



Soil physico-chemical properties of the char kukri-mukri mangrove forest in Bhola district, Bangladesh

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Abstract

The present study analyzes the soil physico-chemical properties, *viz.*, moisture content, maximum water holding capacity, pH, electrical conductivity, organic carbon, total nitrogen, phosphorus, potassium, sulfur, zinc, calcium, magnesium, copper, and manganese of the Char Kukri-Mukri mangrove forest in the Bhola district of Bangladesh, using standard soil analysis methods during 2023-2024. The average values of moisture content and maximum water holding capacity varied from $11.91 \pm 1.01\%$ to $31.57 \pm 0.59\%$ and $43.86 \pm 1.04\%$ to $67.04 \pm 0.86\%$, respectively. The average soil pH value indicates a slightly alkaline reaction, which ranged between 7.72 ± 0.12 and 7.88 ± 0.14 . The electrical conductivity of soil was varied from 4.55 ± 0.21 dS/m to 9.58 ± 0.57 dS/m. The average organic carbon value ranged from $0.12 \pm 0.01\%$ to $1.43 \pm 0.09\%$. The average values of total nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, zinc, copper, and manganese were found to range from $0.010 \pm 0.001\%$ to $0.120 \pm 0.010\%$, 5.84 ± 0.59 $\mu\text{g/g}$ to 13.63 ± 1.37 $\mu\text{g/g}$, 0.21 ± 0.02 meq/100g to 0.36 ± 0.05 meq/100g, 14.61 ± 1.43 meq/100g to 29.8 ± 2.10 meq/100g, 7.97 ± 1.35 meq/100g to 14.64 ± 1.16 meq/100g, 124.8 ± 22.80 $\mu\text{g/g}$ to 321.60 ± 36.82 $\mu\text{g/g}$, 1.42 ± 0.31 $\mu\text{g/g}$ to 2.37 ± 0.46 $\mu\text{g/g}$, 1.47 ± 0.32 $\mu\text{g/g}$ to 4.56 ± 0.76 $\mu\text{g/g}$, and 9.28 ± 2.41 $\mu\text{g/g}$ to 36.99 ± 11.30 $\mu\text{g/g}$, respectively. Significant differences in the mean values of soil parameters were observed at the 5% level according to DMRT. The majority the soil parameters showed correlation with one another at different levels of significance. The comprehensive findings of this study on soil physico-chemical parameters indicate that the edaphic quality of the study area is favorable for restoring degraded areas by planting selected mangrove tree species, which serves as a vital strategy for environmental sustainability, enhancing biodiversity, protecting coastlines, and supporting local communities.

Keywords: Soil physico-chemical properties, char kukri-mukri island, mangrove forest, bhola district

Introduction

Soil physio-chemical characteristics are the result of interactions between various abiotic and biotic factors, including topography, climate, hydrodynamic, tidal margin, sea level changes, vegetation cover, and microbial activities (Saenger, 2002; Hossain and Nuruddin, 2016) [13, 26]. According to Krishna *et al.* (2006) [20], the soil quality depends on the soil nutrient pools and reserves, which are modulated by land use and a number of other management factors. Soil acts as a crucial sink or reservoir of essential plant nutrients, playing a critical role in plant growth and development. It stores and releases these nutrients, making them available to plants through various processes. Plants absorb nutrients from the soil, and when they die and decompose, these nutrients are returned to the soil. These nutrients, categorized as macronutrients and micronutrients, are vital for various plant functions.

The soils of the mangrove habitats differ from those of soils on mainland habitats due to some environmental condition (Dasgupta *et al.*, 2018) [6] of salinity, water logging, tidal inundation, low oxygen content and freshwater table, poor drainage, and sometimes free hydrogen sulfide. The tidal inundation pattern was affected soil properties that can control mangrove species zonation (Saha and Choudhury, 1995) [27]. The soil under mangrove vegetation is classified as extreme in terms of salinity, oxidation, acidity, nutrient availability, soil particle size, and tidal effects (Saenger, 2002) [26]. Because of complex aerial roots system, the mangrove forests serve as sediment trappers (Furukawa *et al.*, 1997; Wolanski, 1995) [8, 32] and the sedimentation rate in mangrove forests usually ranged from 0.1 to 10.0 mm per

year, with an average of 5 mm per year (Alongi, 2012, Breithaupt *et al.*, 2012) [1, 4]. Mangrove sediment contains an essential amount of nutrients and typically rich in organic matter. The growth and development of mangrove forests are strongly influenced by the texture and content of sediment organic matter. The higher range of organic matter with more acceptable particle size perform the better growth and development of mangrove forests.

