Observed changes in water mass properties in the Indian Sundarbans (northwestern Bay of Bengal) during 1980–2007

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We present evidence that the Indian Sundarbans is experiencing the effects of climate change over the last three decades. Observations of selected variables, such as the surface water temperature, salinity, pH, dissolved oxygen, and transparency show significant long-term variation over a period of 27 years (1980–2007). Specifically, the temperature in these waters has risen at the rate of 0.5°C per decade, much higher than that observed globally or for the Indian Ocean. Increasing melting of Himalayan ice might have decreased the salinity at the mouth of the Ganges River, at the western end of this deltaic complex. At the same time, salinity has increased on the eastern sector, where the connections to the meltwater sources have become extinct due to heavy siltation of the Bidyadhari Channel. The long-term changes in dissolved oxygen, pH level, transparency and water quality are also examined. The ecological impact of such changes warrants future study.

Keywords: Bay of Bengal, climate change, deglaciation, hydrological parameters, Indian Sundarbans.

THE Indian Sundarbans at the apex of the Bay of Bengal (between 21°40′N and 22°40′N, lat. and 88°03′E and 89°07′E long.) is located on the southern fringe of West Bengal, on the northeast coast of India (see Figure 1). The region is bordered by Bangladesh in the east, the Hooghly River (a continuation of the Ganges River) in the west, the Dampier and Hodges line in the north, and the Bay of Bengal in the south. The important morphotypes of deltaic Sundarbans include beaches, mudflats, coastal dunes, sand flats, estuaries, creeks, inlets and mangrove swamps[1]. Although the region is situated south of the Tropic of Cancer, the temperature is moderate due to this region's proximity to the Bay of Bengal in the south. Average annual maximum temperature is around 35°C. The summer (pre-monsoon) extends from the middle of March to mid-June, and the winter (post-monsoon) from mid-November to February. The monsoon usually sets in around the middle of June and lasts up to the middle of October. Rough weather with frequent cyclonic depressions lasts from mid-March to mid-September. Average annual rainfall is 1920 mm. Average humidity is about 82% and is more or less uniform throughout the year. Thirty four true mangrove species and some 62 mangrove associated species[2] are found here, which is also the home ground of the royal Bengal tigers (*Panthera tigris tigris*) on the planet. This deltaic complex sustains 102 islands, only 48 of which are inhabited.

In the Indian Sundarbans, approximately 2069 sq km of the area is occupied by the tidal river system or estuaries, which finally end up in the Bay of Bengal. The seven main riverine estuaries are listed in Table 1 from west to east, along with their salient features. The flow of the Ganges through the Hooghly estuary in the western sector of the Indian Sundarbans, ending up in the Bay of Bengal, results in a geographical situation totally different from that of the eastern sector, where five major rivers have lost their upstream connections with the Ganges (Figure 1) due to heavy siltation and solid waste disposal from the adjacent cities and towns[3]. Presently, the rivers in the western part (Hooghly and Muriganga) are connected to the Himalayan glaciers through the Ganges originating at the Gangotri Glacier; whereas the five eastern sector rivers, viz. Saptamukhi, Thakuran, Matla, Gosaba and Harinbhanga, are all tidally fed.

Data sources and quality

Data of three decades (1980–2007) 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 Sunderban complex have been published over the years. References 4–12 give the description of the data (and methods) at different times over the past three decades. A map of the study region is shown in Figure 1. The two main locations for collecting the data were centred around 21°52′20.78″N and 88°7′29.73″E, at the tip of Sagar Island in the Hooghly estuary (western sector) and around 22°15′33.97″N and

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Table 1. Seven most important rivers in the Indian Sundarbans

