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# Inter-annual variation of salinity in Indian Sundarbans

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Using secondary data coupled with real time data, inter-annual variation of surface water salinity in three sectors (western, central and eastern) of Indian Sundarbans during 1984-2013 was studied. Salinity of the aquatic system in the present deltaic complex, situated in the inshore region of Bay of Bengal is primarily regulated by anthropogenic factors (like barrage discharge, run-off from the adjacent landmasses *etc*.) and natural factors (like siltation, plate tectonics *etc*.). Surface water salinity has decreased by 0.63 and 0.86 psu per year in the western and eastern sectors respectively, whereas in the central sector, it has increased 1.09 psu per year. Another important objective of the study is to investigate the future salinity (in 2043, 30 years after 2013) in the three sectors of the deltaic complex considering the present data set of 30 years as the baseline. Our forecast through exponential smoothening method reveals an alarming hypersaline environment in the central Indian Sundarbans.

[**Keywords:** Surface water salinity, Indian Sundarbans, inter-annual variation]

## Introduction

India has been identified as one of the 27 countries, which are the most vulnerable to the impacts of global warming induced sea level rise [1]. Siltation of the Bidhyadhari River since the late 15$^{th}$ century has decreased the fresh water flow in the central sector of Indian Sundarbans to a considerable level[2,3,4,5]. In addition to this, there are reports of rising sea level @3.14 mm per year in Indian Sundarbans[6], which is also a primary factor influencing the spatio-temporal variation of salinity. UNESCO[7] reported that 45-cm rise in sea level (likely by the end of the 21st century, according to the IPCC), combined with other forms of anthropogenic stress on the Sundarbans could lead to the destruction of 75% of the Sundarban mangroves. Diamond Harbour, an area just adjacent to the northern boundary of Indian Sundarbans exhibit a net sea level rise of 5.74 mm/year (considering the subsidence value), which is much higher compared to several others coastal cities of India like Mumbai (1.20 mm/year), Kochi (1.75 mm/year) and Vishakhapatnam (1.09 mm/year)[8] . Present study aims to analyze the decadal variation of salinity since 1984 in Indian Sundarbans region located at the apex of Bay of Bengal. It has great relevance as salinity is the primary criterion regulating the distribution of mangrove species and their growth[1,3,4,9,10,11]. The entire biological spectrum of deltaic Sundarbans along with the livelihood of the local people is also influenced by salinity of the ambient media.

## Material and Method

Deltaic complex of Indian Sundarbans has an area of 9,630 sq. km and houses about 102 islands [12]. 18 sampling sites were selected, 6 each in the western, central and eastern sectors of Indian Sundarbans (Table 1, Fig. 1). Three sectors of Indian Sundarbans are demarcated on the basis of our primary surface water salinity data of 24 years[2] and secondary data (of 27 years)[4].

Table 1: Sampling stations in the western, central and eastern sectors of Indian Sundarbans in the lower Gangetic delta region

