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Study of spatio-temporal variations of soil salinity in the south-eastern coastal part of Bangladesh

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Abstract

Soil salinity (SS) is one of many constraints to sustainable crop production in coastal areas of Bangladesh. With increasing the areas of saline soils in the south-eastern part of Bangladesh, it is of utmost importance to observe the variations in SS at a spatio-temporal scale. Therefore, this study attempted to assess the degree and extent of SS as well as the concentrations of ammonium acetate (NH_4OAc) extractable and water (H_2O) soluble cations along with anions using laboratory and GIS techniques. In connection with this, the middle part of Roypur Union of Anowara Upazila was divided into three different zones considering cropping intensity and location of sampling sites. The representative soil samples were collected from each zone in the pre-monsoon (April) and post-monsoon (December) periods of the year 2018. The results indicate distinct analytical and mapping differences in SS of the studied area in the pre-monsoon and post-monsoon seasons. The correlation of EC with all of the cations and anions was found positive in both seasons. Furthermore, the mean values of EC along with NH_4OAc extractable and H_2O soluble cations as well as anions of all the sampling sites varied significantly ($p<0.01$). The findings of this study successfully indicate the variations in degree and extent of the SS which would help in coping with the suitable crops to grow.

1. Introduction

Among the abiotic stresses, soil salinity (SS) possesses one of the greatest threats to the sustainable production of crops around the world (Etesami and Noori, 2019; Gull et al., 2019; Roy and Chowdhury, 2020a). The solution of saline soils contain substantial quantities of cations such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), and anions such as chloride (Cl^-), sulfate (SO_4^{2-}) and bi-carbonate (HCO_3^-) (Brady and Weil, 2005; Shahid et al., 2018). The extent and distribution of salt affected areas are increasing worldwide. Salt affected soils occupy more than 1100 million hectares (Mha) of lands (Wicke et al., 2011) covering low-lying coastal, irrigated, arid and semi-arid areas worldwide. The coastal regions of Bangladesh constitute more than 30% of the cultivable land of the country of which 54% areas are affected by different degrees of salinity (Haque, 2006). According to the SRDI (2010), saline areas in Bangladesh have increased by about 26.7% (1.06 Mha) compared to the previous estimate of 0.83 Mha in 1973.

Due to an increasing degree of salinity and expansion of the salt-affected areas, normal crop production becomes restricted. However, the crop production due to SS is not impaired to the same extent throughout the year. The SS increases during the months of March to June due to less precipitation (P) and high evaporation (E), whereas SS decreases during July and August due to high P and low E. The lack of P and high E are the important reasons for the SS in dry season (Wenquan et al., 2020). Moreover, cyclone induced storms originating from the Bay of Bengal (BoB) cause the agricultural lands of Bangladesh to become saline through the inundation with salt water (Huq and Shoaib, 2013). Salt accumulation in the dry season can reduce agricultural productivity by 50%, threatening the livelihoods of farmers in the coastal areas of Bangladesh (Clarke et al., 2015). Soil salinity restricts the cultivation of crops in the dry season and also delays the planting of crops in the wet season until rainfall reduces the salt content in the soil (Rahman et al., 2017).

With the increase in the extent and distribution of SS in Bangladesh, there is an urge for better utilization of lands, so that sustainable food security can be ensured for the vast population. Selection of appropriate crops in salt affected areas depending on the spatial and temporal variations in the intensity of salt stress can be one of the approaches for maximum utilization of lands. The study of SS in the south and south-western parts of Bangladesh with special emphasis on seasonal and spatial changes has been carried out in recent years (Rahman et al., 2017; Jamil et al., 2020). However, no such study on spatio-temporal variations in SS in the south-eastern part of Bangladesh was found so far. Considering the research gap, the present study was conducted on Anowara Upazila under the Chattogram district of Bangladesh to observe the spatio-seasonal variations in SS through laboratory analysis and GIS techniques. This study gives an insight into the concentrations of cations and anions associated with SS at different locations in two different seasons (i.e., pre-monsoon and post-monsoon). Moreover, the study focuses on GIS mapping to measure the degree and extent of SS as well as the spatial variations of the major cation (e.g., Na^+) and anion (e.g., Cl^-) in two different seasons.

2. Materials and methods

2.1. Study area

Anowara Upazila (*a sub-unit of a district*) is located in the south-eastern part of Chattogram district and exists in between 22°07' and 22°16' north latitudes and in between 91°49' and 91°58' east longitudes (Fig. 1). It covers an area of 16,413 ha with 11 Union parishads (*a local administrative unit*), of which Roypur Union is one of the listed categories. This Upazila had a population of 219,446 in 1991 with a density of 1300/km^2 and is surrounded by Patiya Upazila on the north, Banskhali Upazila on the south, Chandanaish Upazila on the east and BoB on the west (Bhuiyan, 2012). The study area belongs to Roypur Union under this Upazila which belongs to Chittagong Coastal Plain of Agro-Ecological Zone (AEZ-23) (Huq and Shoaib, 2013), covering approximately 2,456 ha. The physiography of the area is almost level with an inclination of less than 5% (LRUG, 1997).

According to Google earth pro 7.3.3.7786 version (2020), the elevation varies from 3–9 m from the mean sea level (MSL). Agriculture represents 42% of the total income source of the people living in this area. The pre-monsoon or dry period persists from March to April, whereas the post-monsoon or winter period lasts from November to February. The maximum and minimum temperature was observed as 32.48°C and 24.25°C in April and January of 2018, respectively. The average monthly precipitation in the study area varies throughout the year (as per the record of 2018), where maximum and minimum were observed 761.52 mm and 2.44 mm in the month of June and November, respectively (NASA Earthdata, 2018) (Fig. 2). The area is susceptible to salt water intrusion during the monsoon period and varying degrees of SS during the dry season due to low atmospheric moisture and high temperature (LRUG, 1997).