Estuary	Description
Hooghly (R1)	➢ It forms the western border of Indian Sundarbans. ➢ It is the main river of West Bengal and is a direct continuation of the River Ganges. ➢ Most of the coastal industries of West Bengal are concentrated along the western bank of this river.
Muriganga (R2)	➢ It is a branch of the Hooghly River. ➢ It flows along the east of Sagar Island, the largest island in the deltaic complex. ➢ Unique mangrove vegetation is found along its bank.
Saptamukhi (R3)	➢ It has its origin at Sultanpur. ➢ It is connected with the Muriganga (Bartala) branch of the Hooghly River through the Hatania-Duania canal.
Thakuran (R4)	➢ It begins near Jayanagar in 24 Parganas (South) and has a number of connections with the Saptamukhi. ➢ It was connected in the earlier times with the Calcutta Canal through the Kultali and the Piyali rivers, which exist today in a dying state.
Matla (R5)	➢ This river originates at the confluence of Bidyadhari, Khuratya and the Rampur Khal close to the town of Canning in 24 Parganas (South). ➢ Matla is connected to Bidya and ultimately flows to the Bay of Bengal. The fresh water connection and discharge to this river has been lost in recent times. ➢ Salinity of the river water is relatively high (in comparison to Hooghly or Muriganga) owing to freshwater cut-off from the upstream region.
Bidyadhari*	➢ This was a flourishing branch of the Bhagirathi during the 15th and 16th centuries, but now serves only as a sewage and excess rainwater outlet from the city of Kolkata. ➢ The river bed is completely silted and presently is almost in dying condition.
Gosaba (R6)	➢ The waters of Matla and Harinbhanga (Raimangal) through a large number of canals form the estuary. ➢ The estuary and its numerous creeks flow through the reserve forests.
Harinbhanga (R7)	➢ It is the extreme easternmost river in the Indian Sundarbans deltaic complex. ➢ The Harinbhanga (also known as Ichamati and Raimangal) forms a natural demarcation between India and Bangladesh.

*Presently a dying estuary and not considered within the seven major types.

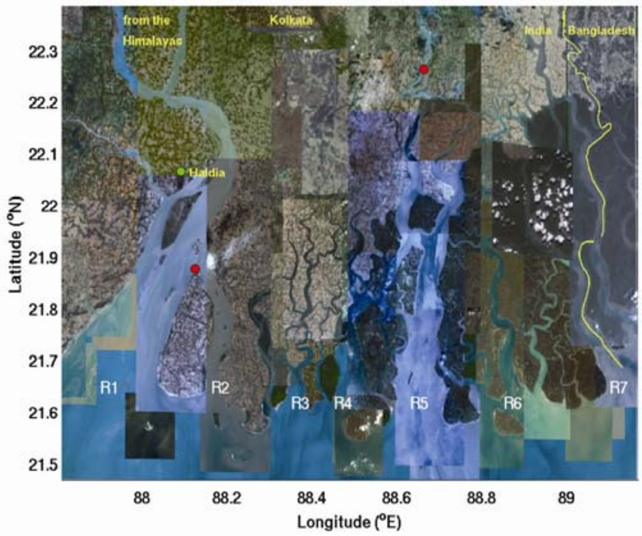

Figure 1. Map of the study region with 2 stations marked in red. The western station is located at 21°52′20.78″N, 88°7′29.73″E, at the tip of Sagar Island. The seven rivers marked by R1 to R7 from west to east are: Hooghly, Muriganga, Saptamukhi, Thakuran, Matla, Gosaba and Harinbhanga. The groundwater discharge systems of the two metropolis of Haldia and Kolkata (Calcutta) are connected to the two western rivers, which are also fed by the meltwater from the Himalayas as shown. The eastern station, at 22°15′33.97″N, 88°39′34.64″E, is connected to the rivers R4 and R5 which do not have such connection with the Himalayas.

88°39′34.64″E (eastern sector). These two stations are considered as the representatives of the two sectors of the Indian Sundarbans for the purpose of this study.

The analysis of temperature, salinity, pH, dissolved oxygen and transparency during pre-monsoon and monsoon periods were carried out after partitioning the data into eastern and western sectors as defined in Figure 1. For each observational station, at least three samples were collected from the surface during high tide condition within 500 m of each other. The mean and standard deviations of these observations are presented sequentially in Figures 2–6. A total of 18 years of observations were available (spread unevenly) during the 27-year study period. The collection method did not change since 1980. The surface water salinity was recorded by means of an optical refractometer (Atago, Japan) in the field and cross-checked in laboratory by employing Mohr–Knudsen method (after Strickland and Parsons, 1968). The correction factor was found out by titrating silver nitrate solution against standard seawater (IAPO standard seawater service Charlottenlund, Slot Denmark, chlorinity 19.376‰). Our method was applied to estimate the salinity of standard seawater procured from NIO and a standard deviation of 0.02% was obtained for salinity. The average accuracy for salinity (in connection to our triplicate sampling) is ± 0.28 psu and for temperature ± 0.035°C. Glass bottles of 125 ml were filled to overflow from collected water samples and Winkler titration was performed for the determination of dissolved oxygen. The pH was obtained via a portable pH meter (Hanna, USA), which has an accuracy of ± 0.1. A Secchi disc was used to measure the transparency of the water column and the data was used to calculate the euphotic depth. The accuracy level of transparency is ± 1 cm. The long-term trends are interpreted as signals of climate change and their possible implications to the biodiverse ecosystem are briefly outlined in this first-order analysis. Detailed analysis will be the focus of a forthcoming study.

