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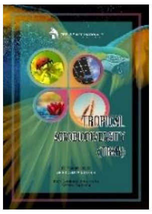

RESEARCH ARTICLE

CHARACTERIZATION OF SOIL PHYSICAL AND CHEMICAL PROPERTIES IN THE SOUTH-CENTRAL COASTAL AREA OF BANGLADESH

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ABSTRACT

Information on soil physical and chemical properties is vital for the major crop production. This information is largely absent in the south-central coastal saline and non-saline region of Bangladesh. This study evaluated the soil properties of 18 surface soil samples (15 cm depth) from various zones in Bamna upazila (sub-district) of the study area. All soil samples were air-dried, separated, and analyzed for multiple fertility indicators, including physical characteristics and chemical properties using standard analytical methods. The fertility of the soil was assessed by computing the nutrient value index. The findings indicated that the average values for pH, EC, NaCl, Cl^-, organic carbon, organic matter, total nitrogen, available sulfur, available phosphorus, and exchangeable potassium across all soil samples were 6.24, 6.87 dS m^{-1}, 2.63%, 668.85 ppm, 1.20%, 2.08%, 0.19 %, 46.13ppm, 25.17ppm, and 0.2606meq/100g, respectively. Most of the chemical properties were found to be in a suitable range for crop production. Approximately 68.91% of the soils were classified as silt, 23.77% as clay, and the remaining as sandy. Moisture content, particle density, bulk density, and porosity were measured at 25.26%, 2.45gcm^{-3}, 1.40gcm^{-3} and 42.73% respectively. The findings from this research will aid stakeholders and local authorities in executing effective strategies for major crop production.

KEYWORDS

Organic Carbon, Organic Matter, Soil Properties, Soil Fertility, Salinity, Coastal Region

1. INTRODUCTION

Soil health is a critical determinant for enhancing agricultural output (Hossain et al., 2019). This necessitates long-term investigations at designated locations to monitor alterations in soil fertility condition. The constantly growing human populations and the demand for land for numerous purposes. Agricultural operations have resulted in significant alterations in land use and soil management practices globally (Ayele et al., 2019).

The coastal region of Bangladesh is designated as an agro-ecologically disadvantaged area, with significant obstacles to agricultural productivity such as salinity, cyclones, and waterlogging (Bhuyan et al., 2023a,b; Roy et al., 2024). Furthermore, variations in land topography influence the chemical and physical properties of soil, with salinity significantly affecting these qualities (Roy et al., 2024).

Physical, chemical, and biological indicators are the three basic types of soil indicators (Delgado and Gómez, 2024). Since these three kinds of indicators do not correspond precisely with any one soil function, they must be combined to get an accurate picture of soil quality. In addition, there are several characteristics that make up soil quality indicators, which are used to assess the functionality and health of soil. Some examples of these characteristics are bulk density, hydraulic conductivity, pH, structure, organic carbon (OC) levels, organic matter (OM) content, bulk density, and holding capacity (Deekor et al., 2012; Roy et al., 2024). There is a substantial relationship between the physical features of the soil and the growth and activity of plants. According to the study, the physical quality of the soil has a direct influence on the plant's nutrition and foundation, root penetration, exposure to air, moisture preservation, and drainage (Delgado and Gómez, 2024). It is also important to note that the physical qualities of soil have an effect on its chemical and biological functions.

The effects of soil solution (soil water and nutrients) are evident in the chemical properties and exchangeable sites (organic matter and clay particles) that influence plant nutritional needs, plant resilience, and the concentration and accessibility of soil pollutants for plant uptake mechanisms. Plant growth relies on essential nutrients including calcium, magnesium, potassium, and phosphorus (Shrivastav et al., 2020). Soil pH is essential in governing many chemical reactions that influence these nutrients (Penn and Camberato, 2019). Sulphate absorption by soil decreases with increasing pH, enhancing its availability in the soil (Barrow and Hartemink, 2023). Nonetheless, elevated pH levels diminish plant absorption, hence decreasing its availability to plants. The impact of pH on plant uptake of phosphate is more pronounced than its effect on soil availability, resulting in reduced uptake when pH rises (Barrow and Hartemink, 2023).

Natural disasters hinder social and economic development in the southern region, increasing the vulnerability of coastal inhabitants. The shifting seasons present various challenges, making the presence of physical hazards a daily challenge for the inhabitants of Bangladesh. The coastal regions of Bangladesh comprise over 20% of the nation's geographical area and more than 30% of its total arable land (Minar et al., 2013). Bangladesh is among the most susceptible nations to natural disasters globally, with 97.1% of its area and 97.7% of its people at risk from numerous natural calamities, including cyclones (Dilley et al., 2005). Bamna, an upazila in the Barguna District of Barisal Division, has considerable climatic variability and notable oscillations in soil nutrient

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levels (Haque et al., 2023; Bhuyan et al., 2024). The native populace adjusts to these diverse conditions by utilising their ancestral knowledge.

Consequently, it is essential to augment and recognise traditional knowledge to adapt to the char land environment. Typically, cultivators of char soils employed low-yielding native crops. Appropriate crop selection and effective soil and crop management strategies possess considerable potential to enhance crop output and yields. Evaluating soil fertility is crucial for sustainable agricultural production and for selecting appropriate crops for a certain land region (Abdel Rahman et al., 2022). However, information regarding soil fertility and land use patterns in Bamna Upazila of Barguna District is severely lacking.

The Government of Bangladesh has designated Bamna Upazila within its revenue sector, recognizing it as a remote, perilous coastal region and a char (riverine island). The majority of farmers in the region are uninformed of the soil's fertility status and exhibit minimal interest in crop cultivation (Uddin et al., 2020). Moreover, no agricultural research institute has directly gathered extensive data on the physical and chemical characteristics of coastal soil in southern Bangladesh. Numerous investigations have been undertaken in the coastal region of Bangladesh, examining the seasonal impacts on soil salinity, soil chemical characteristics, and nutrient dynamics in agricultural soils (Haque et al., 2023; Bhuyan et al., 2023a; Talukder et al., 2023; Roy et al., 2024). Nonetheless, there has been insufficient research on the physical and chemical characteristics of the soils in the Bamna Upazila. This study seeks to fill this gap by providing significant insights on the agriculture of southern Bangladesh. In light of these variables, we conducted a thorough study to delineate the chemical and physical properties of soils in this region.

2. MATERIALS AND METHODOLOGY

2.1 The study area

We conducted the research in the south-central coastal area of Bangladesh, specifically in Bamna Upazila (a sub-unit) of the Barguna district (Figure. 1). Bamna Upazila comprises four union parishads (sub-unit of Upazila) (BBS 2011). For this study, we purposefully selected 16 villages within the sub-district to assess soil salinity, fertility status, and their impacts on crop production. Geographically, Bamna is located at 22°18′6″ N, 90°6′0″ E. In the research area, the average temperature (annual) is 25°C, and 3,200 mm of rain falls on average each year. The hottest month is May (mean temeature 35°C), while January is the coldest, with minimum rainfall of 8 mm and an average temperature of 16°C. The wettest month is July, with an average of 800 mm of precipitation. The region is predominantly an estuarine floodplain, with lying below 3 meters above sea level (MoA, 2018). The coastal zone is characterised by fine-textured soil, primarily composed of clay and clay loam (MoA, 2018).

