

PAPER • OPEN ACCESS

## Dynamics of salinity intrusion in the surface and ground water of Sundarban Biosphere Reserve, India

To cite this article: A Chowdhury *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **944** 012061

View the [article online](#) for updates and enhancements.

### You may also like

- [Response of tilapia \(\*Oreochromis niloticus\*\) behaviour to salinity differences: a laboratory scale study](#)  
A A Fuadi, I R J Hasly, L I Azkia et al.
- [Acute toxicity of salinity to \*Sinogastromyzon Szechuanensis\*](#)  
Xiaojiang Chen, Lin Song, Wei Li et al.
- [Evaluation of soybean tolerance to soil salinity](#)  
A Taufiq, N Nugrahaeni, G W A Susanto et al.

# Dynamics of salinity intrusion in the surface and ground water of Sundarban Biosphere Reserve, India

A Chowdhury<sup>1,2\*</sup>, A Naz<sup>2,3</sup>, S Bhattacharyya<sup>2</sup> and P Sanyal<sup>4,5</sup>

<sup>1</sup> Jindal School of Environment and Sustainability, O.P. Jindal Global University, Sonapat-131001, Haryana, India.

<sup>2</sup> Tagore Society for Rural Development, 46 B, Darjipara, Shobhabazar, Kolkata-700005, West Bengal, India

<sup>3</sup> Department of Environmental Science & Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad – 826004, Jharkhand, India.

<sup>4</sup> School of Oceanographic Studies, Jadavpur University, Kolkata- 700032, West Bengal, India.

<sup>5</sup> Ex-Field Director, Sundarban Tiger Reserve, Government of West Bengal, India

\*E-mail: abhiroop.chowdhury@gmail.com, achowdhury@jgu.edu.in

**Abstract.** Sundarban is the world's largest transboundary contiguous mangrove ecosystem and home of the mangrove dwelling tigers. Sea level rise is destabilizing this ecosystem which is experiencing a rising salinity in surface and ground waters (shallow aquifer). In this study ground water salinity was investigated across Sundarbans and surface water seasonal salinity changes has been investigated along East-west gradient in the region. Statistically significant seasonal as well as spatial variations has been observed in the surface water salinity pattern across this gradient. The post monsoon average surface water salinity was 10.58 ppt while in pre-monsoon it was 27.31 ppt. Ground water salinity was lowest (0.95 ppt) in monsoon while highest in the pre-monsoon season (7.4 ppt). There was a clear east-west gradient in the surface salinity distribution across the delta, indicating a source of fresh water in the eastern corner, bordering Bangladesh. Increasing salinity indicate impact on mangrove diversity with salinity sensitive species (*Heritiera fomes*, *Nypa fruticans*) limited to the eastern corner while salinity resilient species (*Avicennia marina* and *Phoenix paludosa*) were dominating the western and central part of the Indian Sundarbans. Mangrove associate *Acanthus ilicifolius* and *Heliotropium currasavicum* were abundant in the forests under anthropogenic disturbances.

**Keywords:** Biodiversity, Climate change, Delta, Ground water, Mangrove, Salinity, Salinity intrusion, Sea level Rise, Sundarbans, Surface water, Ramsar, Wetland

## 1. Introduction

Sundarban biosphere reserve, India (9630 sq km) is located at the largest delta of the world. It is the home of the largest contiguous mangrove forest and mangrove dwelling tigers. In 2019, it has also been designated as the twenty-seventh Ramsar wetland conservation site of India with an area of 423,000 hectare. This is the largest amongst all other wetland conservation sites in the nation. Indian Sundarbans also supports a staggeringly high population of 4.6 million people and its mangrove forest renders multiple ecological



services such as being the largest blue carbon sink, remediating pollution as well as saving coasts from natural disasters [1-6].

The region has the world's largest contiguous mangrove forest. Mangroves are plant groups that can survive in saline-hypersaline conditions and need tidal inundation as well as fresh water flow for survival. They have a large root system, ideal for stabilizing the loose sediment of newly formed mudflat in the delta. True mangroves are those plants which has physiological, anatomical or morphological adaptations to survive in this saline-physiologically dry soil. These adaptation varies from root buttress to support in loose sediment, pneumatophores or breathing roots to respire in asphyxiated saline soil, pneumatophodes, salt glands in leaves to secrete out excess salt etc. [3]. All other associated flora that exist in this saline environment but don't have any specific adaptations is grouped under 'mangrove associate' species. Mangroves are biological indicators of changing salinity regime in the estuaries as would be evident from this research.

The reclaimed Sundarban is thickly populated and has fallen victim of various adverse effects of climate change. Coupled with sediment load brought down by the Ganga-Brahmaputra- Meghna river systems and due to earth's movement some 200 years back the Bengal basin is tilting east wards. As a result the effect of global accelerated sea level rise shows further acceleration in Sundarban estuary. In Indian portion it is 3.14 mm /y against global average of 2 mm/y [7].

This has results a trend of rising salinity in both surface water as well as saline water intrusion in the aquifer over the years. Salinity rise in the estuaries that exists in a geological equilibrium of fresh water flow from rivers and saline water movement from the sea due to tides is indicative of sea level rise [8]. Freshwater is slightly less dense (lighter) than saltwater, and it tends to float on top of the saltwater. At the estuarine mouth depending on the supply of fresh water from the upstream sources the saline water in the shape of a wedge extends and retreats. This wedge can extend upstream also due to sea-level rise. In this current study we look into the salinity profiles of surface as well as ground water to ascertain the 'myth' behind sea level rise at Sundarbans by studying the 'salinity rise' indicator across the Indian part of the delta.

