Original Research Article

Effect of increasing elevation of lowland coastal saline soils of Sundarbans (India) on soil salinity and its seasonal variation

ABSTRACT:

The delta region of the river Ganges spreads over India (West Bengal) and Bangladesh is popularly known as Sundarbans. Crop productivity of the region is very poor. Agricultural lands of the region are mostly saline and low-lying with drainage congestion due to presence of brackish groundwater table at shallow depth and flat topography. In recent years, improvement in productivity of these lands was witnessed by farmers when the elevation of lowlands was increased through land shaping. In the present study changes in the salinity status of soil were due to raise of land elevation through land shaping was investigated for two years and 3 seasons (winter, summer and late summer). It was found that there was a considerable decrease in soil salinity due to increase in elevation of lowlands through land shaping. The salinity of original lowlands was about 200% higher than the raised lands or uplands made through land shaping. Salinity of rhizosphere soil decreased with depth and there was a strong seasonal variation of soil salinity. At all soil depths soil salinity increased as the dry season progressed from winter to late summer through summer and soil salinity was highest in the surface (0-10 cm). The depth to groundwater table and the groundwater salinity also showed strong seasonal variation and were maximum in late summer season. The drainage condition of soil improved with increasing in land elevation.

(Key word: Coastal saline soil, Soil salinity, Seasonal variation of soil salinity, Land shaping)

1. INTRODUCTION

Saline soils contain excess amount of soluble salts to interfere with plant growth. According to Richards (1954), soils are those which are having electrical conductivity of saturation extract of soil (ECe) > 4.0 dS m^{-1} at 25 °C are saline soils. Saline soils are found in (i) arid or semi-arid regions of the world where excess salt in soil cannot be leached out of soil profile due to poor rainfall (Blaylock *et al*., 1994), (ii) in areas with presence of brackish groundwater table at shallow depth and (iii) along the sea coasts and river deltas due to coastal influence (Biswas, 1990). Saline soils present along the sea coasts and in delta region of rivers are termed as coastal saline soils. The delta regions of the river Ganges is popularly known as Sundarbans, which is spreads over India (West Bengal state and lies between 87°25' and 89° E latitude and 21°30' and 23° 15' N longitude) and Bangladesh (89°02' to 90° E latitude and 21°27' to 22°30' N longitude). It is the biggest delta of the world. Out of total area of 2.5 m ha in Sundarbans, India shares 0.96 m ha and rest falls in Bangladesh (Bandyopadhyay, 2003). Soil salinity is one of the major obstacles for successful crop production in Sundarbans region (Rahman and Ahsan, 2001) and it shows considerable seasonal variation (He *et al*., 2014). Besides soil salinity, low-lying nature of land, high drainage congestion and acute shortage of suitable irrigation water are responsible for low crop production in Sundarbans delta (Chaudhary *et al*., 2008). Permanent reclamation of these lands is highly cost inhibitive due to natural constraints like, direct/

indirect influence of coastal waters and constraints for land drainage (Raju *et al*., 2016). Hence, agronomic management is the only viable alternative for improving crop productivity in the region. Of late, it has been observed that raising elevation of lowlands through land shaping improved crop productivity in the region (Bandyopadhyay *et al*., 2009). In brief, the land shaping techniques involved: digging of a portion of farm land (about 1/5th part) in the form of pond/channel of suitable depth to raise the remaining portion of farm land by about one meter through spreading of dug out soil. While, spreading the dugout soil care was taken to keep the surface soil (0-30 cm) on the surface. Dugout area was used for rain water harvesting for creation of irrigation resources which was scare in the area during dry seasons. The dugout area also facilitated drainage of excess water from land. The details of land shaping technique have been described by Bandyopadhyay *et al*. (2011). The technique is widely used by farmers and it led to considerable improvement in crop productivity in the region has been reported (Mandal *et al*., 2013). But sufficient information on variation in soil salinity through raising land elevation is lacking. In the present paper attempts have been made to investigate into the impacts of raising the elevation of coastal lowlands on salinity status of soil and its variations on timeline for developing efficient management options for improving crop productivity in the region.