Table 1: GPS reading and location names of the study area

Sample No.	Name of the Location	GPS Reading
S1	Bamna, Bamna union	22°31'4''N, 90°05'9''E
S2	Shofipur-1, Bamna union	22°18'9''N, 90°15'3''E
S3	Shofipur-2, Bamna union	22°17'9''N, 90°12'2''E
S4	Amtoli, Bamna union	22°33'8''N; 90°08'4''E
S5	Ramna-1, Ramna union	22°24'9''N; 90°07'3''E
S6	Ramna-2, Ramna union	22°22'5''N; 90°06'6''E
S7	Boloibunia, Ramna union	22°25'5''N, 90°05'2''E
S8	Dewatola, Dewatola union	22°26'0''N, 90°03'5''E
S9	Gudighata, Dewatola union	22°22'4''N, 90°03'8''E
S10	Hogolpati=1, Dewatola union	22°22'1''N, 90°01'3''E
S11	Hogolpati=2, Dewatola union	22°21'2''N, 90°01'2''E
S12	Bukabunia, Bukabunia union	22°30'3''N, 90°06'6''E
S13	Talesshor-1, Bukabunia union	22°29'9''N, 90°03'8''E
S14	Talesshor-2, Bukabunia union	22°30'8''N, 90°10'9''E
S15	Chalitabunia-1, Bukabunia union	22°32'8''N, 90°07'0''E
S16	Chalitabunia-2, Bukabunia union	22°28'7''N, 90°05'2''E

2.2 Soil sample collection and preparation

Soil samples were collected from 16 locations in March 2024 (Figure 1.). Using a spade, existing plants and vegetation were cleared prior to sampling. Samples of topsoil were then taken from each location using an aluminium core in order to assess the bulk density. Composite subsoil samples were collected from the same places (15 cm depth) to analyze the specified qualities. The samples were transported to the Soil Science Laboratory at Patuakhali Science and Technology University (PSTU), where they were air-dried. They were then gently crushed, and larger particles were removed using a 2 mm sieve. The processed samples were further weighed and stored in containers for subsequent analysis. Note that standard methods were followed in the evaluation of all parameters.

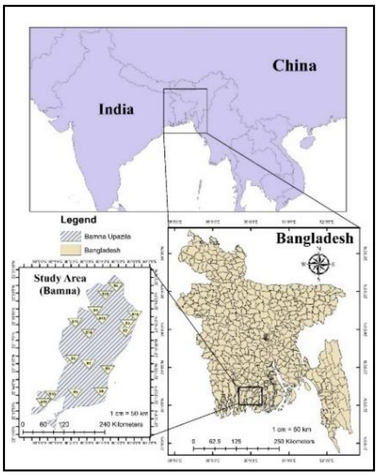

Figure 1: Locations of soil samples collection from Bamna, Barguna, Bangladesh

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2.3 Determination of Soil texture

Hydrometer method was used for particle size analysis (Huluka et al., 2014: Papuga et al., 2018). The USDA system restrictions were followed in the particle separation process. Marshall's Triangular Coordinate diagram was used to figure out the textural classes of the soils (Malone et al., 2021).

2.4 Determination of moisture content (MC)

The gravimetric method was used to estimate the MC of the soil (Dobriyal et al., 2012). This procedure involves measuring the weight of soil in its moist state and comparing it to its dry weight after oven drying. Samples were weighed immediately after collection to record their moist weight. The samples were dried for 24 hours at 100–105°C in an oven until they reached a constant weight, at which point the dry weight was determined. To carry out the procedure, an empty aluminum container was first weighed, after which 40 g of soil was added and weighed again. After that, the soil container was kept in an oven set to 105°C for 24 hours. After drying, the oven-dry weight was note down. The following equation (1) was used to measure soil MC(%) :

$$\% \text{ Soil MC} = (W_1\text{-}W_2/W_2\text{- } W_3) \times 100 \quad (1)$$

Where, W_1 is the weight of moist soil + can; W_2 is the weight of oven-dry soil + can; and W_3 is the weight of the empty can.

2.5 Determination of Bulk density (BD)

The Core sampler method was used to measure the bulk of the soil (Walter et al., 2016). After being pushed into the soil to the required depth, a cylinder-shaped metallic core sampler with defined height and diameter was carefully withdrawn. Both ends of the sample container were cut and flushed with a sharp spatula to guarantee that the soil sample and core volume were equal. Next, the following formula (2) was used to determine the BD.

$$BD = ms/Vt \quad (2)$$

Where, 'BD' denotes the soil's bulk density in gcm^{-3}.; 'ms' denotes the soil's oven-dry weight (g); and 'Vt' denotes the volume of the soil (cm^3) filled in the core sampler.

The following equation (3) was used to determine the volume of soil or core sampler (Vt):

$$Vt = \pi r^2 h \quad (3)$$

Where, 'r' denotes the radius of the core sampler and 'h' denotes the height of the sampler.

2.6 Determination of particle density (PD)

The volumetric flask method was used to assess the soil's PD (Rawlins et al., 2013). The following formula (4) was used to determine the PD.

$$PD\ (gcm^{-3}) = \frac{\text{Weight of oven dried soil in g}}{\text{Volume of soil particles in cm}^3} \quad (4)$$

2.7 Determination of porosity

The total porosity of soil was determined from the formula (5) given by Vomocil shown below:

$$\text{Total porosity (\%)} = 100(1 - Db/Dp) \quad (5)$$

Where, Db denotes the bulk density (gcm^{-3}), Dp denotes the particle density (gcm^{-3}) (Cooper et al., 2012).

2.8 Determination of the pH

A glass-electrode pH meter was used to evaluate the pH of soil in a suspension of water and soil; the ratio of soil to water was 1:2.5 (Makweta et al., 2015). A standard buffer solution was used to calibrate the electrode at pH 4.0 and 7.0 before a pH measurement was made.

2.9 Determination of the electrical conductivity (EC)

In 1:5 soil-water suspensions, the soil EC 1:5 was measured by using EC meter (HANNA EC 214) (Klaustermeier et al., 2016). A 150 ml beaker was filled with 20 grams of air-dried soil from the sample, and then 100 ml of distilled water was added. The mixture was thoroughly stirred over the course of 30 minutes and then filtered. The EC of the soil-water suspension (1:5 ratio) was determined by an EC meter. The obtained EC 1:5 values were then transformed using conversion factors published in the literature to equilibrium conductivity (ECe), a measure of actual soil salinity (Lam et al., 2022; Wang et al., 2017).

2.10 Determination of the organic carbon (OC)

The wet oxidation technique was used to measure the soil's OC (Ramamoorthi et al., 2018). The fundamental theory was to oxidize the organic matter (OM) with an excess of N $K_2Cr_2O_7$ in the presence of conc. H_2SO_4 and conc. H_3PO_4 and to titrate the residual $K_2Cr_2O_7$ solution with N $FeSO_4$ solution. The Van Bemmelen factor (1.73) was multiplied by the amount of OC to determine the OM content, which was then expressed as a percentage.

2.11 Determination of the total nitrogen (N)

Micro-Kjeldahl method was followed to measure the total N content in soil (Upadhyay et al., 2012). Here, soil samples were digested with conc. H_2SO_4 in existence of K_2SO_4 catalyst combination (K_2SO_4:Cu_2SO_4, $5H_2O$: Se = 100:10:1). The N content in the digest was measured by distillation with 10N NaOH, followed by titration of the distillate, which was trapped in an H_3BO_3 indicator solution, using 0.01N H_2SO_4.

