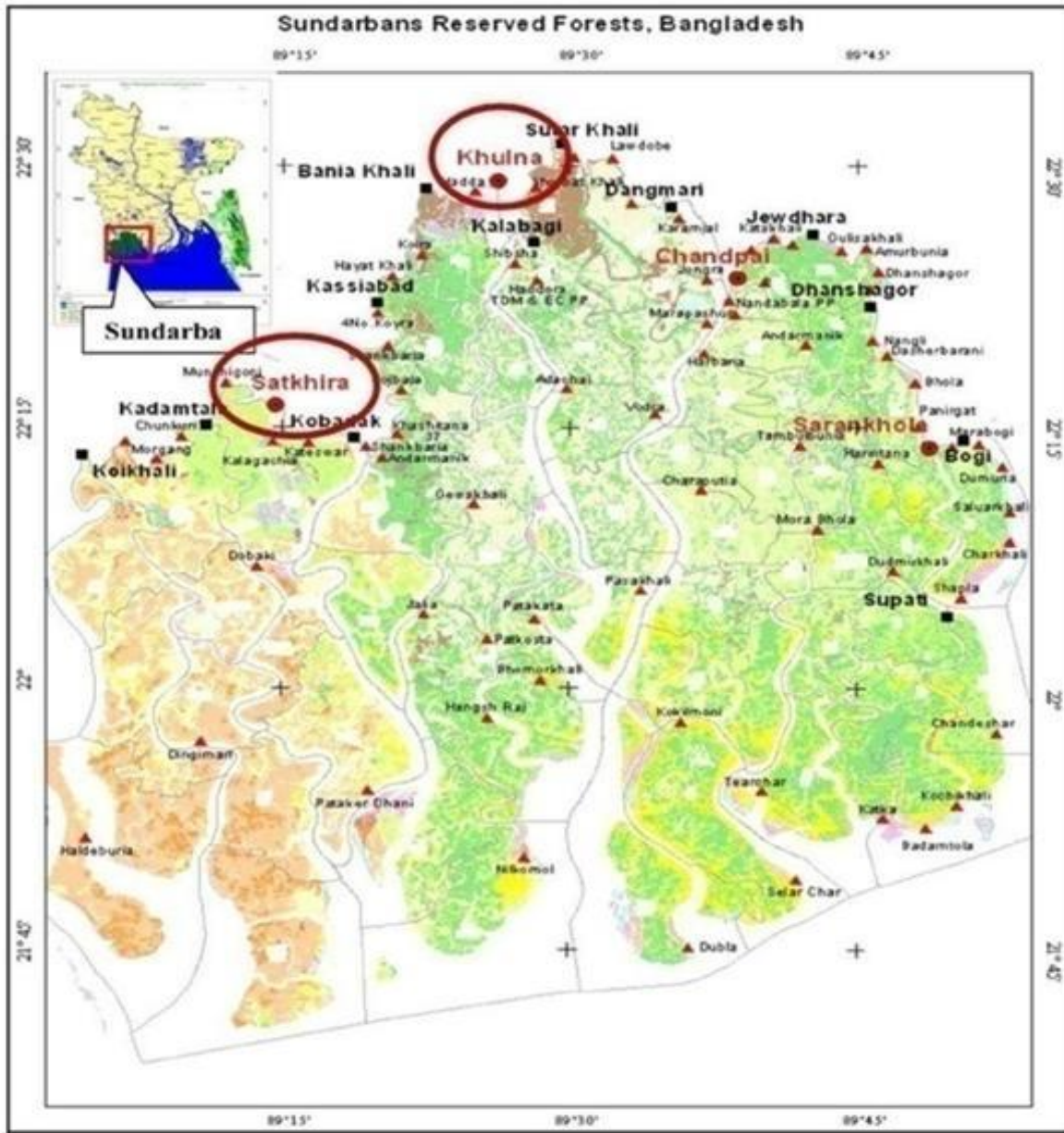


Figure 1. Showing the specific study sites at the location map of the Sundarbans mangrove forest in Bangladesh (Source: Forest Department, Bangladesh).

$$BA = h/a \times d$$

Where: BA = basal area per hectare, h = one hectare, a = area of the plot in a hectare and d = basal area in each plot.