Surface water temperature: a clear signature of climate change

The signal of global warming has already been transmitted to the mangrove-dominated Indian Sundarbans. The surface water temperatures in both the sectors have shown significant rising trends (Figure 2), for both pre-monsoon and monsoon periods. Quantitatively, these temperatures have risen by 6.14% in the western sector and by 6.12% in the eastern sector over the past 27 years, at a rate of approximately 0.05°C/year. This rate is, in fact, much higher than the observed and documented warming trends in the tropical Pacific Ocean (0.01–0.015°C/year), tropical Atlantic Ocean (0.01–0.02°C/year) and the planet itself (0.006°C/year). It is also observed that the period 1993–2007 had a higher rate of temperature increase as compared to 1980–92. This period of higher rate of warming also coincides with the

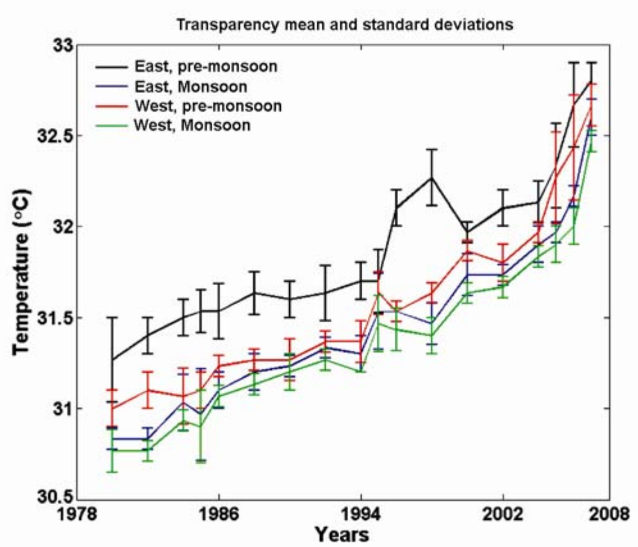

Figure 2. Observed warming trend of surface water temperature (°C) in both western and eastern Indian Sundarbans during pre-monsoon and monsoon. Note the change of the warming rate before and after the middle of 1990s.

period mentioned in the Intergovernmental Panel on Climate Change (IPCC) report[13] (see figure 5.1 of the IPCC report). In fact, for the Indian Ocean, the surface warming increased significantly, at the rate of 0.2°C per decade, for the period 1970–99, compared to a much weaker increase during 1900–70 (see section 5.3.4 of the IPCC report).

Note that a recent study conducted by the Institute of Wetland Management and Environmental Studies, Kolkata revealed a variation in water spread area in Sundarbans between 1982 and 2003. The water spread area was observed to reduce from 1930 sq km in 1982 to 1885 sq km in 2003 whereas there has been no decrease in vegetative cover. Reduction in water spread area due to reduced tidal action could account for some of these observed changes.

The IPCC reviewed relevant published studies of biological systems and concluded that 20–30% of species assessed may be at risk of extinction from climate change impacts within this century if global mean temperatures rise to 2–3°C (3.6–5.4°F) above preindustrial levels[4]. The observed change of 1.5°C over the last three decades presents a clear challenge to the survival of the floral and faunal diversity of this ecosystem in the next three decades.

Surface water salinity: contrasting effects of melting and silting

Global warming might impact the salinity of oceanic waters in two very different ways. First, in the open ocean rising temperature would lead to increased evaporation, which in turn would result in increased salinity. In contrast, the salinity of surface water in bays, estuaries and coastal waters is a function of freshwater input from glaciers, precipitation and subsequent runoff, and intrusion of sea water. That the phenomenon of global warming melts glaciers, brings more rain, and transfers more freshwater into estuaries, coasts and bays is a generalization that does not hold uniformly in all the segments of the Indian Sundarbans. The western station showed a significant and continuous decrease in salinity (1.67 psu/decade) whereas the eastern sector showed an increase in salt (~6 psu over thirty years; see Figure 3). This difference in the rate of change of salinity in both the sectors is due to the difference between their geographical settings as explained here.