2.12 Determination of the exchangeable potassium (K)

The ammonium acetate extraction procedure was used to extract the soil's exchangeable K content. The extraction was performed by continuously mixing and centrifuging 5 g of soil with 25 ml of neutral 1M NH_4OAc, followed by decantation. After putting 5 ml of the extract in a 10-ml test tube, diluted to the appropriate level and analyzed using a flame photometer to obtain the reading (Kenyanya et al., 2013).

2.13 Determination of the exchangeable sodium (Na)

Exchangeable Na content of the soils was evaluated by retaining soil (5gm) in a plastic bottle and adding 25ml of 1M NH_4OAc. After shaking the mixture for five minutes, It was filtered. A 5 ml of the extract was transferred to a 10 ml test tube, diluted to the mark with distilled water, and analyzed using a flame photometer (Elfaki et al., 2015).

2.14 Determination of the available P

Soil was shaken with 0.5 M $NaHCO_3$ (pH 8.5) in order to determine the amount of P that was available. Using phosphomolybdate complex reduction and blue color development with molybdate ascorbic acid reagent, the extractable P in solution was colorimetrically evaluated at 890 ηm wavelength (Koralage et al., 2015).

2.15 Determination of the available S

To assess the available sulfur concentration, the soil samples were extracted using a 0.15% $CaCl_2$ solution. A spectrophotometer set to 420 ηm wavelength was used to determine the S content in the extract turbidimetrically (Chaves et al., 2021).

2.16 Statistical and other analysis

The research area and the collected data were illustrated using ArcMap 10.8.2 software. The gathered data were analyzed via Microsoft Office Excel and STAR 2.0.1 software (Standardized Test for the Assessment of Reading). Subsequent to the ANOVA, Tukey's HSD ($\alpha = 5\%$), DMRT, and LSD were used to compare the soil data. The EC and pH values of soils were evaluated according to land type and land usage. Furthermore, principal component analysis was conducted, and the biplot and correlation figure were visualized using RStudio version 4.3.3.

3. RESULT AND DISCUSSION

3.1 Determination of physical properties of soil

3.1.1 Soil Texture

The mechanical examination was conducted to ascertain the relative proportions of sand, silt, and clay in the soils, ultimately identifying the textural classes (Table 2). The predominant textural class identified was silty, comprising around 68.91%. The maximum silt concentration was recorded in Bamna union, Shofipur-1, and Gudighata, Dewatola union (89.43%-89.64%), whereas the minimum was found in Hogolpati-2, Dewatola union (34.74%). The mean contents of clay and sand were 23.77% and 7.33%, respectively. Furthermore, the particle size distribution findings revealed that silt and silty clay loam were the predominant soil textural classes in the research locations. They also documented many soils textural types in the salty regions of the south-central coast, with silty clay loam and clay loam as the main classifications (Jerin et al., 2021).

3.1.2 Moisture Content (MC)

Table 2 indicates that the moisture range fluctuated between 18.43% and 38.12%. The maximum MC was documented in Shofipur-2, whereas the minimum was noted in Gudighata, Dewatola union, and Bukabunia, Bukabunia union. Soil MC in coastal areas fluctuates according to terrain types and soil textural classifications (Bhuyan et al., 2023ab; Salehin et al., 2018). They previously found that soil moisture levels in lowlands varied from 25% to 36%, in medium-high lands from 20% to 25%, and in high lands from 12% to 25% (Bhuyan et al., 2023a). In our research, we assessed soil moisture within the polders (or embankments) but did not evaluate moisture according to soil type. Salinity is directly correlated with soil MC in the south-central coastal region of Bangladesh (Bhuyan et al., 2023a). Consequently, our research offers significant insights into salinity management in coastal regions.

3.1.3 Bulk density (BD)

The mean BD of Bamna subdistrict was 1.40 g/cm^3. Bulk density is a crucial indicator of soil penetration by plant roots, signifying the degree of soil compaction. It impacts essential soil characteristics and processes, including soil porosity, aeration, rooting depth, water retention capacity, water infiltration, plant nutrient availability, and soil microbial activity, all of which influence overall soil productivity (Shah et al., 2017). The BD data of the research region indicate conditions conducive to plant growth. They indicated that the bulk density of coastal soils ranged from 1.30 to 1.47 g cm^{-3} (Hossin et al, 2022).

3.1.4 Particle density (PD)

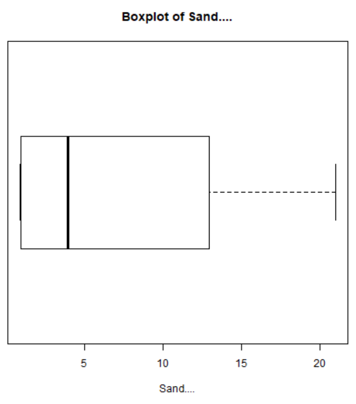
In this study, we noted that PD varied from 2.38 to 2.50 g cm^{-3}, with an average of 2.45 g cm^{-3} (Table 2). The minimum PD of 2.38 g cm^{-3} was observed at Gudighata, Dewatola union. Conversely, the maximum value of 2.50 g cm^{-3} was recorded in Dewatola and Talesshor-1, Bukabunia union. PD data are crucial for comprehending the physical and chemical properties of soil. A low bulk density (<1.0 g cm^{-3}) generally indicates that the soil possesses a substantial quantity of organic matter. Moreover, our results correspond with those, who documented a PD between 2.31 and 2.49 g cm^{-3} in proximity to the coastal belt of the south-central coastal zones (Hossain et al., 2022).

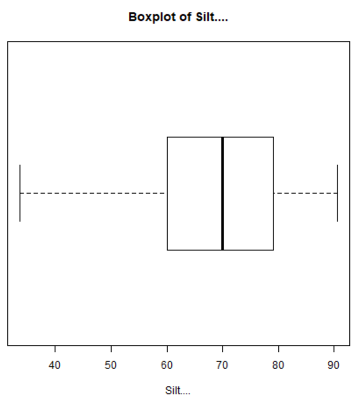
3.1.5 Porosity

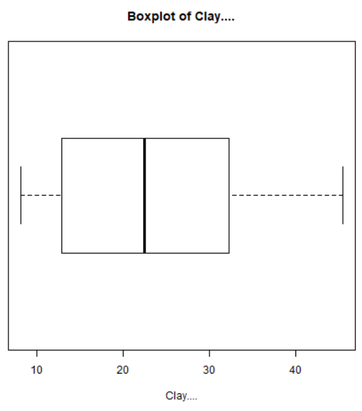
Table 2 demonstrates that soil porosity in the research sites varied from 41.18% to 44.58%. The soil at Talesshor-1, Bukabunia union, demonstrated the highest porosity at 44.58%, while Boloibunia, Gudighata, and Chalitabunia-2 revealed the lowest porosity, ranging from 41.18% to 41.27%. Our findings reveal that the predominant portion of the soil's volume comprises pore space, which is filled with air and water. The pore space is essential for plant growth, water retention, and gas exchange (Dexter et al., 2008). An ideal soil for plant growth comprises approximately 50% pore space within its whole volume (Ramesh et al., 2019). They conducted a GIS-based soil mapping study in Bangladesh, revealing that soil porosity in the south-central region varies considerably, from 50% to 70% (Islam et al., 2017). This variance is mainly due to the prevalence of coarse-textured soils in the coastal regions (Bhuyan et al., 2023b). Consequently, assessing soil porosity is crucial for efficient agricultural planning and land management (Islam et al., 2017).