Soil sample analysis

The prepared soil samples were analyzed in Humboldt Soil Testing Laboratory, Soil Science Department, Bangladesh Agricultural University, Mymensingh and Soil Science Division, Bangladesh Agricultural Research Institute,

Joydebpur, Gazipur. Soil pH was measured by using Glass-electrode pH meter (WTW pH 522) at a soil-water ratio of 1:2. Organic carbon was determined by the wet oxidation method of Walkley and Black (1934). Total nitrogen was determined by the micro-Kjeldahl method (Jackson, 1958). Available P was extracted by the Molybdenum blue method of Bray and Kurtz using a spectrophotometer (Jackson, 1958). Exchangeable K was determined by 1N NH₄OAc extract method using flame photometer (Page et al., 1989). Available Ca and Mg was extracted with 1N NH₄OAc using an atomic absorption spectrophotometer method (Peterson, 2002). Sulfur (S)

Table 1. Description of the study sites

Forest Ranges	Sites No.	Name of the sites	Tree species
Khulna	S ₁	Shibsa river site	Sundori, Bain
	S ₂	Shibsa khal	Keora, Bain
	S ₃	Hodda forest station	Sundori, Poshur, Kankra
	S ₄	The midpoint of Hodda and Kali khal	Gewa
	S ₅	Kali khal	Poshur, Kankra
	S ₆	Bharani khal	Sundori
	S ₇	Jhora khal	Gewa
	S ₈	Phultola khal east	Khulshi, Gewa
	S ₉	Phultola khal west	Kankra, Bain, Poshur
	S ₁₀	Joymuri khal	Bain, Kankra
	S ₁₁	Boumara khal	Sundori, Bain, Kankra
	S ₁₂	Kaintabari khal	Khulshi, Sundori
	S ₁₃	Torudhunja khal	Kankra, Poshur
	S ₁₄	Baniakhali khal	Bain, Gewa, Kankra
	S ₁₅	Gabbunia	Khulshi, Jhana
	S ₁₆	Boropata khali	Sundori, Kankra
	S ₁₇	Chotopata khali	Bain, Kankra
	S ₁₈	Ghoramir khal	Gewa
	S ₁₉	Horipur	Goran, Bain
	S ₂₀	Choto Hossain khali	Bain
	S ₂₁	Boro Hossain Khali	Keora, Bain
	S ₂₂	Tong Ghor khal	Sundori, Bain
	S ₂₃	Boj Boja Forest Station	Keora, Gewa, Jhana
Sathkhira	S ₂₄	Munshigonj forest station	Keora, Jhana
	S ₂₅	Choto Kewakhali khal North	Bain, Goran, Poshur
	S ₂₆	Choto Kewakhali khal	Bain, Goran
	S ₂₇	Boro Kewakhali khal	Kankra, Bain, Goran
	S ₂₈	Kolagachi East	Dhundol
	S ₂₉	Kolagachi North-1	Khulshi
	S ₃₀	Kolagachi North-2	Keora
	S ₃₁	Kolagachi Forest Tohofai	Poshur
	S ₃₂	Kolagachi Forest Tohofai	Poshur, Keora
	S ₃₃	Kolagachi Forest Tohofai	Kankra
	S ₃₄	Kolagachi Forest Tohofai	Khulshi
	S ₃₅	Kolagachi South-1	Jhana, Khulshi
	S ₃₆	Kolagachi South-2	Khulshi
	S ₃₇	Kolagachi West-1	Sundori
	S ₃₈	Kolagachi West-2	Keora
	S ₃₉	Kolagachi North	Sundori
	S ₄₀	Dobaki	Bain, Jhana
	S ₄₁	Kadamtala	Bain, Goran, Poshur
	S ₄₂	Chunkuri-1	Sundori, Bain
	S ₄₃	Chunkuri-2	Keora, Jhana
	S ₄₄	Moragang-1	Khulshi, Jhana
	S ₄₅	Moragang-2	Bain, Goran, Poshur
	S ₄₆	Koikhali	Poshur, Khulshi

was determined by a turbidimetric method using a spectrophotometer (Page et al., 1989). Available Fe and

Zn were determined by a diethylenetriaminepentaacetic acid (DTPA) extraction method using an Atomic

Absorption Spectrophotometer (AAS) (Peterson, 2002). Boron (B) was determined by spectrophotometer technique using a colorimetric reaction with Azomethine-H (Ogner, 1980).

Statistical analysis

The collected data were tabulated and analyzed through a standard computer package statistical procedure MSTAT-C, MS Excel and SPSS software (Gomez and Gomez, 1984). Mean values of soil parameters were computed and employed to compare the results with the relevant findings. A critical limit for interpreting levels of soil nutrient parameters was adopted from Fertilizer Recommendation Guide (2012).

RESULTS AND DISCUSSION

Soil pH

The pH values of the soil samples collected from Khulna and Satkhira ranges of Sundarbans mangrove forest of Bangladesh are presented in Table 2. The pH values in the surface and sub-surface soils across the different sites of Khulna range varied from 7.22 to 7.92 and 7.10 to 7.82, respectively. Similarly, the pH values in the surface and sub-surface soils across the sites of Satkhira range varied from 7.30 to 7.96 and 7.18 to 7.86, respectively (Table 2). The average of Khulna and Satkhira ranges soils pH values are presented in Table 6. The average pH value (7.64) of the surface soils was found higher than the sub-surface soils (7.56) of Sundarbans mangrove forest (Table 6). The results indicated that the soils of the mangrove forest of Sundarbans were neutral to saline in nature and soil salinity might have developed due to the inundation of saline sea water into the forest. Joshi and Ghose (2014), Rao and Rao (2014), Maniruzzarnan et al. (2009) and Muhibbullah et al. (2005) found that the soils of Sundarbans was heavy and slightly saline to saline with high salinity variation where pH ranged from 7.1 to 8.79 which is very much closed to the result of present findings.