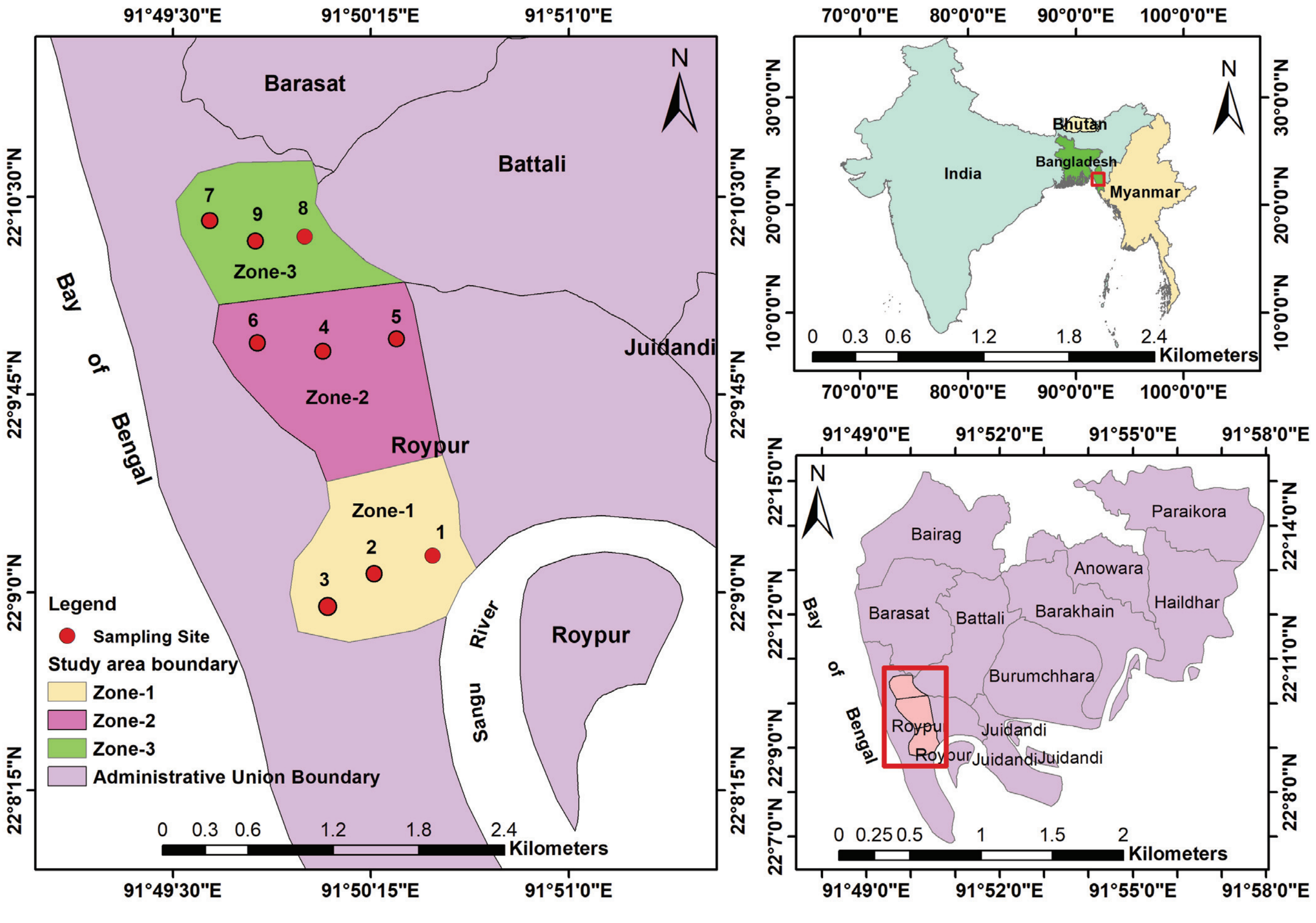

Fig. 1. Location map of the study area (part of Anowara Upazila) with soil sampling sites and station numbers (red circle point symbol)

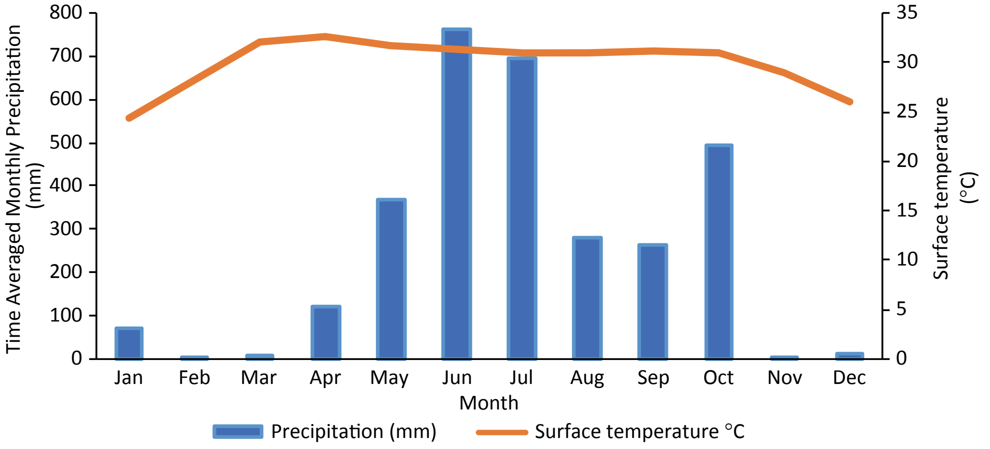

Fig. 2. Time-series area averaged mean monthly precipitation (mm) and surface temperature (°C) observed over the study area for the period January-December 2018

2.2. Collection and processing of soil samples

Based on the crop intensity and location of sampling sites, the middle part of Roypur Union of Anowara Upazila representing 348.09 ha was divided manually into three different zones (zone- 1, 2 and 3) (Fig. 1) with a distance of approximately one kilometer from each other. In zone-1 (fallow land: 114.12 ha) no crop is cultivated for the last 15 years due to extreme SS (according to local people's opinion), whereas zone-2 (arable land: 142.21 ha) and zone-3 (arable land: 91.73 ha) are experienced with single and double crops every year, respectively. The land types range from moderately low to moderately high, and the soils of the study area belong to the *Raozan soil series* of the USDA soil taxonomy and are characterized by clay loam texture, high consistency, low drainage capacity, low organic matter content (LRUG, 1997). The cultivation of rice is commonly practiced at the advent of the rainy season in zone-2, whereas rice followed winter crops is cultivated in zone-3.

Three sampling sites under each zone were selected randomly in an almost parallel way because of the identical characteristics and representative coverage of each zone in map. Approximately 4–5 kg soil samples in triplicates from each site were collected from the top layer in pre-monsoon (April) and post-monsoon (December) seasons in 2018. Therefore, a total number of 54 (9 sites × 3 replications × 2 seasons) soil samples were collected from the study area. Before collecting the soil samples, the plant residues were removed with the help of a spade. After collection, samples were brought immediately to the laboratory of the Department of Soil Science, University of Chittagong, Bangladesh for processing. Hard clods of soil samples were broken with the help of a wooden hammer and sieved through 2 mm stainless steel mesh. Representative sub-samples were separated from the bulk sample for the laboratory analyses.

2.3. Laboratory analyses of soil samples and statistical analysis

The pH and EC of soil samples were measured by using glass electrode pH (Seven CompactTM pH/Ion S220) meter and EC meter (Adwa AD 330), respectively after preparing suspension at 1:5 soil to water ratio (w/v) (Yue et al., 2016). The $EC_{1:5}$ values of soil samples were converted to saturation extract values by multiplying a conversion factor as mentioned in Hazelton and Murphy (2007). The particle size of the soil sample was analyzed by the hydrometer method as described in Huq and Alam (2005). As mentioned in Richard (1954), the determination of ammonium acetate (NH_4OAc) extractable and water (H_2O) soluble cations were performed by extracting the soils with 1N NH_4OAc and distilled H_2O, respectively. The results for individual determination of NH_4OAc extractable and H_2O soluble cations were presented accordingly in the results and discussion section. In the present study, neither were the exchangeable bases determined by subtracting the concentration of H_2O soluble cations from the concentration of NH_4OAc extractable cations nor were the soils pre-washed for the determination of exchangeable bases. The concern was to express the concentration of NH_4OAc extractable and H_2O soluble Na^+, K^+, $Ca^{2+}$and Mg^{2+} in the pre-monsoon and post-monsoon periods. In this regard, NH_4OAc extractable cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) were extracted with 1N NH_4OAc (pH 7.0) at 1:5 ratio (w/v) by shaking for 30 minutes and filtration without any prior washing of soluble salts, whereas H_2O soluble cations were extracted at 1:5 ratio (w/v) with distilled H_2O by shaking for 60 minutes followed by filtration (Thomas, 1982). Both NH_4OAc extractable and H_2O soluble parameters were extracted by destructive methods involving seperate dissolution of the soil samples (Vogel, 1989). The concentrations of Na^+ and K^+ in the extracts were determined by atomic absorption spectrometer (AAS) (Agilent Technologies 200 Series AA), whereas Ca^{2+} and Mg^{2+} concentrations were determined by ethylene di-amine tetra acetic acid (EDTA) method as described in Huq and Alam (2005). The available Cl^- was extracted by shaking the soil samples for 60 minutes with distilled water at the ratio of 1:5 and then the concentration was determined by titrating the extract against standard 0.05 N silver nitrate after adding 2–3 drops of $K_2Cr_2O_4$ (Huq and Alam, 2005). The concentration of SO_4^{2-} was determined by spectrophotometer (SP 3000 nano Optima) at a wavelength of 420 nm following turbidimetric method using Tween-80 (Huq and Alam, 2005) after extracting the samples by shaking with KH_2PO_4 at 1:5 ratio (w/v) for 30 minutes followed by filtration with Whatman filter paper 42 (Gupta, 2001).

