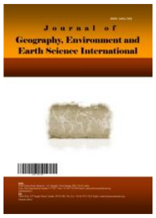

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Distribution and Geospatial Maps Based on Spatial Availability of Soil Physicochemical Characteristics at a Cyclone-affected Area in Southwestern Bangladesh

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Authors' contributions

This work was carried out in collaboration among all authors. Authors AR and ASM designed the study, conducted sample collection, handled the analyses of the study, drew all maps, wrote the protocol and wrote the first draft of the manuscript. Authors MSI and IJ performed the statistical analysis and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

On account of evaluating and mapping the spatial distribution of some selected physicochemical attributes of soil including the percentage of sand, silt and clay, textural class, soil reaction (pH), electrical conductivity (EC), and organic matter contents over a period of last 20 years, an investigation was carried out at cyclone-afflicted Shyamnagar sub-district, Satkhira, Bangladesh. Particle size analysis was examined by following the hydrometer method, whereas pH and EC were determined instrumentally. The carbon content of the soils was examined volumetrically by the wet-oxidation method. The amount of sand was less than the silt and clay fractions in the studied sites. Silt contents were significantly increased for over 20 years. Consequently, siltation has been taken

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place for the last two decades. Soil salinity was associated with the development of silt texture, altered from clay loam texture. The field moisture contents were observed to be increased (52%) which attributed to the increase of clay content with depth. Investigation revealed a very slow to moderate soil permeability class. An incremental trend (4.55% to 27.27%) of pH and EC (12.25 to 46.40 mS/cm) was noticed in the present study in contrast to the study of 1996. Alongside, corresponding spatial variability maps of the selected chemical soil properties were plotted by applying the Inverse distance weighting (IDW) interpolation method. Results demonstrated the southern, southeastern, and southwestern corners of the study area were experienced greater clay content, alkalinity, and significant depletion of organic matter. This situation might become worsened in near future. Moreover, the adoption of several effective countermeasures should be taken in this cyclone-affected soil to alleviate the soil salinity, improve soil health, and thereby deal with a more variable climate.

Keywords: Tropical cyclones; physicochemical properties of soil; geospatial maps; soil health; soil salinity.

1. INTRODUCTION

In pursuance of the Asian Development Bank (ADB), some predominant factors like climate change and global warming are considered as having massive and disastrous consequences for Bangladesh which makes it one of the most vulnerable countries whose 28% of the population are living in the coastal area [1]. Coastal areas, especially heavily populated mega delta regions in South, East, and South-East Asia, will be at greatest risk due to increased flooding from the sea as well as citing a trend since the mid-1970s toward longer duration and greater intensity of storms [2].

The Intergovernmental Panel on Climate Change (IPCC) suggests that by 2080, sea-level rise could convert as much as 33 percent of the world's coastal wetlands to open water. Dasgupta et al. figured out that homogenous 10% future intensification over the next 100 years increases the potential inundation zone to 25.7% of the coastal territory, taking into account sea-level rise [2,3]. This translates to potential inundation for an additional 52 million people, 29164 km^2 of agricultural area, 14991 km^2 of the urban area, 9% of coastal Gross Domestic Product (GDP), and 7% of wetlands, resulting in threatens coastal ecosystems severely [3]. Thus, it is crucial to bring out the dynamic risks and inversion of degraded environmental components in coastal areas. The trend of tropical cyclones hitting the Bangladesh coast is not steady. The result will likely be more devastating coastal storm events, combined with ongoing elevated coastal erosion and flooding, gradual inundation of low-lying lands, and, in many areas, the salinization of groundwater [4-6]. Most of the casualties from cyclones in Bangladesh, as in other parts of the world, are generated by storm surges as climate change will enhance the height of storm surges, leading to greater coastal flooding [6-7].

The southwest area lies between 21°30´ and 23°15´ north latitude, and 89°00´ and 90°00´ east longitude and includes the world's largest mangrove forest [8]. Satkhira, the south-western coastal district of Bangladesh, is thought to be the most disaster-prone region in consequence of frequent natural calamities and higher vulnerability to the effects of global warming, climate change, and sea-level rise. This area is the hub of all types of silent disasters like cyclone Sidr in 2007, Aila in 2009 and Mora in 2018, tidal surges, floods, drought, salinity intrusions, repeated water-logging, and land subsidence.

Devastating cyclonic storms and their consequent tidal surges enhanced the unfitted salinity level in this locality, arousing affect water resources, productive soils, crops, etc. Approximately, 85% of the people of this territory depend on agriculture. Being exacerbated by climate change and rising sea levels, the agricultural lands in those regions may be experiencing extended salinity levels [6-7]. Salinity in Satkhira assumes the form of a serious problem if the monsoon rain is inadequate or delayed or if embankments are damaged. Most of the areas remain fallow during the dry season owing to high salinity and lack of suitable irrigation water. About 1.689 million hectares of land in Bangladesh bordering the northern apex of the Bay of Bengal and constituting the coastal off-shore lands. Out of it, 1.056 million hectares have been affected by soil salinity of various degrees [7,9-10].

The devastating Aila and Mora cyclones might cause not only salinity intrusion but also to aggravate soil quality deterioration that has already posed a serious impediment to the economic development of the southwestern coast of Bangladesh. Up to this date, no studies were reported on the GIS-integrated spatial distribution of soil properties characterization under this cyclone-affected area. Considering the aforementioned facts, the present investigation has been undertaken with the following objectives:

a) To investigate the geospatial changes of physicochemical properties of soil, besides,
b) To reveal their relationship in the selected cyclone Aila and Mora affected study sites in comparison to the data sets of soil resources development institute (SRDI), and
c) To make a recommendation regarding the soil quality of the study sites [10]

2. METHODOLOGY

2.1 Salient Features of the Study Area

Being entangled with severe cataclysms like Sidr, Alia, and Mora, geographically, the coastal Shyamnagar Upazila (22°11' to 22º24' N, 89º00' to 89º19' E) (Upazilla denotes an administrative subunit of districts which is locally named) which is the largest Upazila (1968.24 sq. km.) of Satkhira district, Bangladesh was chosen for the study purpose (the map is shown in Fig. 1). The experimental area belongs to the agro-ecological Zone of AEZ-13 under the Ganges Tidal Flood Plain [11]. Generally, it enjoys a sub-tropical monsoon climate including a very flat and low topography except in its southeast and southwest region. Its elevation is 4 meters above sea level. It is a riparian of the Kholpetua river, streaming as one of the largest rivers of the Ganges-Padma system originating from the Himalayan mountains. Adjacent to the Bay of Bengal, the experimental area is also littoral on the verge of Sundarbans which is recognized as the world’s biggest mangrove forest ecosystem [8]. Major soil resources in the study area are Fluvaquentic Endoaquepts and Typic Endoaquepts, as reported by Rahman [12]. Sedimentation is continuing slowly on this floodplain. The soils are developed in sediments reworked by tidal effects. During sampling, Land and Soil Resource Utilization Guides (LSRUG) of the Soil Resource Development Institute (SRDI) was used. Soil sampling was done by the following LSRUG sampling location as given in Table 1 [10]. Soil samples location map of the studied southwestern coastal area is presented in the following Fig. 1.