Organic matter

The results of organic matter revealed that the surface and sub-surface soils of Khulna forest range across the sites varied from 1.15 to 1.97% and 1.12 to 1.84%, respectively while the organic matter content of Satkhira forest range across the sites varied from 1.58 to 2.04% and 1.18 to 1.84%, respectively (Table 2). The result also revealed that the average content (1.65%) of organic matter of surface soils was observed higher than the sub-surface soils (1.45) of Sundarbans mangrove forest (Table 6). From the result, it can be explained that organic matter content of soils of Sundarbans mangrove forest

was low to medium and this might be due to the removal of leaf litter from the forest floor during inundation. Hossain and Bhuiyan (2015), Hossain et al. (2012) and Maniruzzarnan et al. (2009) found a similar result which is closed to the present study.

Status of soil macronutrients

Primary nutrients (N, P, K)

The results of the total N content of soils at two depths viz. 0 to 15 cm and 15 to 30 cm of Khulna range across the sites varied from 0.06 to 0.20% and 0.05 to 0.11%, respectively (Table 3). Similarly, the values of total N of soils of Satkhira range across the sites varied from 0.07 to 0.22% at 0 to 15 cm depth and 0.05 to 0.10% at 15 to 30 cm depth (Table 3). From the results, it was observed that the values of available P varied from 16.5 to 28.07 ppm at 0 to 15 cm depth and 14.8 to 22.63 ppm at 15 to 30 cm soil depth at Khulna range (Table 3). While in Satkhira range, the available P content in soils varied from 13.61 to 24.50 ppm at 0 to 15 cm depth and 15.65 to 21.94 ppm at a 15 to 30 cm soil depth. Comparing to the Fertilizer Recommendation Guide (2012) of Bangladesh, the available P content of the present study was high to very high at both Khulna and Satkhira ranges of Sundarbans mangrove forest (Table 3). It was also observed from the results that the average values of total N (0.09%) and available P (19.26 ppm) were higher in surface soils compared to sub-surface soils of Sundarbans mangrove forest (Table 6). The values of exchangeable K of surface and sub-surface soils of Khulna range varied from 0.57 to 1.60 meq/100g and 0.82 to 1.71 meq/100g, respectively. While the exchangeable K content at both depths (0 to 15 cm and 15 to 30 cm) of Satkhira range was ranged between 1.19 to 2.02 meq/100g and 1.3 to 2.12 meq/100g, respectively (Table 3). It was observed that the average value of exchangeable K was comparatively higher in Satkhira forest range than that of in Khulna forest range at both soil layers (Table 3). The results also showed that the average (mean of two locations) exchangeable K value of mangrove forest of Sundarbans was higher in sub-surface soil (1.55 meq/100g) and lower (1.33 meq/100g) in surface soil (Table 6). This higher content of K in sub-surface soil might be due to alleviation process (Sadiqui Amin, 2016). Muhibbullah et al. (2005), Ramamurthy et al. (2012), Hossain et al. (2012) and Hossain and Bhuiyan (2015) conducted studies on the nutrient status of Sundarbans mangrove forest soil and they found similar results which were supported to the present findings.

Secondary nutrients (Ca, Mg, S)

The results of Table 4 showed that the amount of available Ca in surface and sub-surface soils of Khulna

Table 2. The status of pH and OM in surface and sub-surface soils of Khulna and Satkhira ranges of the Sundarbans mangrove forest of Bangladesh.