2. THE STUDY AREA

The study area falls under Basanti and Canning-I Blocks (88º 2′ 14″ & 89º4′34″ E latitude, and 21º 31′51″ & 23º13′ 3″ N longitude) in Sundarbans region of West Bengal (Fig. 1) in the district of South 24 Parganas and under coastal agro-eco-region (18.5) of India. The entire Basanti Block is a delta island while Canning-I Block falls under main land.

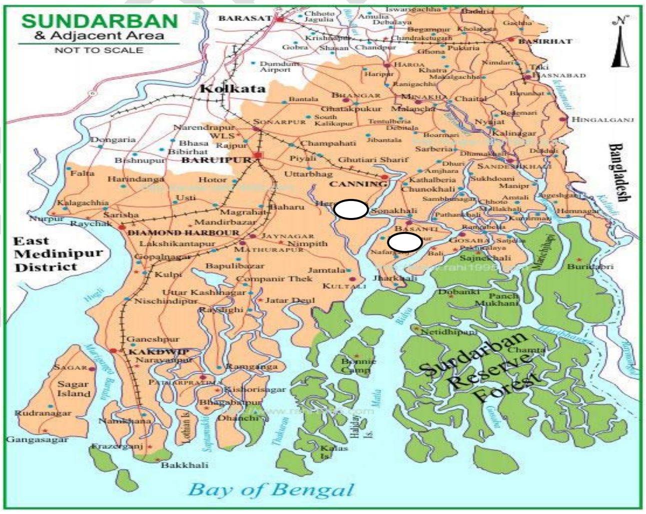

Fig 1: Map of coastal region of Sundarban

The area receives high rainfall (annual rainfall about 1800 mm), mostly under south west monsoon. The extended monsoon season which includes pre-monsoon and post-monsoon periods lasts from June-July to September- October during which almost 80% of the total annual rainfall occurs. Rainfall beyond this period of year is meagre (Table 1). Agricultural lands in the area are mostly low-lying and remains almost waterlogged during monsoon season. Hence rice is almost the single crop grown during monsoon season. The cropping intensity during rest of the period of year is very poor due to lack of irrigation water and high soil salinity.

3. METHOD AND MATERIALS

The soil of the area is heavy with textural class mostly varies between silty clay and silty clay loam. The cation exchange capacity (CEC) of soil in the experimental plot was 20-22 $cmol_c\ kg^{-1}$ soil. The area suffers from drainage congestions due to presence of groundwater table at shallow depth and flat topography. Eight different field locations (labelled, 1 to 8) were selected from Basanti and Canning-I Blocks for the study. Soil samples were collected simultaneously from uplands (denoted as 'U'), made over original lowlands through land shaping and adjacent original lowlands (denoted as 'L') for each location. Sampling plots were so selected that land shaping was done at least 10 years back so that the raised lands (uplands) had reasonably stabilized. The soils of Basanti Block were from farmers' fields (labelled as 1, 2, 3, 4 & 5) and those from Canning-I Block (labelled as 6, 7 & 8) were from research farm of ICAR- Central Soil Salinity Research Institute, Regional Research Station, Canning Town- 743329. For a better idea of salt distribution in rhizosphere soil, samples were collected from 0-10, 10-20 and 20-30 cm soil depth, in three different seasons viz., winter (December-January), summer (March-April) and late summer (May-June) for two years. In each year soil samples were collected during the last week of December, March and May for winter, summer and late summer seasons, respectively. For soil moisture determination samples were collected from 0- 10, 10-20, 20-30, 30-50, 50-70 and 70-90 cm until the groundwater table (WT) was reached. The winter season started just after the extended monsoon season (May-June to September-October) when *in-situ* soil moisture was quite high. Lowlands remained almost waterlogged from June-July to October-November. On cessation of monsoon soils started gradually drying up to Summer/Late summer till the next monsoon season started in June-July. During late summer season, there were occasional pre-monsoon showers as evident from rainfall data (Table 1). Soil salinity (ECe) was measured as electrical conductivity of extract of soil saturation paste with the help of conductivity meter. Soil moisture was estimated gravimetrically and depth to groundwater table was measured through Peziometers installed in fields. Total porosity of soil was estimated from the data on bulk density of soil which as estimated by core sampling following the method of Carter and Gregorich (2008). Air field porosity of soil was estimated by deducting water filled porosity (estimated by volumetric moisture content of soil) from total porosity. Statistical analysis of data was done using IBM SPSS version 22.0. Duncan's multiple range test at P =.05 was used for test of significant.

