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SALINITY INTRUSION AFFECTING THE ECOLOGICAL INTEGRITY OF SUNDARBANS MANGROVE FORESTS, BANGLADESH

Mohammad Zahirul HAQUE[1,2,*], Mohammad Imam Hasan REZA[3,*]

[1] School of Environmental and Natural Resources Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[2] Bangladesh Forest Department, Bono Bhaban, Agargaon, Dhaka 1207, Bangladesh
[3] Southeast Asia Disaster Prevention Research Initiative (SEADPRI), Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.

Abstract

The raising of the sea causes salinity intrusion into fresh water zones such as river, lake, floodplain and other lowlands. Salinity intrusion in the Mangrove forest is a continuous process. However, due to the increasing salinity ecological integrity of the Sundarbans have been largely affected. The compositional and functional aspects of flora and fauna have been changing at a great deal. The objective of this study is to delineate the changes of the structure and composition of the Sundarbans Mangrove Forest due to excess salinity intrusion and how salinity affect its biodiversity, wildlife habitat and other ecosystem components. This study reviewed related literature gathered through an extensive survey of various websites and the secondary data obtained from various departments with necessary modifications. The land use maps collected from the Bangladesh Forest Department were interpreted to achieve an elaborate classification of forest type and its gradual change with increasing salinity. Observations at the periphery of Sundarbans explore the effect of salinity on the population, livestock, aquatic species and the paddy fields. We used ArcGIS 9.3 to visualize the salinity prone zones, the boundary of administrative zones and the forest type to identify the causes and intensity of the issues, and to suggest the appropriate mitigating measures. The study states that the salinity intrusion causes the reduction of fresh water availability in Sundarbans. As a result, fresh water loving species are replaced by the species of the saline zone. Most of the areas are found with the small and bushy typed species that reduce biomass in comparison with their standard volume. The study reveals the effects of salinity intrusion in the Sundarbans Mangrove Forest which may affect its compositional, structural and functional integrity. Long-term and short-term policies are recommended to resolve the issues.

Keywords: *Salinity intrusion; Ecological integrity; Mangrove ecosystem; Biodiversity; Wildlife habitat; Structure and composition of mangrove species*

Introduction

Climate change is the threat to many ecosystems in the world, but it is pressing for the mangrove ecosystems [1]. Climate change raises sea level [2] that causes salinity intrusion in the mangrove forests [3]. Rapid urbanization with the destruction of natural forests and cutting of hills cause soil erosion [4, 5] which form siltation on the river bed in the upstream and the river thus loss the capacity of holding water [6]. In such cases, salinity intrusion due to sea level rise occurs in the rivers of fresh or brackish water within the mangrove area. It replaces the

* Corresponding author: zahirfd@yahoo.co.uk, rezamih@gmail.com

fresh water into saline water or brackish water into the high saline water which causes reduction of its freshwater availability [7, 8]. Soil salinity along the coast is also increased which changes the normal characteristics of coastal soil [9] into unsuitable characteristics for plants and wild animals because its high concentrations of total dissolved solids and certain inorganic constitutes [10]. The Sundarbans mangrove ecosystem in Bangladesh, which is situated predominantly in south-west coast is highly vulnerable to water and soil salinity intrusion because it changes the locations of salinity distribution and inundation level on the mangrove forest floor [11].

Sundarbans ecoregion, situated in Bangladesh and India and its biodiversity is critical to the survival of millions of people from these two countries. These people are benefitted from the coast and the ecosystem services as the source of food, building materials, fisheries shelter belt and carbon cycling [12, 13]. This single largest mangrove forest in the world [14, 15] is recognized for its vast biodiversity of mangrove flora and fauna both on land and water [16, 17]. The distribution, composition and structure of the plant species are changed due to salinity in the soil and water and have an impact on the function as shelterbelt, habitat suitability for wildlife and other ecosystem services like the carbon sink, livelihood for local inhabitants, nursery ground for aquatic biodiversity. Saline water intrusion causes changes in vegetation, destruction of wildlife habitat, etc. and these may change the wildlife behaviour which affects the mangrove ecosystem integrity [17-19]. As a result, the existence of its valuable flora and fauna in particular the key stone species, the Bengal Tiger, are gradually becoming threatened.

Therefore, it is needed to quantify the previous salinity and biodiversity with the immediate changes in the same aspects. The objective of this study is to delineate the changes of the structure and composition of the Sundarbans Mangrove Forest due to excess salinity intrusion and how salinity affect its biodiversity, wildlife habitat and other ecosystem components. Here, we also estimate the salinity expansion in the area and the rate of changing the vegetation due to this. Adopting a sustainable management practice like keeping of the upstream rivers free from sediment deposition, ensuring uninterrupted water flow, slope protection and minimizing deforestation can save Sundarbans from salinity intrusion.

Methodology

Study Area: The Sundarbans Mangrove Forests, Bangladesh

Sundarbans consist of an area of 10,000km^2 of which 66% are land; the rest is water. About 62% (6073km^2.) of the Sundarbans forest is situated in Bangladesh, and the rest is in India [20]. The deltaic environment on the south-west coast of Bangladesh supports extensive mangrove formations due to a gradual intertidal slope and substantial impact on siltation [21]. Sundarbans is the estuary of the Ganges and the Brahmaputra river systems in the Bay of Bengal [22]. Due to the proximity of the Bay of Bengal, the heavy rainfall in the Sundarbans is very frequent, and humidity is high (80%), and about 80% of the rainfall is obtained in the monsoon. Mean annual rainfall varies from about 1800mm at the north of the Sundarbans to 2790mm on the coast.