Sites No.	Khulna Range				Sites No.	Satkhira Range			
	pH		OM (%)			pH		OM (%)	
	SS	SSS	SS	SSS		SS	SSS	SS	SSS
S ₁	7.64	7.46	1.71	1.51	S ₂₄	7.48	7.66	1.58	1.31
S ₂	7.79	7.62	1.56	1.58	S ₂₅	7.72	7.72	1.31	1.51
S ₃	7.49	7.1	1.84	1.84	S ₂₆	7.8	7.42	1.38	1.31
S ₄	7.47	7.54	1.51	1.31	S ₂₇	7.75	7.64	1.84	1.25
S ₅	7.64	7.34	1.25	1.25	S ₂₈	7.81	7.52	2.04	1.58
S ₆	7.49	7.49	1.31	1.31	S ₂₉	7.48	7.49	1.91	1.38
S ₇	7.49	7.39	1.38	1.31	S ₃₀	7.72	7.59	1.38	1.38
S ₈	7.59	7.65	1.25	1.25	S ₃₁	7.78	7.55	1.58	1.18
S ₉	7.44	7.5	1.97	1.25	S ₃₂	7.78	7.84	1.51	1.71
S ₁₀	7.43	7.82	1.38	1.58	S ₃₃	7.84	7.84	2.04	1.84
S ₁₁	7.56	7.46	1.38	1.51	S ₃₄	7.71	7.48	1.58	1.51
S ₁₂	7.47	7.48	1.97	1.31	S ₃₅	7.67	7.46	1.97	1.31
S ₁₃	7.52	7.7	1.25	1.31	S ₃₆	7.55	7.75	1.84	1.43
S ₁₄	7.63	7.58	1.84	1.31	S ₃₇	7.67	7.66	1.51	1.51
S ₁₅	7.22	7.42	1.91	1.12	S ₃₈	7.3	7.52	1.58	1.38
S ₁₆	7.46	7.56	1.58	1.31	S ₃₉	7.74	7.56	1.58	1.51
S ₁₇	7.36	7.48	1.97	1.12	S ₄₀	7.76	7.68	1.68	1.42
S ₁₈	7.89	7.75	1.38	1.51	S ₄₁	7.73	7.85	1.58	1.56
S ₁₉	7.52	7.34	1.91	1.84	S ₄₂	7.69	7.67	1.68	1.59
S ₂₀	7.58	7.44	1.15	1.12	S ₄₃	7.59	7.74	1.71	1.6
S ₂₁	7.92	7.24	1.91	1.18	S ₄₄	7.96	7.64	1.97	1.78
S ₂₂	7.86	7.18	1.84	1.67	S ₄₅	7.76	7.18	1.83	1.67
S ₂₃	7.63	7.62	1.86	1.43	S ₄₆	7.82	7.76	1.76	1.78
	7.22	7.10	1.15	1.12		7.30	7.18	1.58	1.18
Range	to	to	to	to	Range	to	to	to	to
	7.92	7.82	1.97	1.84		7.96	7.86	2.04	1.84
Mean	7.57	7.49	1.61	1.39	Mean	7.70	7.62	1.69	1.50
Sd	0.17	0.175	0.29	0.21	Sd	0.14	0.157	0.21	0.18
CV%	2.2	2.3	17.8	15.1	CV%	1.8	2.1	12.6	11.9

S = Soil sample sites, SS = Surface soil (0-15cm), SSS = Subsurface soil (15-30cm).

range of Sundarbans mangrove forest varied from 6.1 to 16.9 meq/100ml and 5 to 14 meq/100ml, respectively. Accordingly, in Satkhira range the amount of available Ca in surface and sub-surface soils varied from 2.4 to 9.8 meq/100ml and 2.3 to 8.9 meq/100ml, respectively (Table 4). In the case of available Mg, the amount ranged from 2.0 to 4.9 meq/100ml at 0 to 15 cm soil depth and 1.7 to 4.3 meq/100ml at a 15 to 30 cm soil depth of Khulna range (Table 4). While in Satkhira range the amount of available Mg ranged from 0.9 to 3.2 meq/100ml at 0 to 15 cm soil depth and 0.84 to 3.0 meq/100ml at 15 to 30 cm soil depth (Table 4). The result also showed that the amount of available S in surface and sub-surface soils of Sundarbans mangrove forest varied from 100.88 to 232.65 ppm and 84.41 to 208.53 ppm, respectively in the Khulna range (Table 4).

On the other hand, the values of available S in surface and sub-surface soils of Satkhira range varied from 114.12 to 233.23 ppm and 76.18 to 230 ppm, respectively (Table 4). From Table 6 it was observed that the average values of available Ca, Mg and S were higher in surface soils than sub-surface soils of Sundarbans mangrove forest. Maniruzzarnan et al. (2009) and Ramamurthy et al. (2012) also found high Ca and Mg content in soils of Sundarbans mangrove forest which was very supportive of the present study. Maniruzzarnan et al. (2009) found that the available S content in surface and sub-surface soils of mangrove forest of Bangladesh varied between 152.43 to 335.35 mg kg⁻¹ and 101.62 to 223.57 mg kg⁻¹ with their mean values of 225.51 and 162.05 mg kg⁻¹, respectively which is in agreement with the present study result.

Table 3. The status of primary macronutrients (N, P, K) in surface and sub-surface soils of Khulna and Satkhira ranges of the Sundarbans mangrove forest of Bangladesh.