2.2 Methods of Soil Sampling

Sampling depth of 0-30 cm was ascertained because changes in soil quality attributes that took place at this soil depth were most evident. It is also recognized as plough layer of soil in terms of agricultural productivity and concurrently, plant-water-soil relationship. Being entangled to the Bay of Bengal, this coastal area gradually faces intertidal consequences. Because of this, sampling is quite challenging in this region. Also, the availability of undisturbed spots for sampling is in shortage as many areas are used for salt and shrimp production. A total of 22 soil samples was collected from Shyamnagar Upazila using a systematic random composite sampling method for the study purposes (Table 1). Sample coordination (location) was geo-referenced using a global positioning system (GPS, Germin-62s, USA) receiver. The sample location map of the studied sites was drawn up by using ArcMap 10.3 software developed by Environmental Systems Research Institute (ESRI) exhibited in Fig. 1.

2.3 Soil Sample Preparation and Soil Analyses

Using stainless steel soil auger, soil samples from the field were collected in thick double polythene bags. The bags were sealed properly, precluding moisture loss from the sample, and transferred as quickly as possible to the laboratory for their processing. Before analysis, the representative soil samples were sun-dried, ground, and sieved through a 10 mesh (2mm) sieve for physical analysis and 30 mesh (0.56mm) sieves for chemical analysis. Grain size is classified as clay if the particle diameter is <0.002 mm, as silt if it is between 0.002 mm and 0.06 mm, or as sand if it is between 0.06 mm and 2 mm. That’s why 10 mesh (2mm) sieve was used for soil physical analysis. The sieved soil was then stored into a plastic container. In order to assess the magnitude of declining soil health in the surveyed area, the present research has emphasized on laboratory experiments of soil collected from several undisturbed spots in December 2018. The field moisture in freshly collected field soil was examined by the gravimetric method [13]. For particle size analysis, the soil was dispersed by the method of Jackson [14]. The percentages of sand (> 50μm), silt (2 to 50μm), and clay (< 2μm) were determined by the hydrometer method as described by Day [15]. United States Department of Agriculture (USDA) size fractionation

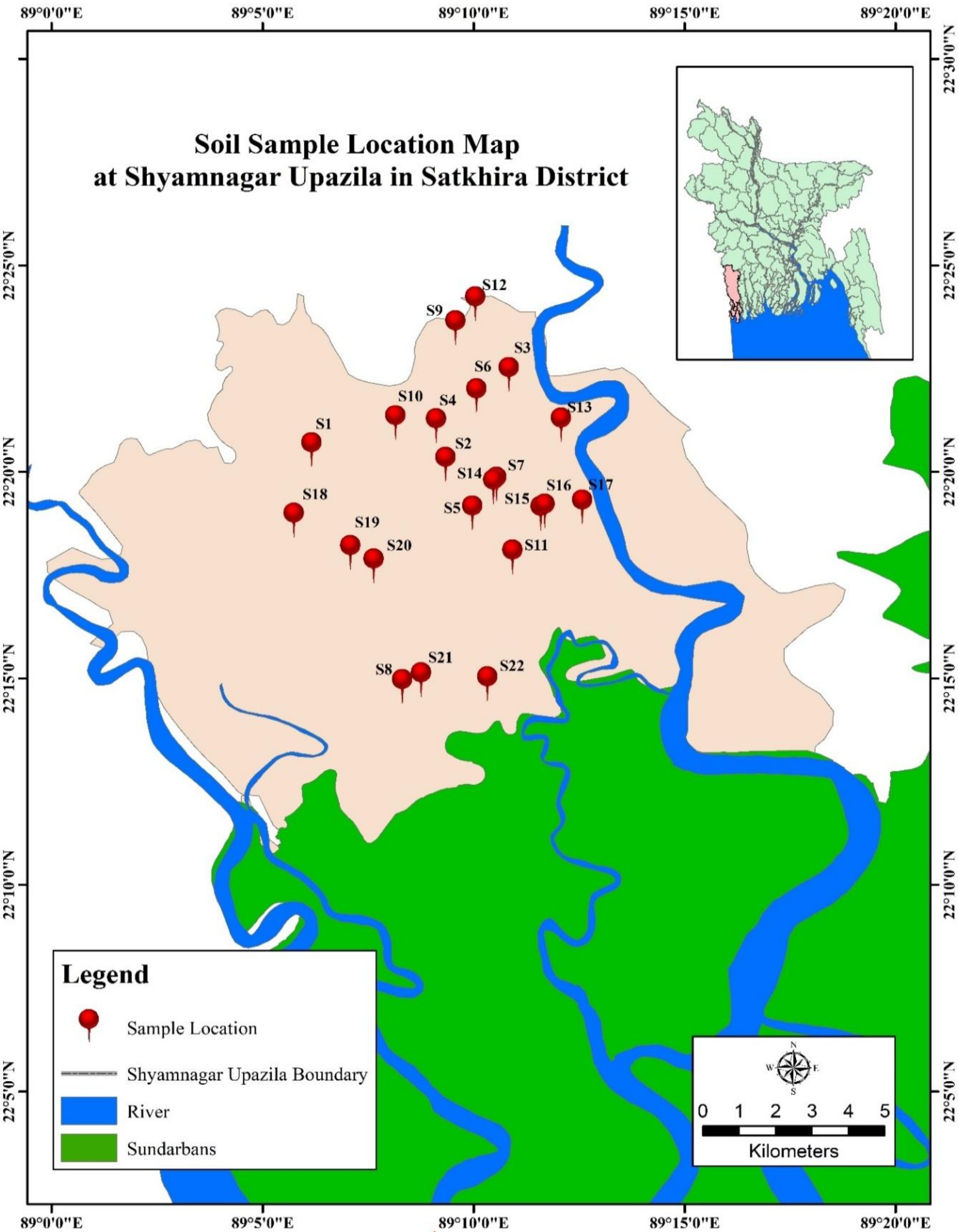

Fig. 1. Map exhibiting soil sampling sites of the Shyamnagar area located on the southwestern coastal verge of Bangladesh

Table 1. Soil sampling location of the study sites with their series identification (present study 2018), and SRDI sampling No. (1996) indicates the analyses were performed by SRDI in these particular points

Sample No.	GPS value of the sampling points	Name of soil series and land type	SRDI sampling No (1996).
S1	22°20'35.1"N and 89°06'10.8"E	Barisal Medium high land	21
S2	22°20'23.7"N and 89°09'02.1"E	Barisal Medium high land	22
S3	22°22'16.2"N and 89°10'44.9"E	Jhalokathi Medium high land	20
S4	22°21'08.4"N and 89°09'05.9"E	Jhalokathi Medium high land	23
S5	22°19'24.7"N and 89°09'57.9"E	Barisal Medium high land	24
S6	22°21'55.3"N and 89°10'09.1"E	Jhalokathi Medium high land	62
S7	22°19'48.5"N and 89°10'31.9"E	Barisal Medium high land	26
S8	22°14'46.0"N and 89°08'21.9"E	Barisal Medium high land	25
S9	22°29'31.9"N and 89°09'07.7"E	Dacope Medium high land	51
S10	22°21'13.4"N and 89°08'9.1"E	Barisal Medium high land	52
S11	22°17'59.9"N and 89°10'59.0"E	Dacope Medium high land	77
S12	22°21'02.0"N and 89°11'10.6"E	Jhalokathi Medium high land	54
S13	22°21'21.5"N and 89°12'07.5"E	Barisal Medium high land	58
S14	22°19'51.0"N and 89°10'30.9"E	Bajoa Medium high land	76
S15	22°19'31.2"N and 89°11'36.9"E	Jhalokathi Medium high land	108
S16	22°19'21.8"N and 89°11'41.3"E	Barisal Medium high land	111
S17	22°19'11.5"N and 89°12'38.6"E	Jhalokathi Medium high land	61
S18	22°18'49.8"N and 89°05'45.6"E	Jhalokathi Medium high land	59
S19	22°18'05.2"N and 89°05'55.3"E	Barisal Medium high land	60
S20	22°17'30.6"N and 89°07'29.3"E	Jhalokathi Medium high land	70
S21	22°14'44.8"N and 89°08'31.8"E	Barisal Medium high land	113
S22	22°14'57.4"N and 89°10'19.8"E	Barisal Medium high land	114