Duncan's Multiple Range Test (DMRT) was performed by using statistical packages for social sciences (SPSS version 16) to measure differences at 5% level of significance between pairs of means of the obtained results for the specific sampling season. Correlation analyses were also performed using the same package.

2.4. GIS map visualization

To further illustrate the data, based on the analytical values, selective important parameters were considered for GIS map making and data visualization using ArcGIS 10.7 software. To monitor the spatio-temporal variations of SS in the two different seasons, first the boundary of Anowara Upazila was considered, where specific study area (*representing a part of Roypur Union*) was delineated and created a study area boundary as a shapefile. The three zones were created based on the user segment choice within the study boundary shapefile and the zone area statistics in ha were created under the area column heading by applying to calculate geometry option in ArcGIS 10.7 software. In the next stage, the selected parameters such as EC, NH_4OAc extractable and H_2O soluble Na^+ as well as available Cl^- in the pre-monsoon and post-monsoon periods were considered for the mapping exercise and data visualization. These have been done by using the Inverse Distance Weighted (IDW) interpolation method as it was found better in previous studies (Karim et al., 2019 and Roy et al., 2020).

To determine the spatio-temporal variations of SS, two sets of distinct maps of individual selective parameters (as mentioned above) were prepared based on the manual breaks method considering high and low values of both pre-monsoon and post-monsoon data of the respective parameters, respectively. For map visualization, the same color code was used to represent high (red) and low (green) values. However, for EC classification, five categories such as low, moderate, high, severe, and extreme were selected by following the established class range adopted from Hardie and Doyle (2012).

3. Results

To assess the spatial and temporal variations in SS, the concentrations of such cations as Na^+, K^+, Ca^{2+} and Mg^{2+}, and such anions as Cl^- and SO_4^{2-} of soil samples collected from different sampling sites in two different seasons were analyzed and presented sequentially. The texture of the soil samples in the study area was clay loom which belongs to the broad group of loam. The average contents of organic matter in zone-1, 2 and 3 were 1.91%, 1.79% and 2.07%, respectively. The maximum water holding capacity (WHC) of soils collected from different sites ranged from 44 to 49%.

3.1. pH and EC

The highest pH value in the pre-monsoon period was found in site-3 followed by site-2 and site-1 belonging to zone-1, and the lowest value was found in site-5 which belongs to zone-2 (Fig. 3A). Similarly, in the post-monsoon period, the highest pH values were observed in sites belonging to zone-1 and the lowest values were observed in sites under zone-2. Compared to the pre-monsoon, the pH values during the post-monsoon period increased by 3.85%–14.72%.

Fig. 3B shows the spatial and seasonal changes in soil EC. During both the pre-monsoon and post-monsoon periods, the highest EC values were observed in zone-1 and the lowest values were observed in zone-3, respectively. During the pre-monsoon period, the EC value in site-3 was found to be 4.33-times higher compared to site-9, whereas in site-1, it was found to be 7.84-times higher compared to site-7 during the post-monsoon period. The EC value decreased from a minimum of 58.42% in zone-1 to a maximum of 78.43% in site-7 during the post-monsoon in comparison to the pre-monsoon period. The mean values of pH and EC among all the sampling sites in both the pre-monsoon and post-monsoon periods differed significantly ($p < 0.01$).

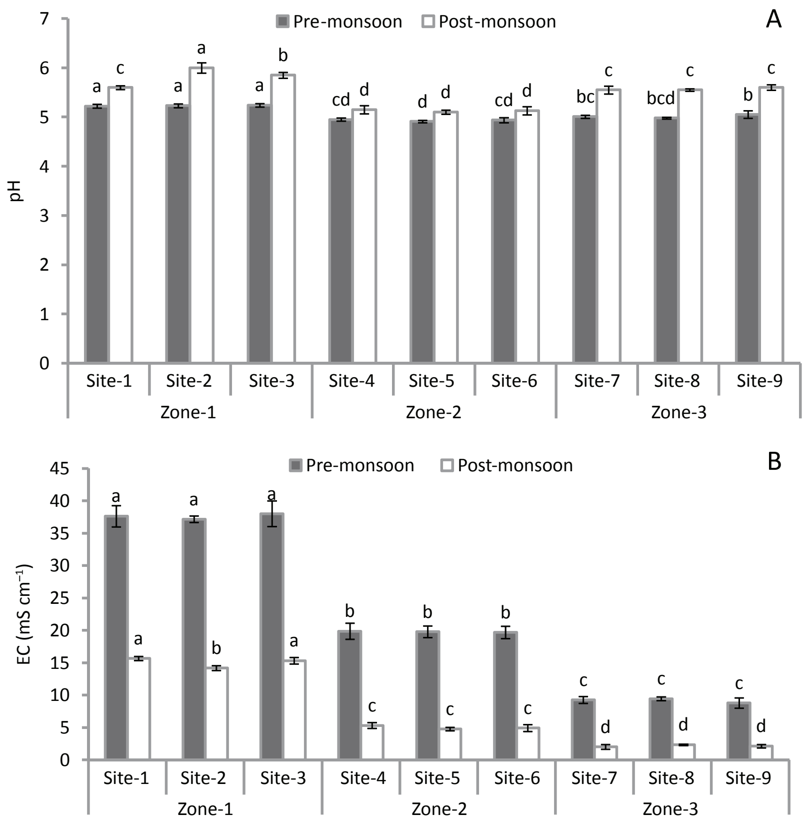

Fig. 3. (A) pH and (B) EC of soil samples collected from different sites in the pre-monsoon and post-monsoon periods

3.2. Concentrations of NH_4OAc extractable and H_2O soluble monovalent cations

Fig. 4 (A-D) shows the concentrations of NH_4OAc extractable and H_2O soluble Na^+ and K^+ of soil samples collected in the pre-monsoon and post-monsoon periods. The concentrations of NH_4OAc extractable and H_2O soluble Na^+ were found to be highest in different sites belonging to zone-1 and the lowest in sites belonging to zone-3 both in the pre-monsoon and post-monsoon periods (Fig. 4A and Fig. 4B). In the pre-monsoon period, the NH_4OAc extractable Na^+ in site-2 belonging to zone-1 was 56.48% higher relative to site-7 belonging to zone-3 (Fig. 4A). Similarly, in the post-monsoon period, the NH_4OAc extractable Na^+ in site-1 was found to be 86.21% higher compared to site-7 (Fig. 4A). On the other hand, the concentration of H_2O soluble Na^+ in site-3 was found to be 56.15% higher compared to site-9 in the pre-monsoon period, and 91.52% higher in site-1 compared to site-7 in the post-monsoon period (Fig. 4B). Both NH_4OAc extractable and H_2O soluble Na^+ concentrations in the post-monsoon period decreased by as highest as 72.86% and 84.92% respectively, relative to the pre-monsoon period.

