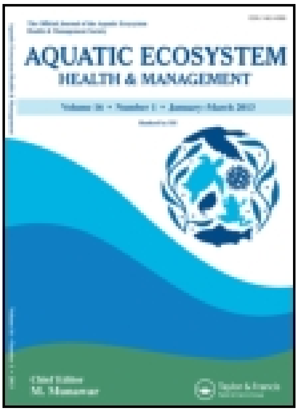

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Spatio-temporal changes of hydro-chemical parameters in the estuarine part of the River Ganges under altered hydrological regime and its impact on biotic communities

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Spatio-temporal changes of hydro-chemical parameters in the estuarine part of the River Ganges under altered hydrological regime and its impact on biotic communities

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Hooghly estuary, the lowermost part of River Ganges in India, following the construction of Farakka barrage in 1975, witnessed improved freshwater inflow in the estuarine stretch of the river with significant impact on the salinity regime, water transparency, suspended sediments and nutrient load leading to alternations in the distribution and abundance of fish and other biotic organisms like plankton and benthos. A detailed seasonal study was conducted in Hooghly estuary during 2010–2012 to evaluate the spatio-temporal changes in selected physico-chemical parameters like temperature, transparency, pH, free CO_2*, dissolved oxygen, specific conductivity, total alkalinity, total hardness, salinity, available nutrients like nitrate, phosphate and silicate under the present hydrological regime in determining the distribution of fish and other aquatic organisms. The salinity based zonation during pre-Farakka period apparently stands modified with a downward shift of freshwater zone. Accordingly, distribution and abundance of biotic communities like plankton and fish now present a completely different scenario from the past.*

Keywords: estuary, Ganga, Hooghly, hydrology, water parameters, Farakka barrage, fish species shift

[Supplementary materials are available for this article. Go to the publisher's online edition of *Aquatic Ecosystem Health and Management* to view the free supplementary files.]

Introduction

Hooghly estuary, formed by Bhagirathi River, the first off-shoot of the River Ganga, lies approximately 21°31′ - 23°20′N and 87°45′ - 88°45′E in West Bengal, India. This longest (∼295 km) estuary of India was subjected to major human induced modification in 1975 through the construction of Farakka barrage to divert a sufficient portion of Ganga water through Bhagirathi for keeping Kolkata port functional. The Farakka barrage on Ganga feeds Bhagirathi-Hooghly River system through a 42 km long feeder canal, starting from Farakka joining River Bhagirathi at Jangipur. On its way to sea, Hooghly estuary receives water from five major tributaries viz. Jalangi, Churni, Damodar, Rupnarayana and Haldi. The estuary always attracted the attention of researchers, especially during the last hundred years, who have contributed significantly to the fields of physical, chemical (including pollution), biological, and other important aspects related to the estuarine ecology. Important reports in the field of hydrological parameters of selected centre(s) of the Hooghly estuary are both pre- and post-Farakka barrage period (Bose, 1956; Basu et al., 1970; Nandy et al., 1983; Chakrabarti and Chattopadhyay, 1989;

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Ghosh et al., 1989; Lal, 1990; Sen et al., 1994; Nath and De, 1996, 1998; Nath et al., 2004). Also, many published papers related to biology had a significant role in dealing with water parameters of a particular centre or stretch (Roy, 1955; Shetty et. al., 1963; Saha et al., 1975; Mukhopadhyay and Saigal, 1986; Chakraborty et al., 1995; Mukhopadhyay et al., 1995; Sinha et al., 1996, 1998; Das and Samanta, 2006, Nath and Banerjee, 2009; Choudhury and Pal, 2011). The hydrological influences due to increased freshwater inflow from Farakka barrage into the Hooghly estuary, induced significant changes in the salinity regime, water transparency, suspended sediments and nutrient load etc. causing major alterations in the estuarine conditions and the distribution and abundance of fish and other biotic organisms like plankton, benthos etc. Few studies have reported the impact of Farakka barrage on physico-chemical and biological aspects of the selected stretch or centres of the estuary and detailed spatio-temporal studies of the water parameters in the entire stretch of Hooghly estuary are lacking. A detailed study was conducted in the estuary during 2010–2012 to evaluate the spatio-temporal changes in selected physico-chemical parameters under the present hydrological regime. The variability of water parameters like salinity, temperature, transparency, pH, free CO_2, dissolved oxygen, specific conductivity, total alkalinity, total hardness, biochemical oxygen demand, dissolved nutrients like nitrate, phosphate and silicate are described in the present article. Discussions have also been made on the impact of changed hydrological regimes on plankton, fish and fisheries of Hooghly estuary.