Bangladesh has been blessed with the different patches of mangrove habitats including the world largest compact tract of the Sundarbans mangrove forest with unique assemblage of biodiversity. The Char Kukri-Mukri mangrove forest in Bhola district of Bangladesh, is mainly located in the central coastal region of the country. This coastal mangrove ecosystem is highly dynamic and one of the most productive and protective ecosystems, which provides a wide range of ecosystem goods and services. However, this ecosystem is extremely vulnerable to both climatic (like cyclone, storm surge, very strong tidal action, salinity intrusion and land erosion) and anthropogenic (like construction of infrastructure, unplanned tourisms, excessive grazing etc.) stressors. These stresses might have caused a massive degradation of its natural habitats as well as ecosystem quality. As a result, this ecosystem has been gradually lost its potential functions, productivity, and soil fertility. Although a very limited number of scientific papers were published earlier on few soil characters of the island, but a comprehensive information on soil status of the mangrove forest ecosystem is still scanty. Therefore, the present research investigation on physico-chemical properties of the study area has been undertaken.

Material and Methods

Description of the study area

Char Kukri-Mukri mangrove forest is located at Char Kukri-Mukri union of Char Fasson upazila in Bhola district of Bangladesh (Fig 1). Geographically, it lies between 21°54'00" to 21°59'10" North latitudes and 90°37'15" to 90°41'15" East longitudes with an elevation of 0.5-1.0 m above sea level. This area is also situated in the Offshore Islands bio-ecological zone belonging to Young Meghna Estuarine Floodplain (Nishat *et al.*, 2002) [23]. The climate of the area is humid tropical monsoon, with an annual rainfall of 2290-2790 mm, and temperature varied from 12°C-34°C.

During the monsoon season, especially at the time of high tides, a large portion of this island is inundated by tidal water. Seasonal tropical cyclones, along with tidal surges are very common climatic phenomenon. Soil of the area is loamy textured with high percentage of silt and neutral to alkaline in reaction. Moreover, the soil is mostly saline and calcareous alluvium in nature. A part of this forest area was declared as the Wildlife Sanctuary. Forested area of this island is plantation mangrove forest type where the major plant species are of keora (*Sonneratia apetala*), baen (*Avicennia officinalis*), gewa (*Excoecaria agallocha*), golpata (*Nypa fruticans*), etc.

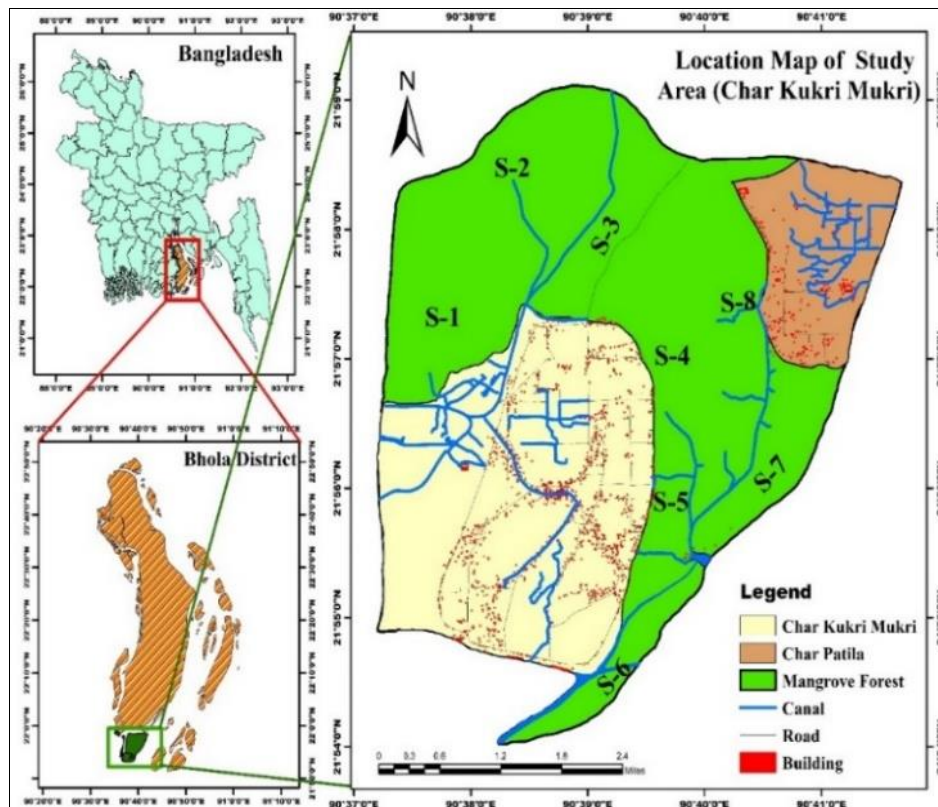


Fig 1: Map of the study area showing study sites of the Char Kukri-Mukri mangrove forest.