The maximum concentration of NH_4OAc extractable K^+ in the pre-monsoon period was observed in site-3 which was 3.43-folds higher compared to site-5 having minimum concentration (Fig. 4C). Similarly, in the post-monsoon period, the concentration of NH_4OAc extractable K^+ was found 5.40-folds higher in site-2 belonging to zone-1 compared to site-6 belonging to zone-2. On the other hand, the concentration of H_2O soluble K^+ in the pre-monsoon and post- monsoon periods were found to be 5.74 and 4.83-folds higher, respectively in site-3 and site-1 compared to site-7 (Fig. 4D). However, the concentrations of NH_4OAc extractable and H_2O soluble K^+ decreased in all the respective sites in the post-monsoon in comparison to the pre-monsoon period. The NH_4OAc extractable K^+ decreased by as highest as 58.09% (Fig. 4C), whereas of H_2O soluble K^+ by 69.01% (Fig. 4D) in the post-monsoon relative to pre-monsoon season. The mean concentrations of NH_4OAc extractable and H_2O soluble Na^+ and K^+ among all sampling sites varied significantly ($p < 0.01$) from each other in both the seasons.

3.3. Concentrations of NH_4OAc extractable and H_2O soluble divalent cations

Fig. 5 (A-D) shows the concentrations of NH_4OAc extractable and H_2O soluble Ca^{2+} and Mg^{2+} of soil samples collected from different sites in the pre-monsoon and post-monsoon seasons. The concentrations of NH_4OAc extractable Ca^{2+} in site-4 were 35.29% and 44.79% lower respectively in the pre-monsoon and post-monsoon periods compared to site-1 (Fig. 5A). On the other hand, the concentration of H_2O soluble Ca^{2+} was found to be 50.00% lower in site-9 compared to site-2 in the pre-monsoon period, whereas 30.95% lower in site-5 compared to site-1 in the post monsoon period (Fig. 5B). Both the concentrations of NH_4OAc extractable and H_2O soluble Ca^{2+} were found lower in the post-monsoon compared to the pre-monsoon period. In the post-monsoon season, NH_4OAc extractable Ca^{2+} content decreased by as highest as 36.67%, whereas H_2O soluble Ca^{2+} content decreased by 80.0% relative to the pre-monsoon season.

The highest concentrations of NH_4OAc extractable Mg^{2+} in both the pre-monsoon and post-monsoon periods were found

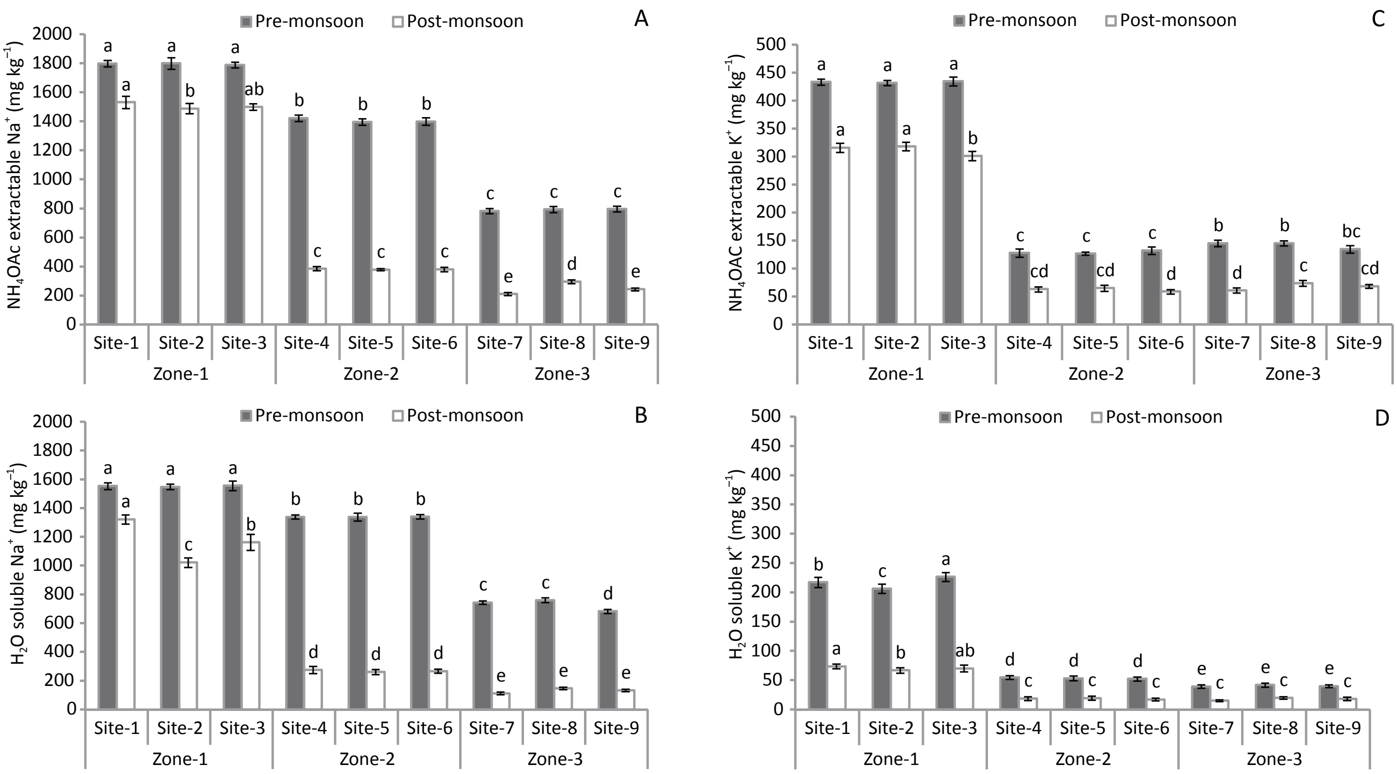

Fig. 4. Concentration of NH_4OAc extractable and H_2O soluble Na^+ and K^+ in the pre-monsoon and post-monsoon periods. (A) NH_4OAc extractable Na^+, (B) H_2O soluble Na^+, (C) NH_4OAc extractable K^+, (D) H_2O soluble K^+