Material and Methods

Surveys were performed at eleven selected sampling centers during 2010–2011 and twelve sampling centers (Nischintapur, a gradient zone sampling center was added) during 2011–2012 in pre-monsoon, monsoon and post-monsoon to understand the present ecological status of Hooghly estuary and its spatio-temporal variation (Figure 1). Water samples were collected at peak high tide (flood tide) and peak low tide (ebb tide) from the surface and bottom. Analysis of water parameters was performed using standard methods (APHA, 1998). About a six hour tidal cycle was observed at Fraserganj, a sea-mouth sampling centre, whereas at Dakhineswar (Kolkata City sampling centre), flood tide was about 4 h and ebb tide was about 8 h.

Data on biotic communities viz. plankton, fish and fisheries in pre- and post-Farakka barrage period was collected from published literature and analyzed based on salinity distribution in pre- and post-Farakka barrage period to understand impact of salinity on fish and fisheries.

For each parameter, one-way analysis of variance (ANOVA) was conducted using SAS software to examine statistical significance of data across sites, zones and seasons. Hierarchical clustering techniques using Primer software was employed to understand present zonation in Hooghly estuary.

Results and Discussions

List of sampling centres in Hooghly estuary, their latitude, longitude, distance from sea, and river width are given in Table S1. Data generated on selected parameters in sampling stations of Hooghly estuary during 2010–2012 are analyzed to understand spatio-temporal changes which are described below. Graphs are plotted using average data of four values collected in a station in a particular day i.e. high tide surface, high tide bottom, low tide surface and low tide bottom. Salinity related parameters are reported to vary significantly between spring tide and neap tide especially at marine zone and gradient zone sampling centres (Fraserganj to Diamond Harbour) (Nath and De, 1996, 1998). Also, diurnal variation of those parameters is also significant on many occasions (Basu and Ghosh, 1970). Average data along with standard deviation are presented here for all the parameters to explain the change between observations. Selected previous published data of both pre- and post-Farakka barrage period are also considered for discussion to understand time scale changes and impact of human induced modification.

Water depth

Higher water depth (14–16 m) was recorded during our study at Diamond Harbour, probably due to the impact of a tributary, River Rupnarayana, just upstream of the sampling centre (Figures S1 and S2 in the online supplemental information). Low water depth at Kadwip and Fraserganj in marine zone indicated that the significant part of estuary mouth is shallow in nature due to sedimentation. Due to