Table 2: Sampling information and physical parameter (mean±SD) of soil of Bamna Upazilla

Samples	Sand (%)	Silt (%)	Clay (%)	Texture	Moisture (%)	BD (gcm^{-3})	PD (gcm^{-3})	Porosity (%)
S1	0.96±0.02	89.44±0.56	9.6±0.69	Silt	24.44±0.64	1.38±0.01	2.42±0.02	42.98±0.12
S2	0.96±0.02	89.64±0.46	9.4±0.12	Silt	32.77±0.64	1.44±0.02	2.49±0.01	42.17±0.64
S3	2.96±0.02	64.59±0.45	32.45±0.52	Silty Clay Loam	38.11±0.55	1.40±0.12	2.44±0.01	42.62±0.12
S4	0.96±0.01	63.29±0.66	35.75±0.46	Silty Clay Loam	28.98±0.12	1.41±0.01	2.46±0.01	42.68±0.64
S5	0.96±0.01	78.6±1.00	20.44±0.25	Silt Loam	23.02±0.57	1.36±0.01	2.43±0.01	44.03±0.57
S6	2.96±0.01	68.38±0.61	28.66±0.64	Silt Loam	30.21±0.64	1.37±0.01	2.42±0.02	43.39±0.69
S7	0.96±0.01	79.74±1.11	19.3±0.52	Silt Loam	27.41±0.46	1.48±0.01	2.52±0.06	41.27±0.69
S8	16.96±0.02	73.84±0.64	9.2±0.64	Silt Loam	25.62±0.64	1.45±0.01	2.5±0.01	42.00±0.58
S9	0.96±0.02	89.64±0.52	9.4±0.69	Silt	18.43±0.23	1.40±0.02	2.38±0.01	41.18±0.64
S10	4.96±0.01	70.74±0.69	24.3±0.17	Silt Loam	25.45±0.64	1.41±0.01	2.47±0.01	42.91±0.08
S11	20.96±0.02	34.74±0.64	44.3±0.64	Clay	20.56±0.64	1.39±0.01	2.47±0.01	43.72±0.69
S12	6.96±0.01	49.02±0.58	44.02±0.58	Silty Clay	18.97±0.12	1.36±0.01	2.4±0.06	43.33±0.64
S13	10.96±0.01	56.96±0.59	32.08±0.60	Silty Clay Loam	22.12±0.06	1.38±0.01	2.49±0.06	44.58±0.52
S14	10.96±0.02	72.73±0.64	16.31±0.75	Silt Loam	20.96±0.49	1.42±0.01	2.42±0.06	41.32±0.64
S15	14.96±0.01	69.42±0.64	15.62±0.45	Silt Loam	25.56±0.69	1.35±0.01	2.42±0.06	44.21±0.52
S16	18.96±0.02	51.74±0.64	29.3±0.24	Silt Loam	21.87±0.52	1.48±0.01	2.40±0.01	41.27±0.52
CV (%)	0.3498	1.69	3.89		3.57	3.86	2.40	2.26
Mean	7.33	68.91	23.77		25.26	1.40	2.45	42.73
Std. Err.	0.0209	0.9506	0.7547		0.7361	0.0443	0.0480	0.7871







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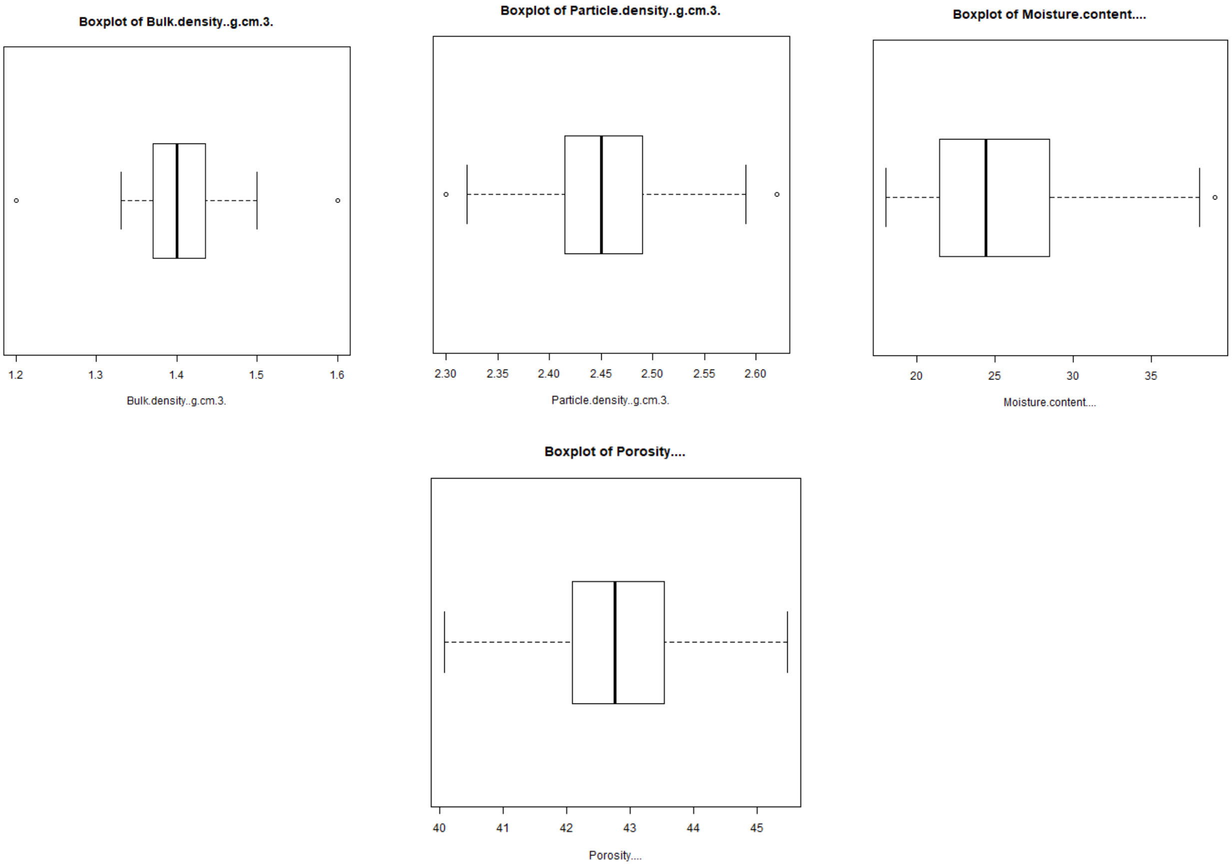

Figure 2: Box plot of Physical properties of Soil samples

The distribution of different soil physical qualities is graphically represented by the series of box plots, which also show significant variability in their statistical characteristics (figure 2.), reflecting inherent variations in the composition and processes that generate the soil. A balanced representation of the data around their medians and a uniform influence of contributing factors are suggested by the relatively symmetrical distributions of several properties, such as clay, silt, and porosity (median ≈ 42.5%), particle density (median ≈ 2.45 g/cm^3), and bulk density (median ≈ 1.4 g/cm^3). For example, the symmetry in bulk density and porosity may suggest a somewhat uniform degree of soil compaction and pore space development throughout the region, while the symmetry in particle density suggests a consistent mineral composition across samples. On the other hand, sand exhibits a modest positive skew, with values reaching up to about 22%. This could be a sign that there are subsamples with a higher sand content because of localised differences in parent material deposition or sorting by wind or water. With an outlier of about 38%, the moisture content likewise shows a slight positive skew. This could be explained by recent localised precipitation events, localised variations in drainage, or variations in the soil's ability to retain water. Additionally, the level of variability varies among the properties; for example, bulk density and porosity seem to exhibit less dispersion, indicating a more homogeneous physical structure, perhaps as a result of consistent management techniques or soil development, whereas sand exhibits more variability, reflecting the heterogeneous distribution of soil texture. Particle density (about 2.3 g/cm^3 and 2.6 g/cm^3), bulk density (approximately 1.2 g/cm^3 and 1.6 g/cm^3), and moisture content (around 38%) all exhibit a small number of outliers, indicating the occurrence of extreme values within these particular parameters. To determine their precise origins and consequences for soil performance, more research is necessary. These outliers most likely reflect localized anomalies such changes in mineral content, compaction, or water buildup.