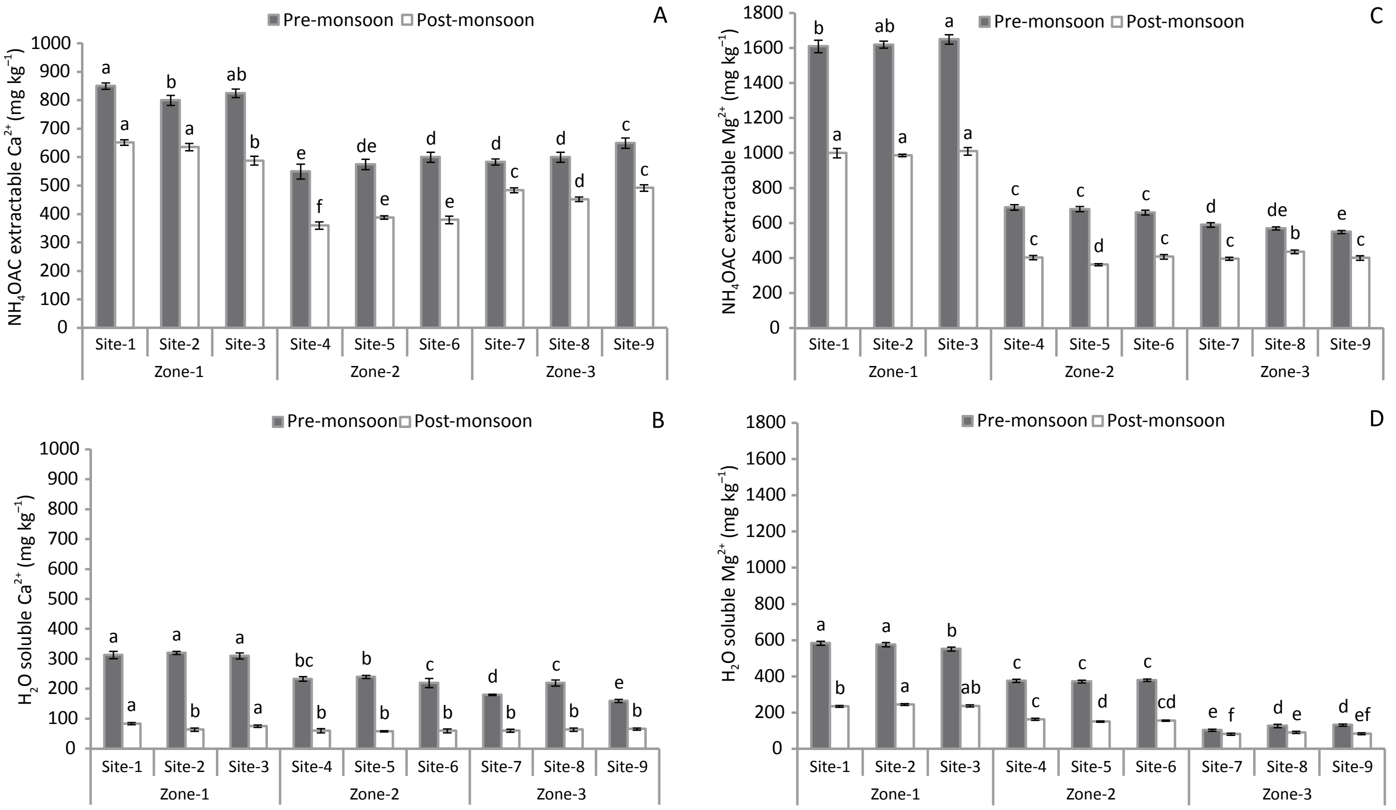

Fig. 5. Concentration of NH_4OAc extractable and H_2O soluble Ca^{2+} and Mg^{2+} in the pre-monsoon and post-monsoon periods. (A) NH_4OAc extractable Ca^+, (B) H_2O soluble Ca^+, (C) NH_4OAc extractable Mg^{2+}, (D) H_2O soluble Mg^{2+}

in site-3 which were 3.0 and 2.79-folds higher compared to sites-9 and site-5 having minimum concentrations (Fig. 5C). Similarly, H_2O soluble Mg^{2+} concentrations in both pre-monsoon and post-monsoon periods were found to be highest respectively in site-1 and site-2 belonging to zone-1, while the minimum concentrations in both seasons were found in site-7 belonging to zone-3 (Fig. 5D). The concentrations of NH_4OAc extractable Mg^{2+} decreased by 23.37–46.71%, whereas of H_2O soluble Mg^{2+} by 21.54–59.73% in the post-monsoon compared to the pre-monsoon period. In both the pre-monsoon and post-monsoon periods, the difference in the mean concentration of NH_4OAc extractable and H_2O soluble Ca^{2+} and Mg^{2+} among all the sampling sites was significant at 1% level.

3.4. Concentrations of Cl^- and SO_4^{2-}

In the pre-monsoon period, the maximum concentration of Cl^- in site-1 was 5.22-folds higher than the minimum concentration observed in site-9, while in the post-monsoon period, the maximum concentration in site-1 was 14.25-folds higher than minimum concentration observed in site-7 (Fig. 6A).

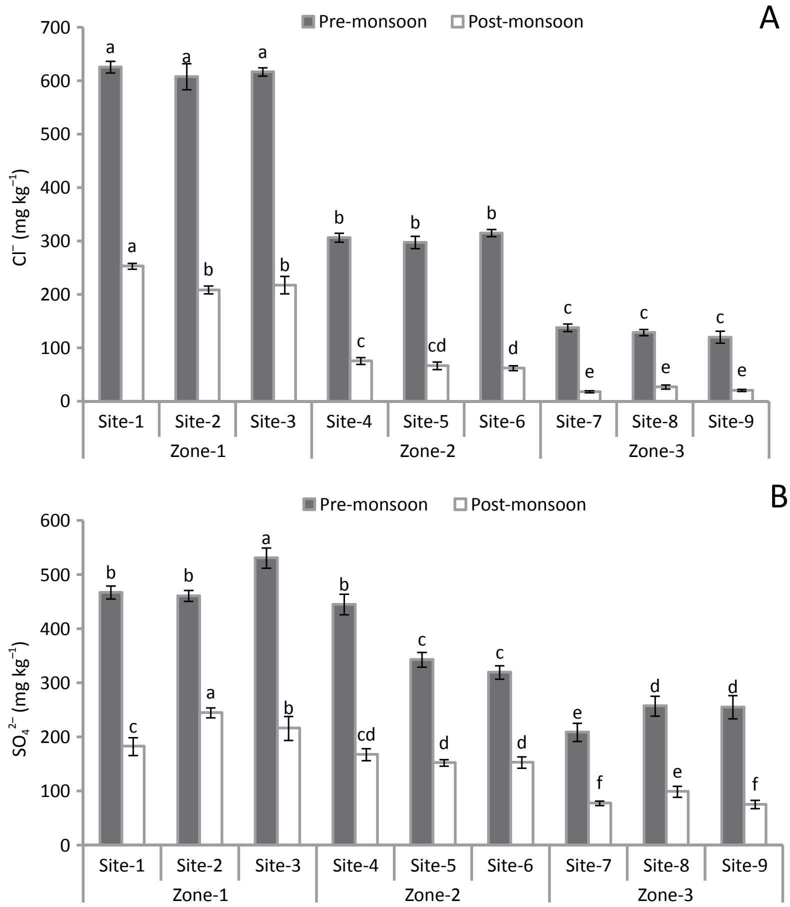

Fig. 6. Concentration of (A) Cl^- and (B) SO_4^{2-} in the pre-monsoon and post-monsoon periods

In the post-monsoon period, the concentration of Cl^- decreased by 59.57%–87.10% relative to the pre-monsoon period. In the pre-monsoon and post-monsoon periods, the highest concentrations of SO_4^{2-} were observed in site-3 and site-2, which were 2.54-folds and 3.24-folds higher compared to sites-7 and site-9, respectively (Fig. 6B). The concentration of SO_4^{2-} decreased in their respective sites ranging from 46.87% to 70.38% in the post-monsoon compared to the pre-monsoon season. The mean concentrations of Cl^- and SO_4^{2-} among all sampling sites varied significantly ($p < 0.01$) in both the seasons.

3.5. Correlation co-efficient (r)

The correlation between EC with all NH_4OAc extractable mono- and di-valent cations in the pre-monsoon and post-monsoon seasons was positive and highly significant ($p < 0.01$) (Table 1). Similarly, the relationship between EC with all H_2O soluble mono- and di-valent cations as well as available anions (Cl^- and SO_4^{2-}) was found positive and significant at 1% level except EC and H_2O soluble Ca^{2+} in the post-monsoon period ($p < 0.05$) (Table 2).

3.6. Map visualizations

Furthermore, the sampling sites were categorized from low saline to extreme saline for both the pre-monsoon and post-monsoon periods based on the manual breaks classification method (5 classes are generated in this regard) shown in Fig. 7. The total study area has been calculated as 348.09 ha.