| Sectors | | Sampling stations | Latitude | Longitude |
|---|---|---|---|---|
| **Western sector** | **Stn. 1** | Chemaguri ($W_1$) | 21$^0$38'25.86"N | 88$^0$08'53.55" E |
| | **Stn. 2** | Saptamukhi ($W_2$) | 21$^0$40'02.33"N | 88$^0$23'27.18"E |
| | **Stn. 3** | Jambu Island ($W_3$) | 21$^0$35'42.03"N | 88$^0$10'22.76"E |
| | **Stn. 4** | Lothian ($W_4$) | 21$^0$38'21.20"N | 88$^0$20'29.32"E |
| | **Stn. 5** | Harinbari ($W_5$) | 21$^0$44'22.55"N | 88$^0$04'32.97"E |
| | **Stn. 6** | Prentice Island ($W_6$) | 21$^0$42'47.88"N | 88$^0$17'55.05"E |
| **Central sector** | **Stn. 7** | Thakuran Char ($C_1$) | 21$^0$49'53.17"N | 88$^0$31'25.57"E |
| | **Stn. 8** | Dhulibasani ($C_2$) | 21$^0$47'06.62"N | 88$^0$33'48.20"E |
| | **Stn. 9** | Chulkathi ($C_3$) | 21$^0$41'53.62"N | 88$^0$34'10.31"E |
| | **Stn. 10** | Goashaba ($C_4$) | 21$^0$43'50.64"N | 88$^0$46'41.44"E |
| | **Stn. 11** | Matla ($C_5$) | 21$^0$53'15.30"N | 88$^0$44'08.74"E |
| | **Stn. 12** | Pirkhali ($C_6$) | 22$^0$06'00.97"N | 88$^0$51'06.04"E |
| **Eastern sector** | **Stn. 13** | Arbesi ($E_1$) | 22$^0$11'43.14"N | 89$^0$01'09.04"E |
| | **Stn. 14** | Jhilla ($E_2$) | 22$^0$09'51.53"N | 88$^0$57'57.07"E |
| | **Stn. 15** | Harinbhanga ($E_3$) | 21$^0$57'17.85"N | 88$^0$59'33.24"E |
| | **Stn. 16** | Khatuajhuri ($E_4$) | 22$^0$03'06.55"N | 89$^0$01'05.33"E |
| | **Stn. 17** | Chamta ($E_5$) | 21$^0$53'18.56"N | 88$^0$57'11.40"E |
| | **Stn. 18** | Chandkhali ($E_6$) | 21$^0$51'13.59"N | 89$^0$00'44.68"E |

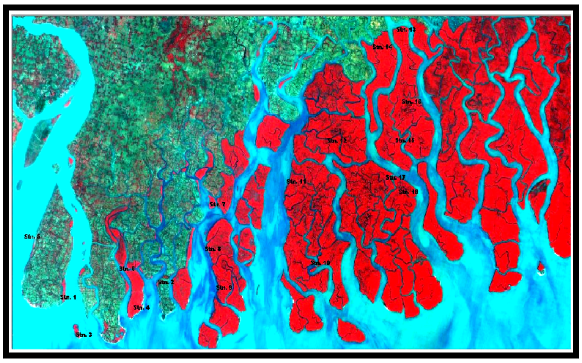

Fig. 1- Location of sector-wise sampling stations in Indian Sundarbans; the red colour indicates the mangrove vegetation

A data set of 30 years in this first order analysis as per the minimum standard norm of climate related researches is considered in this study. World Meteorological Organization and the Intergovernmental Panel on Climate change (IPCC)[13] define "climate" as the average state of the weather over time with the period generally being 30 years (although for some marine climate parameters such as storminess, longer averages are required)[14].

More than two decades of data (1984 - 2013) were compiled from the archives of the Department of Marine Science, University of Calcutta for this study. A number of studies on different aspects of the Sundarban complex have been published over the years, which include description of the data (and methods) at different times for more than two decades[2,4,11,15,16,17,18,19,20,21,22]. Real time data (through field sampling by the authors) were also collected simultaneously since 1998 from 18 sampling stations in the lower Gangetic region during high tide condition to assure quality and continuity to the data bank. For each observational station, at least 30 samples were collected within 500 m of each other and the mean value of 30 observations was considered for statistical interpretations.

*In situ* surface water salinity was estimated from the selected stations during high tide condition with the help of a refractometer (VEEGEE STX-3). For cross-checking, water samples from the selected stations were brought to the laboratory in ice-freezed condition and analyzed for chlorinity by argentometric method and converted into salinity through standard equation.

Time series analysis was performed to forecast the trend of surface water salinity on the basis of the past thirty year's real time data. Exponential smoothing method produces maximum-likelihood estimates and can reflect the future trend of the selected variable. This approach was adopted to forecast the values for surface water salinity in the ambient media of the sampling station till 2043.