Table 1: Month-wise mean (58 years' mean) rainfall (mm) during (1966-2013)

Months	1966-1975	1976-1985	1986-1995	1996-2005	2006-2013	TOTAL	AVERAGE
January	22.93	9.84	11.63	13.98	18.0	76.4	15.3
February	17.1	31.54	25.28	10.37	22.0	106.2	21.2
March	37.14	37.54	34.39	43.41	14.4	166.9	33.4

April	49.83	71.79	55.55	73.53	54.7	305.4	61.1
May	109.09	162.27	150.43	153.7	150.3	725.7	145.1
June	268.86	337.32	331.17	329.98	217.7	1485.0	297.0
July	386.63	340.36	368.08	406.33	358.5	1859.9	372.0
August	420.27	331.39	309.34	359.78	390.5	1811.3	362.3
September	298.89	247.22	392.35	282.14	362.7	1583.3	316.7
October	162.29	84.45	137.77	232.36	130.0	746.9	149.4
November	31.95	7.58	77.97	39.25	14.7	171.4	34.3
December	17.02	15.01	3.27	5.51	5.0	45.8	9.2
Total	1822	1676.31	1897.23	1950.34	1738.3	9084.2	1816.8

4. RESULTS AND DISCUSSION

4.1. Soil salinity variation according to land situation and soil depth:

The mean salinity of soil at different locations compiled over seasons and year (Table 2**)** showed that soil salinity of lowlands (L) over the years was significantly higher (*P* =.05) than to uplands (U). The soil salinity differences between lowland and upland were variable among the sample site. The differences in soil salinity variation between lowland and upland ranged from ranging from 125.3% to 312.6% with mean of 201.1% higher in lowlands compared to uplands (Table 2**)**. The compiled mean value of soil salinity of lowlands and uplands also showed that the mean soil salinity (ECe) of uplands was 3.52 dS m^{-1} which could be termed as non-saline soils according to Rechards (1954). While, the mean soil salinity (ECe) of lowlands was 7.08 dS m^{-1}, which were moderately saline soils. Thus, it clearly indicated that there was definite reduction in soil salinity on increase in elevation of lowlands (through land shaping), which might have resulted in enhancement of productivity of coastal lowlands due to land shaping as reported by Bandyopadhyay *et al*. (2011).

Table 2: Mean soil salinity (ECe, dS m^{-1}) at different field locations at upland and lowland situations over depths (0-10, 10-20 and 20-30 cm) and seasons (winter, summer & late summer) and years

Land situation	Field locations								
	1	2	3	4	5	6	7	8	Mean
Upland (U)	2.55	3.09	4.67	2.6	2.43	3.49	2.54	6.78	3.52^{a}*
Lowland (L)	4.32	5.33	5.85	7.13	7.13	6.63	7.94	12.3	7.08^{b}
% increase in soil sanity in L compared to U	169.4	172.5	125.3	274.2	293.4	190.0	312.6	181.4	201.1

*Figures denoted by different alphabets are statistically different at 5% probability level by DMRT

The mean soil salinity of uplands and lowlands compiled over seasons, year and locations is presented in Fig. 2. It was found that among the different soil depth categories (0-10, 10-20 and 20-30 cm) soil salinity was always higher in surface 0-10 cm and it gradually decreased with increasing soil depth. The soil salinity at 0-10 cm soil depth in lowlands was highly saline (ECe 8.52 dS m^{-1}) while, the salinity at the same depth in uplands was 3.78 dS m^{-1}, which falls under non-saline category.

Thus, non-saline resistant crops (normal crops) can be recommended for uplands but for selecting crops for lowland coastal soils salt resistant and deep rooted crops should be preferred so that plant roots can have access to lower soil salinity zones at higher soil depth.