There is six months dry season during which evaporation exceeds precipitation. The most saline conditions prevail in February–April; Temperatures rise from daily minima of 2–4ºC in winter to a maximum of about 23ºC in March and may exceed 32ºC in the monsoon. Storms are common in May and October, November and may develop into a cyclone with tidal waves of up to 7.5m high [23] The deltaic mangrove swamps of Sundarbans are extremely low-lying and subjected to regular tidal inundation. The general elevation above mean tide level is between 1.5 and 2 meters [24]. Higher ground extends up to 3.4 meters. The river flow is influenced twice daily by high and low tides at approximately six hourly intervals. The maximum and minimum tide level varies according to lunar days and seasons. Siltation is a common phenomenon in the river systems. Soil erosion is extensive due to the heavy thrust of waves of water along the banks of the main rivers in Sundarbans like Raimangal, Bal, Malancha, Hongshoraj, Arpangasia Sibsa, Passur Morjat, and Shela Gaang.

This microenvironment region in Bangladesh administratively falls in Khulna and Bagerhat districts of Khulna division [13]. Sundarbans was declared reserve forest (Sundarbans Reserve Forest (SRF)) in 1879, and since then it has been directly administered and managed by the Forest Department. Sundarbans mangrove forests lie between the longitudes 89° 00' and 89° 55' east and latitudes 21° 30' and 22° 30' north. Among the total area, 1.756km^2 is in the form of rivers, canals and creeks, varying from a few meters to several kilometres [25]. There are 55 compartments in the Sundarbans Reserved Forests distributed in the 4 Ranges namely Satkhira, Khulna, Chandpai and Shoronkhola Range (Fig. 1).

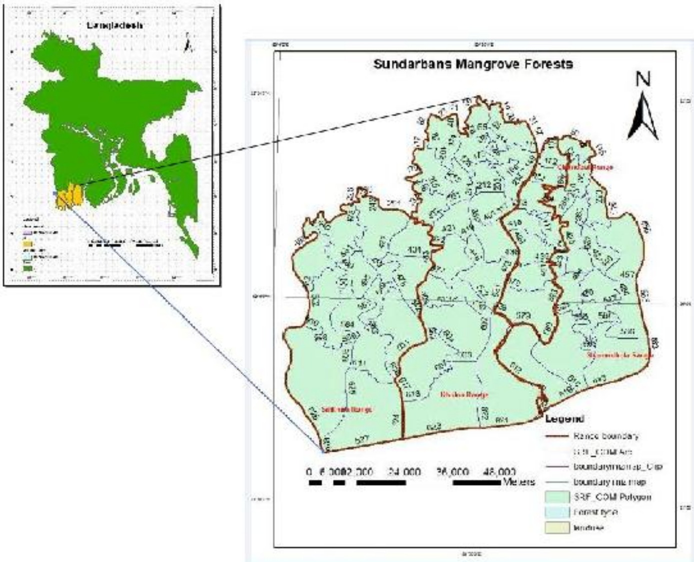

Fig. 1. Sundarbans Mangrove Forest

Forest types, salinity intrusion, and the density of species varies compartment wise (Fig. 1), state that the management and development activities of compartments are implemented by Range, division and circle administration of the Forest Department (Table 1). The entire mangrove ecosystem has significant conservation value and has been protected under various legislative categories such as Sundarbans reserved forests, Sundarbans West Wildlife Sanctuary, Sundarbans East Wildlife sanctuary, Sundarbans South Wildlife sanctuary, Sundarbans Ramsar site and World Heritage site.

Table 1. Administrative Jurisdiction of Sundarbans Reserved Forests, Bangladesh

Circle	Division	District	Thana	Range	Range H/Q	Area of Range (ha)	Compartment No.
Khulna Circle	Sundarbans West Forest Division	Khulna	Dacope Paikgachha Koyra	Khulna	Nalian	1,70,610	16 to 20, 32 to 40, 43 & 44
		Satkhira	Shyamnagar	Satkhira	Burigoalini	1,86,731	41,42,46,47,48,49,60a, 50b,51a,51b,52 to 55
	Sundarbans East Forest Division	Khuna	Dacope	Chandpai	Chandpai	13686.85	29,30,31
		Bagerhat	Mongla	Chandpai	Chandpai	80756.19	9,10,12a,13,14,15,21-27(part 28)
			Morelganj	Chandpai	Chandpai	3001.88	27 (part)
			Sarankhola	Sarankhola	Sarankhola	145599.4	1to 8,11, 12b,24 &45

To prepare this paper related works were reviewed, and secondary data were cited with modification. The primary data for this paper has been obtained from the office records of Bangladesh Forest Department, and a survey was carried out on the Livelihood profile of the people living to the surrounding of the Sundarbans to identify the relation of the tiger attacking with their livelihood and living style. Related maps were used after the modification with GIS tools and Excel software.

Secondary Data Review Process

After specification had done about the focus area, we collected the materials on following topics such as the flora and fauna diversity in the Sundarbans, ecology and distribution of Sundarbans flora and fauna, dominant species data, soil and water quality. The organizations, institutions, and academia that explicitly work on the ecology and biology of the Sundarbans flora and fauna were our prime target to study. For our critical review of the data, we constructed our keywords to search materials from different databases. The primary keywords were as follows, “ecological integrity”, “diversity of flora and fauna”, “soil and water quality” and “distribution of species in different zones”. Any material found discussing these issues was counted as our prospective source of study.