technique was used during determination. The textural class experimented from the triangular co-ordinates as devised by the USDA Staff [16]. The soil reaction (pH) was measured at a saturated paste extract keeping a ratio of 1:1 with deionized water by using a digital glass electrode pH meter [17]. According to the method by Rhoades, a 1:2 soil to water ratio, allowing to stand overnight under 25°C with the help of conductivity meter, EC of the soils was analyzed at saturated paste extract [18]. The carbon content of the soil was examined volumetrically by wet-oxidation method of Walkley and Black using normal potassium dichromate and concentrated sulphuric acid mixture and rapid titration with 1N ferrous sulfate solution, and henceforth, the organic matter content of the soil was calculated by multiplying the percentage of organic carbon with conventional Van-Bammelen‘s factor of 1.724 as narrated by Nelson and Sommers [19]. All analysis was performed in the laboratory of the Department of Soil, Water, and Environment under University of Dhaka. The collected data were compiled and tabulated in proper form and were subjected to further statistical analysis.

2.4 GIS and Statistical Analyses of Data

Geospatial maps of the clay content of soils, pH, and EC distribution with their spatial variability with changes of the time were derived using ArcGIS-10.3 software developed by ESRI. Inverse Distance Weighting (IDW) interpolation was drawn to observe the distribution pattern of individual soil properties in geospatial maps. IDW is an interpolation method that shows the spatial distribution of values of variables from the sampling site which is assigned and indicated by geographic coordinates. 22 sampling locations for each soil property are integrated with IDW geostatistical procedure to get a spatial distribution map of soil physicochemical attributes to identify their changes over the last 20 years.

Descriptive statistics (mean, standard deviation (SD), coefficient of variation (CV), minimum, maximum were used to analyze related soil properties (Sand, silt, clay, field moisture, pH, EC, and org C). Statistical analyses of the data were performed using computer-based statistical program Minitab-19, Grapher, and IBM SPSS® Statistics 25. The regression analysis ® was obtained by using SPSS software. Correlation and Regression analysis, and the Box-Whisker plot were applied to evaluate and compare relationships among several parameters.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

The results of the particle size distribution of investigated soils are demonstrated in Fig. 2. Among the analyzed soil samples, the sand content is less than 11% except for sample number S1. Higher amounts of sand (39.07%) contained in the Barisal soil series at sample number S1. The average sand content in the study sites was around 5%.

Silt is the dominant size fraction in the studied area. Silt contents in the experimental sites were varied from 38.02 to 81.85% (Fig. 2). Containing the highest amount of silt content, Jhalokathi and Barisal soil series at sample number S15 and S22 (Table 1), respectively is considered to be the most silt dominant site in the experimental area (Fig. 2). The lowest silt content was recorded in the sample number S8 (Fig. 2). The average silt content of the analyzed soil samples was 54.28%. Such a high level of silt content was related to the nature of the siltation in the study sites. Concentrations of clay fraction in the studied sites ranged from 12 to 60%, the average was around 41%. The maximum amount of clay (60.58%) was found in the Barisal soil series at S8 sample whereas the minimum amount of clay (12.53%) was analyzed in the Barisal soil series at the sample number of S1 and S22 (Fig. 2). Spatial mapping regarding the variability in the percentage of clay content is exhibited in Fig. 3 which illustrates that the clay content was increased in the south and south-western corners in contrast to the rest of the study area.

Most probably, severe sedimentation took place due to the natural disaster Aila and Mora. The amount of sand was less than the silt and clay fraction. Because of the insufficiency of the sand fraction, it might not be able to provide a congenial physical condition to the soil for plant growth. The very low percent of sand fraction in the soils under the present investigation corroborates the general observation of Brammer that the texture of the soil across Bangladesh becomes gradually finer as one moves from north to south [20]. The present study revealed that the studied soils had higher silt and clay fraction than sand. Moreover, it might be said that the siltation has been taken place on this site for the last few decades due to natural cyclonic disasters. This finding should be considered when seeking sites for the construction of new ponds or farms in the studied area.

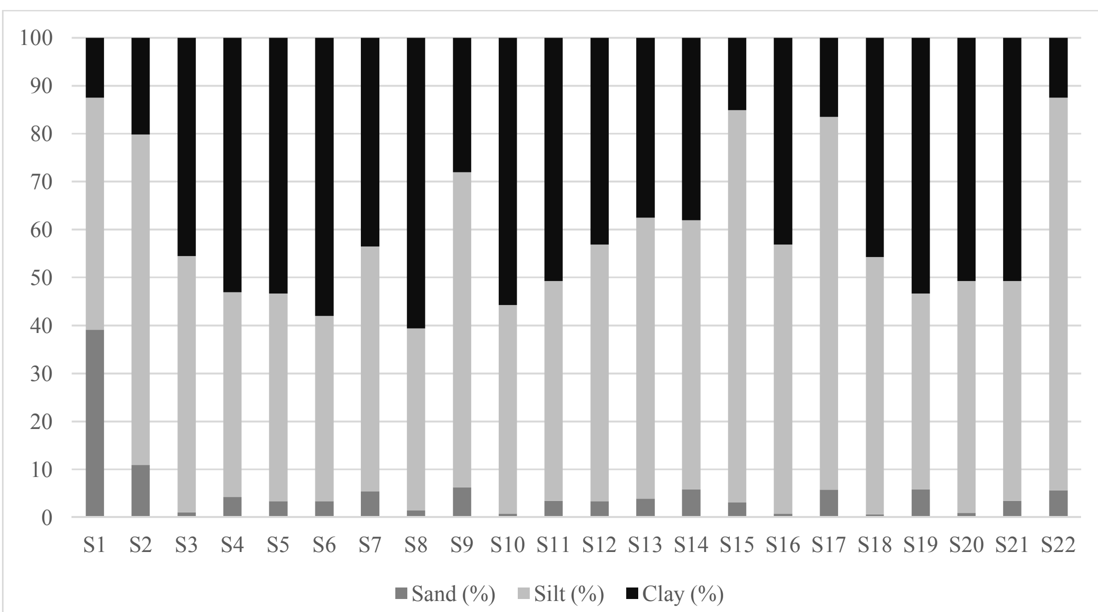

Fig. 2. Particle size distribution (Sand, Silt, and Clay percent) of the soils of the investigated coastal region at different sampling stations