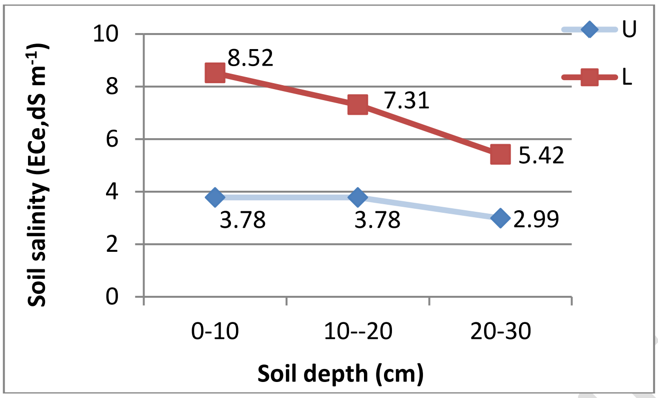

Fig. 2: Soil salinity in upland and lowland situation at different soil depth compiled over all locations, season and years

4.2. Seasonal variation of soil salinity:

Mean soil salinity compiled over depths, locations and years is presented in Fig. 3. It showed that soil salinity continued to increase gradually from winter to late summer through summer. Thus, there was lesser soil salinity in the beginning of any season compared to later part of the season. Hence, seasonal crops should be planted in earlier part of any season so that the plant roots are exposed to lesser soil salinity at the initial part of growth when plants are usually less tolerant to soil salinity. In any season soil salinity was higher in lowlands compared to uplands. Even in Late summer uplands remained only marginally saline (ECe 4.02 dS m^{-1}) while, the salinity of lowlands were quite high (ECe 7.84 dS m^{-1}).

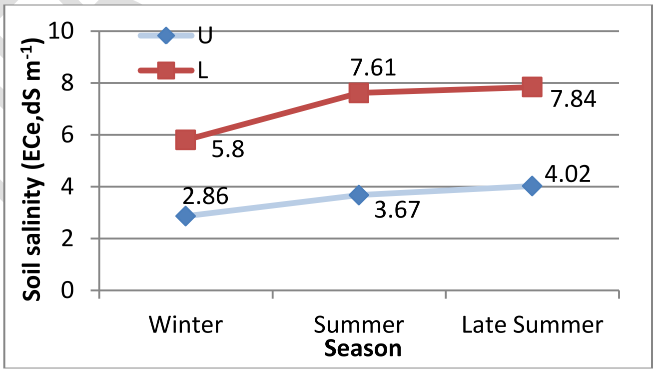

Fig 3: Soil salinity of uplands and lowlands situations at different seasons compiled over all locations, depths and years

Table 3: Mean soil salinity (ECe, dS m^{-1}) of three different soil depths at three different seasons compiled over all locations, land situations and years

Soil depth (cm)	Season			Average
	Winter	Summer	Late summer	
0-10	5.45	8.08	4.93	6.15[a]*
10-20	4.06	4.85	7.73	5.55[b]
20-30	3.49	3.99	5.14	4.21[c]
Mean	4.33[c] (13.00)**	5.64[b] (16.92)	5.93[a] (17.80)	

*Figures denoted by different alphabets are statistically different at 5% probability level by DMRT.
**Figures in parenthesis ( ) indicate total of mean soil salinity at 3 soil depths (0-10, 10-20, 20-30 cm)

However, a contrast phenomenon was observed in Table 3 that in case of late summer season when mean soil salinity was highest in 10-20 cm soil depth (7.73 dS m^{-1}) than at 0-10 cm (4.93 dS m^{-1}) soil depth. This might be because of the fact that in late summer season there was an increase in rainfall (Table 1) in the area due to pre-monsoon showers. The increased rainfall might have leached down some amount of salts from surface 0-10 cm that accumulated in 10-20 cm soil depth as revealed from the data that total mean soil salinity at 3 soil depths (0-10, 10-20, 20-30 cm) was highest in late summer (17.80 dS m^{-1}) followed by summer (16.92 dS m^{-1}) and winter (13.0 dS m^{-1}).