In the pre-monsoon season, the EC of zone-1 was found more than 32.0 mS cm^{-1}. Besides, the EC was reported in the range of 16.0–32.0 and 8.0–16.0 mS cm^{-1} in zone-2 and zone-3, respectively. On the other hand, in the post-monsoon season, the degree of salinity in zone-1 decreased representing EC within the range of 8.0–16.0 mS cm^{-1}. Similarly, the degrees of salinity in both zone-2 and zone-3 declined with EC values in the range of 4.0–8.0 and 2.0–4.0 mS cm^{-1} respectively (Fig. 7). Similar to SS mapping, the variations in the concentrations of the major cation (e.g., Na^+) and anion (e.g., Cl^-) which contribute to SS are shown in Fig. 8–10. The spatial and temporal differences in the concentrations of NH_4OAc extractable and H_2O soluble Na^+ as well as available Cl^- were depicted with the color gradient, where red color represented high concentration and green color represented low concentration (Figs. 8–10).

Table 1
Correlation among NH_4OAC extractable ions in pre-monsoon and post-monsoon

	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}
pH	1	0.528	0.645*	0.723*	0.855**	0.729*
EC	0.680*	1	0.987**	0.961**	0.773**	0.962**
Na^+	0.489	0.962**	1	0.993**	0.857**	0.991**
K^+	0.883**	0.915**	0.771**	1	0.910**	0.997**
Ca^{2+}	0.907**	0.851**	0.691*	0.972**	1	0.903**
Mg^{2+}	0.839**	0.959**	0.846**	0.991**	0.948**	1

Orange color and green color represent correlation co-efficient (r) values in pre-monsoon and post-monsoon repectively
** Correlation is significant at the 0.01 level (1-tailed)
* Correlation is significant at the 0.05 level (1-tailed)

Table 2
Correlation among H_2O extractable ions in pre-monsoon and post-monsoon

	pH	EC	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}
pH	1	0.528	0.580	0.685*	0.504	0.359	0.521	0.320
EC	0.680*	1	0.989**	0.973**	0.743*	0.962**	0.994**	0.876**
Na^+	0.350	0.914**	1	0.989**	0.819**	0.918**	0.994**	0.802**
K^+	0.851**	0.951**	0.744*	1	0.805**	0.885**	0.976**	0.780**
Ca^{2+}	0.633*	0.963**	0.877**	0.902**	1	0.570	0.768**	0.354
Mg^{2+}	0.530	0.973**	0.977**	0.856**	0.929**	1	0.953**	0.963**
Cl^-	0.687*	1.000**	0.909**	0.953**	0.959**	0.970**	1	0.854**
SO_4^{2-}	0.606*	0.920**	0.903**	0.837**	0.889**	0.928**	0.914**	1

Orange color and green color represent correlation co-efficient (r) values in pre-monsoon and post-monsoon repectively
** Correlation is significant at the 0.01 level (1-tailed)
* Correlation is significant at the 0.05 level (1-tailed)

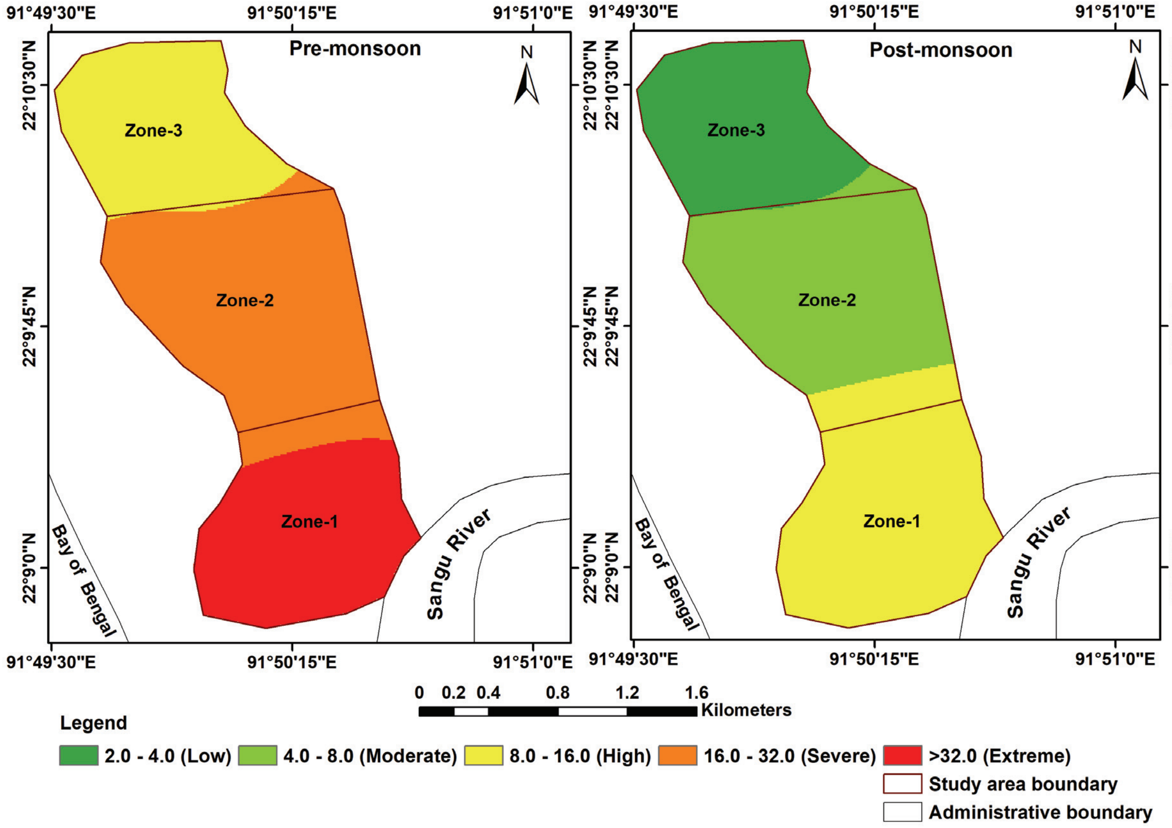

Fig. 7. Visualization of the extent and degree of SS in terms of EC (mS cm^{-1}) in the pre-monsoon (left) and post-monsoon (right) periods