The rivers in the western sector of the Indian Sundarbans (Hooghly and Muriganga), being continuations of the River Ganges, receive the snow melt water of the Himalayas (see Figure 1). The Himalayan glaciers, popularly called ‘the lifelines of major Indian rivers’, have entered into the phase of deglaciation on account of global warming. The 30.2 km long Gangotri Glacier is receding rapidly: the rate of retreat over the last three decades has

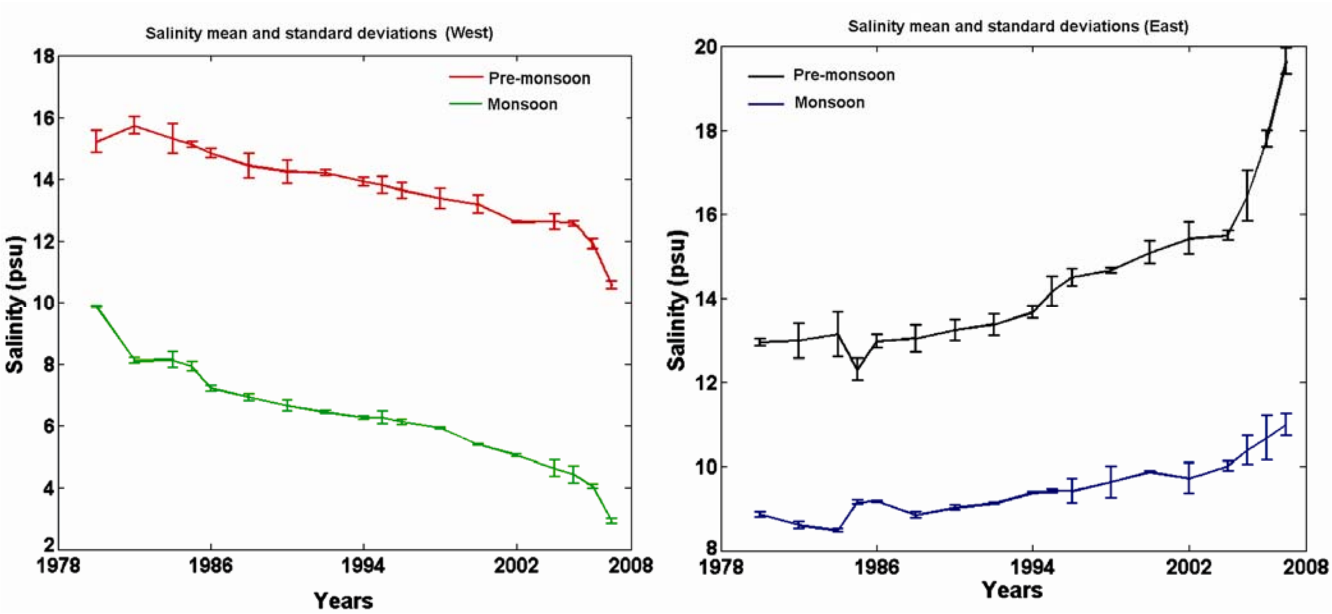

Figure 3. Salinity decreased during the last 30 years on the western (left) sector whereas it increased on the eastern (right) sector of the Indian Sundarbans. Trends are similar in both pre-monsoon and monsoonal periods. The left panel shows the increasing freshening in the western station due to meltwater, whereas the right panel shows the increasing salinity to the east. Note the 5 psu bias between the monsoon and pre-monsoon salt content in the water at both stations.

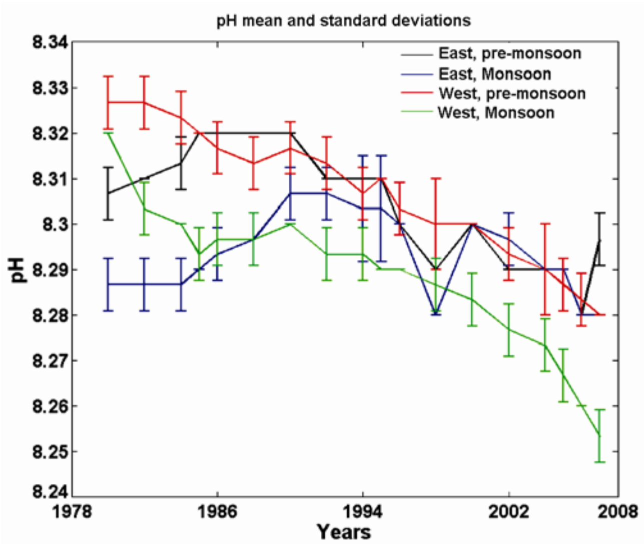

Figure 4. Decreasing surface water pH in both western and eastern sectors of Indian Sundarbans. Note the shift in behaviour after the middle of 1990s including an increasing trend during the 1980s in the eastern sector.