## 2. Materials and methods

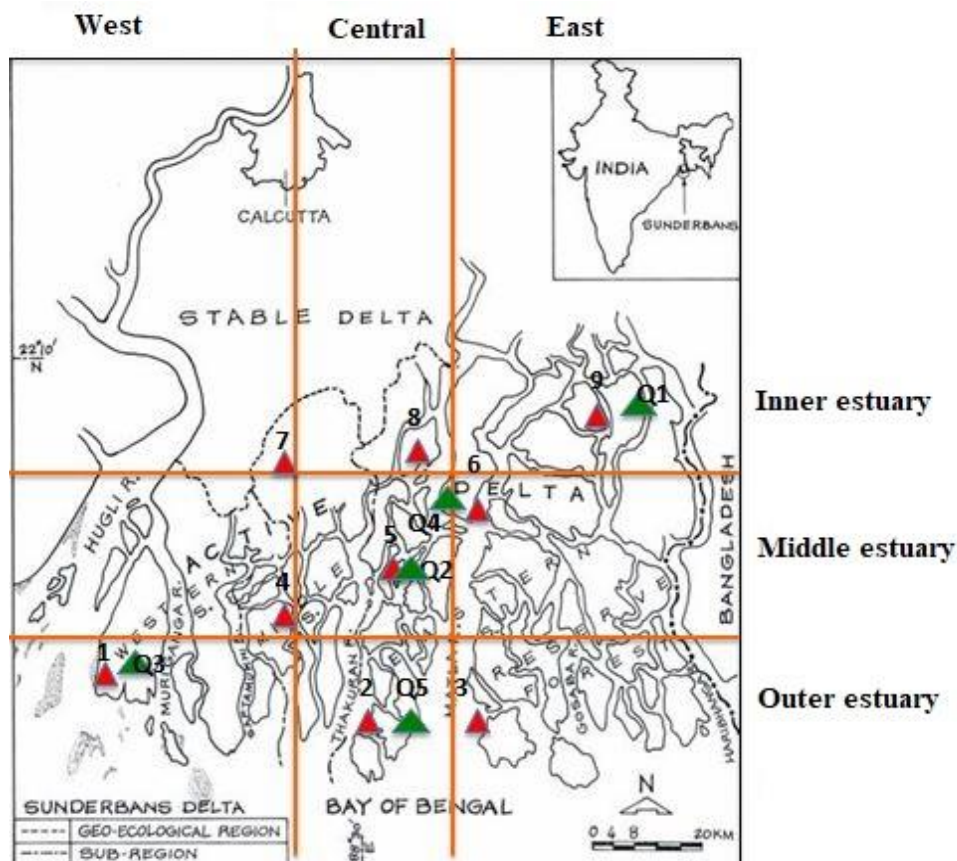
### 2.1. Fresh water collection and analysis method

There exists lot of variables for studying salinity in the surface waters of Indian Sundarban. The upstream flow of fresh water comes mainly from the Ganga River whose flow is now influenced by the periodic release of fresh water from the Farakka barrage and monsoon rain freshets. This barrage is responsible for maintaining the flow of Ganges water into Bhagirathi-Hooghly River (western border of Sundarbans in India) and Padma River (Eastern boundary of Sundarban in Bangladesh). Thus, the salinity measurements of Sundarban creek are dependent on four factors - Tidal condition (High and Low tide), Seasonal variation, Release/closure of Farakka water and Location of measurement sites within the estuary (East to West and Outer/Middle/Inner estuary). From 30<sup>th</sup> May to 31<sup>st</sup> December Farakka barrage remains open.

The current data for the surface waters had been collected during Farakka barrage open period for two seasons (pre-monsoon, monsoon) and during February-March for winter data. Surface water samples were collected during high and low tide in separate bottles. Surface water collections were made from near shore at 15 cm depth from the respective points. Hence, the whole delta was divided into three sectors (inner, outer and middle estuary) and three regions (West, East and Central) for the sampling process.

Surface water salinity was measured using three methods. The first method was that collection of water samples from locations scattered across the study area for titrimetric analysis (Mohr-Knudsen method). In this method fresh Silver Nitrate solution was prepared in a dark bottle and was first standardized being titrated with 'Standard Sodium Chloride'. Then the sample was titrated with this standardized Silver Nitrate

using Potassium Chromate indicator to quantitatively precipitate the Silver Chloride. The free Silver ion will form red tinge at the end. The surface water was collected during 2010-11.



**Figure 1.** The sampling locations for surface, ground water and mangrove biodiversity samplings. The numerical numbers (1-9) signifies the location serial number as presented in Table 2 while biodiversity assessment locations (Q1-Q5) is as presented in Table 3. Red icon indicates sites of surface and ground water sampling while green icon indicates the location for biodiversity sampling quadrat sites.