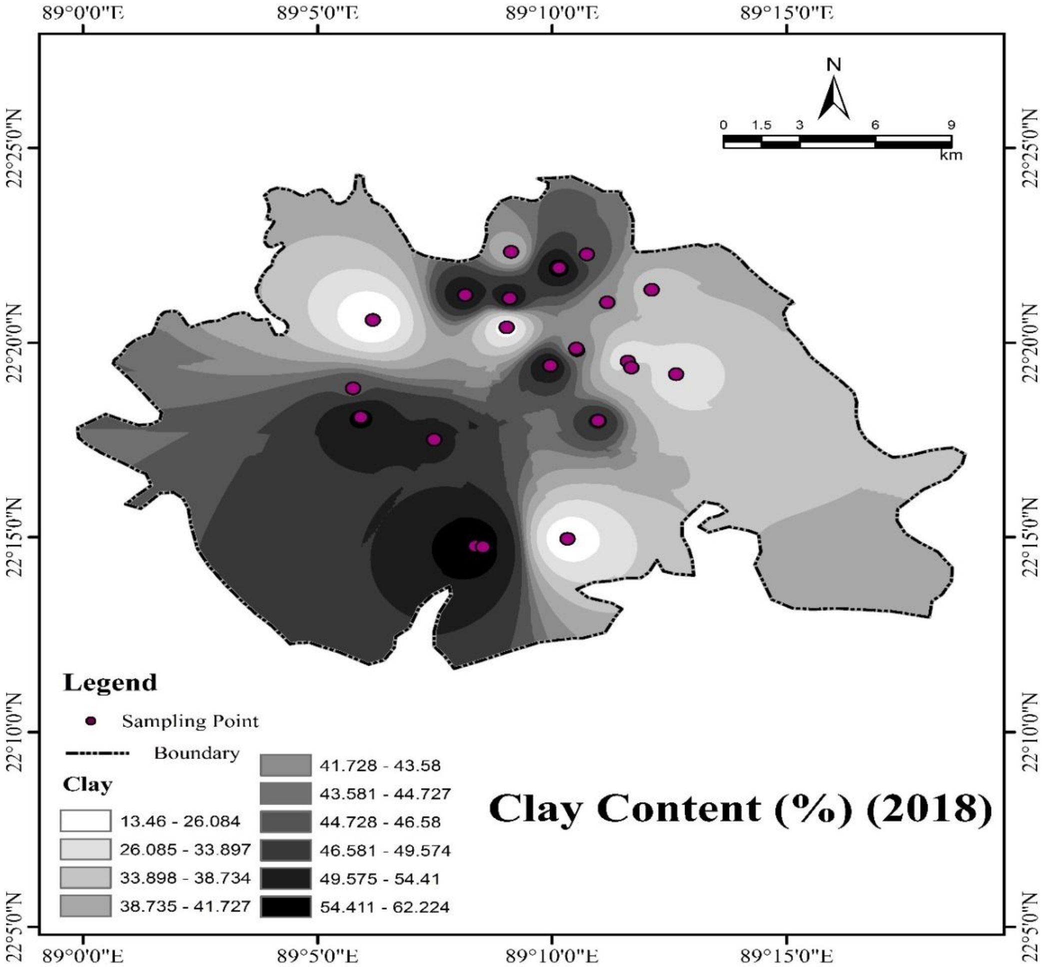

Fig. 3. Spatial distribution of clay content of soils in the study area using IDW interpolation

3.2 Soil Texture

The amount of sand, silt, and clay fractions in the soil determine the soil texture. The result demonstrated that the soils belong to silty loam, silty clay loam, silty clay, silt, clay, and loam texture (Table 2). Among the variation of soil textures, silty clay was the most dominant textural class, representing about 55% soil samples were silty clay (Fig. 4) whereas almost all the sites of our investigated points were highly clay dominated in the study of 1996 (Table 2).

Depending on soil texture, salinity holding capacity varies. Generally, sandy soils tend to be less saline because sand particles are less coherence to each other and salt leach easily. Peat soils also contribute leaching saline easily because of their surface drainage network. But salts tend to attach to clay particles and clay soils tend to be more saline for longer [20-21]. As reported by Berry et al. [22], crop production largely depends on soil properties influenced by soil texture include drainage, water-holding capacity, aeration, susceptibility to erosion, organic matter content, cation exchange capacity, pH buffering capacity, and soil tilth.

The soil was gradually turned into more saline because clay soils can hold salt for a longer period because of its high-water holding capacity, very slow drainage rate and, poor aeration system [22-23]. Subsequently, it turned into silty clay texture under the circumstances of siltation over the last twenty years. It was observed that silt contents were expanded in the study sites for over 20 years. It was significantly changed after the disaster Aila and Mora.

Table 2. Distribution (Mean±SD) of field moisture, textural class, pH, EC, and organic matter of the studied soils with their comparison in contrast to the status of 1996

Sampling stations	Field moisture (%)	Textural class		pH		EC		Organic matter	
		2018	1996	2018	1996	2018	1996	2018	1996
S1	30.21±0.11	Loam	Clay loam	7.3±0.05	6.4	22.80±1.40	17.10	2.06±0.14	2.53
S2	32.30±0.08	Silty loam	Clay loam	6.2±0.08	5.3	21.60±1.52	17.74	2.17±0.09	2.29
S3	27.23±0.06	Silty clay	Clay loam	7.1±0.10	5.1	18.11±0.90	14.57	2.89±0.12	3.12
S4	27.55±0.09	Silty clay	Clay loam	6.0±0.05	4.5	21.60±0.75	18.37	4.26±0.05	4.83
S5	38.70±0.13	Silty clay	Clay	7.6±0.12	6.7	14.25±1.60	8.11	4.14±0.10	3.96
S6	49.23±0.04	Clay	Loam	5.9±0.17	4.3	23.15±1.10	21.28	4.47±0.22	4.51
S7	25.63±0.05	Silty clay	Clay	7.2±0.07	4.1	37.40±1.15	34.26	2.58±0.17	6.38
S8	36.93±0.08	Clay	Clay loam	7.2±0.09	5.2	24.00±0.98	19.00	4.62±0.15	2.51
S9	12.74±0.02	Silt	Clay loam	7.0±0.07	6.4	19.80±1.45	13.68	1.89±0.11	1.95
S10	31.23±0.07	Silty clay	Clay	6.4±0.12	4.1	24.25±1.15	21.28	4.33±0.09	3.39
S11	27.88±0.09	Silty clay	Clay	6.0±0.06	5.2	16.20±1.19	11.46	3.01±0.13	5.75
S12	24.28±0.12	Silty clay	Clay	7.5±0.08	5.1	17.25±2.25	12.03	2.32±0.08	3.88
S13	48.21±0.13	Silty clay loam	Clay loam	7.1±0.11	5.2	39.10±1.87	36.95	2.20±0.13	2.51
S14	51.98±0.15	Silty clay loam	Clay loam	5.7±0.14	4.6	24.56±1.95	22.62	2.23±0.25	3.3
S15	14.61±0.05	Silty loam	Clay loam	7.1±0.04	5.2	34.90±0.92	33.81	1.75±0.34	1.41
S16	31.91±0.04	Silty clay	Clay	5.0±0.05	3.8	46.40±2.55	43.21	2.24±0.06	6.59
S17	18.25±0.08	Silty loam	Loam	6.7±0.12	6.7	30.60±2.10	27.55	2.03±0.08	1.79
S18	37.68±0.09	Silty clay	Clay	6.2±0.15	6.1	30.13±1.85	28.00	2.67±0.17	2.71
S19	26.58±0.11	Silty clay	Clay loam	7.3±0.18	4.5	20.70±1.50	13.81	4.32±0.15	4.01
S20	23.64±0.04	Silty clay	Clay loam	6.5±0.09	4.8	21.12±2.75	16.47	3.57±0.16	3.21
S21	24.67±0.07	Silty clay	Clay loam	6.0±0.11	5.8	12.25±1.18	7.35	3.36±0.09	3.01
S22	28.68±0.10	Silty loam	Clay loam	7.8±0.15	7.6	26.40±2.60	24.42	1.92±0.12	1.58
Mean ± SD*	30.40±10.23			6.67±0.73	5.31±0.99	24.84±8.52	21.04±9.57	2.96±0.99	3.42±1.43
CV**	0.34			0.11	0.19	0.34	0.45	0.34	0.42