**Result**

It is interesting to note the significant spatio-temporal variation of surface water salinity in the study region. In the western sector, the salinity decrease ranged from 0.58 psu/ year (at Jambu Island) to 1.46 psu/ year (at Harinbari). Although station 2 (Saptamukhi) is situated in the western sector, but the salinity has increased by 0.51 psu/year (Fig. 2). Considering all the six stations in the western sector, the decrease of salinity is 0.63 psu/year, which represents a decrease of 7.50 psu per decade. Salinity has decreased from 17.30 % (in Jambu Island) to 43.76 % (in Harinbari) over a period of 30 years (Fig. 2).

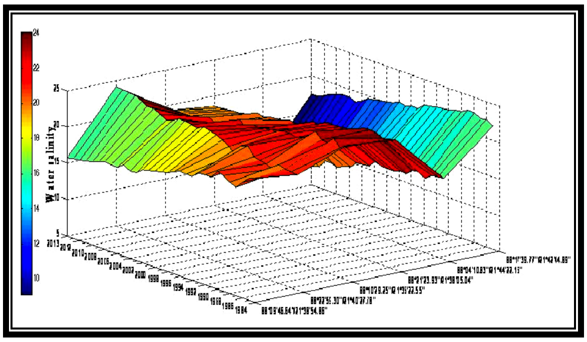

Fig. 2- Spatio-temporal variation of salinity in western Indian Sundarbans

The exponential smoothing method that produces maximum-likelihood estimate of the variable predicts a salinity value of 13.05 psu in 2043 (Fig. 3), which is a decrease of 38.4% since 1984 (over a span of 60 years).

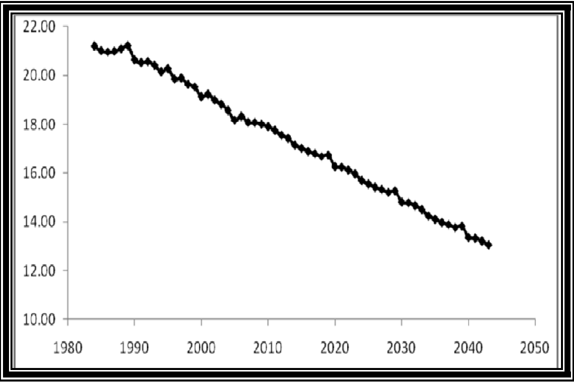


Fig. 3- Future trend of surface water salinity in western Indian Sundarbans

Central sector presents a completely reverse picture in terms of aquatic salinity. Irrespective of stations, salinity has increased (Fig. 4) between the range 1.05 psu/ year (in Chulkathi) to 1.12 psu/ year (in Matla and Pirkhali). Considering the salinity values of selected six stations, the increase is 1.09 psu/year, which is equivalent to 13.05 psu/decade. Percentage of salinity increase in this sector range from 31.49 psu (in Chulkathi) to 33.64 psu (in Matla) with an average of increase 32.62 % over a period of 30 years (Fig. 4).

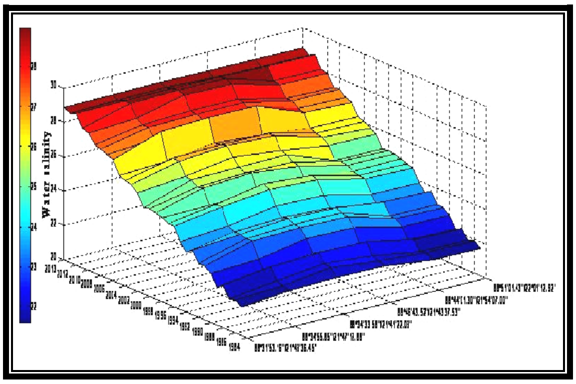

Fig. 4- Spatio-temporal variation of salinity in central Indian Sundarbans

Considering the observed data set of 30 years (1984 – 2013), we predict that salinity will be around 36 psu after a period of 30 years in the central sector of Indian Sundarbans (Fig. 5), which is an indication of alarming hypersaline condition (a rise by 67.1%) in 2043 in this sector.