Sites No.	Khulna Range						Sites No.	Satkhira Range					
	N (%)		P (ppm)		K (meq/100g)			N (%)		P (ppm)		K (meq/100g)	
	SS	SSS	SS	SS	SS	SSS		SS	SSS	SS	SSS	SS	SSS
S ₁	0.08	0.07	18.03	18.03	0.62	1.19	S ₂₄	0.08	0.07	14.80	19.39	1.29	1.45
S ₂	0.08	0.08	20.41	20.58	0.72	1.24	S ₂₅	0.07	0.08	16.16	21.94	1.24	1.91
S ₃	0.09	0.09	20.24	21.26	0.82	1.45	S ₂₆	0.07	0.06	13.61	15.65	1.19	1.35
S ₄	0.07	0.06	18.37	20.75	0.67	0.93	S ₂₇	0.09	0.06	18.03	16.50	1.40	1.30
S ₅	0.20	0.06	17.18	15.31	0.82	0.82	S ₂₈	0.11	0.07	21.26	20.50	1.76	1.55
S ₆	0.07	0.07	17.35	19.56	0.57	0.88	S ₂₉	0.10	0.07	15.82	17.63	1.55	1.55
S ₇	0.07	0.07	17.35	17.69	0.78	1.03	S ₃₀	0.07	0.07	17.35	20.75	1.91	1.50
S ₈	0.06	0.07	21.26	18.35	1.03	1.19	S ₃₁	0.07	0.05	14.12	17.69	1.24	1.50
S ₉	0.07	0.06	20.24	17.69	1.03	1.14	S ₃₂	0.08	0.08	17.18	17.63	1.55	1.97
S ₁₀	0.07	0.08	19.73	19.46	1.19	1.55	S ₃₃	0.08	0.10	17.69	18.54	1.71	1.86
S ₁₁	0.07	0.08	23.99	22.63	1.24	1.29	S ₃₄	0.11	0.08	17.52	17.63	1.66	2.02
S ₁₂	0.07	0.06	19.05	21.94	1.29	1.19	S ₃₅	0.08	0.06	20.75	18.37	1.40	1.76
S ₁₃	0.06	0.07	19.05	18.31	1.00	1.35	S ₃₆	0.11	0.07	24.50	19.49	2.02	2.12
S ₁₄	0.10	0.06	21.09	22.29	1.29	1.71	S ₃₇	0.09	0.07	21.94	18.37	1.81	1.71
S ₁₅	0.10	0.05	28.07	15.31	1.19	1.45	S ₃₈	0.22	0.07	18.37	18.54	1.24	1.71
S ₁₆	0.08	0.06	21.09	20.07	1.45	1.60	S ₃₉	0.08	0.08	23.31	20.65	1.55	1.76
S ₁₇	0.07	0.05	17.35	14.80	1.35	1.60	S ₄₀	0.08	0.06	16.79	17.64	1.71	1.86
S ₁₈	0.07	0.07	21.35	20.07	1.45	1.66	S ₄₁	0.07	0.08	18.72	19.63	1.66	2.02
S ₁₉	0.10	0.10	21.09	20.01	1.09	1.50	S ₄₂	0.09	0.06	21.65	19.47	1.48	1.86
S ₂₀	0.07	0.05	19.02	20.75	1.29	1.45	S ₄₃	0.09	0.05	22.50	19.69	2.01	1.98
S ₂₁	0.09	0.05	17.86	17.66	0.98	1.66	S ₄₄	0.08	0.06	20.94	19.47	1.87	1.79
S ₂₂	0.10	0.11	16.50	18.54	1.60	1.66	S ₄₅	0.11	0.07	20.27	19.44	1.38	1.78
S ₂₃	0.08	0.06	17.76	17.65	1.45	1.47	S ₄₆	0.07	0.06	19.31	18.85	1.57	1.87
	0.06	0.05	16.5	14.8	0.57	0.82		0.07	0.05	13.61	15.65	1.19	1.30
Range	to	to	to	to	to	to	Range	to	to	to	to	to	to
	0.20	0.11	28.07	22.63	1.60	1.71		0.22	0.10	24.50	21.94	2.02	2.12
Mean	0.08	0.07	19.71	19.07	1.08	1.35	Mean	0.09	0.069	18.81	18.85	1.57	1.75
Sd	0.03	0.016	2.58	2.17	0.30	0.27	Sd	0.03	0.011	2.97	1.45	0.25	0.23
CV%	34.0	22.9	13.1	11.4	27.5	19.8	CV%	34.4	16.6	15.8	7.7	16.0	12.9

S = Soil sample sites, SS = Surface soil (0-15cm), SSS = Subsurface soil (15-30cm).