Sampling design, sample collection and analysis

The study area was divided into eight representative sites on the basis of its forest administrative units, geo-spatial locations, topographic features, habitats and vegetation patterns. These sites were recognized as site 1, site 2, site 3, site 4, site 5, site 6, site 7, and site 8 (Fig 1). For this study, altogether 24 fresh soil samples were collected from these designated sites during February 2024 following the procedures outlined in the Soil Survey Manual (Anonymous 1993) [2]. From every sampling site, three soil samples were collected using a soil sampler reaching a depth up to 15 cm. For each sample, 500g of soil was taken into the separate into air-tight polybag after removal of plant materials and other debris. The soil samples were air-dried in the laboratory after the immediate determination of soil moisture content and maximum water-holding capacity. After a certain period of time, the dried soil samples were smashed and then passed through a 2 mm sized sieve to eliminate all forms of debris for the preparation of analysis. Soil moisture content (MC) and maximum water holding capacity (MWHC) were determined following the gravimetric method (Black 1965; Reynolds, 1970) [3, 25]. Soil

pH was determined through preparing a soil-water (1:2.5 ratio) suspension and measuring the pH with a calibrated pH meter as outlined by Jackson (1962) [15], while the electrical conductivity (EC) was measured through preparing a soil-water (1:5 ratio) suspension and by the help of EC meter described by USDA (2004) [30]; organic carbon (OC) was measured by using wet oxidation method (Walkley and Black, 1934) [31] and organic matter (OM) was calculated by multiplying with a conversion factor of 1.724. The total nitrogen (TN) of soil was determined by Kjeldahl's method which described by Jackson (1973) [16]; phosphorus (P) using Olsen's method (Olsen and Sommers, 1982) [24]; potassium (K) using flame photometer (Ghosh *et al.*, 1983) [9]; available sulfur (S) content using the turbidimetric method as described by Fox *et al.* (1964) [7]; available zinc (Zn) was determined by DTPA extraction method using NOV AA-300 Atomic Absorption Spectrophotometer (SRDI, 2012) [29]; calcium (Ca) and magnesium (Mg) were determined by the titrimetric method (Lanyon and Heald, 1982) [21]; copper (Cu) and manganese (Mn) were analyzed by the DTPA extraction method using a NOV AA-300 Atomic Absorption Spectrophotometer (SRDI, 2012) [29].

Results and Discussion

Physical and chemical properties of soils collected from the Char Kukri-Mukri Island were evaluated and the accumulated data were presented in Table 1 to Table 4 and Figure 2. The average moisture content values of soils were found to range from $11.91\pm 1.01\%$ to $31.57\pm 0.59\%$. The highest value of $31.57\pm 0.59\%$ was recorded in the soil samples collected from site 3, which was followed by $28.62\pm 0.54\%$, $28.59\pm 0.53\%$, $28.44\pm 0.99\%$, $25.24\pm 0.69\%$, $24.25\pm 0.63\%$, $17.42\pm 0.83\%$ were recorded from the soil samples of site 4, site 5, site 8, site 2 and site 1, and site 6, respectively. Whereas, the lowest value of $11.91\pm 1.01\%$ was recorded in the soil samples collected from site 7. Similarly, the average values of maximum water holding capacity were found to vary from $43.86\pm 1.04\%$ to $67.04\pm 0.86\%$. The highest value of $67.04\pm 0.86\%$ was recorded in the soil samples collected from site 3, which was followed by $66.48\pm 0.55\%$, $63.90\pm 1.37\%$, $63.45\pm 1.31\%$, $61.51\pm 0.63\%$, $60.56\pm 1.05\%$, and $54.90\pm 1.34\%$ were recorded in the soil samples of site 5, site 2, site 4, site 8, site 1, and site 6, respectively. while the lowest value of $43.86\pm 1.04\%$ was recorded in the soil sample collected from site 7 (Table 1).

The average soil pH values of the study sites were slightly alkaline in reaction, and its values found to range between 7.72 ± 0.12 and 7.88 ± 0.14 (Table 1). The maximum pH value of 7.88 ± 0.14 was recorded in the soil samples collected from site 2, followed by 7.87 ± 0.10 , 7.86 ± 0.13 , 7.84 ± 0.10 , 7.83 ± 0.12 , 7.80 ± 0.18 , and 7.73 ± 0.13 were recorded from soil samples of site 1, site 8, site 3, site 2, site 5, and site 7, respectively. Whereas the minimum pH value of 7.72 ± 0.12 was recorded in the soil sample collected from site 4 (Table 1). The present finding supported by the findings of Hassan and Razzaque (1981)^[10], Siddiqui (2009)^[28], Mannan *et al.* (2012)^[22], and Hossain (2013)^[11]. They observed that the soil pH of some selected sites in the Sundarbans varied from 7.10 to 8.5. The present records are also corroborated by the findings of Islam (2023)^[14], who conducted research on the mangrove forest ecosystem of Barguna district and observed it values varied from 7.18 to 8.20. In contrast, the finding of Jamil *et al.* (2020)^[17] records of 6.23 to 6.57 pH value in the dry season from the coastal Bhola Island, including Bhola Sadar, Daulatkhan, and Manpura Island, indicates the acidic in nature, which is conflicting with the present findings.