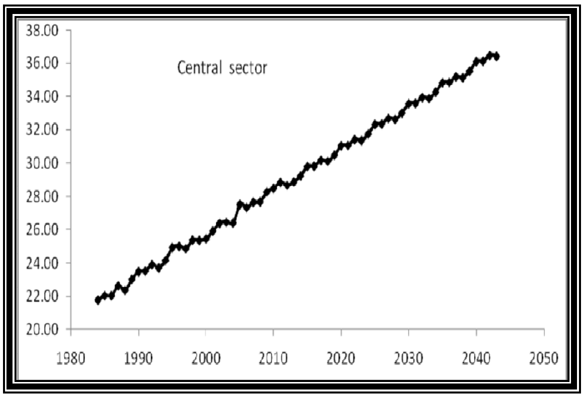


Fig. 5- Future trend of surface water salinity in central Indian Sundarbans

In the eastern sector, salinity has decreased (Fig. 6), which ranges from 0.54 psu/year (in Chamta) to 0.98 psu/year (in Jhilla). Considering all the six stations in eastern Indian Sundarbans, the average decrease of salinity is 0.86 psu/year, equivalent to a decadal decrease of 10.30 psu. Over a period of 30 years, the average percentage decrease of salinity is 25.66 psu (Fig. 6).

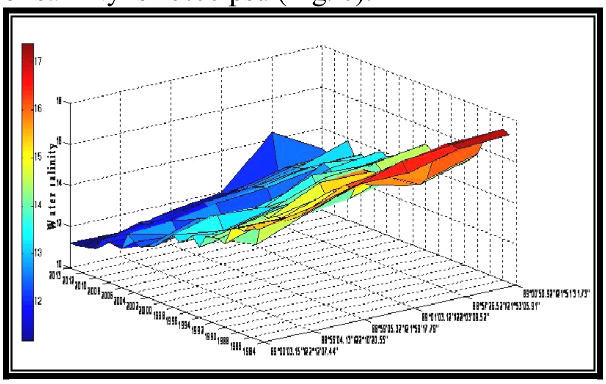

Fig. 6- Spatio-temporal variation of salinity in central Indian Sundarbans

On the basis of observed data, the prediction of salinity in 2043 is around 7.54 psu (Fig. 7), which is decrease of 52.4% considering a time span of 60 years.

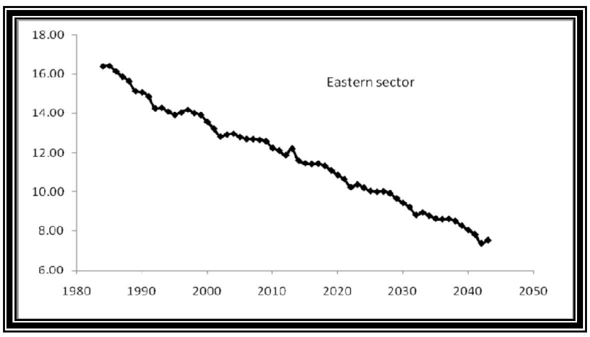


Fig. 7- Spatio-temporal variation of salinity in eastern Indian Sundarbans

## Discussion

The results of the long term observed data on surface water salinity clearly confirms significant spatio- temporal variations of the salinity in the study region ($p<0.01$). Basically a bell- shaped salinity profile can be a representation for the region with a hypersaline environment in the central sector (mean salinity = 25.43 ± 2.24 psu) between two hyposaline sectors *viz*. western (mean salinity = 19.46 ± 3.46 psu) and eastern (mean salinity = 13.85 ± 1.48 psu).

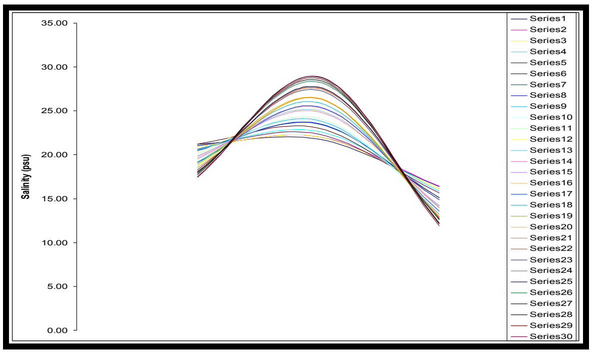


Fig. 8- Bell-shaped nature of salinity profile of Indian Sundarbans based on 9200 readings; 30 series represent 30 consecutive years (1984 – 2013).