3.2 Determination of chemical properties of soil

The basis of balanced soil chemistry is the equilibrium of minerals in the soil. Soil fertility is affected by multiple factors, including nutrient availability, soil pH, salinity, electrical conductivity, and organic matter content. Salt stress inhibits plant growth on agricultural land, and nutrient deficiencies resulting from salt can adversely impact agricultural productivity. The chemical characteristics of soils in Bamna Upazila, Barguna, Bangladesh, are encapsulated in Table 3.

3.2.1 Concentration of pH

Table 3 reveals that the mean pH value in Bamna Upazila was 6.24, signifying somewhat acidic soil. In the research area, pH values ranged from 5.12 to 6.85. Ramna-1 exhibited the lowest pH value, whereas Chalitabunia-1 demonstrated the highest pH value. Our results are inconsistent with those, who documented pH values between 7.2 and 8.5 in the southwestern coastal area of Bangladesh (Ashrafuzzaman et al., 2022). This may be attributed to the elevated salinity levels in this region, as the saline soil exhibits a pH of less than 8.5 (Osman et al., 2018). Soil pH influences nutrition availability by altering the chemical forms of nutrients in the soil (Neina, 2019). Modifying the soil pH to the recommended range can improve the availability of vital nutrients. Most plants flourish at pH values exceeding 5.5, with a pH of 6.5 typically regarded as optimal for nutrient availability (Osman, et al., 2018).

3.2.2 Salinity concentration

The salinity concentration in the investigated locations exhibits geographic variability. Moderate to elevated salinity levels (6.05–11.90 dSm^{-}1) have been observed in proximity to the coastline unions, including Hogolpati=1, Dewatola, Ramna-1, Chalitabunia-1, Ramna-2, Talesshor-1, Talesshor-2, and Hogolpati=2. Conversely, reduced salinity levels (1.85-4.70 dSm^{-}1) are observed in interior regions situated further from the the coast, including Boloibunia, Chalitabunia-2, Shofipur-1, Bamna, and Amtoli. Our findings align with those, who indicated that salinity levels are elevated in coastal locations relative to inland regions (Bhuyan et al.,2023a). This is mainly attributable to the direct flooding of coastal land by tidal waters, resulting in salt deposition in the topsoil (Bhuyan et al., 2023a).

The soil's salt concentration is denoted by the proportion of NaCl present. The current investigation noted that the most significant percentage values of NaCl were identified in Ramna-1, Dewatola, and Hogolpati=1. The minimal NaCl percentage values were identified at Amtoli; Hogolpati=2; and Bamna (1.50%, 1.40%, and 1.20%,

3.2.3 Cl concentration

The mean Cl concentration in Bamna Upazila is 668.85 ppm. They also recorded chlorine concentrations between 2000 and 3000 ppm in the southern coastal area of Bangladesh (Ashrafuzzaman et al., 2022). Chloride is regarded as a nutrient and a helpful ion for higher plants (Geilfus and Mühling, 2014). A Cl content of 100 ppm in soils is considered optimal for crop growth (White and Broadley, 2001). The Cl concentration in Bamna Upazila ranges from 198 ppm to 1270 ppm.

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3.2.4 Concentration of organic carbon (OC)

The minimum concentration of OC (0–15 cm depth) was recorded at 0.58-0.64% in Shofipur-1 and Talesshor-2. Conversely, Gudighata demonstrated the highest percentage of organic carbon (1.76%). In Bamna Sub-district, the mean organic carbon concentration in agricultural land is 1.20% (Table 3). Soil OC is a vital indication of soil quality, affecting nutrient availability and plant growth, and significantly contributes to agricultural productivity, especially in arid and semi-arid zones (Uddin et al., 2019). They report that the percentage of organic carbon in coastal regions varies from 0.28% to 0.77% (Miah et al., 2021). Likewise, documented a low OC concentration in the southern coastal region, varying from 0.87% to 1.82% (Shaibur et al., 2017). Ideally, soil OC should range from 0.5% to 3% in highland soils; nevertheless, the OC concentrations in the research area are approaching the ideal range. Additionally, a substantial amount of arable land in coastal regions goes uncultivated during arid intervals, leading to progressive carbon depletion from the soil (Uddin et al., 2022). Consequently, efficient land management is crucial for augmenting soil carbon reserves.

3.2.5 Concentration of organic matter (OM)

Soil OM levels in the research area were rather low, ranging from 1.00% to 3.04%. (Table 3). Gudighata had the highest OM concentration (3.04%). Similarly, found that OM content in different south-eastern coastal regions of Bangladesh ranged from 1.91% to 2.07% (Roy et al., 2021). According to the study, OM is critical for enhancing water-holding capacity, maintaining and delivering nutrients, improving soil structure, and reducing CO_2 emissions to combat climate change (Johnston et al., 2009). Most productive agricultural soils should contain between 3% and 6% organic matter (Celestina et al., 2019). According to the study and the Ministry of Agriculture, the bulk of Bangladeshi soils have less than 1.5% OM (BARC, 2005). However, OM concentrations in Bamna Upazila are not unusually low. The bulk of coastal soils are saline, which may have a negative impact on OM levels, especially along the coastline (Morrissey et al., 2014).

3.2.6 Concentration of total nitrogen (N)

The total N levels in the research region range from 0.11% to 0.29%. The highest concentration was noted in Talesshor-1, Shofipur-1, Ramna-1, and Dewatola, whilst the lowest concentration was detected in Chalitabunia-1 and Shofipur-2. The low nitrogen level is mainly due to the relatively low organic matter content of the soils. Moreover, inadequate nitrogen management has led to heightened leakage of reactive nitrogen into the natural environment (Rahman et al., 2021). They reported an average nitrogen concentration of roughly 0.1% in the southwestern coastal area of Bangladesh (Moslehuddin et al., 2015). Furthermore, they noted fluctuations in nitrogen percentages along a distance gradient in the coastal area, varying from 0.05% to 0.07% (Ahmed et al., 2020). As per study, nitrogen is a crucial macronutrient for crops, with an ideal soil nitrogen concentration for fertility being 2.27% (MoA, 2010). Conversely, Bamna Upazila exhibits an average nitrogen concentration of 0.190% (Table 3), signifying that nitrogen levels in the soils of this area are markedly below optimal values.