In the second method, samples collected from the locations were tested with physical salinity measurement instrument, viz Optical refractometer (Atago, Master series) and Conductivity meter for high turbidity samples. In the third method, changes in salinity profile across the delta was assessed using multiparameter analyzer across 70- 80 points from east (Raimangal River) to West (Basanti) on Matla river for both monsoon (May-June 2013) and post- monsoon (October 2013) seasons. In the third method, electrical Conductivity (EC)/ salinity measurement was done on the sampling spot using Multiparametre analyzer (Multi-Parameter Tester™ 35 Series of Eutech Instruments, Oakton©), but as the instrument could only effectively measure EC/Salt below 10 ppt (parts per thousand), so samples had been diluted in ratio of 1:10 with Mili Q deionized water for EC analysis.

### 2.2. Ground water collection and analysis method

Ground water was collected in nearby locations (tube well) from where the surface water was collected as mentioned in Figure-1. Thus, total samples collected during pre-monsoon period is  $2 \times 9 = 18$  for surface waters and another 8 for ground water *i.e.* sum total of 26 samples were analyzed via Mohr–Knudsen method and through optical refractometer.

### 2.3. Biodiversity assessment

Along with sample collections during winter, 10m x 10m replicated random quadrats were laid out at forested sampling locations of Outer, Mid and Inner estuaries during October 2011. Tree species composition and richness were ascertained through relative density.

$$\text{RelativeDensity}(D) = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all the species}} \times 100$$

This estimator shed light into the status of particular species in relation to the whole community (all the species present in the area) and this helps to draw a comparative inference on the relative position of that species in the target ecosystem.

### 2.4. Statistical analysis and GIS modeling

Geographical extents can constrain the properly display Hence, interpolation techniques were employed in the last step to display the spatial variations of the salinity variations in cartographic outputs. GIS based models and interpolations were used by numerous researchers to interpret water quality spatially and temporally [9]. Calculation of unknown spatially dispersed value from known estimator can be called an interpolation. Many techniques are used but IDW (Inverse Distance Weighted) interpolation gives a comparatively unbiased estimator as it tries to keep the mean residual error value to minimum, no requirement of prior model verification and thus is widely used in estuarine environment with river networks [10]. Arc GIS 9.3 software was used for preparing the maps. Standard deviation and statistical analysis have been done in SPSS and Microsoft Excel. Coefficient of variation (C.V%) had been used to test the robustness of the data while Analysis of Variance (ANOVA- one way) was used to test the difference in mean between Inner, Outer and Mid estuary samples.

## 3. Results and discussion

The surface water salinity profile is presented in Table 1. Due to accumulation of monsoon freshets in the coast high tide data was low in all cases. It became profound in case of the largest river Matla at its Outer estuary. It is evident from the Table -1 salinity dataset that there is a significant variation in surface water salinity both amongst sector (spatial variation) as well as between two seasons (temporal variation). Salinity is the result of two factors, (a) intrusion of saline water from Bay of Bengal through diurnal tidal regimes from south to north, and (b) the flow of fresh water from the Ganges-Brahmaputra-Meghna Rivers system from north to south. Both balances the overall salinity across the estuary. The major ‘sea-level rise hypothesis’ revolves around the assumption that rising water levels will push in more salt water into the inner estuary through tides while due to glacier melting (global warming scenario) the fresh water flow in the rivers will decrease. So ‘salinity rise’ can be an indicator of sea level rise-climate change.

**Table 1.** Results of Pre-monsoon and Monsoon surface water salinity. Where PS is Physical Salinity and CS is Chemical Salinity in ppt. ppt=parts per thousand. The highest salinity recorded in a particular season is underlined for easy identification. ppt= parts per thousand. HT= High tide, LT= Low tide. CV% of only one data at Eastern Sector Outer estuary exceeds 10%, all other data on mean are acceptable.

	Seasons Place	Pre-Monsoon Salinity (ppt)				Monsoon Salinity (ppt)							
		PS		CS		Mean	CV %	PS		CS		Mean	CV %
		HT	LT	HT	LT			HT	LT	HT	LT		
Outer estuary													
1	Sagar Point	13.0	13.4	15.3	14.9	14.2	8.1	13.9	15.4	14.1	15.6	14.8	7.2
2	Kalas khal	31.2	31.2	33.8	32.4	32.2	3.8	15.9	16.9	15.9	16.9	16.4	3.6
Mid Estuary													
3	Matla mouth	30.9	31.2	31.8	32.0	31.5	1.6	9.7	15.9	9.99	15.9	12.9	27.2
4	Ramgang a	31.1	30	32.9	32.4	31.6	4.2	13.4	14.3	13.5	14.4	13.9	3.8
5	Kishorimohanpur	26.4	26.9	27.7	27.9	27.2	2.6	19.4	20.5	19.8	20.6	20.08	2.9
6	Bidya	27.4	28.2	29.3	30.6	28.9	4.9	21.0	22.2	21.07	22.4	21.66	3.4
Inner Estuary													
7	Raidighi	26.8	26.9	27.7	28.8	27.6	3.41	12.8	13.1	13.03	13.2	13.0	1.2
8	Jatar Deul	26.3	25.7	27.8	26.5	26.6	3.32	11.1	11.4	11.5	12.2	11.5	3.9
9	Bagna	22.3	22.8	22.95	24.8	23.2	4.71	9.7	10.2	9.78	10.4	10.0	3.3

The value of PS is lower than CS, due to the fact that turbidity of water hindered actual salinity estimation through refractometer and reduces the estimated value. Hence PS is followed by a CS estimation.