Status of soil micronutrients (Fe, B, Zn)

The result showed that the available Fe content of surface and sub-surface soils ranged from 17 to 27 µg/ml and 14 to 22 µg/ml and the calculated mean values were 22.65 and 19.04 µg/ml, respectively in Khulna range of Sundarbans mangrove forest of Bangladesh (Table 5). While the available Fe content of surface and sub-surface soils ranged from 14 to 31 µg/ml and 13 to 25 µg/ml, respectively in Satkhira range. However, the calculated mean values of available Fe were 22.78 and 19.70 µg/ml, respectively in Satkhira range of Sundarbans mangrove forest (Table 5). In the case of available B content, the values in surface and sub-surface soils ranged from 0.10 to 0.76 µg/ml and 0.32

to 0.70 µg/ml, respectively in Khulna range. The calculated mean value of available B was noted as 0.63 µg/ml in surface and 0.59 µg/ml in sub-surface soils of Khulna range in Sundarbans mangrove forest (Table 5). Similarly, In Satkhira range the available B content of surface and sub-surface soils varied from 0.54 to 0.75 µg/ml and 0.46 to 0.70 µg/ml and the calculated mean values were 0.69 and 0.64 µg/ml, respectively (Table 5). The surface and sub-surface soils in Khulna range of the mangrove forest of Sundarbans contained the available Zn ranged from 3.0 to 9.16 µg/ml and 2.64 to 7.88 µg/ml, respectively. The calculated mean value of available Zn was 5.77 µg/ml in surface soil and 4.95 µg/ml in sub-surface soil in Khulna range. Accordingly, the available Zn content of surface and sub-surface soils ranged from

Table 4. The status of secondary macronutrients (Ca, Mg, S) in surface and sub-surface soils of Khulna and Satkhira ranges of the Sundarbans mangrove forest of Bangladesh.

Sites No.	Khulna Range						Sites No.	Satkhira Range					
	Ca (meq/100ml)		Mg (meq/100ml)		S (ppm)			Ca (meq/100ml)		Mg (meq/100ml)		S (ppm)	
	SS	SSS	SS	SSS	SS	SSS		SS	SSS	SS	SSS	SS	SSS
S ₁	16.5	12.4	4.8	4.0	177.65	174.71	S ₂₄	4.0	3.8	1.4	1.3	126.76	122.06
S ₂	13.1	11.3	4.1	4.0	165.59	84.41	S ₂₅	3.2	3.0	1.2	1.1	136.76	160.29
S ₃	13.5	11.2	4.1	3.9	126.18	156.76	S ₂₆	5.5	5.1	1.8	1.7	169.12	76.18
S ₄	16.9	14.0	4.8	4.2	232.65	119.12	S ₂₇	4.3	4.0	1.5	1.4	233.23	90.29
S ₅	14.5	13.0	4.3	4.2	167.65	186.47	S ₂₈	6.9	6.2	2.4	2.1	120.29	89.12
S ₆	14.1	11.6	4.3	4.0	151.76	140.59	S ₂₉	3.5	3.4	1.2	1.2	202.94	208.53
S ₇	15.1	13.6	4.6	4.3	146.76	161.47	S ₃₀	7.1	6.6	2.4	2.3	115.29	130.59
S ₈	16.9	13.3	4.9	4.3	147.35	125.00	S ₃₁	5.8	5.2	2.0	1.8	114.12	172.06
S ₉	15.2	12.3	4.7	4.1	232.42	165.00	S ₃₂	4.5	4.0	1.6	1.4	133.23	195.71
S ₁₀	14.6	12.1	4.3	4.1	150.59	208.53	S ₃₃	4.0	3.8	1.3	1.3	212.06	155.00
S ₁₁	15.0	12.6	4.5	4.1	179.41	160.00	S ₃₄	2.4	2.3	0.9	0.8	148.82	178.23
S ₁₂	14.9	11.1	4.4	4.0	216.18	168.23	S ₃₅	5.0	5.1	1.7	1.7	133.23	230.00
S ₁₃	13.4	11.1	4.1	3.5	216.18	180.00	S ₃₆	4.4	4.2	1.5	1.4	230.88	208.53
S ₁₄	13.8	11.1	4.3	4.0	169.12	177.65	S ₃₇	9.8	8.9	3.2	3.0	201.76	173.82
S ₁₅	6.1	5.0	2.0	1.7	100.88	126.47	S ₃₈	4.6	4.3	1.6	1.4	127.03	186.76
S ₁₆	6.7	6.1	2.3	2.1	118.82	171.47	S ₃₉	6.4	6.1	2.2	2.0	208.53	194.71
S ₁₇	9.6	8.5	3.1	3.0	180.29	137.35	S ₄₀	4.2	3.9	1.4	1.5	202.66	165.80
S ₁₈	13.4	11.1	4.1	3.5	204.41	130.69	S ₄₁	3.4	3.3	1.9	1.8	168.82	178.23
S ₁₉	10.9	9.8	3.4	3.1	125.00	166.76	S ₄₂	5.2	5.6	1.6	1.9	123.23	203.70
S ₂₀	11.1	10.4	3.3	3.2	201.47	159.12	S ₄₃	4.9	3.2	1.7	1.6	223.98	205.53
S ₂₁	13.1	12.3	4.1	4.0	170.59	108.82	S ₄₄	8.8	6.8	3.1	2.9	199.76	185.82
S ₂₂	9.6	9.0	3.5	3.1	156.47	132.35	S ₄₅	4.7	4.5	1.8	1.6	137.03	196.76
S ₂₃	11.5	9.8	4.1	4.3	185.65	138.76	S ₄₆	6.8	6.6	2.6	1.9	208.53	198.71
Range	6.10	5.0	2.0	1.7	100.88	84.41	Range	2.4	2.3	0.9	0.8	114.12	76.18
	to	to	to	to	to	to		to	to	to	to	to	to
	16.9	14.0	4.9	4.3	232.65	208.53		9.8	8.9	3.2	3.0	233.23	230
Mean	13.02	10.99	4.00	3.68	170.57	151.29	Mean	5.19	4.78	1.83	1.70	168.61	169.84
Sd	2.92	2.22	0.76	0.70	35.72	28.48	Sd	1.78	1.55	0.59	0.52	42.21	41.75
CV%	22.4	20.2	18.9	19.0	20.9	18.8	CV%	34.3	32.5	32.2	30.7	25.0	24.6