3.2.7 Phosphorus (P) concentration

P is an essential nutrient for plant growth, significantly contributing to various processes, including photosynthesis, enzyme regulation, energy transmission and storage, and carbohydrate transport. The total phosphorus contents in the soil within the research area ranged from 9.56 to 48.56 parts per million. The greatest concentrations of phosphorus were identified in Chalitabunia-1, where the soil salinity is quite low, measuring 39.35 ppm and 49.68 ppm, respectively. In the southern coastal soils of Bangladesh, phosphorus availability ranges from 9 to 27 ppm (Sarkar et al., 2021). The phosphorus availability status of the coastal soils varies from 8 to 36 ppm (Rahman et al., 2014). They identified a phosphorus concentration of 261.3 ppm, while reported accessible phosphorus levels ranging from 1 to 25 ppm (Haque et al., 2018; Moslehuddin et al., 2015). The P value in Bamna upazila is comparable to that of other research sites in the coastal region of Bangladesh.

3.2.8 Potassium (K) concentration

K, which is intricately linked to plant growth, is an essential component for soil fertility. The minimum potassium concentration (12.76) was recorded in Bamna, where non-saline soil was identified. Talesshor-2, a non-saline region, with the highest potassium concentration at 110.55. The mean potassium concentration in Bamna Sub-district is 046.13 (Table 3). In comparison to the SRDI data from 2020, the potassium levels in this study area are optimal. The fluctuation of potassium in soil salinity is less pronounced than the change of nitrogen and phosphorus in the research area. The research conducted revealed the greatest potassium level (51.2 ppm) in southern coastal soil (Haque et al., 2018). They identified potassium (K) concentrations ranging from 0.15 to 0.33 meq/100 g in the southeastern coastal zone of Bangladesh (Islam et al., 2017). The potassium content ranged from 0.12 to 0.40 meq/100 g in the Barishal district and from 0.23 to 0.61 meq/100 g in Patuakhali (Ansari et al., 2020). They report that the soil in the southwest coastal region (Shyamnagar Upazila) has a cation exchange capacity ranging from 12.0 to 27.6 meq/100 g (Ashrafuzzaman et al., 2022). Consequently, the potassium concentration in Bamna upazila is comparable to that observed in other research conducted in different study areas.

S concentration

The figure 3. illustrates the distribution of ten soil properties in boxplots: available sulfur (Avail. S), chloride (Cl), organic carbon (OC), electrical conductivity (EC), exchangeable potassium (Ex. K), and sodium chloride (NaCl), organic carbon (OC), organic matter (OM), pH, and total nitrogen (TN).

The concentrations of sulphur and chloride exhibit a moderate range, with most samples ranging from 100 to 200 ppm for sulphur and 400 to 600 ppm for chloride. Organic carbon displays a broader range, with a median of 200 ppm and a considerable number of outliers. The electrical conductivity has a moderate range, centred around 0.5 dS/m. Exchangeable potassium exhibits a limited range, with a median approximately 0.2 meq/100g. The sodium chloride content exhibits considerable variability, with a median approximately at 2 and numerous outliers. The boxplots indicate that the soil samples in this study exhibit a moderate concentration of accessible sulphur and chloride, with fluctuations in organic carbon, electrical conductivity, exchangeable potassium, and sodium chloride influencing the overall soil fertility and quality. Organic carbon and organic matter display a moderate range, with medians of 1.5% and 2.5%, respectively. The pH distribution is right-skewed, signifying a greater proportion of samples with lower pH values. Total nitrogen exhibits a limited range, centred around 0.15%. The boxplots indicate that the soil samples in this study possess a moderate concentration of organic carbon and matter, with fluctuations in pH and total nitrogen influencing the overall soil fertility and quality.

Table 3: Sampling information and chemical properties (mean±SD) of soil samples of Bamna Upazilla

Samples	pH	ECe (dSm^{-1})	NaCl (%)	Cl^- (ppm)	OC (%)	OM (%)	TN (%)	Avail. P (ppm)	Avail. S (ppm)	Ex. K (meq $100g^{-1}$)
S1	6.41±0.23	2.55±0.29	1.2±0.12	271±11.55	0.87±0.12	1.51±0.02	0.12±0.01	22.65±0.69	12.76±0.64	0.24±0.03
S2	6.02±0.17	3.45±0.43	1.6±0.13	421±17.32	0.58±0.06	1.00±0.02	0.32±0.06	26.87±0.64	28.90±0.69	0.15±0.03
S3	6.23±0.17	5.6±0.87	2.3±0.10	522±28.87	1.62±0.17	2.80±0.02	0.11±0.02	17.21±0.64	49.04±0.59	0.22±0.06
S4	6.04±0.23	1.85±0.17	1.5±0.13	198±16.17	0.72±0.07	1.25±0.02	0.21±0.06	25.67±0.69	20.11±0.64	0.29±0.06
S5	5.12±0.06	10.8±0.58	4.2±0.22	1270±23.09	1.23±0.08	2.13±0.03	0.17±0.05	15.76±0.29	28.93±0.64	0.23±0.04
S6	6.11±0.17	9.1±0.40	2.1±0.12	860±11.55	1.52±0.12	2.63±0.01	0.14±0.02	20.98±0.69	44.56±0.64	0.29±0.04
S7	5.56±0.29	4.7±0.64	1.7±0.10	502±18.48	1.12±0.12	1.94±0.03	0.21±0.05	20.45±0.64	22.78±0.69	0.31±0.05
S8	6.68±0.12	11.6±0.20	3.7±0.10	987±11.55	1.41±0.06	2.44±0.02	0.31±0.06	22.54±0.64	45.86±0.64	0.24±0.05
S9	6.83±0.06	7.65±1.44	3.2±0.07	912±8.82	1.76±0.12	3.04±0.02	0.16±0.02	40.23±0.64	98.98±0.12	0.34±0.06
S10	6.74±0.12	11.9±0.32	4.5±0.12	1031±19.05	1.21±0.06	2.09±0.02	0.06±0.01	16.94±0.69	22.02±0.06	0.21±0.06

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Table 3(cont): Sampling information and chemical properties (mean±SD) of soil samples of Bamna Upazilla

S11	6.46±0.23	6.05±0.29	1.4±0.12	311±12.70	1.51±0.06	2.61±0.02	0.13±0.03	12.95±0.64	75.51±0.64	0.29±0.05
S12	5.93±0.23	4.2±0.38	3.4±0.10	834±20.78	1.34±0.08	2.32±0.03	0.17±0.03	9.56±0.64	32.67±0.64	0.28±0.03
S13	5.95±0.12	8.6±0.23	3.2±0.10	862±17.32	1.13±0.06	1.95±0.02	0.29±0.03	30.57±0.64	88.64±0.64	0.28±0.02
S14	6.57±0.17	7.9±0.46	2.3±0.08	732±23.09	0.64±0.08	1.11±0.02	0.18±0.03	29.44±0.06	110.55±0.64	0.25±0.02
S15	6.85±0.06	9.65±0.58	3.1±0.11	607±11.55	1.38±0.10	2.39±0.03	0.11±0.02	48.56±0.64	16.87±0.64	0.21±0.03
S16	6.31±0.01	4.3±0.06	2.7±0.01	385±1.15	1.15±0.01	1.99±0.02	0.21±0.01	42.40±0.01	39.89±0.01	0.34±0.02
CV (%)	4.73	1.22	1.10	4.42	1.88	1.87	5.74	3.94	2.17	4.80
Mean	6.24	6.87	2.63	668.85	1.20	2.08	0.1900	25.17	46.13	0.2606
Std.Err.	0.2411	0.0687	0.0236	24.16	0.0184	0.0316	0.0089	0.8091	0.8183	0.0102