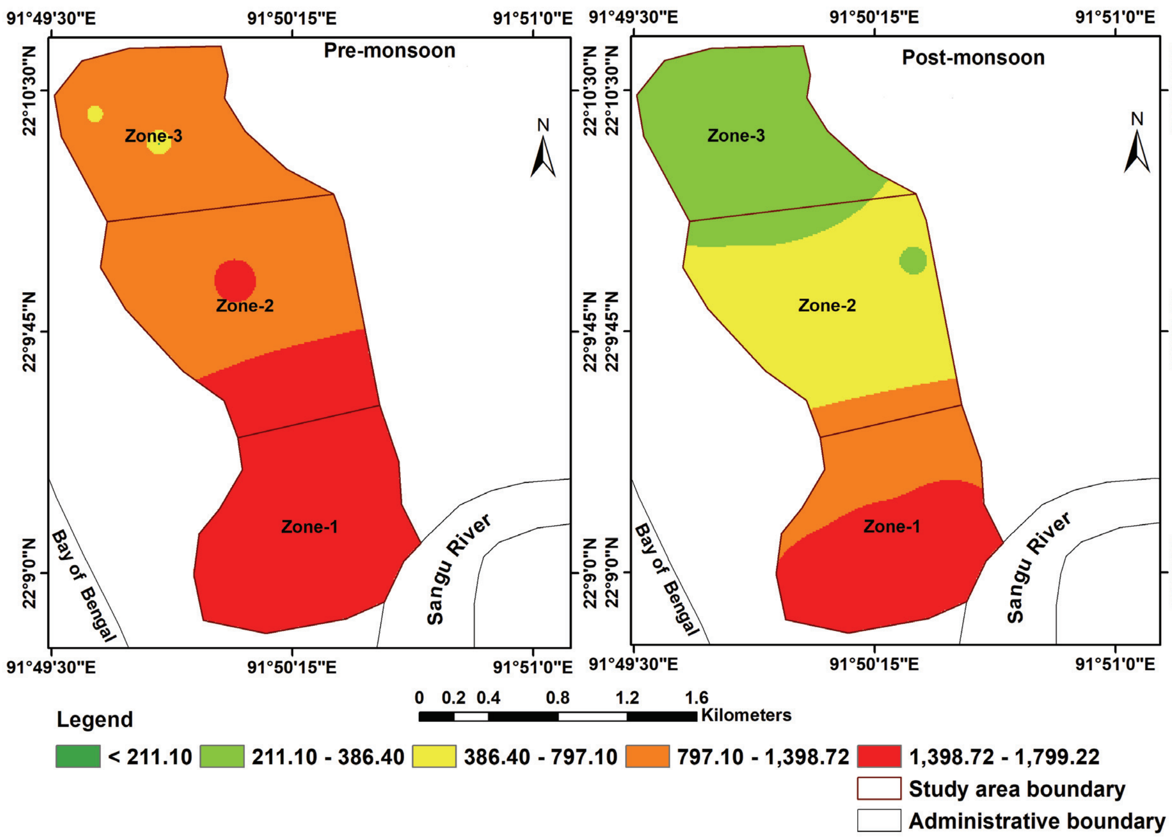

Fig. 8. Visualization of NH_4OAc extractable Na^+ (mg kg^{-1}) in the pre-monsoon (left) and post-monsoon (right) periods

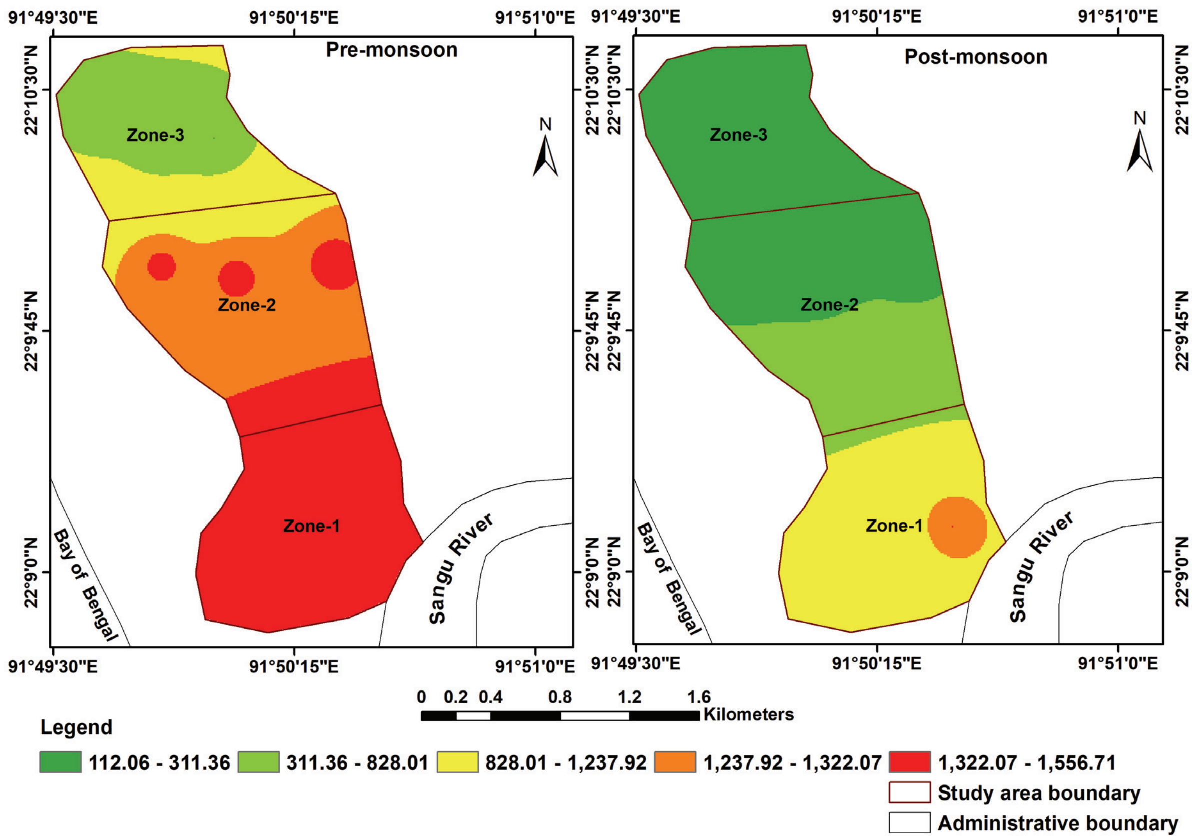

Fig. 9. Visualization of H_2O soluble Na^+ (mg kg^{-1}) in the pre-monsoon (left) and post-monsoon (right) periods