To find the related discussions we have looked in journal articles, case studies, reports (departmental and projects), conference proceedings and books for getting insights from academic contributions. We also looked at websites of various institutions, organizations and policymaking authorities as well as online reports, blogs of experts, manuals and working papers developed by specialized organizations in the respected fields of works. Besides, we have also used Google search engine and Google Scholar for searching our resources. The major abstract and citation databases for example, ISI Web of Science, and Scopus journals together with UN and World Bank patronized reports, research papers, manual and other documents and links were given preference in our search.

Digitizing soil and geological data layers

Digitization in GIS is a process of “tracking”, in a geographic correct way, information from images/maps. The land use map of Sundarbans was obtained from the Bangladesh Forest Department. This map was used as the base maps for the digitizing process (scale 1:200,000) and the part of the thematic paper maps (i.e., Soil maps from the Soil Research Development Institute - SRDI, Bangladesh) were scanned in a high-performance HP Scanner. The scanned maps were saved in the Tagged Image File Format (tiff) form and used in the ArcGIS 9.3 for the digitizing process. Before the digitizing process, georeferencing the data layers were done, which relies on the coordination of points on the scanned image (data to be georeferenced) with points on a geographically referenced data map. By “linking” points on the image with those same locations in the geographically referenced data a polynomial transformation was created that converts the location of the entire image to the correct geographic location.

After georeferencing each image, digitization process was performed using ArcGIS 9.3. Digitizing is the process of converting paper map or image data to vector digital data. In ArcGIS, point, line or polygon of an image can be redrawn following the source data. In this case, redrawing was done through controlling a cursor using a computer mouse and sample vertices were drawn to define those attributes. The structures of these vertices can be seen on the images of the data layer at its editable form where those features are assigning additional spatial and non-spatial attributes. Through this process, a digital version of maps was generated which have an attribute table associated with them. The digitizing process was started by creating new layers (vector layer) in ArcCatalog, and then adding features to them in ArcMap (ArcGIS 9.3 Desktop). *Editor* tool bar was used for the digitization of the data layer in the newly created vector layer/shape file. In this study, shapefile for the compartment, administrative range boundary, salinity zone, temporal variation of salinity were created.

Results and Discussions

***The natural succession and retrogression process*s**

The succession and retrogression processes in Sundarbans Mangrove Forests are unique and systemic. In a continuous process, sediments carried out from the upstream with river water get accumulated and gradually new land is created. According to the thumb rule process of succession, a grass named 'Dhanshi' (*Porteresia coarctata)* is introduced naturally in the newly accreted land. This grass enriches the soil with organic matter, nitrogen phosphorus, potassium and other nutrients. Thus, the soil becomes mature for the species 'Keora' (*Sonneratia apetala*) to be established replacing Dhanshi. The longevity of Keora is about 50 years. When Keora is eliminated the area is covered by Gewa (*Excoecaria agallocha*), Goran (*Ceriops decandra*), Bain (*Avicennia officinalis*), Kakra (*Bruguiera gymnorrhiza*), and some understory mangrove species. In the climax stage, the dominant species Sundri (*Heritiera fomes*) or Gewa generate [26, 27]. There are various factors for the variation in the succession process [28] such as availability of fresh water, inundation by high tide, distribution and composition of plants and wildlife. These factors are directly related to salinity intrusion.

Structure, composition and distribution of major tree species in Sundarbans

Floral diversity of Sundarbans mangrove forests (SMF) is richer compared to other mangroves in the world. *R.L. Heining* [29] recorded 69 species under 34 families in the whole of Sundarbans (Bangladesh and India) territory. *A. Karim* [30] reported 123 plant species belonging to 22 families representing 30 genera in SMF in Bangladesh. *A.B. Hossain* [31] reported 44 undergrowth species of Sundarbans mangrove forest. Sundarbans ecosystems comprise of more than 375 terrestrial wildlife species, which includes around 35 reptiles, 300 birds and 42 mammals and 291 aquatic species (210 white fish, 24 shrimps, 14 crabs, and 43 molluscs). Besides, there are numerous species of phytoplankton, fungi, bacteria, zooplankton, benthic invertebrates, molluscs, reptiles, amphibians and mammals. Significant variation in species composition and community structure can be observed from eastern part to western part of the forest, and along the hydrological and salinity gradients. The Sundarbans represents the trees of 22 families from 30 genera [13]. Table 2 shows that Sundri (*Heritiera fomes*) of family Sterculiaceae and Gewa (*Excoecaria agallocha*) of family Euphorbiaceae are the dominant canopy species among which first one occurs in the Oligohaline zone, and the later grows in all zones in Sundarbans.

Table 2. Main tree species in Sundarbans Mangrove forest (updated the list after verification from the works of *M. Iftekhar and M. Islam* [13] and *S.H. Rashid et al.*[25].