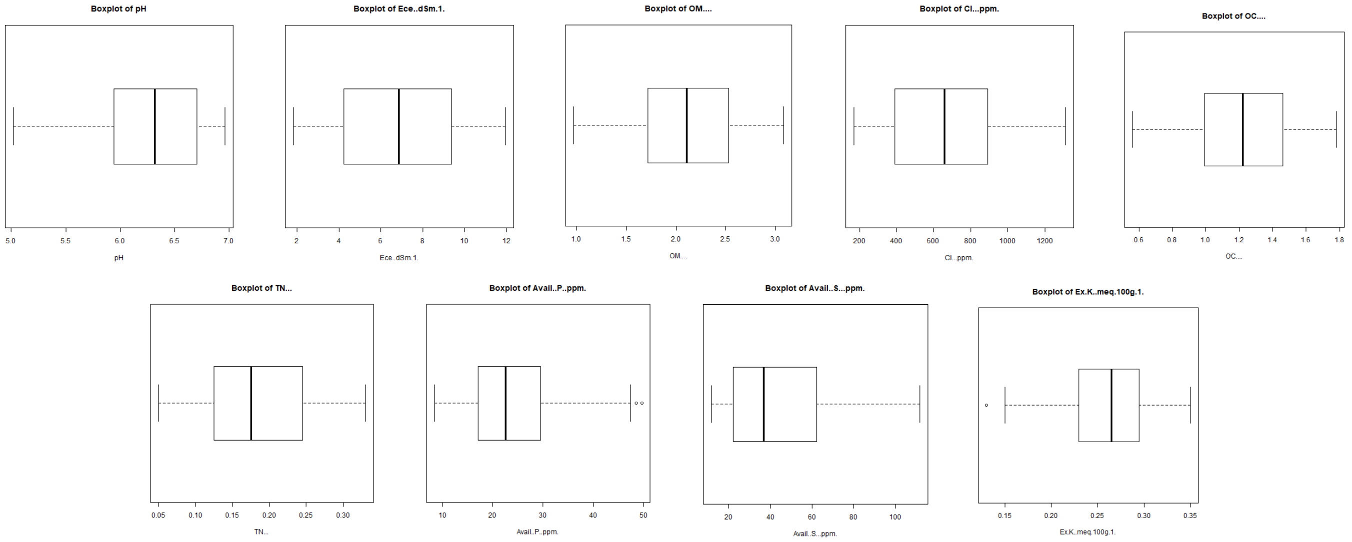
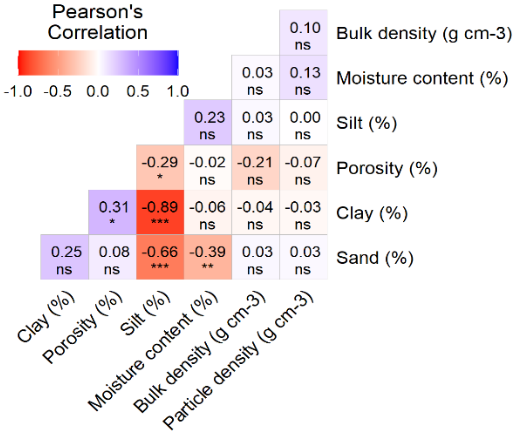


Figure 3: Box plot of chemical properties of soil samples

Notes: OM= Organic matter, OC= Organic carbon, TN= Total nitrogen, EC= Electric conductivity

Inherent variances in soil formation processes and composition are reflected in the series of box plots that graphically depict the distribution of different soil chemical properties, exposing significant discrepancies in their statistical characteristics (figure 3.). A balanced representation of the data around their medians and a uniform influence of contributing factors are suggested by the relatively symmetrical distributions of several properties, such as Organic Matter (OM) (median ≈ 2.0), Total Nitrogen (TN) (median ≈ 0.17), and Organic Carbon (OC) (median ≈ 1.2). For example, the symmetry in the distributions of OM, TN, and OC suggests a steady rate of organic matter breakdown and nutrient cycling among samples, suggesting a rather constant soil organic matter state. A consistent influence of factors affecting salt accumulation, such as weathering of minerals or irrigation practices, is suggested by the relatively symmetrical distributions of Chloride (Cl) (median ≈ 600 ppm), Sodium Chloride (NaCl) (median ≈ 2.5), and Electrical Conductivity (Ece) (median ≈ 7 dSm^{-1}). On the other hand, the pH (median ≈ 6.4) exhibits a tiny negative skew, with the box tilted towards higher pH values. This could suggest a trend towards slightly alkaline conditions, which could be caused by leaching patterns or the presence of carbonate minerals. With values extending to roughly 110 ppm and 50 ppm, respectively, Available Sulphur (Avail. S) (median ≈ 40 ppm) and Available Phosphorus (Avail. P) (median ≈ 22 ppm) both exhibit a positive skew, which may suggest the presence of subsamples with higher nutrient concentrations as a result of localized fertilization or mineralization. In addition, the degree of variability varies; for example, pH seems to exhibit less dispersion, indicating a well-buffered system, perhaps as a result of the presence of carbonates or clay minerals, whereas properties such as Ece and Cl exhibit more variability, reflecting the heterogeneous nature of salt distribution. Only Exchangeable Potassium (Ex.K) (about 0.15 meq/100g) and Available Phosphorus (around 50 ppm) exhibit outliers, indicating the occurrence of extreme values within these particular parameters. These outliers probably reflect localised abnormalities such changes in nutrient inputs or mineral content, which calls for more research to determine their precise causes and effects on soil fertility and health.

3.3 Correlation between different physical properties of soil

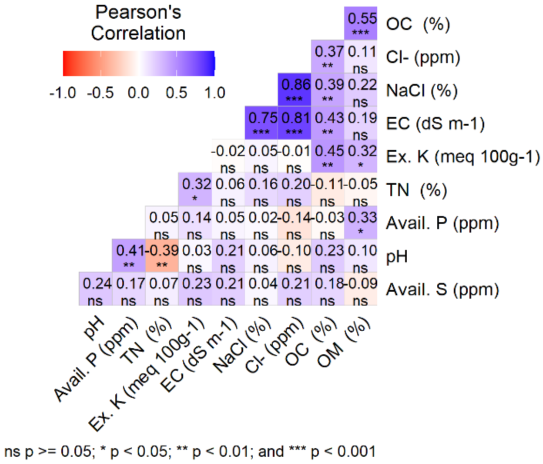


ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001

Figure 4: Correlation between different physical properties of soil

Figure 4 illustrates the Pearson correlation coefficients of diverse soil parameters. It illustrates the interactions among clay, porosity, silt, moisture content, bulk density, particle density, and sand. The colour gradient from red to blue signifies a transition from negative to positive association, while the asterisks represent the level of significance. A robust negative association (−0.89, ***) occurs between silt concentration and porosity. The current correlation indicates that an increase in silt significantly affects porosity. Moisture content and bulk density exhibit a negative correlation of -0.66, signifying that denser soils retain less moisture. Consequently, clay content has a positive connection with porosity (0.31, *), clearly suggesting that pore space increases as clay concentration rises. The bulk of other interactions, such as those between sand and particle density, exhibit weak or statistically negligible associations. The interdependencies of soil physical parameters are crucial for comprehending soil structure in relation to water retention and overall soil health in agricultural and environmental research.