S = Soil sample sites, SS = Surface soil (0-15cm), SSS = Subsurface soil (15-30cm).

1.01 to 9.23 µg/ml and 1.1 to 8.51 µg/ml and the calculated mean values were 2.67 and 2.29 µg/ml, respectively in Satkhira range of Sundarbans mangrove forest (Table 5). From the results of Table 6, it was observed that the average values (mean of two locations) of available Fe, B, and Zn were comparatively higher in surface soils than sub-surface soils of Sundarbans mangrove forest. Maniruzzaman et al. (2009), Ramamurthy et al. (2012), Rao and Rao (2014) and Hasan et al. (2016) conducted various studies on Sundarbans soils and found similar results in case of available Fe, B, and Zn which was very much supportive to present findings.

Tree stands density of the study area

The result of Table 7 revealed that in the selected sites

of Khulna range, a total of 84 trees were found in all (10 m×10 m) quadrat samples with an average number of 5 trees/plot and an average stand density 525 (trees/ha) (Table 7). Accordingly, the selected sites of Satkhira range, a total of 91 trees were recorded with an average number of 6 trees/plot and an average stand density 569 (trees/ha) (Table 7). Joshi and Ghose (2014) conducted a study on community structure, species diversity, and above ground biomass of the Sundarbans mangrove swamps and found that the density of trees with dbh ≥10 cm to be 556 trees/ha and 498 trees/ha in Coastal *Avicennia alba* community and Tidal *Avicennia marina* community, respectively which was closed to the present study result. Hossain et al. (2013), Mamun et al. (2015) and Hossain et al. (2015) also found a very close result for the different forest of Bangladesh which was supportive to the present study.

Table 5. The status of micronutrients (Fe, B and Zn) in surface and sub-surface soils of Khulna and Satkhira ranges of the Sundarbans mangrove forest of Bangladesh.