Vernacular	Latin name	Family	Status	Zones
Sundri	*Heritiera fomes*	Sterculiaceae	mc	Oligohaline zone
Gewa	*Excoecaria agallocha*	Euphorbiaceae	mc	All zones
Passur	*Xylocarpus mekongensis*	Meliaceae	oc	Oligohaline zone
Keora	*Sonneratia apetala*	Sonneratiaceae	oc	All zones
Baen	*Avicennia officinalis*	Avicenniaceae	oc	Oligohaline zone
Kankra	*Bruguiera gymnorrhiza*	Rhizophoraceae	oc	Oligohaline zone
Dhundal	*Xylocarpus granatum*	Meliaceae	oc	Saline zone
Goran	*Ceriops decandra*	Rhizophoraceae	u	Saline zone
Khalsi	*Aegiceras corniculatum*	Myrsinaceae	u	Saline zone
Hargoza	*Acanthus ilicifolius*	Acanthaceae	u	All zones
Tiger fern (hudo)	*Acrostrichum aureum*	Pteridaceae	u	All zones
Shingra	*Cynometra ramiflora*	Fabaceae	u	Oligohaline zone
Bhola	*Hibiscus tiliaceus*	Malvaceae	u	Oligohaline zone
Golpata	*Nypa fruticans*	Palmae	u	All zones
Keya	*Pandanus foetidus*	Pandanaceae	u	Oligohaline zone
Hental	*Phoenix paludosa*	Palmae	u	All zones
Angorlata	*Vitis trifoliate*	Vitaceae	u	All zones
Dhanshi	*Porteresia coarctata*	Gramineae	u	Oligohaline zone
Jhana Garjan	*Rhizophora mucronata*	Rhizophoraceae	u	Oligohaline zone
Bawalilata	*Sacrobolus globosus*	Asclepiadaceae	u	All zones

Other canopy species are Passur (*Xylocarpus mekongensis*), Keora (*Sonneratia apetala*), Baen (*Avicennia officinalis*), Kankra (*Bruguiera gymnorrhiza*) and Dhundal (*Xylocarpus granatum*). Passur, Baen and Kankra predominantly grow in brackish water zone whereas Keora is seen in all zones and Dhundal mostly in the saline zones. The most dominant undergrowth species are Goran (*Ceriops decandra*), Golpata (*Nypa fruticans*), Hental (*Phoenix paludosa*), Jhana Garjan (*Rhizophora mucronata*) and Dhanshi (*Porteresia coarctata*). Other available understory plants are Khalsi (*Aegiceras corniculatum*), Hargoza (*Acanthus ilicifolius*), Tiger fern (hudo) (*Acrostrichum aureum*), Shingra (*Cynometra ramiflora*), Bhola (*Hibiscus tiliaceus*), Keya (*Pandanus foetidus*), Angorlata (*Vitis trifoliate*) and Bawalilata (*Sacrobolus globosus*). Some of these grow in brackish water zone and some are preferred in saline zone. The understory species play a major role in ecosystem functions like habitat suitability, soil erosion protection, resisting landslide at river bank etc. and ecosystem services like providing housing materials, food etc. Table 2 describes the species in the form of vernacular and Latin name and family, tree status (S) like major canopy species (mc), other canopy (oc) understory species (u) and the site where these species grow (zones) [13, 32].

F. Blasco [33] stated that the most dominant trees in Sundarbans mangrove forests are *Sonneratia apetela*, *Heritiera fomes*, and *H. littoralis* and several *Avicennia* species. Also, there is one species of grass named Dhanshi (*Porteresia coarctata*) which is commonly seen in the newly accreted land. The river banks are low for a considerable distance from the ocean. In this riparian thickets, the first species onwards the landslide is usually Dhanshi (*Porteresia coarctata*) grass. Beyond this, the patch is dominated by *Avicennia officinalis* and *Hibiscus tiliaceus* with some occasional *Sonneratia apetala*. A climber like *Casalpinia cristata* and *Dalbergia spinosa* are abundant in the riverine patches making them almost impenetrable. In the small open patches, under-shrubs of *Achanthus* are predominating. The influence of the ocean is reflected in the floral composition. *Avecinnia marina* along with *Sonneratia apetala* and some rare *Rhizoporaceae* increase in frequency towards the ocean side while *Hibiscus tiliaceus*, disappear there completely. The *Aegialitis rotundifolia* and *Aveccinia marina* are found only in areas of high salinity. The other two species of *Avecennia* viz. *A. alba* and *A. officinalis* show a wider range of salt tolerance.

Brownlowia tersa and *Merope angulata*, are found mostly in small creeks. *Phoenix* comes up in degraded areas and occurs in high abundance in some patches. *Hibiscus tiliaceus* is a species of drier areas of the northeast site, where water level has gone down, and the area is not inundated anymore. *Sonneratia* occurs in the shoreline and survives on loose substratum. Based on the FRMP (1995-96) land use map for Sundarbans, major vegetation types and its distribution are identified as stated in Table 3.

After analyzing the land use map, it reveals that the forest is divided into 55 compartments which are bordered by natural rivers, canals or creeks. These compartments are distinguished by their forest types, soil pH and salinity. Compartments 1 to15 are mainly rich with the forest type of *Heritiera*, *Heritiera-Excoecaria* and *Excoecaria-Heritiera* and *Sonneratia-Heritiera*. The site is situated at the eastern part of the forest and consists of 1361.56km^2 of the forest. Soil pH and soil salinity in this area are around 7.5 to 7.8 and 0 to 15 respectively. In the nearly center of the forest, compartments 16, 17 and 18 with 295.84km^2 of forest area are situated where the species are *Heritiera-Excoecaria-Ceriops*. Soil pH and salinity found here are approximately 7.8 and 10 respectively. From center towards north east part, the forest types are again *Heritiera-Excoecaria-Ceriops* and these are fallen in compartments 19, 20, 21 and 22. The total area for these compartments is 309.95km^2. Soil pH and salinity in these compartments range from 7.5 to 7.8 and 0 to 10ppt respectively. The soil pH and soil salinity in Compartments 23 to 29 range from 6.8 to 8.5 and 0 to 5ppt respectively and the area with 342.82km^2 is situated at the north-east part of the forests, accomplished with the forest type *Heritiera-Bruguiera-Xylocarpus-Avicennia and Excoecaria-Heritiera*. The most north side of the forest is abundant with *Heritiera-Bruguiera-Xylocarpus-Avicennia* species which is fallen in compartments 30 to 35.