3.4 Correlation between different chemical properties of the soil



ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001

Figure 5: Correlation between different chemical properties of the soil

Figure 5. shows Pearson's correlation coefficients for some selected chemical properties of soils relating to organic carbon (OC) chloride (Cl^-), sodium chloride (NaCl), electrical conductivity (EC), exchangeable potassium (Ex. K), total nitrogen (TN), available phosphorus (Avail. P), pH, and available sulfur (Avail. S). The correlation is color-coded from red - to blue, through asterisks to indicate the level of statistical significance. A significant positive correlation of NaCl and EC (0.86, ***) indicates the contribution of sodium chloride to soil conductivity. Having a corresponding value of 0.75, EC and Ex. K are also significantly correlated (***), suggesting some inherent relationship between conductivity and availability of potassium. OC is moderately positively correlated to TN (0.55, ***); thus, soils rich in organic matter have high nitrogen content. Nevertheless, Ex. K and TN had a moderate negative correlation (-0.39, **), which may imply competition or selective accumulation of such nutrients. Other correlations that included pH, Cl^-, and Avail. S were weak or statistically insignificant. This correlation analysis certainly offered a precursor basis for investigating soil nutrient interactions, which will aid soil fertility, salinity management, and ultimately agricultural productivity.

3.5 Principal component analysis of physical and chemical properties of soil samples

Table 4 presents the findings of the Principal Component Analysis (PCA) performed on sampled soils. This illustrates the soil qualities that account for the first two primary components, designated as PC1 and PC2. The eigenvalues of 3.540 and 2.731 signify the relative significance of PC1 and PC2 in elucidating the overall variance of the data set. The variation attributed to PC1 is 20.824%, while PC2 accounts for 16.066%, resulting in a cumulative variance of 36.891% for the two principal components. This indicates that these two primary components encompass a significant proportion of the variability in soil parameters.

The eigenvectors of soil parameters in the table show the way in which each soil parameter contributes to PC1 and PC2. The higher the absolute value, the more the contribution to that principal component. Sand content (0.285), clay content (0.097), pH (0.162), electrical conductivity (EC) (0.388), sodium chloride (NaCl) (0.380), chloride (Cl-) (0.339), organic carbon (OC) (0.376), organic matter (OM) (0.285), and available phosphorus (Avail. P) (0.077) are positively contributing to PC1; hence, this component is mainly based on soil texture, salinity, and organic composition. Moisture content (-0.276), bulk density (-0.109), particle density (-0.109), and silt content (-0.212) have negative contributions to this principal component, implying that they have an inverse relationship with PC1.

On PC2, silt (-0.514), clay (-0.494), moisture content (0.047), porosity (0.101), and total nitrogen (TN) (0.173) formed most significant contributors. Negative contributions of silt and clay thus indicate that PC2 captures variations relating to texture, but the positive contributions of moisture, porosity and TN hint that this component relates to soil fertility and water-holding capacity. However, negative contributions to PC2 were found from electrical conductivity (-0.259), sodium chloride (-0.287), and chloride (-0.275), suggesting that salinity-related variables are less effective in this dimension.

Consequently, the comprehensive results of PCA may reveal significant characteristics that distinguish soil samples. PC1 mostly pertains to soil texture and salinity, whereas PC2 include variations related to fertility and moisture content. The integration of two primary components provides a comprehensive overview of soil variability, facilitating accurate classification and evaluation of soil health and quality.

Table 4: Results of PCA of collected soil samples

	PC1	PC2
Eigenvalue	3.540	2.731
Variance (%)	20.824	16.066
Cumulative Variance (%)	20.824	36.891
Eigenvector		
Sand	0.285	0.282
Silt	-0.212	-0.514
Clay	0.097	0.494
Moisture	-0.276	-0.047
Bulk density	-0.068	0.003
Particle density	-0.109	-0.009
Porosity	0.137	0.101

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Table 4(cont): Results of PCA of collected soil samples

pH	0.162	0.019
EC	0.388	-0.299
NaCl	0.380	-0.287
Cl$^-$	0.339	-0.375
OC	0.376	0.050
OM	0.285	0.144
TN	0.019	-0.173
Avail. P	0.077	-0.100
Avail. S	0.207	0.025
Ex. K	0.204	0.146

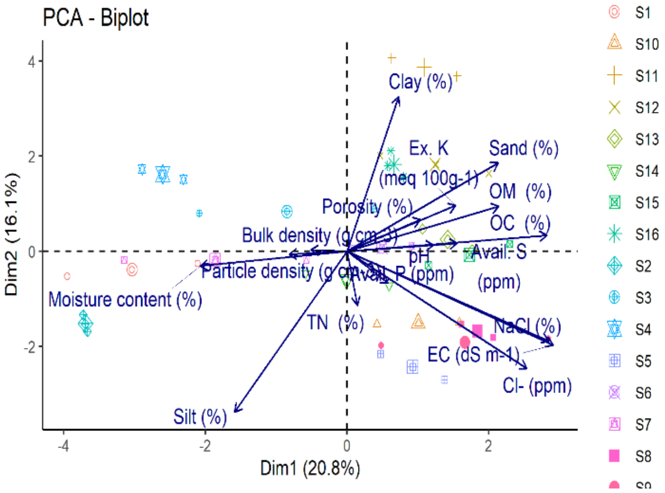

Figure 5: PCA biplot and correlation of physical and chemical properties of collected soil sample from Bamna Upazila

This biplot is derived from Principal Component Analysis (PCA) of a dataset encompassing diverse soil parameters of Bamna Upazila (Figure 5). The initial two components, Dim1 and Dim2, account for 20.8 percent and 16.1 percent of the overall variation, respectively. The plot displays soil samples labelled S1 to S16 as points. Each sample is designated with a unique symbol and colour that distinguishes it from the others. The principal soil parameters examined included moisture content, bulk density, porosity, particle density, pH, total nitrogen (TN), available phosphorus (P), exchangeable potassium (Ex. K), organic matter (OM), organic carbon (OC), and the percentages of sand, silt, clay, electrical conductivity (EC), sodium chloride (NaCl), and chloride (Cl-). The direction and magnitude of the arrows indicate their influence on the primary components.

For example, moisture content is negatively oriented to Dim1 and Dim2, which means it would be causing variance against the others such as silt content that was also quite strongly negatively correlated along Dim1. Conversely, significant factors such as sand content, organics, and organic carbon strongly influence the positive direction of Dim1. EC, NaCl, and Cl- have a strong positive correlation with Dim1 and slight negative correlation with Dim2.

The arrangement of soil samples on the biplot reveals patterns of resemblance. Samples that are relatively proximate are likely to exhibit similarities in soil parameters. Samples S4, S3, and S2 exhibit proximity to one another, suggesting they may have originated from soil of analogous composition. Samples S11 and S10 are significantly apart from one another, suggesting they likely possess distinct features. This PCA biplot illustrates soil variability, encompassing correlation and clustering patterns derived from the chemical and physical parameters of the soil samples.

4. CONCLUSION

This study examines the physical and chemical characteristics of soils in the saline and non-saline area of Bangladesh's south-central coast. The soil in this region generally shows a neutral pH, with OC content varying from medium to high levels. The availability of N and P was classified as moderate to elevated. Conversely, the available K varies from low to high, and the available S is exceedingly high. Furthermore, the presence of OM was at a moderate level. Consequently, the results of this research will assist various stakeholders, including policymakers and scientists, in making informed efforts to promote sustainable coastal soil management in Bangladesh. This research primarily focusses on a specific saline coastal area of Bangladesh. Subsequent research ought to concentrate on additional regions within the study areas to obtain comprehensive results.

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