4.3. Depth to groundwater table and groundwater salinity:

A study of the groundwater table of the area showed that groundwater was higher at shallower depth during winter (January). Like soil salinity the depth to groundwater table was also highly variable with the season. In case of lowlands the groundwater table was very close to the surface at only 7.75 cm below the soil surface (-7.75 cm) during January (Winter) and gradually moved down to 46.74 cm (Fig. 4) below the surface soil (-46.74 cm) during May (Late summer). It then again, started rising upward and was above the surface of soil during June-July-August (monsoon season) when the lowlands were submerged when no other crops than rice could be cultivated on these lands. The movement of groundwater table in uplands followed the same seasonal pattern as that of lowlands. The depth to groundwater table in uplands was at 84.75 cm (-84.75 cm) below the surface soil in January and reached its lowest at 136.23 cm (-136.23 cm) during May. Even in June-July-August (monsoon season) it never reached the soil surface, which indicated that the uplands were never submerged. Thus, uplands were suitable for cultivation of various crops throughout the year. From the study of the month-wise rainfall data presented in Table 1 and the depth to groundwater table presented in Fig. 4, it was evident that the depth to groundwater table was very much related to the rainfall. With increase in rainfall the depth to groundwater table decreased.

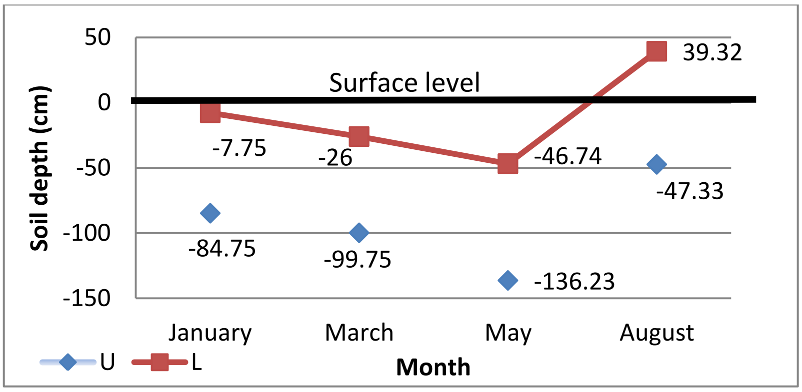

Fig.4: Depth to ground water table (cm) of upland and lowland at different period of time

The salinity level of groundwater in the area is presented in Fig. 5. It was observed that like the depth to groundwater table it also had high seasonal variation. With increase in depth to groundwater table the salinity of groundwater also increased, reached its maximum in May- June and then started decreasing and reached its minimum in July-August- September when the rainfall was maximum (Table 1). It appeared that with high downpour in monsoon period the salinity of ground water decreased due to dilution, leaching (both vertical and horizontal) and washouts (runoff). Obviously, with increase in volume of groundwater due to increase in rainfall the groundwater table started moving upward and reached above the soil surface i.e. when the land (lowlands) was submerged.

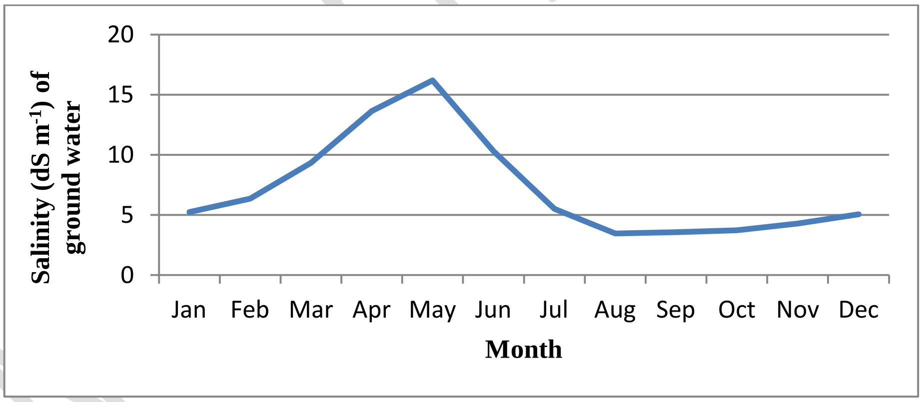

Fig. 5: Salinity of groundwater at different months of year

4.4. Moisture status of soil at different seasons:

The depth-wise moisture status of soil up to 90 cm soil depth showed that at any soil depth soil moisture was always higher in lowland situation compared to upland (Table 4) although it was likely that uplands might have received some intermittent light irrigations due to cropping activities. While, the lowlands were fallow lands and received no irrigation. The data on total porosity and air filled porosity in summer season presented in Table 5 showed that both the total porosity and air filled porosity was higher in uplands than in low lands. The uplands were better drained or aerated than the lowlands. This was important for successful crop cultivation in the area as poor drainage condition of soil was one of the major hindrances for successful crop production in the area.