Table 1. Mean values of moisture content, maximum water holding capacity, pH, electrical conductivity, and organic carbon in the soils of the Char Kukri-Mukri mangrove forest.

Sites	MC (%)	MWHC (%)	pH	EC (dS/m)	OC (%)
Site 1	$24.25\pm 0.63c$	$60.56\pm 1.05c$	$7.87\pm 0.10a$	$7.12\pm 1.00b$	$0.64\pm 0.06b$
Site 2	$25.24\pm 0.69c$	$63.90\pm 1.37d$	$7.83\pm 0.12a$	$4.55\pm 0.21a$	$0.80\pm 0.11c$
Site 3	$31.57\pm 0.59e$	$67.04\pm 0.86e$	$7.84\pm 0.10a$	$9.58\pm 0.57c$	$1.04\pm 0.07d$
Site 4	$28.62\pm 0.54d$	$63.45\pm 1.31d$	$7.72\pm 0.12a$	$6.65\pm 0.83b$	$0.88\pm 0.12c$
Site 5	$28.59\pm 0.53d$	$66.48\pm 0.55e$	$7.80\pm 0.18a$	$8.75\pm 0.72c$	$0.80\pm 0.05c$
Site 6	$17.42\pm 0.83b$	$54.90\pm 1.34b$	$7.88\pm 0.14a$	$7.00\pm 0.48b$	$0.12\pm 0.01a$
Site 7	$11.91\pm 1.01a$	$43.86\pm 1.04a$	$7.73\pm 0.13a$	$9.10\pm 0.54c$	$1.15\pm 0.09d$
Site 8	$28.44\pm 0.99d$	$61.51\pm 0.63c$	$7.86\pm 0.13a$	$7.08\pm 0.19b$	$1.43\pm 0.09e$

Notes: MC= moisture content, MWHC= maximum water holding capacity, EC= electrical conductivity, OC= organic carbon; The data represent average values of three replications; The common letters displayed in the same column are not significantly distinct from one another at 5% level after DMRT.

The average electrical conductivity (EC) values of soil samples the study area was varied from 4.55 ± 0.21 dS/m to 9.58 ± 0.57 dS/m (Table 1). The maximum EC value of 9.58 ± 0.57 dS/m was observed in the soil samples collected from site 3, which was followed by 9.10 ± 0.54 dS/m, 8.75 ± 0.72 dS/m, 7.12 ± 1.00 dS/m, 7.08 ± 0.19 dS/m, 7.00 ± 0.48 dS/m, and 6.65 dS/m were recorded from soil samples of site 7, site 5, site 1, site 8, site 6, and site 4, respectively. Whereas the minimum EC value of 4.55 dS/m was recorded in the soil sample collected from site 2 (Table 1). The finding of Jamil *et al.* (2020)^[17] is disagreed with the present findings, because they showed that the electrical conductivity ranges of 1.04 dS/m to 2.98 dS/m in dry season and 0.68 dS/m to 1.22 dS/m in wet season, which were recorded from the coastal Bhola island including Bhola Sadar, Daulatkhan, and Manpura island. On the other hand, the present finding is partially corroborated with the lower limit of the findings of Hossain (2013)^[11] and Islam (2023)^[14], because they reported that this value ranged from 4.32 dS/m to 18.51 dS/m, and 7.70 dS/m to 22.49 dS/m, respectively, in the soil samples of the Sundarbans and Barguna mangrove forests.

The average soil organic carbon (OC) values were found to vary between $0.12\pm 0.01\%$ and $1.43\pm 0.09\%$ (Table 1). The

highest OC value of $1.43\pm 0.09\%$ was recorded from the soil samples of site 8, which was followed by $1.15\pm 0.09\%$, $1.04\pm 0.07\%$, $0.88\pm 0.12\%$, $0.80\pm 0.12\%$, $0.80\pm 0.11\%$, and $0.64\pm 0.06\%$, were recorded from the soil samples of site-7, site-3, site-4, site-2, site-5, and site-1, respectively. At the same time, the lowest OC value of $0.12\pm 0.01\%$ was recorded in the soil sample collected from site-6 (Table 1). The present findings are totally different from the findings of Zafar *et al.* (1999)^[33], where they stated that OC values varied from 4.99% to 11% in the intertidal muddy beach of the Bankhali in Cox's Bazar district. On the other hand, the present findings are more or less similar with the findings of Hossain and Bhuiyan (2016)^[12] and Jamil *et al.* (2020)^[17], where Hossain and Bhuiyan (2016)^[12] showed the mean values of total OC during winter and monsoon seasons were 1.09% and 1.34% respectively, while Jamil *et al.* (2020)^[17] observed the values as ranged from 0.82% to 1.03% and 0.63% to 1.11% during dry and wet seasons, respectively in the coastal islands of Bhola district.