The One way ANOVA of mean values of Monsoon surface water High tide and Low tide salinities of a) Outer, b) Middle and c) Inner estuaries were found to be significantly different ( $F=5.32$   $p=0.047$ ) *i.e.* there was only <5% probability of the three sets of data to be similar. Most significant difference was obtained when Monsoon and pre-monsoon data of Inner estuaries were compared ( $F=82.22$  and  $p=0.001$ ) *i.e.* only 1% probability exists for the two sets of data to be similar.

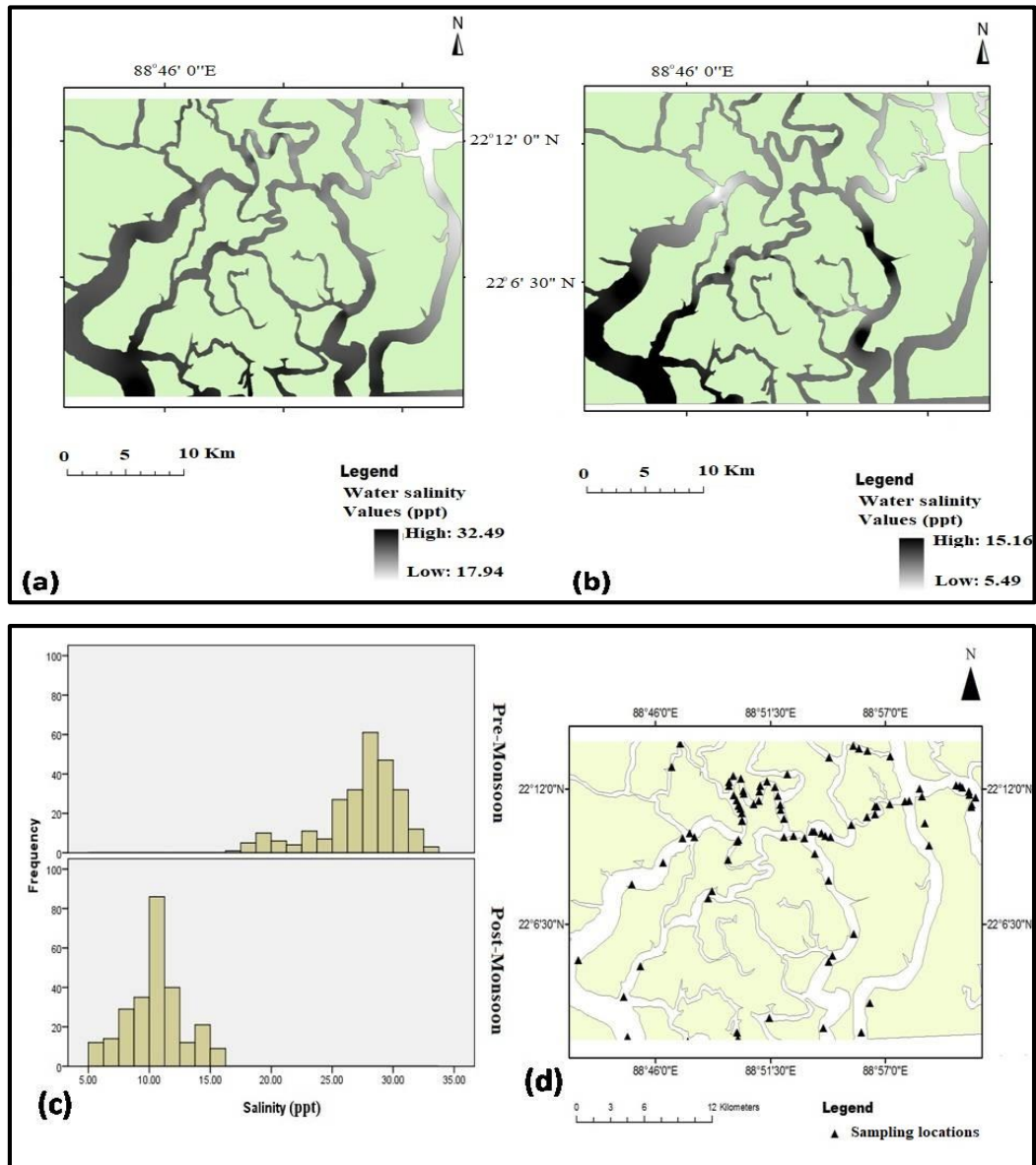
The salinity profile of the ground water for pre-monsoon and monsoon seasons has been elucidated in Table 2. Except the data obtained at Kalas khal (location with serial number 2) others have CV% < 10 and were acceptable mean. Due to monsoon turbidity chemical result was taken into consideration for Kalas khal (1.24 ppt). One-way ANOVA applied on the dataset of groundwater salinity, revealed no significant differences among a) Outer, b) Mid and c) Inner Estuarine monsoon data ( $F=0.81$ ,  $p=0.487$ ). One way ANOVA was also conducted for the Pre-monsoon versus Monsoon data for each Stratification (Outer, Mid, Inner) but data were not significantly different. F value was less than 5 and  $p > 0.05$  in all 3 cases.

**Table 2.** Results of Pre-monsoon and Monsoon salinity measurements of groundwater. Where PS is Physical salinity and CS is Chemical Salinity in ppt. ppt= parts per thousand. The highest salinity recorded in a particular season is underlined for easy identification.