Table 3. Forest Types and pH and Salinity in Sundarbans Mangrove Forests (Source: modified from Sundarbans Land use map (FRMP, 1995-96) and *S.H. Rashid et al.* [25])

Sl. No	Compartment No.	Area (ha)	Forest type	pH	Salinity (ppt.)	Sites for samples for salinity and pH
1	30,32,33,34,29	30198.13	*Heritiera-Xlyocarpus-Bruguiera; Heritiera- Excoecaria*	6.8	4.6	Jongra Beel
2.	28,27,25,26	18563.25	*Heritiera-Bruguiera-Xylocarpus-Avicennia*	8.5	5	Mirgamaria
3	24,23,22,13	22523.72	*Excoecaria-Heritiera*	7.6	0	Sharonkhola Panirghat
4	2,3,4,5	28565.17	*Excoecaria-Heritiera*	7.7	0	Shorankhola: South of Dhabribarani
5	1,12A,12B,21,14,15	28701.14	*Heritiera-Excoecaria, Excoecaria-Heritiera*	7.5	0	Sharonkhola Terabecka Khal
6	7,9,10,11	48881.36	*Heritiera-Excoecaria-Sonneratia, Sonneratia-Heritiera-Excoecaria, Sonneratia*	7.7 7.6 7.8	1.3 1 7	Kotka Range Office, Kotka North Jamtala, Pakhirchar
8	6	19237.28	*Sonneratia-Heritiera-Excoecaria; Sonneratia-Excoecaria-Heritiera; Heritiera-Sonneratia-Excoecaria*	7.7 7.9 7.8	1.5 3 4.5	Kotka South Jamtala, Deemyer char Kochikhali
10	40,37	12528.63	*Heritiera-Xylocarpus-Bruguiera*	7.6	17	Dhanshiddher Char
11	38,39	16019.58	*Heritiera-Excoecaria*	7.5	16.5	KNM collection Centre
12	36	8456.47	*Sonneratia-Heritiera-Excoecaria*	7.5	16.5	Kewrabunia Char
13	47	11750.45	*Excoecaria-Ceriops-Xylocarpus; Excoecaria-Heritiera-Xylocarpus-Avicennia*	6.9 7	20.5 14.5	Kalagachia Danokhal, Kalogachia
14	16,17,18,1,20,42	59628.50	*Heritiera-Excoecaria-Ceriops; Excoecaria- Heritiera*	7.8	10	Patakata
15	8	19395.65	*Sonneratia-Excoecaria-Ceriops*	7.6	15	Tiarchar
17	45,44	55452.85	*Excoecaria-Sonneratia*	7.5	20.5	Dublar Char
18	54,53	40704.72	*Excoecaria-Ceriops*	6.8	20	Mandarbaria
19	52,51A,51B,43,49	60093.23	*Ceriops-Excoecaria-Sonneratia*	5.9	20.2	Kalir Char (north)
21	48	10624.24	*Bruguiera-Heritiera-Xylocarpus*	6.8	20.5	Koikhali
24	31	7838.27	*Heritiera-Sonneratia-Ceriops-Nypa*	7.9	4.4	Karamjal
25	35	8681.49	*Bruguiera-Heritiera-Sonneratia*	7.6	16	Hodda
26	41	9647.86	*Ceriops-Excoecaria-Avecennia-Xylocarpus;*	7.7	18	Andharmanik
28	46,50A,50B	25694.80	*Sonneratia-Xylocarpus-Excoecaria, Sonneratia-Ecoecaria-Avecennia*	7.5	21.22	Dobeki, Kobadak
29	55	34655.00	*Ceriops-Excoecaria-Xylocarpus; Ceriops-Excoecaria*	7.4 5.1	23 22	Notabeki, Puspha Kathi

These compartments' area is around 411.36km^2. The soil pH and salinity in compartments 30, 31, 32, 33 and 34 vary from 6.8 to 7.9 and 4.4 to 4.6 respectively but the compartment 35 has these parameters around 7.6 and 16 respectively, might be due to the location of the area beside the river Shibsa through which salinity intrusion takes place. The North-West side is also seen with the same type of tree species like *Heritiera-Bruguiera-Xylocarpus-Avicennia* species which are fallen in compartments 36, 37, 38, 39 40 and 41.The total area for these compartments is 466.52km^2. This area bears the soil pH and salinity at the scale of around 7.5 to 7.7 and 10.5 to 18 respectively. The forest type *Excoecaria-Sonneratia and Bruguiera-Heritiera-Xylocarpus* occur in the compartments 42 to 48 with a vast area of 1201.35km^2 in the west part of the forests. Compartments 49 to 55 are located in the south along the coast of the Bay of Bengal covering 1302.02km^2 area, and the forest type is mostly *Ceriops-Excoecaria-Sonneratia, Sonneratia-Xylocarpus-Excoecaria Sonneratia-Ecoecaria-Avecennia*. The soil pH and salinity in the west and south part ranges from 5.1 to 7.5 and 20.5 to 23 respectively. This analysis reveals that north, northeast and eastern part of the forest occur comparatively less salinity and healthy plant species like *Heritiera-Xylocarpus-Bruguiera*, *Heritiera-Sonneratia-Excoecaria,* etc. and the south, south-west, and west part of the forest occur high salinity and forest type is *Ceriops-Excoecaria-Xylocarpus*, *Bruguiera-Heritiera-Xylocarpus,* etc.