The average TN values ranged between $0.01\pm 0.001\%$ and $0.120\pm 0.010\%$ (Table 2). The highest value of $0.120\pm 0.010\%$ was recorded in the soil samples collected from site 8, which was followed by $0.100\pm 0.004\%$, $0.089\pm 0.005\%$, $0.076\pm 0.005\%$, $0.069\pm 0.006\%$, and

0.055±0.008% were recorded, from the soil samples of site-7, site-3, site-4, site-2, and site-5, and site-1, respectively. In contrast, the minimum TN value of 0.010±0.001% was recorded in the soil sample collected from site-6 (Table 2). The present findings regarding the average values of TN have been partially corroborated with the findings of Mannan *et al.* (2012) [22], Hossain (2013) [11], Hossain and Bhuiyan (2016) [12], Jamil *et al.* (2020) [17], and Islam (2023) [14], where the TN content found to range from 0.061% to 0.136% by Mannan *et al.* (2012) [22], and 0.04% to 0.08% by Hossain (2013) [11] in the soils of the Sundarbans mangrove forest, Islam (2023) [14] found this range from 0.08% to 0.11% in the soils of the Barguna mangrove forests, while Jamil *et al.* (2020) [17] observed this range from 0.08% to 0.09%, and 0.06% to 0.12%, respectively in dry, and wet seasons in the coastal islands of Bhola district.

The average values of available P content in the soil

samples of study area were found to range between 5.84±0.59 µg/g and 13.63±1.37 µg/g (Table 2). The highest P value of 13.63±1.37 µg/g was recorded from the soil samples of site 3, which was followed by 13.34±0.76 µg/g, 10.73±2.06 µg/g, 10.12±1.11 µg/g, 8.40±1.54 µg/g, 7.05±1.82 µg/g, and 6.59±1.33 µg/g were recorded from the soil samples of site 2, site 7, site 1, site 6, site 5 and site 4, respectively. At the same time, the lowest phosphorus value of 5.84±0.59 µg/g was recorded in the soil sample collected from site 8 (Table 2). The present findings have been corroborated with the findings of upper limit of Hossain (2013)'s [11] 10.86 µg/g, and lower limit of Jamil *et al.* (2020)'s [17] 11µg/g. But this value showed much lower than that of the upper limit of Mannan *et al.* (2012)'s [22] 49.58 µg/g, Khan and Amin (2019)'s [19] 62.56 µg/g, and Jamil *et al.* (2020)'s [17] 52.99 µg/g, which are totally disagreed with the present finding.

Table 2: Mean values of some common macronutrients in the soils of the Char Kukri-Mukri mangrove forest.

Sites	TN (%)	P (µg/g)	K (meq/100g)	Ca (meq/100g)	Mg (meq/100g)	S (µg/g)
Site-1	0.055±0.008b	10.12±1.11b	0.30±0.07ab	24.04±5.15b	12.97±1.06de	321.60±36.82d
Site-2	0.069±0.006c	13.34±0.76c	0.35±0.06b	29.80±2.10c	9.67±0.97abc	290.52±65.27d
Site-3	0.089±0.005d	13.63±1.37c	0.35±0.07b	25.06±2.73b	11.97±1.84cd	311.40±43.79d
Site-4	0.076±0.005c	6.59±1.33a	0.36±0.05b	17.64±1.77a	11.35±0.94bcd	124.80±22.80a
Site-5	0.069±0.005c	7.05±1.82a	0.30±0.04ab	16.45±2.68a	11.05±1.52bcd	285.28±34.07d
Site-6	0.010±0.001a	8.40±1.54ab	0.21±0.02a	14.61±1.43a	8.96±1.26ab	146.00±26.41ab
Site-7	0.100±0.004e	10.73±2.06b	0.34±0.05b	16.53±0.99a	7.97±1.35a	209.04±24.86bc
Site-8	0.120±0.010f	5.84±0.59a	0.23±0.02a	15.02±1.29a	14.64±1.16e	267.96±40.59cd

Notes: TN= total nitrogen, P= phosphorus, K= potassium, Ca= calcium, Mg= magnesium, S= sulphur; The data represent average values of three replications; The common letters displayed in the same column are not significantly distinct from one another at 5% level after DMRT.

The average K values were found to vary from 0.21±0.02 meq/100g to 0.36±0.05 meq/100g. The maximum K value of 0.36±0.05 meq/100g was recorded from the soil samples of site-4, which was followed by 0.35±0.07 meq/100g, 0.35±0.06 meq/100g, 0.34±0.05 meq/100g, 0.30±0.07 meq/100g, 0.28±0.04 meq/100g and 0.23±0.02 meq/100g were recorded from the soil samples of site 2 and site 3, site 7, site 1, site 5, and site 8, respectively. In contrast, the minimum K value of 0.21±0.02 meq/100g was recorded in the soil samples of site 6 (Table 2). The present finding is partially consistent with the findings of Chaffey *et al.* (1985) [5], Karim (1988) [18], Siddiqui (2009) [28], and Jamil *et al.* (2020) [17]. Chaffey *et al.* (1985) [5] record this value ranged from 0.20 meq/100g to 1.00 meq/100g in the surface soil of the Sundarbans. Karim (1988) [18] found this value ranged from 0.30 meq/100g to 1.30 meq/100g, and Siddiqui (2009) [28] showed this value ranging