Sites No.	Khulna Range						Sites No.	Satkhira Range					
	Fe (µg/ml)		B (µg/ml)		Zn (µg/ml)			Fe (µg/ml)		B (µg/ml)		Zn (µg/ml)	
	SS	SSS	SS	SSS	SS	SSS		SS	SSS	SS	SSS	SS	SSS
S ₁	23.0	19.0	0.58	0.54	6.72	5.29	S ₂₄	19.0	20.0	0.54	0.52	1.17	1.22
S ₂	25.0	21.0	0.64	0.60	8.55	7.23	S ₂₅	15.0	15.0	0.58	0.48	1.13	1.15
S ₃	25.0	20.0	0.72	0.66	3.00	2.64	S ₂₆	15.0	13.0	0.68	0.62	2.06	1.80
S ₄	21.0	18.0	0.62	0.60	9.16	7.88	S ₂₇	14.0	15.0	0.62	0.60	1.01	1.10
S ₅	24.0	20.0	0.48	0.42	8.42	7.14	S ₂₈	26.0	21.0	0.74	0.70	3.27	2.64
S ₆	22.0	17.0	0.64	0.58	7.52	6.23	S ₂₉	28.0	21.0	0.72	0.70	2.17	1.72
S ₇	24.0	20.0	0.54	0.52	4.22	3.94	S ₃₀	18.0	14.0	0.62	0.50	3.39	2.83
S ₈	23.0	19.0	0.62	0.56	3.46	3.01	S ₃₁	21.0	18.0	0.54	0.46	2.66	2.14
S ₉	23.0	20.0	0.70	0.66	6.49	5.28	S ₃₂	26.0	21.0	0.74	0.70	1.87	1.19
S ₁₀	25.0	21.0	0.70	0.50	6.78	6.02	S ₃₃	19.0	15.0	0.75	0.66	1.23	1.10
S ₁₁	23.0	20.0	0.75	0.70	6.72	5.98	S ₃₄	28.0	22.0	0.70	0.66	2.33	2.01
S ₁₂	24.0	19.0	0.70	0.66	7.02	5.94	S ₃₅	25.0	23.0	0.70	0.66	2.09	1.88
S ₁₃	17.0	15.0	0.70	0.68	3.39	3.00	S ₃₆	24.0	23.0	0.74	0.70	9.23	8.51
S ₁₄	25.0	20.0	0.72	0.70	3.98	3.26	S ₃₇	21.0	20.0	0.72	0.68	1.70	1.10
S ₁₅	21.0	19.0	0.76	0.70	4.54	4.15	S ₃₈	25.0	20.0	0.70	0.66	2.02	1.75
S ₁₆	22.0	17.0	0.72	0.68	4.71	4.13	S ₃₉	31.0	24.0	0.72	0.68	3.96	3.11
S ₁₇	23.0	19.0	0.70	0.66	4.79	4.29	S ₄₀	19.0	17.0	0.65	0.56	1.33	1.18
S ₁₈	25.0	21.0	0.72	0.66	4.44	3.90	S ₄₁	27.0	25.0	0.73	0.66	2.35	2.08
S ₁₉	20.0	14.0	0.72	0.70	5.99	5.20	S ₄₂	26.0	22.0	0.75	0.65	2.19	1.98
S ₂₀	17.0	16.0	0.74	0.70	3.16	2.84	S ₄₃	21.0	20.0	0.74	0.71	7.23	6.51
S ₂₁	24.0	20.0	0.10	0.40	8.26	7.20	S ₄₄	22.0	20.0	0.70	0.68	1.79	1.29
S ₂₂	27.0	22.0	0.44	0.32	5.74	4.83	S ₄₅	24.0	21.0	0.72	0.69	2.35	1.95
S ₂₃	18.0	21.0	0.46	0.34	5.67	4.38	S ₄₆	30.0	23.0	0.73	0.68	2.99	2.41
Range	17 to 27	14 to 22	0.10 to 0.76	0.32 to 0.70	3.0 to 9.16	2.64 to 7.88	Range	14 to 31	13 to 25	0.5 to 0.75	0.46 to 0.71	1.01 to 9.23	1.1 to 8.51
Mean	22.65	19.04	0.63	0.59	5.77	4.95	Mean	22.78	19.70	0.69	0.64	2.67	2.29
Sd	2.64	2.03	0.15	0.12	1.87	1.55	Sd	4.81	3.38	0.06	0.08	1.93	1.77
CV%	11.7	10.7	23.7	20.4	32.4	31.4	CV%	21.1	17.1	9.4	12.1	72.2	77.4

S = Soil sample sites, SS = Surface soil (0-15cm), SSS = Subsurface soil (15-30cm).

Table 6. Average values of pH, OM, N, P, K, Ca, Mg, S, Fe, B and Zn status in surface and sub-surface soils of Sundarbans mangrove forest in Bangladesh.

Soil depth	pH	OM	%N	P (ppm)	K (meq/100g)	Ca (meq/100ml)	Mg (meq/100ml)	S (ppm)	Fe (µg/ml)	B (µg/ml)	Zn (µg/ml)
SS	7.64	1.65	0.09	19.26	1.33	9.11	2.92	169.59	22.72	0.66	4.22
SSS	7.56	1.45	0.07	18.96	1.55	7.89	2.69	160.57	19.37	0.62	3.62

SS = Surface soil (0-15cm), SSS = Subsurface soil (15-30cm).

Table 7. Number of trees and stand density of Khulna and Satkhira ranges of the Sundarbans Mangrove forest in Bangladesh

Forest Ranges	Average no. (trees/plot)	Stand density (trees/ha)
Khulna	5	525
Satkhira	6	569

Conclusion

The results of this study indicated that the soil pH, OM, primary macronutrients (N, P and K), secondary macronutrients (Ca, Mg and S) and micronutrients (Fe, B and Zn) contents were observed comparatively higher in surface (0 to 15 cm depth) soils than sub-surface (15 to 30 cm depth) soils except exchangeable K of Sundarbans mangrove forest. Tree stand density result exhibits comparatively higher in Satkhira range than Khulna range, but the stand density is much lower than standard tree stand density. Human activities at present in Sundarbans mangrove forest are reducing the tree stand densities which ultimately affect the soil nutrient status. Therefore, the study suggests that increasing of the forest coverage might be prior need to conserve our natural forest as making appropriate tree stand density and improved soil fertility. The results of soil properties and tree stand density might be helped to researcher and policymaker for better understanding and management of Sundarbans.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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