Distribution of Plant species by land type of Sundarbans Mangrove Forests

Salt marshland: The species of the family Rhizophoraceae such as *Ceriops decandra* exist in more saline areas in the south and west, but they are also found in the north and east, although relatively infrequently. *Bruguiera gymnorhiza of the same family* occurs throughout the SMF and is not affected by the various degrees of salinity. *Porteresia coarctata* was the pioneer on the new islands with alluvial soil deposits. This vegetation type covered around 4% of the entire Sundarbans forests in Bangladesh.

*Palm swamps***:** The sea-dates (*Phoenix paludosa*) were commonly observed as dense pure sands along the edge of the river bank, especially high saline area. The common associates are *Heritiera, Excoecaria, Aviccennia, Xylocarpus, Thespesia, Achanthus and salvadora* species. This vegetation type is visible in the west part of the forest.

Brackish water mixed forests: This may be the most dominant vegetation type of the Sundarbans Mangrove Forests covering around 47%. The vegetation community was composed of *Excoecaria* and *Heritieria* dominated stand with their associates such as *Rhizophora, Avacennia, Thespesia, Heritieria, Brownlowia, Cynometra, Bruguiera, Kandelia, Sonneratia, Casalpinia, Pongamia, Hibiscus, Salvadora, Tamarix, Lummitzera, Acrosstichum Salacia* etc.

Saltwater mixed forests: In this zone species such as *Excoecaria, Cynametra, Heritieria, Avicennia, Sonneratia and Phoenix* are commonly associated with species like *Kandelia, Acrosstichum, Achanthus, Pandanus, Salvadora* and *Caesalpenia.* Around 53% of the whole forests are covered with such vegetation (Table 4).

Table 4. Landscape and land use characteristics of Sundarbans Mangrove Forests

Sl. No.	Vegetation/Habitat type	Area (km^2) (approx.)	%
1	Water bodies	1756	26
2	Brackish water mixed mangrove	2721	47
3	Salt water mixed mangrove	3058	53

Mangrove forests: Excoecaria, Avicennia, Rhizophora, Sonneratia dominated the stands. Common associates were *Ceriops, Rhizophora, Thespesia, Heritiera, Xylocarpus, Aegealitis, Aegeicerus, Amoora, Salacia, Hibiscus, Kandea, Brownlowia, Achanthus, Dalbergia, Phoenix, Salvador and Suaeda* species. Other associates were *Porteresia coarctata* and *Myriostachya wightiana.*

Mangrove scrubs: These are *Excoecaria, Avicennia, Ceriops, Cynometra, Achanthus* dominated areas with associates such as *Aegiceras, Aegialitis, Rhyzzophora, Pandanus, Hibiscus* species.

Salinity intrusion in Sundarbans Mangrove Forests

Salinity is one of the most important determinants of mangrove forest growth and distribution. Mangrove develops well in a place where the salt concentration is between 20 and 35%. Too high a salt concentration (40–80%) diminishes the number of species and their size. In a place where salt concentration reaches 90%, a few species can exist and after then they grow slowly [3]. Sea level rise changes the distribution of salinity and freshwater in mangrove areas. Freshwater from river, channel and rain reduces the quantity of the salinity of sea water and make into the brackish water which is suitable for many of the mangrove species such as *Heritiera fomes, Xylocarpus mekongensis, Avicennia officinalis, Bruguiera gymnorrhiza,* etc.

In the Bangladesh Sundarbans forests, the largest rivers from west to east are the Raimangal, Bal, Sibsa, Passur and Sela Gang. All of these rivers face salinity intrusion from the Bay of Bengal. To check the salinity, the river Goroi is the primary source of freshwater input to these distributaries which is, in turn, a distributary of the Ganges diverging about 50km downstream of the India-Bangladesh border and 70km upstream of its confluence with the Brahmaputra River. The river Baleswar is also a source of relatively small amount of fresh water for far eastern portion of the Sundarbans, which obtains most of its flow from the Ganges but from well below its confluence with the Brahmaputra. The rivers Kobadek and Batula are the only sources of fresh water in the far western portion of the Sundarbans [34].

M. Iftekhar and P. Saenge [27] divided the whole Bangladesh Sundarbans into three ecological zones. Based on salinity and distribution of species composition these are i) less saline/fresh water zone named as Oligohaline zone, ii) moderately salt water/moderately saline zone designated as Mesohaline zone and iii) salt water zone/active saline zone called as Polygohaline zone. Out of 6121.42km^2 forest including water body Oligohaline zone covers 1228.93km^2, Mesohaline zone covers 2263.55km^2 and polygohaline zone covers 2628.94km^2 of forest area. Oligohaline, Mesohaline and Polyhaline zones are situated at south-east to the northeast, center to north and south, southwest to northwest parts of the forest respectively (Fig. 2).