from 0.26 meq/100g to 0.82 meq/100g in the soil of the mangrove ecosystem. Jamil *et al.* (2020) [17] showed the K value ranged from 0.17 meq/100g to 0.28 meq/100g, and 0.15 meq/100g to 0.33 meq/100g during dry, and wet seasons respectively in the soils of coastal islands of the Bhola district. But this value exhibit much lower than that of the findings of Mannan *et al.* (2012) [22], Hossain (2013) [11], and Islam (2023) [14]. Mannan *et al.* (2012) [22] observed the K value as ranged between 0.70 meq/100g and 1.14 meq/100g, Hossain (2013) [11] showed this ranged from 0.66 meq/100g to 1.67 meq/100g, and Islam (2023) [14] stated this value varied from 0.41 meq/100g to 0.93 meq/100g in the soil samples of mangrove forest ecosystems.

The average Ca values in the soil samples of the study area were ranged between 14.61±1.43 meq/100g and 29.80±2.10

meq/100g (Table 2). The highest Ca value of 29.80±2.10 meq/100g was recorded from the soil samples of site-2, which was followed by 25.06±2.73 meq/100g, 24.04±5.15 meq/100g, 17.64±1.77 meq/100g, 16.53±0.99 meq/100g, 16.45±2.68 meq/100g, and 15.02±1.29 meq/100g were recorded from the soil samples of site-3, site-1, site-4, site-7, site-5, and site-8, respectively. At the same time, the lowest Ca value of 14.61±1.43 meq/100g was recorded in the soil sample collected from site-6 (Table 2). The present findings have been consistent with the findings of Chaffey *et al.* (1985) [5], Mannan *et al.* (2012) [22], and Khan and Amin (2019) [19]. Chaffey *et al.* (1985) [5] recorded the highest Ca content in the soil as 22.2 meq/100g and the lowest as 6.8 meq/100g. Mannan *et al.* (2012) [22] reported this value as ranged from 7.36 to 21.98 mg/g, whereas Khan and Amin (2019) [19] recorded this range from 8.00 to 24.43 mg/g. But the upper limit of Ca value recorded from mangrove ecosystem by Karim (1988) [18], Hossain (2013) [11], and Khan and Amin (2019) [19] have far exceeded of the present findings.

The average Mg values of the soils were observed to range between 7.97±1.35 meq/100g and 14.64±1.16 meq/100g (Table 2). The maximum Mg value of 14.64±1.16 meq/100g was recorded from the soil samples of site 8, which was followed by 12.97±1.06 meq/100g, 11.97±1.84 meq/100g, 11.35±0.94 meq/100g, 11.05±1.52 meq/100g, 9.67±0.97 meq/100g, and 8.96±1.26 meq/100g, which were recorded from the collected soil samples of site 1, site 3, site 4, site 5, site 2, and site 6, respectively. Whereas, the minimum Mg value of 7.97±1.35 meq/100g was recorded in the soil sample collected from site 7 (Table 2). The present finding partially agrees with the findings of Chaffey *et al.* (1985) [5],

Siddiqui (2009) [28], Mannan *et al.* (2012) [22], and Hossain (2013) [11]. Chaffey *et al.* (1985) [5] found this value with a range from 3.40 meq/100g to 9.90 meq/100g; Siddiqui (2009) [28] recorded this value with a range from 7.80 meq/100g to 10.60 meq/100g; and Mannan *et al.* (2012) [22] observed this value with a range from 4.30 meq/100g to 8.71 meq/100g, whereas Hossain (2013) [11] recorded this value ranging from 5.88 meq/100g to 10.65 meq/100g from mangrove forest ecosystems. In contrast, the present finding differs from the finding of Jamil *et al.* (2020) [17], who showed this value of a range from 2.19 meq/100g to 3.07 meq/100g in the coastal islands of Bhola district and also Islam (2023) [14], who stated this value with a range from 3.79 meq/100g to 7.56 meq/100g in the soil samples of different mangrove ecosystems in Barguna district.

The average S values were found to range from 124.8±22.80 µg/g to 321.6±36.82 µg/g (Table 2). The highest S content of 321.6±36.82 µg/g was recorded in the soil samples of site 1, which was followed by 311.40±43.79 µg/g, 290.52±65.77 µg/g, 285.28±34.07 µg/g, 267.96±40.59 µg/g, 209.04±24.86 µg/g, and 146.00±26.41 µg/g were recorded in the soil samples of site 3, site 2, site 5, site 8, site 7, and site 6, respectively. At the same time, the lowest S value of 124.8±22.80 µg/g was recorded in the soil sample collected from site 4 (Table 2). The present findings fully agreed with the findings of Siddiqui (2009)'s [28] 169.93 µg/g to 239.08 µg/g and Hossain (2013)'s [11] 123.29 µg/g to 215.89 µg/g, and partially corroborated with the finding of Khan and Amin (2019)'s [19] 151.77 µg/g to 438.75 µg/g. But the findings of Jamil *et al.* (2020) [17], who observed this value as ranged from 39.22µg/g to 48.30µg/g in dry season and 36.23µg/g to 61.17µg/g in wet season in the soils of coastal islands of the Bhola district have been considerably lower than that of the present findings.