Table 4: Moisture percentage at different depth of soil in different season

Season	Land situation	Winter					
		0-10	Oct-20	20-30	30-50	50-70	70-90
Winter	U	29.9	27.6	26.5	26.8	32.7	40.2
	L	38.9	WT	WT	WT	WT	WT
Summer	U	23.0	22.0	18.5	18.3	20.7	28.2
	L	29.1	30.9	33.8	WT	WT	WT
Late summer	U	23.6	25.5	24.8	22.6	21.2	19.1
	L	30.2	28.1	27.5	32.0	WT	WT

In lowlands the moisture content in soil increased with soil depth except in late summer (Table 4) when soil moisture of surface 0-10 cm soil depth was higher than the depth below (10-20 cm), obviously it was due to increased rainfall in May-June (Late summer) due to pre-monsoon showers. The increase in soil moisture with soil depth in lowlands throughout the year indicated that the source of this moisture was the groundwater table. Groundwater moved upward due to upward capillary pull created following differences in soil moisture potential between soil adjacent to groundwater and the top soil (0-10 cm) on account of drying of soil surface during dry months. Since, the groundwater was brackish it was quite clear that the source of salinity in coastal soils was the groundwater. These findings agree with findings of Biswas *et al*. (1990) and Bandyopadhyay *et al*. (2003) (who reported that upward capillary

Table 5: **Total Porosity (%) and air field porosity (%) of soil at different field locations during summer season compiled over depths (0-10, 10-20 and 20-30 cm) and year**

Soil porosity	Land situation	Field location								Mean
		1	2	3	4	5	6	7	8	
Total porosity (%)	U	48	46.7	47.9	46.9	47.6	46.1	50	49.9	47.89^{b}*
	L	42.9	44.3	46.3	46.6	46.6	45	45.8	49.4	45.86^{a}
Air field porosity (%)	U	29.3	24.5	30.7	22.1	24.1	23.3	32.3	27.4	26.7^{b}
	L	12.4	9.0	13.6	14.3	14.3	11.7	18.2	23.2	14.6^{a}

*Figures denoted by different alphabets are statistically different at 5% probability level by DMRT

flow of brackish groundwater was responsible for salinity build up in coastal soils of Sundarbans during dry month. Groundwater moves upward to the surface, get evaporated, leaving the salts in soil surface. Thus, the salinity of soil increased as the dry season progressed as also observed by Rasel *et al*. (2013). Grattan *et al*. (2002) and Boivin *et al*. (2002) also found that evapo-transpiration of water from the surface increased salinity in surface soil. Haque (2006) reported that the critical depth for capillary rise of groundwater was about 1.0 m in coastal soils of Sundarbans. Since, the surface soil in lowlands were closer to brackish groundwater table and was very much within the capillary fringe of this heavy texture soil, the salinity increased was more in lowlands compared to uplands.

5. CONCLUSION:

The results of the study revealed that:-

a) Salinity build up in coastal soils of Sundarbans can be curtailed considerably through land shaping or increasing elevation of lowland saline soils of coastal region. Moderately saline lands can be converted into non-saline lands. This is important for efficient management of coastal saline soils for higher crop production.
b) The drainage condition of elevated land improved considerably. This is very important for successful crop cultivation in the area since; drainage congestion of soil is one of the major hindrances for higher crop productivity in the area.
c) There was high seasonal variation of soil salinity. Salinity of soil increased with time as the dry seasons progressed. This necessitates the urgency for proper crop planning according to the soil salinity variation of the land. In any season early planting will be beneficial as plants will be exposed to lesser soil salinity.
d) Soil salinity decreased with soil depth and highest was at the surface soil. Thus, deep rooted crops should have preference over shallow rooted crops for these soils so that the plant roots can take the advantage of lower salinity zones.

Suggested Additional Research Need:

Further studies may be undertaken on details of changes in other physical, chemical and biological properties of soil in the area due to application of Land shaping technology. These are important for both practical and academic purposes. Study may also be undertaken to investigate into changes that may occur in quality of brackish groundwater table at shallow depth of the area when large scale rainwater harvesting is done in dug out areas.

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