been found to be more than three times the rate during the previous 200 years or so. The average rate of recession has been evaluated by comparing the snout positions on the 1985 topo-sheet map and the satellite panchromatic satellite imagery; the results reflect an average recession for this period of about 23 m/year (refs 14–16). This alteration of glacial system is in alignment with the present situation in the Asian subcontinent as found by Tandong *et al.*[17] who determined that the number of retreating glaciers has risen from 90% in the 1980s to 95% in the 1990s and up to 2004. Thus, the observed long-term salinity decrease over the western sector is best attributed to the rapid recession of ice from the Himalayas.

According to multiple reports by the Working Group on Himalayan Glaciology (WGHG) of the International Commission for Snow and Ice (ICSI) (1999) and the World Wide Fund for Nature Report[18], 67% of the Himalayan glaciers are receding rapidly, and by the year 2035 there is a high likelihood that these glaciers will disappear, causing widespread water shortage among a one-third of the world's population[19].

On the other hand, for the eastern sector, the increase of 6 psu over three decades in salinity (~2 psu/decade) is much higher than that documented for the average in the Indian Ocean (0.01–0.02 psu/decade) (IPCC report). In a separate study, Curry *et al.*[20] found that the increase in salinity over the last 40 years in tropical Atlantic was on the order of 0.4–0.5 psu. This is at a rate of 0.125 psu per decade, which is an order of magnitude less than that observed in the study area. Furthermore, most of the salinity increase (3.67 psu/decade) happened during the last 15 years (Figure 3 and Table 2). This increase may be due to clogging of the connections of the estuaries with the main channel of the Ganges[3] on account of heavy siltation and solid waste disposal from the city of Kolkata. Thus, the footprint of global warming is felt through rising temperature and increased salinity (Figure 3) in the river mouths due to intrusion of saline water via tides from the adjacent Bay of Bengal region.

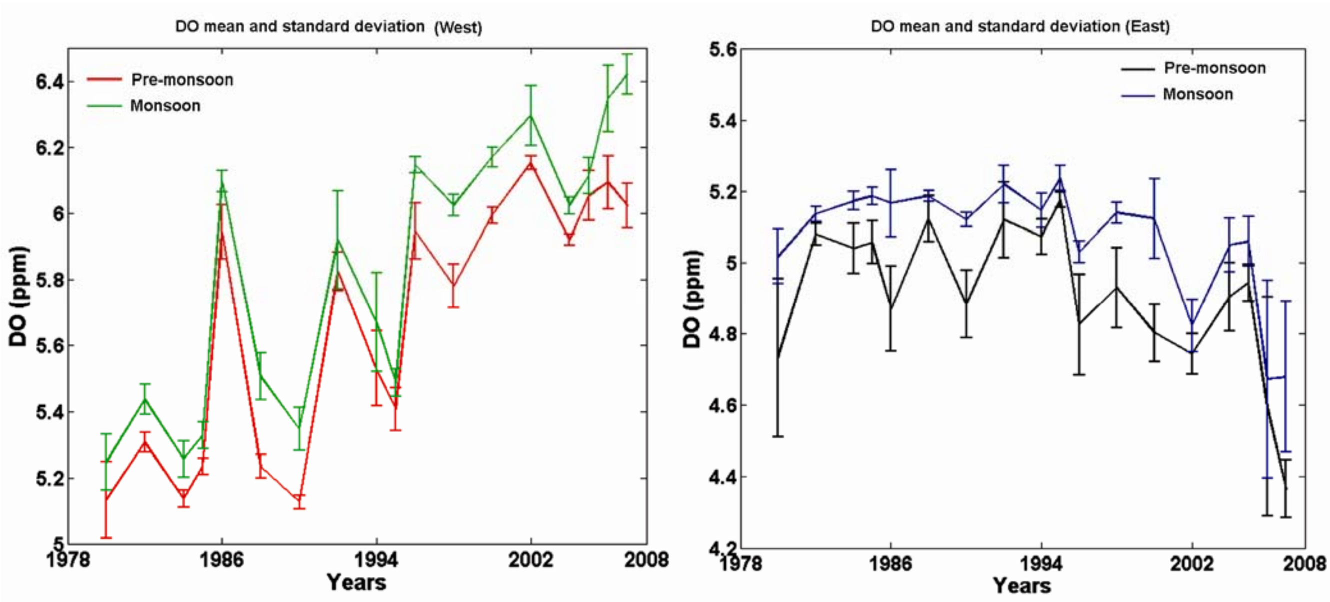

Figure 5. Dissolved oxygen (in ppm) fluctuation in western (left) and eastern (right) Indian Sundarbans. The decrease in DO on the eastern side is only significant in recent years after the middle of 1990s.