**Standard Deviation*
***Coefficient of Variation*

Correspondingly, due to the incremental nature of salinity, soil drainage was restricted and thereby plant growth was confined in the study sites. The elevated salinity was associated with the development of silty texture in the study sites. To account for reining unanticipated topsoil salinity, unintended degradation of soil health as well as optimizing yield capacity, soil texture is relevant to crop choice in agriculture. Silty soils would be suitable for shrubs such as blackberry, beach rose, and raspberry; climbers such as cucumber, hops; cash crops like betel leaf, betel nut, and coconut; and grapes; grasses such as rye, wheat, and corn; and perennials such as ginger, strawberry, and tomato. Many moisture-loving trees as well as vegetable and fruit crops do well in silty soils that have adequate drainage [24]. So, this might be considered to conduct proper land management and plantation activity in the studied area.

Hitherwards, it is also substantive that soil that is best for plant growth is directly related to the type of plants which is being grown. Having a silt clay to loam texture, the studied coastal soils are very fragile under natural conditions. If irrigation facilities could be developed during the dry season the potential of these soils would elevate to a greater extent generating much higher quantities of food grains.

3.3 Soil Permeability

To combat rising soil salinity, relevancy was constructed between soil permeability and textural class. O'Geen [25] pointed out that soil permeability classes are incorporated into the estimation of permeability rates by using the textural class of soil. Alternately, the studied soil samples revealed very slow to moderate permeability class along with permeability rates ranging from < 0.13 to 6.3 cm/hr as data reported by O'Geen [25].

The permeability of soil is largely influenced by its infiltration rate. Clay soils have small pore spaces, are known to have low permeability, resulting in low infiltration rates and poor drainage whereas coarse sand soils have very rapid permeability [23-25]. Siltation might cause the alteration status of soil permeability in the investigated area. Soil permeability can feasibly increase when soil compaction begins to loose with extended pore spaces, resulting in detrimental impact for agricultural tailored soils as a slightly compacted soil can speed up the rate of seed germination because it promotes good seed-to-soil contact.

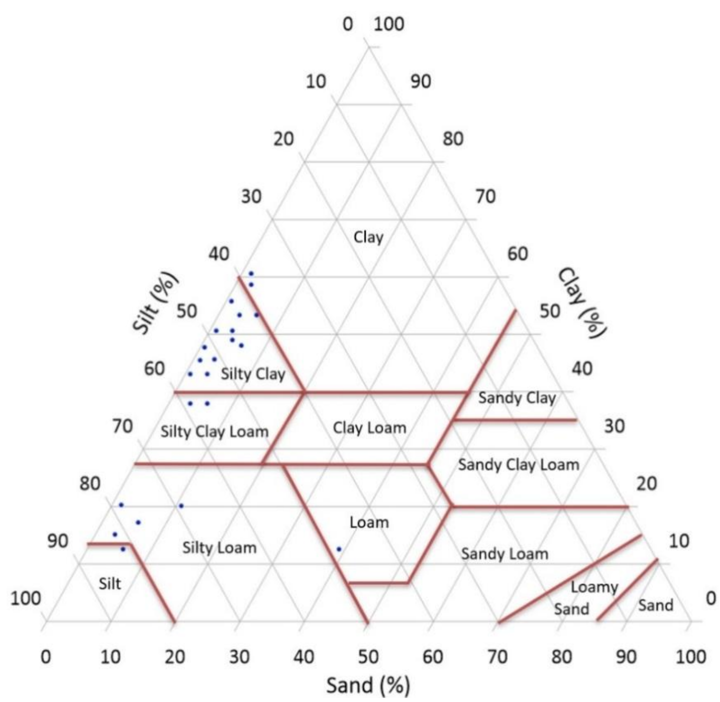

Fig. 4. Textural distribution of soils- (plotted on USDA textural triangle) for studied samples

3.4 Moisture Percentage in the Field Condition

The percentage of moisture at the field condition of the studied soils is presented in Table 2. The field moisture contents were within a range of 12 to 52%. The average field moisture content was 30.40%. The lowest amount of field moisture was audited in Dacope soil series at sample number of S9 whereas the highest amount was observed in Bajoa soil series at sample number S14. It is known that good water holding capacity represents the good physical condition of the soil. The SRDI observed the variation in field moisture percent values with the variation in texture of different soils [26]. In particular, they stated that the increase of moisture percentage of the soils imposed on the increase of clay content with depth. The decomposition of organic matter is mainly depending on the soil moisture. If the water becomes too low, a plant becomes stressed. Water is present more in the soil; it is not available to plants due to a high degree of salinity.

3.5 Nature of Soil Reaction (pH)

To measure the degree of soil acidity and alkalinity, soil pH is a very important variable and it helps to know about soil properties chemical, biological, and indirectly physical environment including both nutrients and toxins [23,25-27]. The result of the pHs of the investigated sites is shown in Table 2 and Fig. 6. The highest pH value was recorded as 7.80, while the lowest pH value was 5.0. In all of the soil samples, soil pH was ranged from 5.0 to 7.80. In the present study sites, most of the soil was found as alkaline (pH > 7.5).

This pH is suitable for shrimp aquaculture but not for agricultural production [26,28]. The admissible range of pH in the soil is 6.0 to 6.5 because most of the plants' nutrients become available in this stage [25,27]. In the year 1996, soil pH in the study sites was not as much elevated as the present and both years showed a significant correlation at 95% confidence level (Fig. 6). The highest pH value was 7.60 and the lowest pH value was 3.80 in 1996 (Table 2). In 1996, only 4.55% of soil samples were moderate basic whereas it was elevated up to 27.27% in the present study (Table 3).

The spatial distribution map of pH values at the investigated sites indicated that the pH values were comprehensively lessened in the northern corner of the study area as compared to the study of 1996. Alongside, soil acidity has prevailed in the southern side of the investigated area to some extent in contrast to the previous study (Fig. 5I and 5II). It might be due to the influence of coastal flooding, resultant in tropical cyclones in this area. The saline water intrusion from the Bay of Bengal had a pivotal role in the pH status of the soil. The spatial distribution map of EC shows that higher values of EC were recorded in the southern and south-eastern corner of the study area in this study (Fig. 5III and 5IV). This corner is completely exposed to the Bay of Bengal and highly prone to coastal flooding.