The average Zn content in the soils were varied from 1.42±0.32 µg/g to 2.37±0.46 µg/g (Table 3). The highest Zn content of 2.37±0.46 µg/g was recorded from the soil samples of site 5, which was followed by 2.09±0.19 µg/g, 2.07±0.33 µg/g, 1.84±0.38 µg/g, 1.69±0.31 µg/g, 1.58±0.27 µg/g, and 1.51±0.39 µg/g were recorded from the soil samples of site 1, site 8, site 3, site 4, site 2, and site 6, respectively. Whereas, the lowest Zn content of 1.42±0.32

µg/g was recorded in the soil samples of site 7. The lower limit of the present findings has been partially corroborated with the upper limit of the findings of Islam (2023) [14], who reported the Zn value with a range from 0.69 µg/g to 1.28 µg/g in the soil samples of different mangrove ecosystems in Barguna district. In contrast, the present findings have been completely disagreed with the finding of Siddiqui (2009) [28] who reported this value ranging from 3.40 meq/100gm to 9.70 meq/100gm, which is much higher than that of the present findings.

Table 3: Mean values of some micronutrients in the soils of the char kukri- mukri mangrove forest

Sites	Zn (µg/g)	Cu (µg/g)	Mn (µg/g)
Site-1	2.09±0.19bc	3.97±0.43cd	14.58±2.36a
Site-2	1.58±0.27ab	3.20±0.20bc	36.99±11.30b
Site-3	1.84±0.38abc	4.04±0.32d	14.26±2.60a
Site-4	1.69±0.31ab	4.00±0.38cd	12.50±2.55a
Site-5	2.37±0.46c	4.56±0.76d	12.76±2.84a
Site-6	1.51±0.39ab	1.47±0.32a	9.28±2.41a
Site-7	1.42±0.31a	2.69±0.54b	10.42±2.21a
Site-8	2.07±0.33abc	4.14±0.40d	10.35±2.26a

Notes: Zn= Zinc, Cu= Cupper, Mn= Manganese; The data represent average values of three replications; The common letters displayed in the same column are not significantly distinct from one another at 5% level after DMRT.

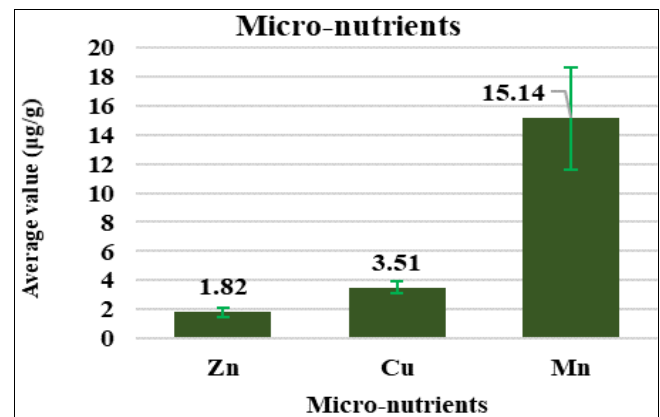


Fig 2: Micronutrients in the soils of the char Kukri-Mukri mangrove forest. [Zn=Zinc, Cn=Copper, Mn=Mnaganese]

Table 4: The 2-tailed Pearson correlation among different physico-chemical parameters in the soils of Char Kukri Mukri mangrove forest of Bhola district.

Parameters	MC	MWHC	pH	EC	OC	TN	P	K	Ca	Mg	S	Zn	Cu	Mn
MC	1													
MWHC	.952**	1												
pH	.144	.198	1											
EC	-.029	-.147	.139	1										
OC	.279	.036	-.057	.279	1									
TN	.268	.028	-.078	.279	.987**	1								
P	-.053	.027	.293	.091	-.002	.001	1							
K	.188	.166	.114	.202	.296	.317	.533**	1						
Ca	.296	.398	.236	-.245	.006	.025	.778**	.569**	1					
Mg	.671**	.554**	.480*	.092	.419*	.410*	-.195	.026	.102	1				
S	.392	.405*	.429*	.193	.325	.321	.474*	.283	.580**	.472*	1			
Zn	.529**	.513*	.572**	.331	.232	.213	-.057	.193	.077	.679**	.602**	1		
Cu	.758**	.644**	.180	.263	.578**	.573**	-.040	.423*	.231	.706**	.549**	.768**	1	
Mn	.179	.323	.259	-.517**	.005	.009	.586**	.480*	.775**	-.033	.444*	.064	.108	1

Notes: **. Correlation is significant at the 0.01 level; *. Correlation is significant at the 0.05 level.