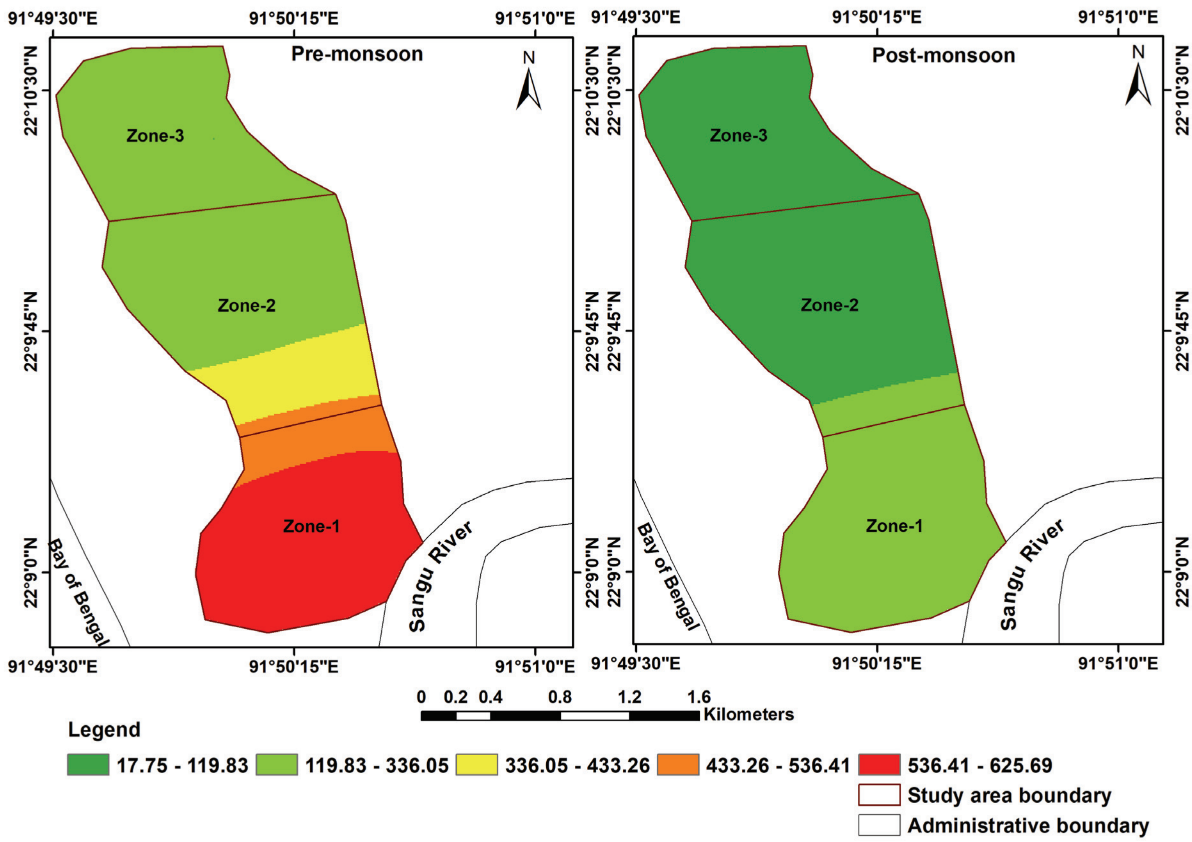

Fig. 10. Visualization of Cl^- (mg kg^{-1}) in the pre-monsoon (left) and post-monsoon (right) periods

4. Discussion

All the collected soil samples belonging to zone-1, 2 and 3 were acidic in nature which was found in consistent with other observations (Brammer, 1996; LRUG, 1997). Salt affected soils having low pH are rare throughout the world and these soils show characteristics identical to the acidic-salt affected soils (Gunarathne et al., 2020). The dominance of SO_4^{2-} over Cl^- might be responsible for lowering the pH of saline soils. Several researchers also reported the acidic nature of saline soils that exist in different coastal parts of Bangladesh (Chowdhury, 2016; Haque, 2018; Jamil et al., 2020). Compared to the pre-monsoon season, the soil pH of all the sampling sites in the post-monsoon season increased which was likely due to the removal of SO_4^{2-} with rain water during the monsoon period. In the recent study, Roy and Chowdhury (2020b) observed that the leaching of acidic saline soils resulted in an increased pH compared to non-leached soils. In contrast to the present study, Chaganti et al. (2015) found a significant decrease in pH when the soils amended with organic matters were subjected to irrigation.

In general, soils having EC of saturated soil extract greater than 4 mS cm^{-1} are referred to as saline soils (Brady and Weil, 2005). The study area was grouped from low to extremely saline depending on EC values of saturation extract. All the sampling sites belonging to zone-1 were found in the class of extremely saline in the pre-monsoon season and highly saline in the post-monsoon season, whereas all the sites belonging to zone-2 fell in the group of severely saline in the pre-monsoon and moderately saline in the post-monsoon period (Fig. 7). On the other hand, all the sampling sites collected from zone-3 were found in the categories of highly saline and low saline in the pre-monsoon and post-monsoon periods, respectively (Fig. 7). The salinity of soil and the concentrations of cations and anions decreased with increasing distance from the Sangu River valley (SRV) toward the north. A similar observation was found by Hoque et al. (2019), where salinity decreased with the distance from the coastal belt. The variation in the degree and extent of soil salinity might be due to tidal influences in the depressions, washing off salts with freshwater from the upper ground, or complex geological formations (Rahman et al., 2017). It is worth mention that, the coastal plains of Bangladesh are characterized by the almost level, clay landscape and crisscrossed by numerous interconnected tidal rivers and creeks causing shallow to moderate periodical submergence by flash flood (Huq and Shoaib, 2013). Despite of uniform sediment characteristics, the salinity in these coastal areas is mainly influenced by the climatic elements especially variations in temperature and rainfall, as well as changes in sea level rise (Dasgupta, 2014). The low lying coastal belts of Bangladesh are highly vulnerable to sea level rise and saline water intrusion as a result of global climate change (Clarke et al., 2015). In the post-monsoon period, the salinity levels were found lower in all the respective sites compared to the pre-monsoon period, which was in agreement with the findings of Jamil et al. (2020). Moreover, Hoque et al. (2019) also observed that the salinity and concentration of Cl^- decreased in the wet season compared to the dry season. This could be due to the leaching of soluble salts during monsoon rain. Saline soils contain salts of Na^+, K^+, Ca^{2+} and Mg^{2+} in association with Cl^-, SO_4^{2-} and HCO_3^- which are soluble and leachable with irrigation water (Zhang et al., 2014; Roy and Chowdhury, 2020b).

In coastal areas of Bangladesh, the degree of SS increases continuously from the beginning of winter and reaches its peak during the months of March to April, whereas the intensity of salinity decreases with the advent of the rainy season and reaches its minimum during the months of July to August. The seasonal changes in SS with respect to temperature and rainfall in the year of 2018 is clearly visible from Fig. 2. This phenomenon has been also reported by Yan et al. (2015) that the levels of SS change with the season, where SS increases gradually reaching its peak in the dry season and decreases in monsoon period. This could be due to the release of ions from the exchange sites and concomitant removal from the soil solution with percolating water during the monsoon period. In another study, Clarke et al. (2015) stated that salts are significantly deposited on the agricultural land during the dry season and monsoon rains determine the accumulation of salts by regulating the removal of these salts through leaching. A similar observation was found by Cucci et al. (2016), where rain water of the autumn-winter period ensures good control of SS. Mojid and Acharjee (2013) also observed that the monsoon rainfall resulted in a significant decrease in salt content at the end of the rainy season that accumulated in the top soil layer due to irrigation by synthetic saline water.

The magnitude of the mean concentration of cations of all the sampling sites in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ was in consistent with the previous observation (Roy et al., 2020). SRDI (2010) also stated that Na^+, Ca^{2+}, Mg^{2+} and K^+ are the dominant cations found in saline soils, and the ionic preponderance decreased in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ in areas under the influence of brackish water. The positive correlation of EC with that of other cations and anions (Table 1 and 2) in the present study was in consistent with other findings (Cebas-Csic et al., 1997; Roy et al., 2020; Roy and Chowdhury, 2020b). The EC of soil solution is the measure of its ability to conduct an electric current which usually depends on the number of ions present in the soil, and the higher the concentration of dissolved ions in soil solution, the higher its EC (Brady and Weil, 2005). A strong relationship between EC and total dissolved salts (TDS) was also observed by Rusydi (2018) and Jemily et al. (2019).

5. Conclusions

It can be concluded from the present work that the degree and extent of SS as well as the concentrations of associated cations and anions decreased in the post-monsoon compared to the pre-monsoon period, and also with increasing distance from the SRV. These variations of SS in the coastal areas are influenced by a number of factors including seasonal changes in temperature and rainfall, almost level landscape, and a number of interconnecting tidal rivers. Moreover, the relationship of EC with that of all NH_4OAc extractable and H_2O soluble cations as well as anions was positive and highly significant. The magnitude of the mean concentration of cations of all the sampling sites was observed in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$.

Soil salinity is one of the most severe environmental factors limiting the production of crops in the coastal area of Bangladesh. The identified trend in SS regarding spatial and seasonal variations could provide guidelines for developing sustainable crop production in the coastal areas of Bangladesh. Growing short duration winter crops can be practiced with proper soil management during the months of December to February to better use of agricultural lands in the study area. Taking into account the severity of the problem to sustainable crop production, it is recommended to take a large number of soil samples from the coastal zones of Bangladesh to assess the spatio-temporal variations of SS to a great extent through laboratory and GIS techniques in the future research.

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