Table 3. Classification of soil pH of the samples according to the standard of Boyed (1995)

pH range	Type	Soil Samples		Percentage (%)	
		2018	1996	2018	1996
< 4.0	Strongly acidic	-	S10	-	4.55
4.1 - 5.0	Acidic	S10	S2, S5, S6, S8, S11, S16, S17	4.55	31.82
5.1 - 6.8	Moderately acidic	S1, S2, S5, S8, S13, S14, S15, S16, S17, S18, S20	S1, S3, S4, S7, S9, S12, S13, S14, S15, S18, S19, S20, S21	50.00	59.09
6.9 - 7.1	Neutral	S3, S4, S12, S21	-	18.18	-
7.2 - 7.9	Moderate basic	S6, S7, S9, S11, S19, S22	S22	27.27	4.55
8.0 to 8.9	Basic	-	-	-	-
> 9.0	Strongly basic	-	-	-	-

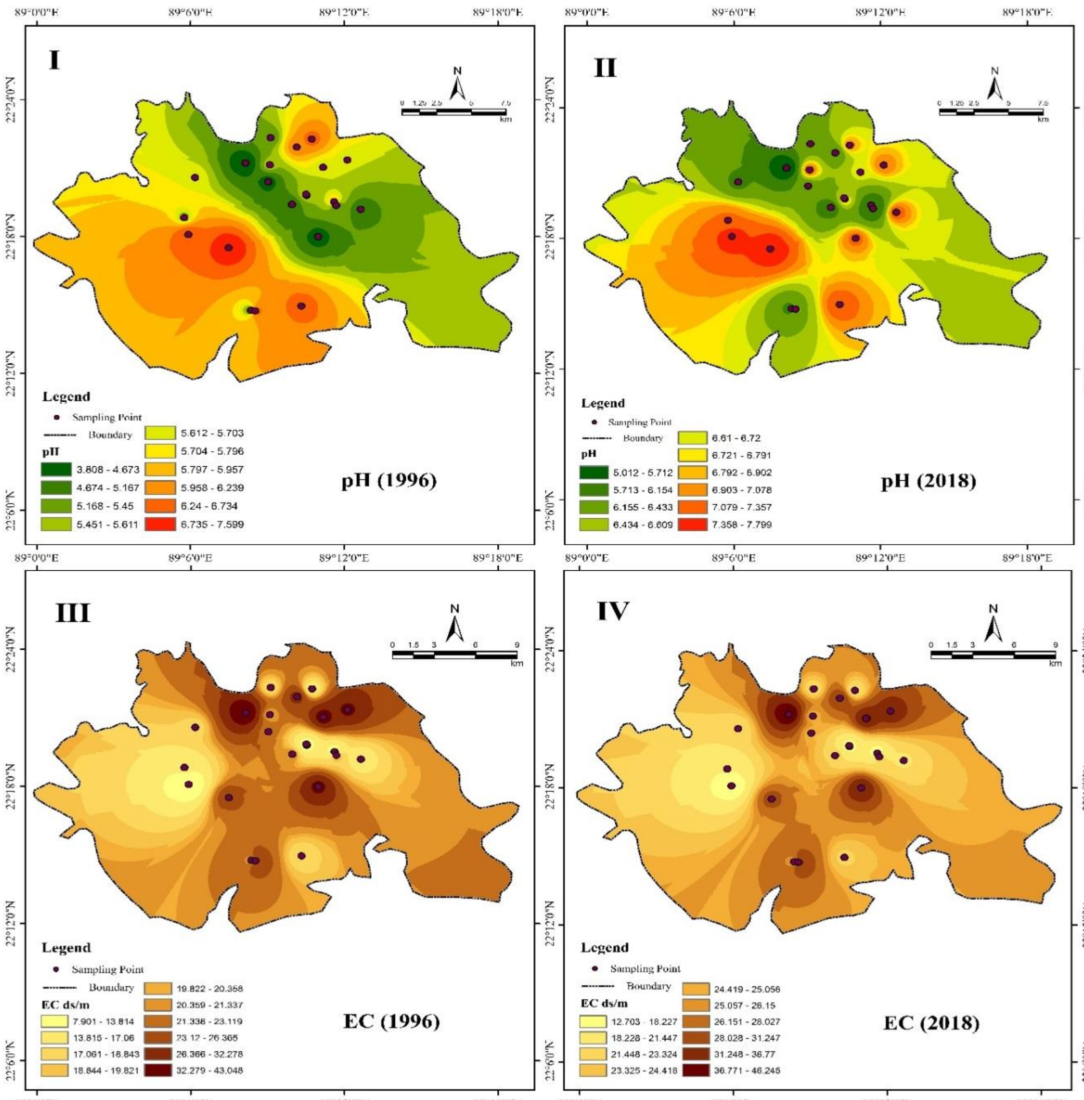

Fig. 5. Spatial distribution map for pH and EC in Shaymnagar Upazilla using IDW interpolation. Spatial variability can be seen through the color changes indicating concentration ranges of the area. Dark color notifies the higher concentration values of the variables

An incremental trend of pH was noted in the present study. It might be due to the influence of disasters like Aila and Mora. The saline water from the Bay of Bengal had a pivotal role in the pH status of the soil. These impacts could be in the groundwater as well as in the topsoil by inundation or by a capillary movement which might be the ultimate result of cyclone Mora and Aila disaster. From the pH observation, it can be said that the present pH range has motivated the local farmers to the shrimp cultivation in the study sites.

Acid sulfate soils constituted uniformly in drowned coastal and estuarine environments can eventually be highly acidic when drained or unearthed. Latterly, it might increase the degree of pH in the investigated area of Shaymnagar, resulting in soil health deterioration. The elevating trend of soil pH is contradictory to the equilibrium between available nutrients in the soil environment, certainly interrupt soil fertility to plant growth. In most cases, the pH range of 6.0-7.5 is optimum for the adequate availability of nutrients in the soil [27-29].

3.6 Electrical Conductivity (EC)

EC is the most convenient method to measure soil or water salinity. In agricultural standards, soils with an EC greater than 4 mS/cm are considered as saline soil [22]. Ranging from 12.25 to 46.40 mS/cm along with an average value of 24.84 mS/cm in the present study (Table 2, Fig. 6), EC plays a regulative role for the comprehensive distribution of unfitted soil salinity in the investigated area.

Based on the classification of soil EC of the samples, in conformity with SRDI [28], BARC [29], Chowdhury et al. [30], Islam Shitangsu and Hassan [31]; 72.73% samples in 1996 and 90.91% samples in 2018 had a very high range of EC. The highest and lowest EC was examined in the sample number of S16 (46.40 mS/cm) and S21 (12.25 mS/cm), respectively. Meanwhile, the EC was varied from 7.35 to 43.21 mS/cm with a mean value of 21.04 mS/cm in 1996 [10]. A significant correlation was marked between the years 2018 and 1996 at 95% confidence level and showed in Fig. 6. Out of the total soil samples, 72.73% of soil samples in 1996, and 90.91% of samples in 2018 had a very high range of EC. An EC value less than 1 indicates that soils are highly suitable for cultivation, between 1-3 is injurious to crop growth, between 3 and 4 will cause yield reduction, and soils with EC value more than 4 are designated as saline soils and need reclamation to restore them for satisfactory cultivation [32]. The finding of the present study is quite analogous to the study of Rahman [33], and Islam Shitangsu and Hassan [31] who found that the EC value was ranged from 12.70 to 20.70 mS/cm and 23.93 to 28.64 mS/cm, respectively in several salt-affected areas of Satkhira district.