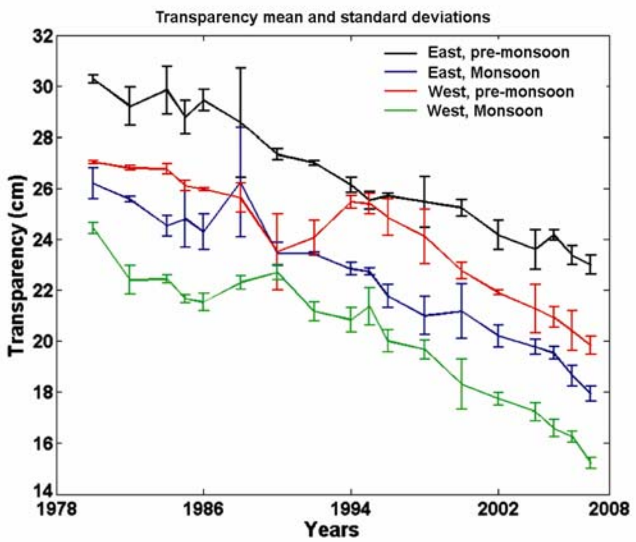

Figure 6. Transparency (in cm) variation in western and eastern Indian Sundarbans shows a consistent decrease over the last 30 years during pre-monsoon and monsoon periods.

The observed trends in the salinity are also interesting from two other perspectives. First, the salinity decreased by almost 5 psu for both pre-monsoon and monsoon periods over 30 years in the west, in contrast to the east. In the east, the salinity during monsoon held steady or minimally increased; whereas there is an increase in the past 15 years mostly during pre-monsoon times. This increase is probably due to huge siltation and the slow dying of Bidyadhari River since the 16th century that was once a conveyor belt for freshwater from the Himalayas to the eastern Indian Sundarbans[3]. Additionally, the reduction of water spread area mentioned earlier could also account for part of the increase of salinity due to reduced tidal activity.

Second, the melting of ice has increased in the Himalayan range[5–7], which added freshwater and thereby decreased the salinity of the western Sundarbans by almost 5 psu over 30 years. Note that the average difference between pre-monsoon and monsoon salinity every year is also about 5 psu. This leads us to conclude that the accumulated effect of melt waters over 30 years in the Ganges delta is almost equivalent to one annual monsoon precipitation over this region! Note also that the western sector is also affected by intentional increase of freshwater in the Hooghly to maintain safe level for ship draft, however its contribution to the observed decrease needs to be evaluated.

Surface water pH: indicator of atmospheric CO_2 budget

Over the past three centuries, the concentration of carbon dioxide has been increasing in the Earth's atmosphere because of human influences[21]. Since the early 1700s, carbon dioxide has increased from 280 to 380 ppm in 2005. As carbon dioxide builds up in the atmosphere, a large fraction dissolves into the ocean, increasing the total amount of dissolved inorganic carbon and shifting seawater chemistry towards a lower pH condition[22]. This indicates rising acidification of coastal waters and a decrease in the carbonate ion ($[CO_3^{2-}]$), which is believed to affect the ability of marine animals which build shells. As shown in Figure 4, observed surface water pH over the

Table 2. Summary observations during pre-monsoon over the last three decades

	West			East			
	1980	2007	Trend (/decade)	1980	1995	2007	Trend* (/decade)
Temperature (°C)	31	32.6	+0.5	31.25	31.65	32.7	+0.27/+0.67
Salinity (psu)	15	10	–1.67	13	13.5	19	0/+3.67
pH	8.325	8.28	–0.015	8.305	8.3	8.29	0/0
DO (ppm)	5.1	6.0	+0.3	5.1	5.1	4.5	0/–0.4
Transparency (cm)	27	20	–2.3	30	27	23	–2.3/–2.3
Water quality index	75	91	+16	75	76	64	+0.7/–8
Density ($\sigma_\theta = \rho - 1000$)	+6.5	+3.0	–1.2	+4.7	+5.0	+9.1	+0.2/+2.9

*The trend for the eastern sector is given in two bands: the first for the period 1980–95, and the second for the period 1995–2007, separated by '/'. 'Zero trend' indicates that there was no significant trend obtained.

past 30 years shows an overall decreasing trend in both sectors.