The average Cu content in the soil samples of the study area were found to range between 1.47±0.32 µg/g and 4.56±0.76

µg/g (Table 3). The highest Cu content value of 4.56±0.76 µg/g was recorded in the soil samples of site 5, which was

followed by 4.14 ± 0.40 $\mu\text{g/g}$, 4.04 ± 0.32 $\mu\text{g/g}$, 4.00 ± 0.38 $\mu\text{g/g}$, 3.97 ± 0.43 $\mu\text{g/g}$, 3.20 ± 0.20 $\mu\text{g/g}$, and 2.69 ± 0.54 $\mu\text{g/g}$, which were recorded from the collected soil samples of site 8, site 3, site 4, site 1, site 2, and site 7, respectively. At the same time, the lowest Cu content value of 1.47 ± 0.32 $\mu\text{g/g}$ was recorded in the soil samples of site 6 (Table 3). The present findings have been corroborated with the finding of Siddiqui (2009) [28] and Islam (2023) [14]. Siddiqui (2009) [28] reported this value as ranged between 2.86 $\mu\text{g/g}$ and 4.20 $\mu\text{g/g}$, and Islam (2023) [14] stated this status with a range from 2.35 $\mu\text{g/g}$ to 3.68 $\mu\text{g/g}$. In contrast, the upper limit of the finding of Hossain (2013)'s [11] 9.43 $\mu\text{g/g}$ recorded in the soils of the Sundarbans mangrove forest, has far exceeded from the present finding.

The average Mn values in the soils were observed to vary from 9.28 ± 2.41 $\mu\text{g/g}$ to 36.99 ± 11.30 $\mu\text{g/g}$ (Table 3). The maximum Mn value of 36.99 ± 11.30 $\mu\text{g/g}$ was recorded in the soil samples of site 2, which was followed by 14.58 ± 2.36 $\mu\text{g/g}$, 14.26 ± 2.60 $\mu\text{g/g}$, 12.76 ± 2.84 $\mu\text{g/g}$, 12.50 ± 2.55 $\mu\text{g/g}$, 10.42 ± 2.21 $\mu\text{g/g}$, and 10.35 ± 2.26 $\mu\text{g/g}$ were recorded in the soil samples of site 1, site 3, site 5, site 4, site 7, and site 8, respectively. Whereas, the minimum Mn value of 9.28 ± 2.41 $\mu\text{g/g}$ was recorded in the soil samples collected from site 6 (Table 3). The present findings have been fully agreed with the findings of Hossain (2013) [11], who stated this value as ranged from 13.12 $\mu\text{g/g}$ to 34.68 $\mu\text{g/g}$ in the soils of the Sundarbans mangrove forest, on the other hand, the present findings have been partially supported by the findings of Siddiqui (2009) [28] and Islam (2023) [14], where Siddiqui (2009) [28] reported this value with a range from 5.79 $\mu\text{g/g}$ and 17.33 $\mu\text{g/g}$ in the soils of the Sundarbans mangrove forest, and Islam (2023) [14] reported this value with a ranged from 6.57 $\mu\text{g/g}$ to 9.86 $\mu\text{g/g}$ in the soil samples of different mangrove ecosystems in Barguna district.

The two-tailed Pearson correlation analysis of soil parameters revealed a highly significant positive correlation between moisture content (MC) and maximum water holding capacity (MWHC), as well as between organic carbon (OC) and total nitrogen (TN), at the 1% ($\alpha = 0.01$) level of significance (Table 4). The pH value showed a positive significant correlation with the values of Mg, S, and Zn at different levels of significance. The value of Zn also showed a positive significant correlation with the values of MC, S, and Mg at the 1% level of significance. The Mg content showed a positive significant correlation with the values of MC and MWHC at the 1% level of significance. The value of Cu exhibited a positive significant correlation with the values of MC, MWHC, OC, TN, Ca, Mg, and S at the 1% level of significance. The S content showed a positive significant correlation with the value of Ca at the 1% level of significance. The Ca value expressed a positive significant correlation with the values of two intercorrelated parameters of P and K at the 1% level of significance. The value of Mn showed a positively significant correlation with the values of P, K, Ca, and S at different levels of significance but expressed a negative but significant correlation with the value of EC at the 1% level of significance (Table 4).

Conclusion

Based on the current extensive analysis of soil physico-chemical properties in the mangrove forest ecosystem of Char Kukri-Mukri Island, it is concluded that the overall

edaphic quality is suitable for restoring degraded areas through the planting of specific mangrove tree species. The present finding serves as a crucial strategy in fostering environmental sustainability, boosting biodiversity, safeguarding coastlines, and aiding local communities.

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