The bell- shaped salinity profile in the present study region is not merely a representation of salinity pattern, but it can be a test bed for future climate related research due to following reasons:

1. Presence of unique mangrove- centric gene pool in the deltaic complex [from microbes to Royal Bengal Tiger (*Panthera tigris tigris*)] primarily influenced by salinity.
2. Ecosystem services of the system to about 4.2 million people dwelling in the delta region.
3. No trans-boundary related research has yet been taken up considering Sundarbans as an integrated system, although Farakka discharge (a trans-boundary anthropogenic component) has great influence on the mangrove health and livelihood of the integrated Sundarbans.

Similar profile is also observed in the Bangladesh part of Sundarbans, where three salinity zones have been identified *viz*. less saline zone (5- 15 ppt), Moderately Saline Zone (15-25 ppt) and Strong Saline Zone (25-30 ppt) based on degree of salinity[23].

Hyposaline environment of western Indian Sundarbans may be attributed to Farakka barrage discharge situated in the upstream region of Ganga- Bhagirathi -Hooghly river system. 10-year surveys (1999 to 2008) on water discharge from Farakka dam revealed an average discharge of $(3.7 \pm 1.15) \times 10^3\ m^3s^{-1}$. Higher discharge values were observed during the monsoon with an average of $(3.81 \pm 1.23) \times 10^3\ m^3s^{-1}$, and the maximum of the order 4524 $m^3s^{-1}$ during freshet (September). Considerably lower discharge values were recorded during premonsoon with an average of $(1.18 \pm 0.08) \times 10^3\ m^3s^{-1}$, and the minimum of the order 846 $m^3s^{-1}$ during May. During postmonsoon discharge, values were moderate with an average of $(1.98 \pm 0.97) \times 10^3\ m^3s^{-1}$ as recorded by earlier workers[1].

Central sector represents a hypersaline environment due to complete obstruction of the fresh water flow from the upstream region owing to Bidyadhari siltation since the late 15$^{th}$ century[1,4,9,11]. Matla estuary in the central Indian Sundarban cannot be referred to as an ideal estuary as there is no head on discharge or dilution of the system with fresh water. Thus Matla can be designated as a tidal channel, whose survival depends on the tidal flow from Bay of Bengal.

The eastern sector of Indian sector exhibits a low saline profile possibly due to inter-connection with several creeks and channels of Harinbhanga estuary (the aquatic border of India and Bangladesh Sundarbans) with the tributaries of Bangladesh Sundarbans that arise from Padma Meghna (Fig. 9) river system.

On the basis of significant spatio-temporal variations of salinity and its future trend, we recommend a trans-boundary coordinated programme of long-term research linking monitoring, process studies and numerical modeling on the foundation of a diverse, inter-disciplinary, multi-institution approach and establishment of a strong institutional network between researchers and decision makers of India and Bangladesh.

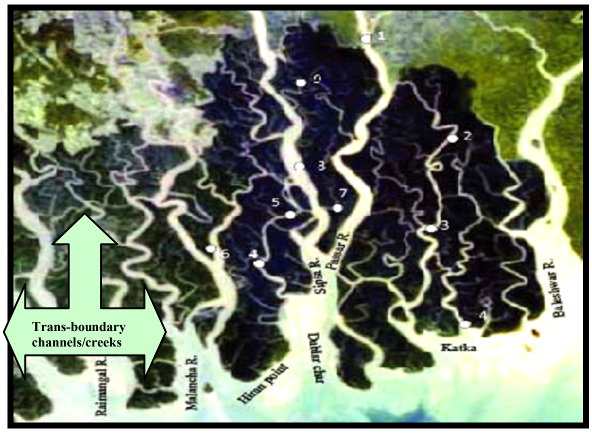

Fig. 9- Trans-boundary channels feeding freshwater to eastern sector of Indian Sundarbans

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