There are three important aspects of this long-term trend in the pH level. First, the observed range of pH (8.25–8.33) is higher than the global average of 8.179. Second, the rate of decrease of pH on the western side is about 0.015 per decade. This might be directly related to excess CO_2 absorption during this period from anthropogenic sources. Last, the observed level of pH during pre-monsoon is generally higher than that during monsoon by about 0.02. Again, this is somewhat similar to the long-term freshening phenomenon, i.e. the reduction of pH over a decade is equivalent to having an extra monsoon over a decade. Note however that on the eastern side, pH shows a slight increase from 1980–90, 1996–98 and 2006–07; whereas on the western side there is a continuous decrease without any such oscillations. There is also a noticeable shift in the mid-1990s. A possible reason could be direct continuous input of waste material from the Hooghly river system into the western side in contrast to the eastern side. A number of diverse industries are situated on the banks of the Hooghly[20].

Dissolved oxygen: a possible link to climate change

The concentration of dissolved oxygen (DO) in the western sector of the Indian Sundarbans (Figure 5 *a*) showed an increasing trend in contrast to the eastern part over the study period (Figure 5 *b*). The observed increase in the dissolved oxygen levels is around 1 mg/l over the past 30 years. This increase of DO concentration in the western side is in contrast to the prevalent notion of decrease in the DO levels with increasing temperature. As explained in the salinity subsection earlier, the increased melt water supply through Hooghly estuary via the Ganges may account for higher concentration of dissolved oxygen in the western sector.

The signal on the eastern sector is however, complicated. Here, the DO concentration follows similar oscillatory behaviour to the pH signal. Furthermore, there seems to be a shift in the behaviour after 1995. The DO concentration remained steady before 1995 and decreased significantly from 1995 at a rate of about 0.5 ppm per decade. Depletions in dissolved oxygen can cause major shifts in the ecological habitation. On an average, the DO concentration during monsoon is about 0.15 ppm higher than that during pre-monsoon irrespective of the sectors.

Transparency: an indirect effect of climate change

Global warming accelerates the process of erosion in coastal and estuarine zones either through increased summer flow from the glaciers (where the estuaries are connected to the glaciers) or by increased tidal amplitude due to sea level rise. Erosion and sedimentation processes, along with subsequent churning action increase the saturation of suspended solids, thus decreasing the transparency. The signature in the deltaic Sundarbans is uniform in both the sectors with respect to decreasing transparency (see Figure 6) – an effect of embankment erosion due to higher tidal amplitude in the eastern sector, and increased flow of freshwater carrying silt particles due to Himalayan deglaciation in the western sector.

The overall rate of decrease of transparency for this region is obtained as 7–9 cm over 27 years, or about 2.3 cm per decade. Interestingly, the oceanic waters on the eastern sector are more transparent than the fresher western waters by about 3 cm. It is also observed that the transparency is higher during pre-monsoons as compared to the monsoons by about 4–6 cm, which is probably due to higher river run-offs during the pre-monsoon.

The effect of reduced transparency should be readily perceived by the phytoplankton community, which depends on the light availability for growth and survival. Damage to this community may adversely affect the food chain in this mangrove-dominated deltaic complex, which is the nursery and breeding ground of 150–250 species of fin fish[23]. In light of the overall decrease in transparency, we suggest careful scientific monitoring and developing a sustainable management strategy for this region as soon as feasible.

Water quality and density: long-term trends of two diagnostic variables

The trends of all observational variables are summarized in Table 2. In addition to listing their initial (1980) and final (2007) observational values, we have listed their corresponding value for 1995 on the eastern side to highlight the behavioural shift for temperature, salinity, pH and DO. Furthermore, two derived physical variables, water quality and density, were computed and their values are listed in Table 2. Whereas the former depends on the temperature and DO, density depends on temperature and salinity.

We carried out a simple water quality analysis (and trend) using temperature, DO and water level (2 m) information for 1980, 1995 and 2007 using web formulation[24] from http://www.fivecreeks.org/monitor/do.html. Simply put, the ratio of the dissolved oxygen content (ppm) to the potential capacity (ppm) gives the percentage of saturation, which is an indicator of water quality. Starting from an initial value of 75 on both sectors in 1980, the water quality index has risen to 91 in the western sector and dropped to 64 in the eastern sector by 2007. Depletions in dissolved oxygen (and resulting decrease in water quality) can cause major shifts in the kinds of aquatic organisms found in water bodies and evidences of such shifts, if any, need to be properly documented for the eastern Sundarbans. The water quality dropped at a rate of 8 per decade over the last 15 years in the eastern sector.