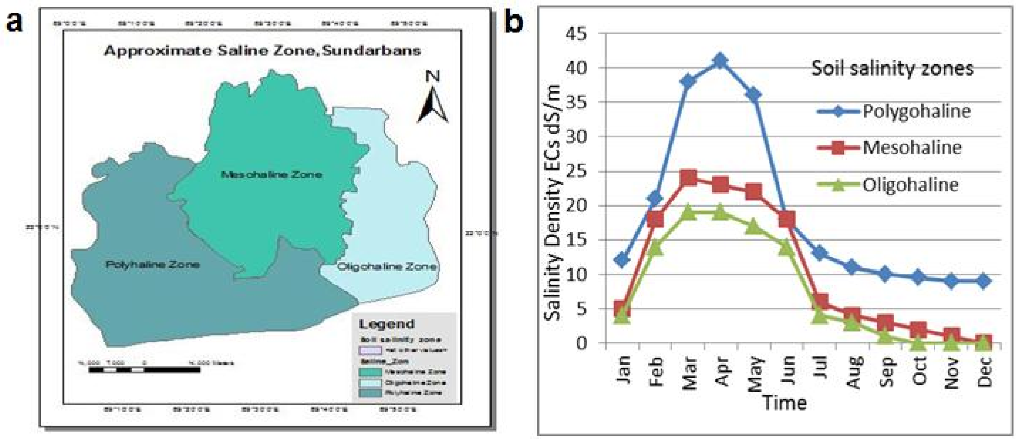

Fig. 2. Distribution in zone of Sundarbans Mangrove Forests of the water salinity density:
a. Saline Zone of Sundarbans Mangrove Forests, Bangladesh (redrawn after *M. Iftekhar and P. Saenger* [27]);
b. Water salinity density in Saline Zones (modified from *M.S.N. Islam and A. Gnauck* [35])

Soil types are silt clay though Oligohaline zone contains clay particles also (Fig. 2a). Water salinity density [35] **(**Fig. 2b**)** in 3 Saline Zones is minimum in the months of September to January for Oligohaline and Mesohaline zones it is below 5 ECs dS/m, but in these months, Polyhaline zone contains nearly 10 ECs dS/m. From March to late June salinity density remains the maximum in all three zones. During this period Polygohaline zone bears more than 40 ECs dS/m, Mesohaline contains nearly 25 ECs dS/m and the saline water density for Mesosaline zone is from 15-18 ECs dS/m. Soil salinity density is the lowest in Oligohaline zone with 1-3.5dS/m then Mesohaline zone with 3.5 to 15dS/m and the highest salinity density belongs to Polygohaline with 15 to 40dS/m [27].

Although the Sundarbans has been classified with above mentioned three saline zones, a comparative study for soil salinity carried out using Soil Salinity map of Soil Research Development Institute for the period of 1973 and 1997. The study shows that soil of Sundarbans mangrove forest has been facing newly high salinized area within 24 years [36]. Using GIS tools Figure 3 was calculated. It states that in 1973 out of 4982.39km^2 of Sundarbans Mangrove forests, high salinity area was 2945.28km^2, the moderate high saline area was 1780.06km^2 and the moderate slightly salty area was 257.05km^2. On the other hand, the 1997 saline map for the same area shows that out of 5040.8km^2 of total forest high salinity area was 4224.61km^2 and the moderate high saline area was 816.2km^2. This means that 1279.33km^2 of land have been converted into high saline area from moderate high saline and moderate slightly saline area within 24 years.

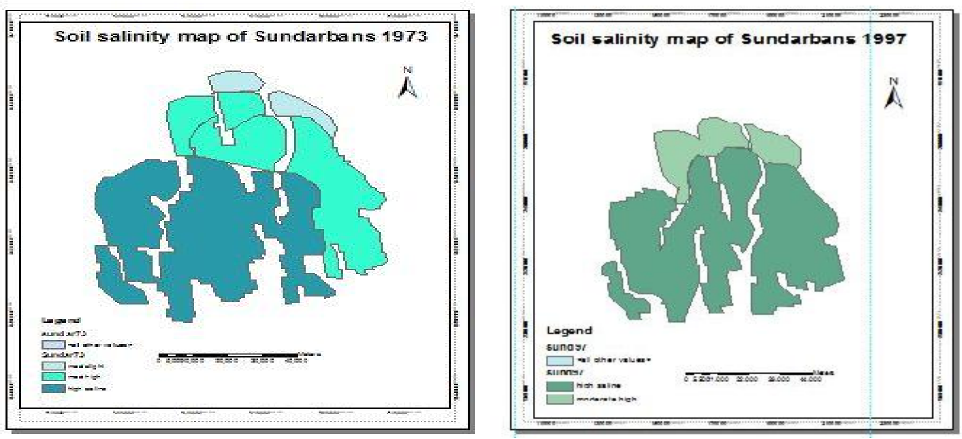

Fig. 3. Variation of soil salinity Sundarbans Mangrove Forests, 1973 vs 1997

From this scenario, it can be predicted that the continuous increasing of salinity would change the north, northeast and east part's forest type into that of the south, south-west and west parts. The essential characteristics of high saline zone plant species are observed as is the height and girth of the main stem are small and the depth of the roots of the species are shallow comparing with those of north and east part. During field visit by the main author data were collected regarding these phenomena which states that tree height were 13 to 22m, 8–12m and 2–6m; tree girth were 0.5 to 2m, 0.2 to 1.8m and 0.06m to 0.9m, and crown cover was 60 to 90%, 40 to 70%, and 25 to 60% in Oligohaline, Mesohaline and Polyhaline zones respectively. This affects the shelter belt protection capability of the forest during cyclone and storms and the habitat of wildlife. Increasing in salinity will change the succession process and ultimately total structure and composition of the stand. One of the dominant species in high a saline zone is Gewa, which is the softwood species.