The present result showed that the soils were extremely saline which caused adversity of soil health and thereby impeded agricultural activities and crop production. Salinity is being thought to be a silent poison for the massive loss of crop production in the studied area. Salinity tended to be higher in arable lands that had compacted subsoils, which trapped saline cyclonic sediments and held saline water for longer duration as well as in these poorly drained, low-lying areas. Widespread plus repeated practices of shrimp cultivation in and around the experimental sites may remarkably increase the level of EC in soil and deteriorating soil health because of saline water intrusion from the coast affecting local cropping pattern, stagnant saline water in the shrimp culture site for a long time and replacement of arable lands into shrimp ponds. Sooner or later, it imposes an extensive threat to soil productivity, local vegetation, the biodiversity of coastal species, and ultimately, the local environment with a more variable climate. From the observation, it can be said that this situation might become worsened in near future.

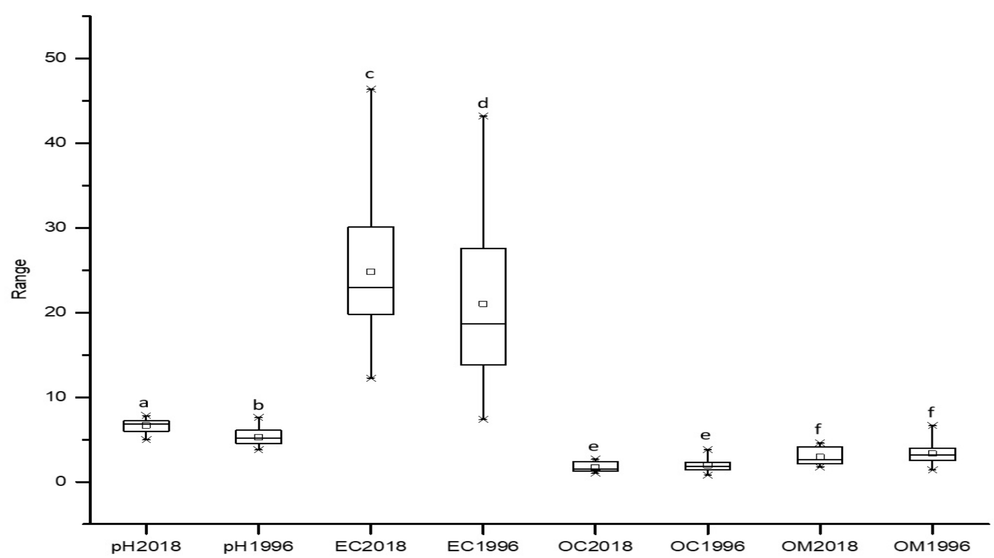

Fig. 6. Comparison of the parameters by Box and Whisker plot with denoting correlation is significantly different at 95% confidence level using the same small letter between parameter in 2018 and 1996

3.7 Soil Organic Matter Content

The highest soil organic matter (SOM) was inspected in Barisal soil series in the sampling station, S8. The organic matter of soils was varied from 1.75 to 4.62% and the average value of organic matter was noted as 2.96% (Table 2). Far from it, in 1996, the average value of organic matter was 3.42% with a range of 1.41 to 6.59%. From the observation, it can be stated that the organic matter content in the present study sites was comprehensively reduced. It might be due to the destructive influences of cyclonic disasters.

Spatial variability mapping of organic matter content in the study site illustrates that SOM content in the present study sites was comprehensively reduced. Amid the entire study area, the organic matter was notably decreased in the south-eastern, eastern, and east-northern corners with the advent of time (Fig. 7I and 5II). In the meantime, an incremental trend of SOM content was visualized in the western and west-southern parts. A high concentration of sodium salt prevailed by the salinity intrusion caused a significant depletion of SOM content in soils, creating extremely hazardous conditions in crop production, especially in low-lying areas [31].

The increment of soil organic matter content was caused for maximum retention of field moisture content in the studied sites. 7.44% of the total variation in the field moisture in the studied areas could be elucidated by the organic matter content of that soils (Fig. 8i). From the observation, it can be stated that soil organic matter tended to increase as the clay content was augmented in the present study. 70.4% of the total variation in the organic matter content was explained by the clay content (Fig. 8ii).

As reported by Rice [34], soils with higher clay content enhanced the potential for aggregate formation which physically sheltered the organic matter molecules from further mineralization. Consequently, the deposition of organic matter content has prevailed. Here-after, this result is in confirmatory with the investigation analyzed by Rice [34]. In Table 3, soil pH classification was determined according to the standard reported by Boyed [35].

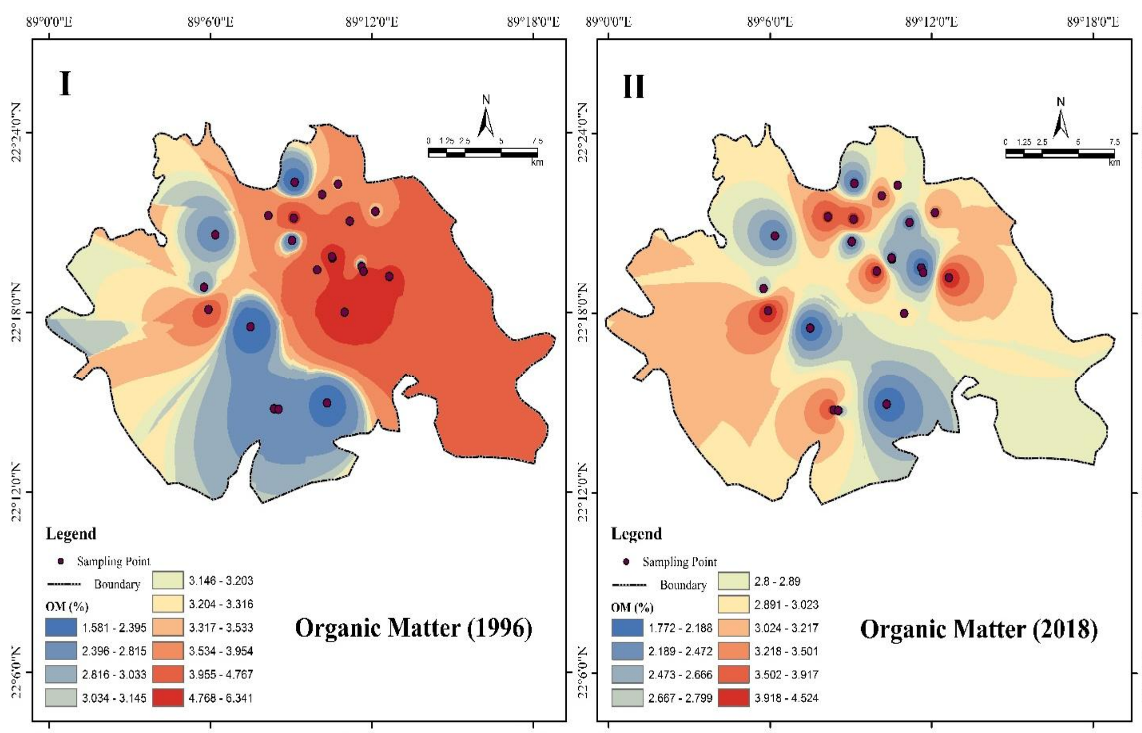

Fig. 7. Spatial distribution of organic matter content of the studied soils using IDW interpolation. It depicts the geospatial variability of the analyzed soil properties for a time interval