Sl No.	Season Place	Pre-monsoon Salinity (ppt)				Monsoon Salinity (ppt)			
		PS	CS	Mean	CV%	PS	CS	Mean	CV%
Outer estuary									
1	Sagar Point	7.3	7.52	7.41	2.10	2.7	2.84	2.77	3.57
2	Kalas khal	1.4	1.06	1.23	<u>19.55</u>	1.4	1.08	1.24	<u>18.25</u>
3	Matla mouth	1.4	1.06	1.23	<u>19.55</u>	1.4	1.08	1.24	<u>18.25</u>
Mid estuary									
4	Ramganga	1	1.04	1.02	2.77	1	0.9	0.95	7.44
5	Kishorimohanpur	5.6	5.63	5.62	0.38	2.7	2.65	2.68	1.32
6	Bidya	4.9	4.69	4.80	3.10	3	2.94	2.97	1.43
Inner estuary									
7	Raidighi	2	2.07	2.04	2.43	2.8	2.79	2.8	0.25
8	Jatar Deul	5.7	5.75	5.73	0.62	2.7	2.72	2.71	0.52
9	Bagna	4.6	4.45	4.53	2.34	2.4	2.47	2.44	2.03

It is apparent from the above studies that except in case of Kalas Tube well (CV>10) in all other cases the Mean value was acceptable. In case of Kalas tube well we may adapt the conductivity data since the water was clear/ non-turbid. Fresh water exists in a dynamic balance that resist the salt water intrusion in the costal aquifers. But more saline water and excess extraction of water from these stressed coastal aquifers can instigate a salinity intrusion episode as per Ghyben-Herzberg relation between fresh and saline water. Hence, salinity intrusion in below ‘sea level’ can be common but its intrusion in near to surface (shallow aquifers) can be a major problem. The East-west variation, fresh water flow path and frequency distribution of surface water salinity were represented in Figure 2a-d. The mangrove species distribution and their relative density are represented in Table 3.

The data suggested noticeable variations in surface water as well as ground water salinity over the seasons (pre-monsoon and monsoon) and different sectors across the delta. Sea level rise is pushing in saline sea water in most of the deltaic regions across the globe destabilizing the salinity profile in the region. Delta of Mekong, Nile, Ganga-Brahmaputra-Meghna, Irrawaddy, Red Rivers are all being impacted with salinity intrusion due to sea level rise-climate change [11- 16]. Ganga-Brahmaputra-Meghna delta is facing serious salinity intrusion may be because of sea level rise as well as subsidence due to sedimentation [17]. The present investigation indicates that monsoon rain plays a major role in ameliorating the salinity profile across the Sundarban biodiversity reserve, India. Summer salinity of surface water is high. Highest surface water salinity in the pre-monsoon season was recorded (32.2 ppt) in the Outer estuary, central region sampling station of Kalas while in monsoon the highest salinity (20 ppt) was observed at Mid-estuary, central region sampling station of Kishorimohanpur. Thus central part of the Sundarban biosphere reserve has the highest impact of salt intrusion from the Bay of Bengal, may be because of the delta’s tilt towards eastward coupled with lesser flow of fresh water from the Ganges-Brahmaputra river system. The probable flow of fresh water in the delta was from the eastern sector as depicted in Figure 3.



**Figure 2.** (a) The salinity distribution at the delta during pre-monsoon (May-June) assessment, (b) The salinity distribution at the delta during monsoon (October) assessment, (c) Frequency distribution histogram of salinity profile in both the seasons, (d) sampling locations for the assessment (= 73 locations).

Ground water sampling revealed that during pre-monsoon the highest salinity (7.41 ppt) was recorded in the sampling station of ‘Sagar’ which is in the outer estuary and in the western sector of the delta. The monsoon sampling revealed highest salinity (2.97 ppt) in the Inner estuary and eastern sector sampling station of Bagna. This indicates a salinity intrusion in the aquifer during the summer (pre-monsoon) months. Mangrove plants shows sensitivity towards the salinity profile of the tidal waters as evident from works of

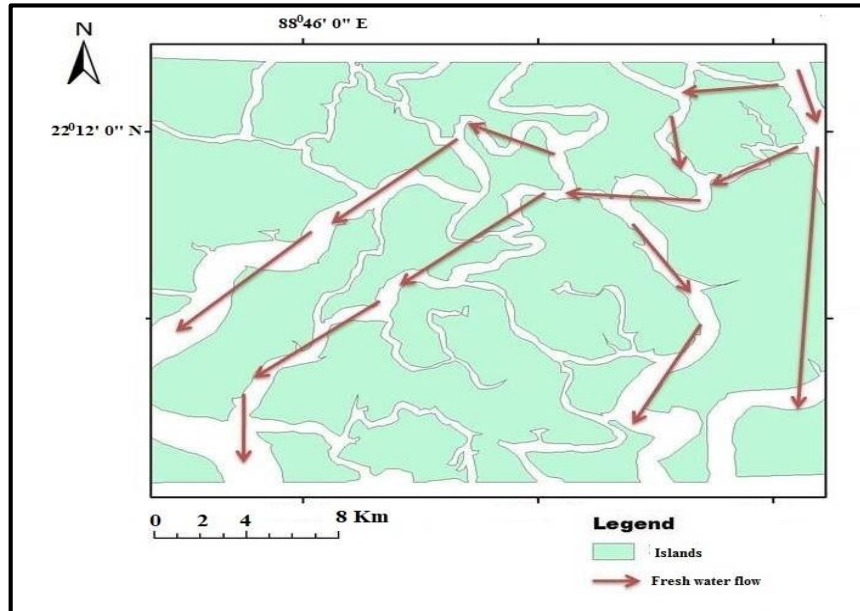


Chowdhury *et al.* 2016 [3]. Some major mangrove species find in different areas of Sundarbans has been depicted in Figure 4 and their biodiversity assessment, relative density depicted in Table 3.