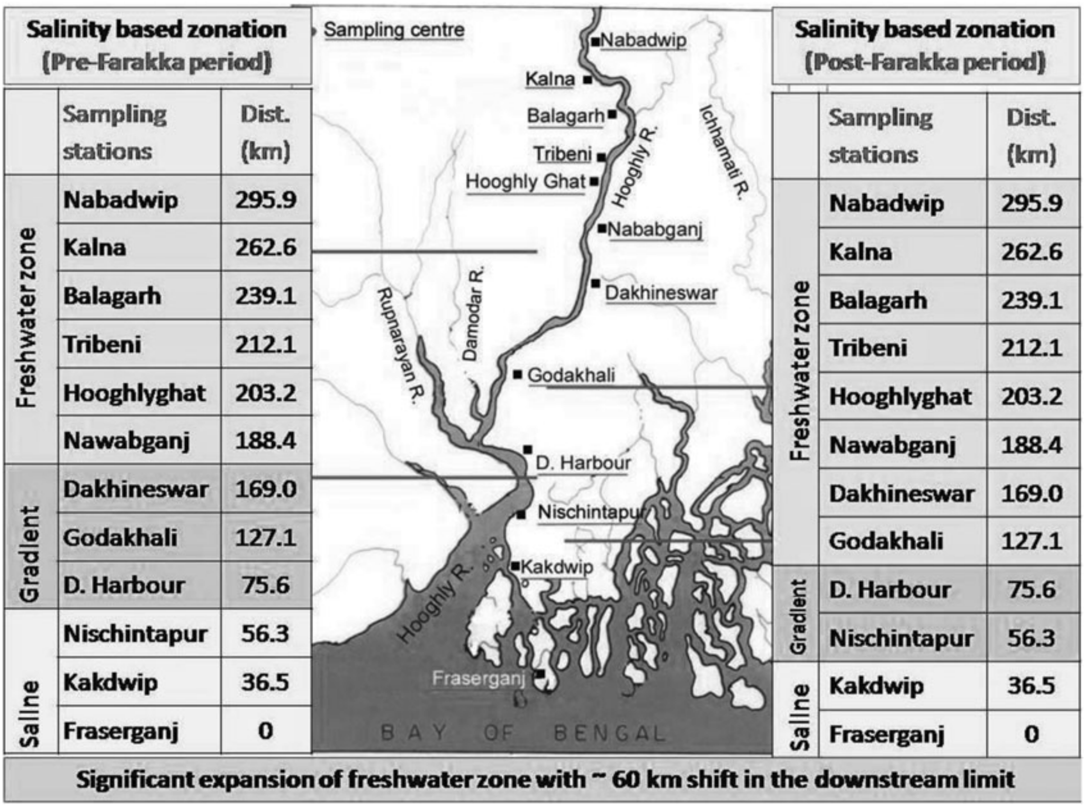

Figure 1. Salinity based zonation of Hooghly estuary (pre- and post-Farakka barrage period).

semi-diurnal tidal rhythm, up to 3–4 m variation in river depth is quite common especially in gradient and marine zone sampling centres in Hooghly estuary. River depth is cited as having an important role in migration of *Tenualosa ilisha* from sea through the estuarine corridor to river for breeding (Bhaumik et al., 2011). During the early part of twentieth century, Hora (1943) reported severe scarcity of freshwater discharge through the river with evidence of 'a foot depth' of water in parts of Hooghly during low tide. Higher freshwater discharge through feeder canal in post-Farakka period increased the water depth of Hooghly estuary significantly. The same locations as indicated by Hora (1943) are now retaining about 6–8 m throughout the year (Figures S1 and S2).

Water temperature

During our study in 2010–2011, water temperature varied in the range of 17.5°C at Dakhineswar during post-monsoon and 32.6°C at Tribeni during pre-monsoon (Figure S3). During 2011–2012, slightly higher temperatures were recorded with 18.6°C at Nawabganj during pre-monsoon and 36.6°C at the same place during post-monsoon (Figure S4). Previous monthly studies in Hooghly estuary revealed bimodal variation of water temperature with major peak during Mar-June and minor peak during Sepember–October (Lal, 1990). Absence of vertical thermal stratification in Hooghly estuary was attributed to characteristic morphology of the river and the vigorous tidal mixing. Nath (1998) recorded higher temperature in gradient zone as compared to freshwater and marine zone which was attributed to higher turbidity of the gradient zone. Water temperature is known to control the distribution of fishes and other aquatic organisms. Warm water fishes seemed to have moved to cold water region, a phenomenon that was cited as evidence for global warming. For example, in River Ganga, *Glossogobius giuris* and *Xenentodon cancila* shifted to colder stretch due to climate change (Vass et al., 2009). Temperature appears to influence the time of occurrence of different phytoplankters in Hooghly estuary as reported by Roy (1955).