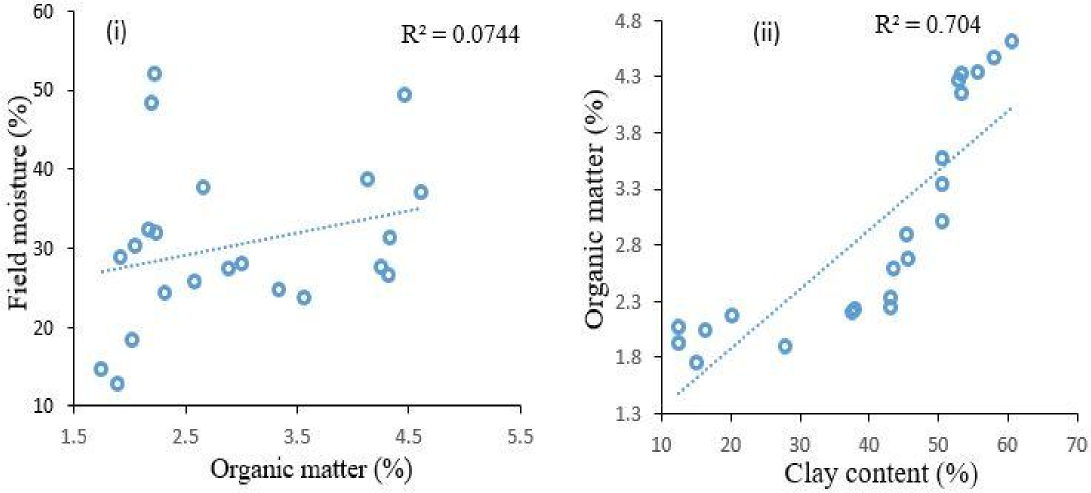

Fig. 8. Relationship of organic matter with field moisture and clay content of the studied soil

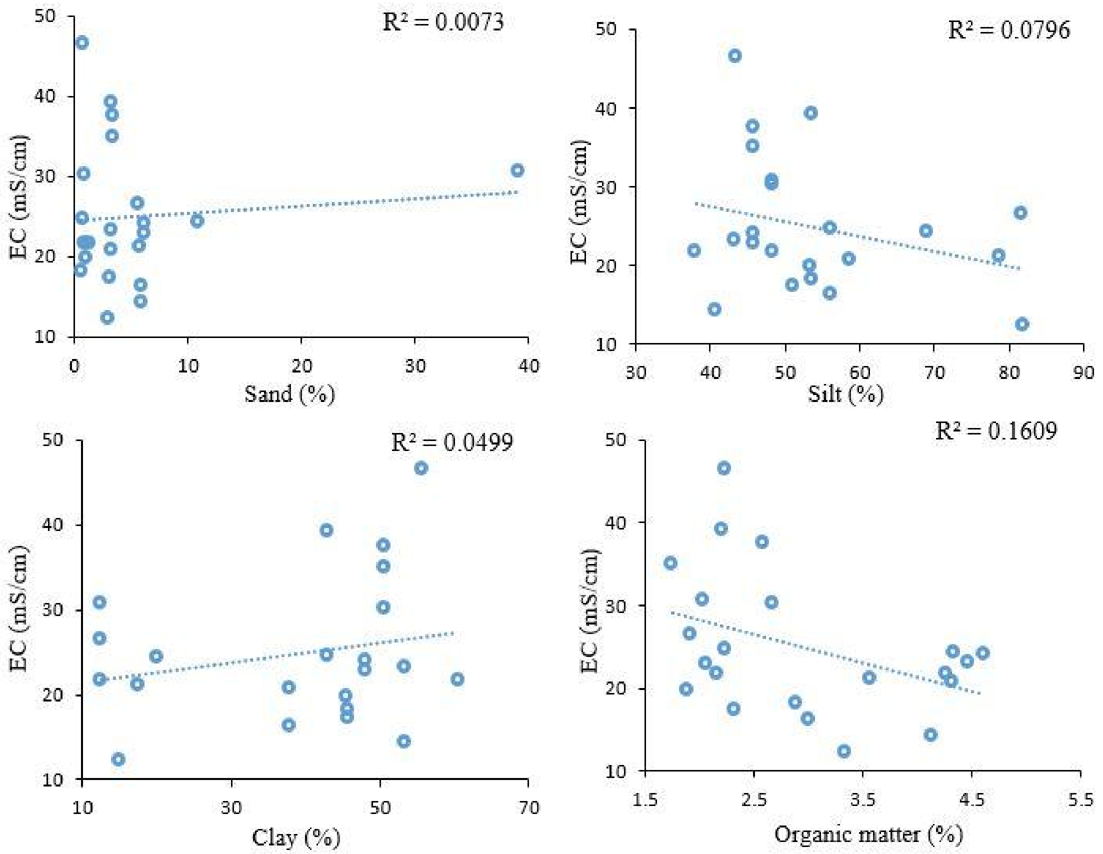

Fig. 9. Relationship of variability between Electrical conductivity and (a) Sand, (b) Silt, (c) Clay, and (d) Organic matter contents of soil. R^2 value indicates to predict the changes in one variable by the value of another variable

3.8 Relationship between EC and Other Properties of the Studied Soil

The EC of the soils was regulated by other properties of the studied soil such as the percentage of sand, silt, clay, and organic matter. The intrusion of salty water during the cyclonic disasters might change the aforesaid properties which augmented the salinity level in the studied sites. The 0.73% of the total variation in EC was elucidated by the sand fraction of the experimental soil, whereas the 7.96% of the total variation in EC was explained by the silt fraction and 4.99% of total EC by clay fraction (Fig. 9). It is demonstrated from the Figure that the EC content of the soil was greatly influenced by the silt fraction followed by the clay and sand fraction. A strong relationship (R^2 =16.09%) was noted between the EC and organic matter contents of the soil.

4. CONCLUSION

It has been deduced from the present study that the salinity level of the studied soils was greatly incremented as compared to 1996 due to the ramifications of the catastrophic cyclonic disasters. Intimidating cyclonic seawater inundation and resulting sedimentation introduced salinity into coastal areas where it had never before been a problem. The degree of deterioration of soil properties was medium to higher as demonstrated in geospatial maps of Shyamnagar, Satkhira. The soil health was degraded which might threaten the agricultural productivity, cropping pattern, coastal agro-forest ecosystem, and ultimately the coastal environment in those regions on a large scale. The situation might become worsened in near future if adequate safeguarding and viable measures would not be taken as soon as possible. Furthermore, adoption of crop residue management, afforestation, incentivizing of increases in water-use efficiency, adequate groundwater application, proper drainage system, etc. might alleviate the soil salinity, improve soil health and thereby ensure sufficient crop production in this cyclone-affected soils.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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