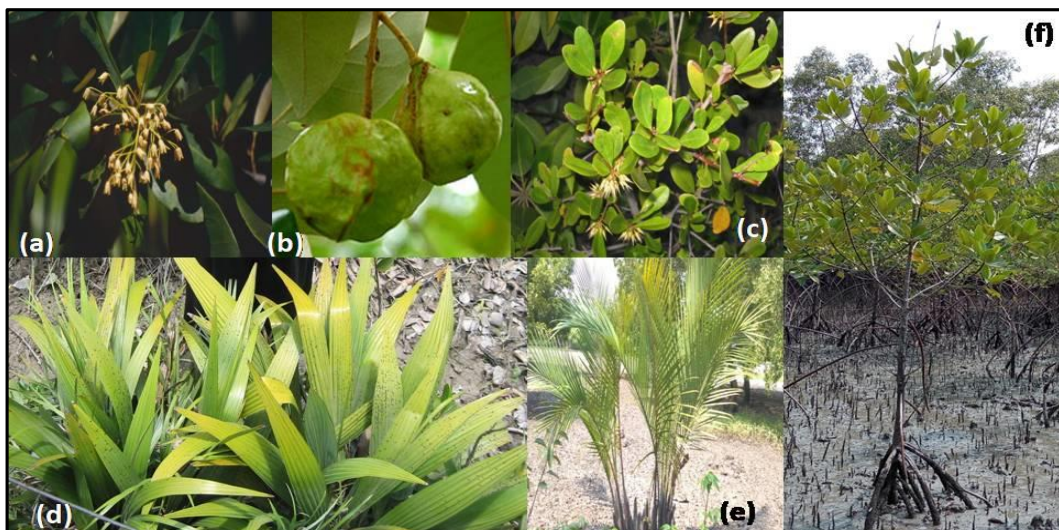
**Table 3.** The species compositions and relative density in five biodiversity sampling plots (10m x 10m).

Sl No.	Quadrat	Q1		Q2		Q3		Q4		Q5	
	Location	Jhilla		Kishorimohan pur		Sagar		Jharkhali		Kalas	
	Position	Inner Estuary/ Eastern side		Mid estuary/ Central part		Outer estuary/ Western part		Mid estuary/ Eastern part		Outer estuary/ Central part	
	Species	Av	D	Av	D	Av	D	Av	D	Av	D
1	<i>Acanthus ilicifolius</i>	17	3.9	26	8.0	11	6.3	55	<b>15.4</b>	20	4.6
2	<i>Aegialitis rotundifolia</i>	11	2.6	24	7.4	23	12.8	15	4.2	33	7.4
3	<i>Aegiceras corniculatum</i>	24	5.6	7	2.0	0	0.0	11	3.1	17	3.8
4	<i>Aglaia cucullata</i>	15	3.6	1	0.2	0	0.0	3	0.8	0	0.0
5	<i>Avicennia alba</i>	6	1.3	7	2.2	2	0.9	12	3.2	18	4.1
6	<i>A. marina</i>	10	2.3	17	5.1	27	15.1	21	5.7	28	6.3
7	<i>A. officinalis</i>	5	1.2	4	1.1	6	3.1	8	2.1	5	1.0
8	<i>Brownlowia tersa</i>	14	3.2	1	0.2	0	0.0	4	1.0	0	0.0
9	<i>Bruguiera cylindrica</i>	11	2.6	2	0.5	0	0.0	3	0.7	13	2.9
10	<i>B. gymnorrhiza</i>	31	7.2	23	7.1	2	0.9	33	9.2	28	6.3
11	<i>Ceriops decandra</i>	7	1.5	17	5.1	14	7.7	11	2.9	32	7.2
12	<i>C. tagal</i>	11	2.6	27	8.2	2	1.1	24	6.7	38	8.6
13	<i>Clerodendron inerme</i>	27	6.3	7	2.0	23	12.8	12	3.4	6.5	1.5
14	<i>Derris trifoliata</i>	18	4.2	11	3.4	0	0.0	11	3.1	11	2.5
15	<i>Excoecaria agallocha</i>	26	6.1	9	2.6	7	3.7	20	5.6	27	6.2
16	<i>Heliotropium currasavicum</i>	11	2.6	29	8.8	30	<b>17.1</b>	30	8.3	0	0.0
17	<i>Heretiera fomes</i>	36	8.4	19	5.9	0	0.0	22	6.2	23	5.2
18	<i>Kandelia candel</i>	14	3.3	3	0.9	0	0.0	0	0.0	2	0.5
19	<i>Nypa fruticans</i>	16	3.7	7	2.2	0	0.0	0	0.0	16	3.6
20	<i>Phoenix paludosa</i>	11	2.6	53	<b>16.2</b>	28	15.7	37	10.2	48	<b>10.8</b>
21	<i>Rhizophora apiculata</i>	0	0.0	0	0.0	0	0.0	0	0.0	5	1.1
22	<i>Rhizophora mucronata</i>	37	<b>8.7</b>	17	5.2	2	1.1	11	2.9	20	4.6
23	<i>Sonneretia apetala</i>	20	4.8	3	0.8	0	0.0	8	2.2	18	4.0
24	<i>S. griffithii</i>	21	4.9	9	2.8	2	1.1	3	0.8	11	2.4
25	<i>Xylocarpus granatum</i>	17	3.9	5	1.5	1	0.6	3	0.8	11	2.5
26	<i>Xylocarpus moluccensis</i>	13	3.0	3	0.8	0	0.0	5	1.3	14	3.1