Given the contrast between the direct effect of warming at both stations and the indirect effect of meltwater in preferential freshening in the west, it is informative to study the density variation over the years. Simple density calculations indicate that the western sector is becoming warmer, fresher and lighter, whereas the eastern sector is becoming warmer, saltier and denser. Such horizontal contrast might lead to changes in (1) circulation, (2) ecosystem and (3) intensity, extent and paths of monsoonal storms due to differential in available energy distribution from the ocean surface. Studies[25] reveal that the frequency of destructive cyclones has increased from the 17th to the 21st century. Also, the severity of cyclones has increased in the Bay area from 1980 to 1999 (ref. 26).

Seawater density in the eastern sector was lower ($\sigma_\theta = 4.7$) than that of the west ($\sigma_\theta = 6.5$) in 1980. In 2007, after the effect of warming and resulting differential effects of salinity decrease/increase due to melting/silting in the western/eastern sectors, the eastern waters have become denser ($\sigma_\theta = 9.1$) than the western water ($\sigma_\theta = -1.2$). Thus, the density contrast has not only increased between the east and the west by almost 12 sigma units, it has also changed signs. Such a change might have serious impact on the pressure–gradient driven currents and might induce reverse flow during pre-monsoon times. Further detailed studies involving high-resolution numerical modelling for this region are needed to understand and quantify such circulation variability which might affect the path and amplitude of cyclones passing through this region.

Conclusions

- Surface water temperature in the deltaic complex of Indian Sundarbans experienced a gradual increase from 1980 through 2007 at a rate of 0.5°C per decade. This rate is much higher than the globally observed warming rate of 0.06°C per decade, and the IPCC documented rate of 0.2°C per decade in the Indian Ocean during 1970–99.
- The waters of the western rivers (Hooghly and Muriganga) are fresher now than in the 80s and 90s, probably, primarily due to the increased amount of meltwater from the Gangotri Glacier which is receding at the rate of 23 m/year.
- The waters in the eastern sector of the Indian Sundarbans show increasing salination due to siltation, mixing with ocean water and possible global warming led evaporation, while being deprived of the meltwater.
- The variations of temperature, salinity, pH and DO show a shift in behaviour around the mid-1990s in the eastern sector. The trends in the later years are more significant than those in the previous 15 years.
- Surface water pH decreased (–0.015/decade) in the western sector of the mangrove-dominated Indian Sundarbans. This is probably due to increased anthropogenic impact. However on the eastern side, the pH shows an oscillating behaviour where it increases from 1980–90, 1996–98 and 2006–07. More study on this aspect is needed to quantify the effects produced by local effluents and increased run-off induced by climate change.
- Dissolved oxygen showed increasing (+0.3 ppm/decade) and decreasing (–0.4 ppm/decade) trends in western and eastern sectors respectively, due to variable dilution of the system with fresh water. We suggest that the meltwater increase in the western sector is responsible for increasing DO through the river waters of Hooghly and Muriganga.
- The eastern waters were found to be more transparent than the western waters by 3 cm. The transparency has decreased uniformly (–2.3 cm/decade) in both sectors possibly as a result of the huge silt contribution by the Ganges in the western part and massive erosions in the eastern part. Transparency was lower in both sectors during monsoon compared to pre-monsoon probably due to seasonal increase of land runoff and subsequent silting.

- In short, between 1980 and 2007, the waters in the western sector became gradually warmer, fresher and lighter with lesser pH concentration (more absorbed CO_2), incurred more DO, and became less transparent, while its water quality has increased.
- During the same three decades, the eastern waters became warmer, saltier, denser and less transparent, whereas their water quality has deteriorated considerably. The signals for pH and DO are complicated with a shifting from no-trend to near-trend or significant-trend behaviour in the midnineties.
- Factors in addition to climatic effects should be considered for a full quantitative study. Reduction of salinity in the western sector could be a combination of meltwater and human intervention (forced discharge of freshwater). Increase in salinity to the east could be a combination of lack of freshwater and tidal water supply. These combined effects could be reasons for the observed variation in pH and dissolved oxygen.
- Finally, although observed changes could result from a combination of climate change and human interventions and related phenomena, the changes are real and their impact will be felt in the ecosystem in the coming years.

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