Each plant species has a tolerance limit to some degree of salinity for survival and optimal growth as well. Tolerance to flooding with saline water varies in some mangrove species. It is observed that the maximum and minimum tolerance limit differed in flooding situation among five tree species as follows: *Avicennia marina* > *Aegiceras corniculatum* > *Rhizophora stylosa* > *Bruguiera gymnorrhiza*. This study suggests the possible changes in community composition and distribution of plant species of the whole forest concerning salinity intrusion [37]. These may be resulting in changes in ecosystem structure, dynamics and phenology [38].

As the salinity intrusion changes the physiographic condition, therefore the supporting services like habitat for plants and animals, nursery ground for fisheries and wildlife are also significantly affected [39]. If the Sundarbans is extinct, the habitat for much valuable fauna would also be lost. A significant reduction in freshwater inflow increases salinity and changes in sedimentation have severely affected the biodiversity such as rapidly declining of *Heritiera fomes*, increasing of *Nypa fruticans* and *Phoenix paludosa* which indicate the degradation of the ecosystem complex. At this stage redistribution of species of affected habitats may be impaired during migration [40], especially to the north where there is still a small patch of forest land with less salinity but ultimately will be blocked by human settlements there [40]. This observation revealed that salinity intrusion will affect the suitable area of Sundri tree by decreasing its stock 14% by 2050 and 45% by 2100. But the suitable area of 'Gewa' will be reduced 7% by 2100 because of its high salinity tolerance limit.

Finally, it may be stated, if this mangrove ecosystem is affected, the southwest part of Bangladesh may be merged into the water, and millions of people will be homeless, agricultural paddy fields, and other lands will be damaged, many valuable flora and fauna will disappear (17). Intangible benefit from this ecosystem such as carbon sequestration, pollution free environment and tourism sector will be severely affected [42]. Sundarbans played an important role to protect the country's southwest part from the severe cyclone and storms occurred in 2007 and 2009 [43]. The salinity intrusion is a serious problem not only for the mangrove for other economic sectors as well. The salinity extension towards north and northeast will cross human inhabitants and may seriously affect the irrigation in paddy fields.

Conclusion

Mangroves are the only woody halophyte-dominated ecosystem situated at the confluence of land and sea. Most mangrove forests are highly productive and net autotrophic, helping to support coastal food chains, including commercially valuable fish, crustaceans and molluscs. Mangroves are a valuable ecological and economic resource, being important nursery grounds and breeding sites for birds, fish, crustaceans, shell- fish, reptiles and mammals; a renewable source of wood; accumulation sites for sediment, contaminants, carbon and nutrients; and offer protection against coastal erosion

The mangrove ecosystem will respond by changing in productivity, areal extent or species diversity or by migrating. These changes will likely modify fish, shrimp, and crab and wildlife populations living in the mangrove forest. The more that the mangrove forest is reduced greater impact from salt water intrusion and erosion on the neighbouring land and the greater the vulnerability to storm- induced flooding.

The distribution of tree species including undergrowth grows in a suitable environment and relates to salinity. It is observed that most of the healthy and vigorous trees and undergrowth species were found growing in the Oligohaline to Mesohaline zones that are towards north and northeast part of the forests, because of lower salinity levels. Many of the plant species and undergrowth species cannot tolerate intense salinity as mentioned in the brackish water forest types. It is interesting to note that the salinity is playing a key role for the growing plants. Therefore, the values of salinity are influencing the vegetation as positively or negatively as well as high or poor diversity. It can also be concluded that the rich diversity of plants species of healthy individuals might be indicative of the healthy mangrove forest of the low saline zone. On the other hand, poor variety of undergrowth, as well as their stunted growth might be indicative of the ill mangrove forest of the high saline zone. Due to salinity intrusion already many changes are taking place such as top dying of Sundri (*Heritiera fomes*), and invasion of Gewa (*Excoecaria agallocha*) etc. in Sundarbans mangrove forests [44]. In such cases biomass will be decreased which result in lowering of Carbon might sink, weakening as shelterbelt, increasing soil erosion potentials.

Sundarbans is the habitat of many rare and endangered terrestrial animals like *Batagur baska*, *Pelochelys bibroni*, *Chelonia mydas* and especially the Royal Bengal tiger (*Panthera tigris*). Javan rhino, wild buffalo, hog deer, and barking deer are already extinct from the area. It is also a sensitive habitat for much significant avifauna and aquatic fauna. Wildlife, both predator and prey species will lose their habitat regarding shelter, the source of food and drinking water. Many aquatic species changes their breeding ground for high salinity. Moreover, they shift or migrate towards the suitable sites leaving this mangrove ecosystem which impacts on birds and other avifauna. In these reverse circumstances, the ecosystem will be hampered, and its service to human beings and environment will be diminishing. To protect this mangrove ecosystem from the salinity intrusion, massive action plans, both long term and short term are needed to be adopted.

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