Av= mean number of individuals in 2 quadrat replicate plots, D= Relative density, Q1-Q5= Quadrat plots as represented in Figure 1. The species with highest 'Relative Density (D)' at each sector/region is marked 'bold' in the Table 3 for easy identification.



**Figure 3.** The probable flow of fresh water from Ganges-Brahmaputra river system as speculated from spatial variations of salinity as depicted in Figure 2(a-b).



**Figure 4.** Major salinity, stress sensitive or indicative mangrove species found at Indian Sundarbans. (a) Flower of salinity sensitive *Heretiera fomes* (locally called ‘Sundari’ from which Sundarban got its name) can be found around Jhilla island, (b) fruit of *Heretiera fomes*, (c) Flowering shoot of *Aegiceras corniculatum* located at Kalas sampling station, (d) the edaphic sub- climax mangrove palm *Phoenix paludosa* predominant at at Kalas station, (e) salinity sensitive mangrove palm *Nypa fruticans* with negatively geotropic pneumatophodes, found only in the less saline Jhilla island quadrat spot, (f) the true mangrove member *Rhizophora mucronata* found near the Eastern sector of Indian Sundarbans along with its prominent stilt root system.

In the spatial biodiversity assessment, the more saline areas like ‘Sagar’ in the outer estuary/western sector, salinity tolerant *Avicennia marina* of Acanthaceae family was found to be dominant (Relative density= 15) following after *Phoenix paludosa* (Arecaceae) with relative density 15.7, while *Heliotropium currasavicum* (Boraginaceae) has the highest relative density of 17. While in the lesser salinity region of inner estuary/eastern sector we find more luxuriant mangroves with true mangrove family (Rhizophoraceae) member, *Rhizophora mucronata* having the highest relative density (Relative density= 8.7) followed by *Heretiera fomes* (Malvaceae) with relative density of 8.4.

This site also has the salt sensitive mangroves such as *Kandelia candel* (Rhizophoraceae), *Heretiera fomes* (Malvaceae), *Aglaia cucullata* (Meliaceae) and mangrove palm- *Nypa fruticans* (Arecaceae). In the outer sector/ central region station - Kalas having a high salinity values and predominance of edaphic sub-climax mangrove palm, *Phoenix paludosa* (Arecaceae) with its relative density around 10.8. Very few members of *Rhizophora apiculata* was seen in the same spot but in negligible numbers. Salinity tolerant, mangrove associate *Excoecaria agallocha* (Euphorbiaceae) was observed in more numbers at Sagar, Jharkhali and Kalas, all these sites having higher salinity tidal profiles than other sampling stations. Past researches have shown that both *Avicennia marina* and *Excoecaria agallocha* can tolerate higher salinity than other mangroves [18-19].

Mangrove associates like *Acanthus ilicifolius* (Acanthaceae) was seen to dominate the disturbed forest landscape at Jharkhali having a relative density of 15. *Phoenix paludosa* (Arecaceae) is dominant at Kishorimohonpur with relative density of 16.2. Amongst all the quadrat sampling stations Jharkhali has the highest anthropogenic stress due to nearby aquaculture/ pisciculture farms followed by Sagar while Jhilla has the lowest stress being near a conserved forest location. Both these anthropogenically stressed forests (Jharkhali and Sagar) have higher relative densities (8 and 17 respectively) for *Heliotropium currasavicum* (Boraginaceae) which indicates disturbed ecosystem. *Acanthus ilicifolius* (Acanthaceae) is also an indicator of disturbed forest. Two mangrove timber yielding species – *Xylocarpus granatum* and *Xylocarpus moluccensis* of Meliaceae family was found in substantial numbers only in the undisturbed forests of Kalas and Jhilla. *Aegiceras corniculatum* (Primulaceae family) had the highest relative density at Jhilla (5.6) followed by Kalas (3.8) and Jharkhali (3.1). Increased number of this species may prove progressive salinity rise in these areas as also evident from our salinity assessment data [20].

#### 4. Conclusion

This study concluded with the finding that the delta is under salinity intrusion threat that may be due to sea level rise. There is a spatial variation of surface water salinity across the delta with eastern region, inner estuary having the least salinity whereas outer and western locations having the greatest. So this proves that proximity to the Bay of Bengal and flow of fresh water from the river stream at East plays a role in defining spatial salinity variations. Fresh water flow is restricted to the North-eastern part of the region whereas sea water from Bay of Bengal is intruding on the most of the outer, middle and some parts of the inner estuary. There was a statistically significant seasonal variation in salinity profile of both ground water as well as surface water. Ground water is also showing a seasonal as well as spatial trend in salinity variation across the delta. This salinity rise has a direct impact on mangrove biodiversity with salinity tolerant species dominating the saline region while fresh water loving true mangrove family members in the lesser salinity zones. This study gives a strong recommendation of taking salinity fluctuations seriously in terms of mangrove conservation as with more and more salinity intrusions will result in replacement of mangrove species with salinity tolerant members, hence changing the biodiversity of this unique region.

#### Acknowledgments

Authors acknowledge the funding from project “Assessing the status and trend of salinity of surface and ground waters of the Indian Sundarban Mangrove ecosystem” sanctioned by World Bank at 2011.

## References

- [1] Chowdhury A, Naz A and Bhattacharyya S 2019 Plantation methods and restoration techniques for enhanced blue carbon sequestration by mangroves *In Sustainable Agriculture Reviews* **37** (Springer, Cham.) pp 127-144
- [2] Chowdhury A, Naz A, Bhattacharyya S and Sanyal P 2018 Cost–benefit analysis of ‘Blue Carbon’ sequestration by plantation of few key mangrove species at Sundarban Biosphere Reserve, India *Carbon Manag.* **9**(6) 575-86
- [3] Chowdhury A, Sanyal P and Maiti S K 2016 Dynamics of mangrove diversity influenced by climate change and consequent accelerated sea level rise at Indian Sundarbans *Int. J. Global Warm.* **9**(4) 486-506
- [4] Chowdhury A, Maiti S K and Bhattacharyya S 2016 How to communicate climate change ‘impact and solutions’ to vulnerable population of Indian Sundarbans? From theory to practice *SpringerPlus* **5**(1) 1-7
- [5] Chowdhury A, Naz A and Maiti S K 2021 Bioaccumulation of potentially toxic elements in three mangrove species and human health risk due to their ethnobotanical uses *Environ. Sci. Pollut. Res.* **28** 33042–59
- [6] Chowdhury A and Maiti S K 2016 Identification of metal tolerant plant species in mangrove ecosystem by using community study and multivariate analysis: a case study from Indian Sunderban *Environ. Earth Sci.* **75**(9) 744
- [7] Hazra S, Ghosh T, DasGupta R and Sen G 2002 Sea level and associated changes in the Sundarbans *Sci. Culture* **68**(9/12) 309-21
- [8] Mulamba T, Bacopoulos P, Kubatko E J and Pinto G F 2019 Sea-level rise impacts on longitudinal salinity for a low-gradient estuarine system *Clim. Change* **152**(3) 533-50
- [9] Chowdhury A and Maiti S K 2016 Assessing the ecological health risk in a conserved mangrove ecosystem due to heavy metal pollution: A case study from Sundarbans Biosphere Reserve, India *Hum. Ecol. Risk Assess.* **22**(7) 1519-41
- [10] Ashraf S, Abbas F, Ibrahim M, Rashid U, Khalid S, Ahmad H R, Hakeem K R and Majeed T 2015 Application of GIS for the identification and demarcation of selective heavy metal concentrations in the urban groundwater *J. Geogr. S.* **25**(2) 225-35
- [11] Trieu T T N and Phong N T 2015 The impact of climate change on salinity intrusion and Pangasius (*Pangasianodon Hypophthalmus*) farming in the Mekong Delta, Vietnam *Aquac. Int.* **23**(2) 523-34
- [12] Elshinnawy I A and Abayazid H O 2011 Vulnerability Assessment of Climate Change Impact on Groundwater Salinity in the Nile Delta Coastal Region—Egypt *In Coastal Engineering Practice* pp 422-35
- [13] Akter R, Asik T Z, Sakib M, Akter M, Sakib M N, Al Azad A S M and Rahman M 2019 The dominant climate change event for salinity intrusion in the GBM Delta *Climate* **7**(5) 69
- [14] Banerjee K, Gatti R C and Mitra A 2017 Climate change-induced salinity variation impacts on a stenocious mangrove species in the Indian Sundarbans *Ambio.* **46**(4) 492-9
- [15] Win S, Towprayoon S and Chidthaisong A 2019 Adaptation of mangrove trees to different salinity areas in the Ayeyarwaddy Delta Coastal Zone, Myanmar Estuar *Coast. Shelf Sci.* **228** 106389
- [16] Nguyen Y T B, Kamoshita A, Matsuda H and Kurokura H 2017. Salinity intrusion and rice production in Red River Delta under changing climate conditions *Paddy Water Environ.* **15**(1) 37-48
- [17] Alam M 1996 Subsidence of the Ganges—Brahmaputra Delta of Bangladesh and associated drainage, sedimentation and salinity problems *In Sea-level Rise and Coastal Subsidence* (Dordrecht : Springer) pp 169-192

- [18] Nguyen H T, Meir P, Sack L, Evans J R, Oliveira R S and Ball M C 2017 Leaf water storage increases with salinity and aridity in the mangrove *Avicennia marina*: integration of leaf structure, osmotic adjustment and access to multiple water sources *Plant, cell environ* **40**(8) 1576-91
- [19] Chowdhury, Rajojit, et al 2019 Effects of nutrient limitation, salinity increase, and associated stressors on mangrove forest cover, structure, and zonation across Indian Sundarbans *Hydrobiologia* **842** 191-217
- [20] Tusharbhai Patel N and Nath Pandey A 2009 Salinity tolerance of *Aegiceras corniculatum* (L.) Blanco from Gujarat coasts of India *Anales de biología* **31** 93-104