Transparency/turbidity

During 2010–2011, pre-monsoon and monsoon sampling indicated high turbidity of water with Sechhi depth at less than 20 cm in most sites; whereas during post-monsoon improvement in water transparency was noticed, especially in freshwater zone and at Fraserganj in estuary mouth (Figures S5 and S6). Similar higher transparency during post-monsoon i.e. winter months was recorded by earlier workers also (Gopalkrishnan, 1971; Nath, 1998). During post-monsoon, transparency of gradient zone sampling centres like Diamond Harbour and Nischintapur was lower as compared to freshwater or marine zone. Similar observation of lower transparency in gradient zone was reported by Nath (1998).Transparency/turbidity exerts influence on prey-predator relationship of various groups of fishes, thereby influencing the fish species assemblage structure in natural aquatic ecosystems. Turbidity appeared to be inversely correlated with phytoplankton abundance in Hooghly estuary as reported by Roy (1955). Hooghly estuary is predominantly turbid almost in all seasons, due to the nature of bottom sediment formed mainly by deposition of suspended silt carried by the river runoff from large catchment areas and also due to the influence of strong tidal action.

Water pH

Water pH was consistently alkaline in nature in Hooghly estuary during our studies ranging from 7.5 to 8.8, indicative of being congenial for survival and growth of aquatic organism (Figures S7 and S8). Hooghly estuary was known to provide a good buffering environment by earlier workers (Nandy et al., 1983). The freshwater stretch showed higher pH during post-monsoon marking a relatively stable environment that promoted higher photosynthetic rate and thereby higher pH. Similar higher pH was reported in freshwater zone of the Hooghly estuary by Nath (1998). Previous reports also highlighted about constant alkaline environment of Hooghly estuary (Bose, 1956; Ray, 1981; Lal, 1990; Nath, 1998). Lal (1990) was unable to find any impact of Farakka barrage on water pH of Hooghly estuary during post-Farakka barrage period.

Free CO_2

Trend of free CO_2 was similar in both the years with higher values during monsoon and mostly absent during post-monsoon (Figures S9 and S10). Absence of free CO_2 in post-monsoon during both the years signifies the relatively stable environment for increased phytoplankton activity and thereby utilization of free CO_2 from river water. On the other hand, free CO_2 was mostly present at all the sampling stations during monsoon. Overall, city stretch of Nawabganj to Diamond Harbour observed higher free CO_2 as compared to other zones showing the impact of city effluents on Hooghly estuary. Nath (1998) recorded higher free CO_2 in marine zone as compared to gradient or freshwater zone in Hooghly estuary, contrary to our observation.

Dissolved oxygen

During our study, dissolved oxygen of >5 mg l^{-1} was recorded in most of the occasions in Hooghly estuary to support survival and growth of aquatic biota (Figure S11 and S12). Significant improvement of dissolved oxygen (4.7–10.6 mg l^{-1}) in Hooghly estuary during post-Farakka barrage period was mentioned by Nandy et al. (1983) as compared to that in pre-Farakka barrage period (3.4–5.1 mg l^{-1}) as reported by Bose (1956). Higher dissolved oxygen (8.5–11.5 mg l^{-1}) in post-Farakka barrage period as compared to pre-Farakka barrage period was also observed by Lal (1990).

This may be attributed to high flow regime and large volume of freshwater discharge sufficient to offset the impact of anoxic sewage loading from cities and towns along its course. Violent tidal flow and mixing of large volume of water due to wind and wave action may have induced sufficient dissolved oxygen in Hooghly estuary. Post-monsoon was characterized by significantly higher dissolved oxygen especially in the freshwater zone. Similar observation of higher dissolved oxygen in post-monsoon was reported by Kundu et al. (1996). Oxygen deficiency in Hooghly estuary during monsoon was reported by Ghosh et al. (1991). Lower dissolved oxygen was also recorded during monsoon. Higher dissolved oxygen was recorded in freshwater zone as compared to gradient or marine zones during our study. Similar observation of higher dissolved oxygen in freshwater zone was reported by Nath (1998).

Specific conductivity (μS cm^{-1})

During our study, freshwater zone was characterized by significantly higher specific conductivity during post-monsoon in both the years as compared to that in pre-monsoon and monsoon (Figures S13 and S14). Higher freshwater discharge during monsoon reduced specific conductivity significantly in the entire estuary. During 2010–11, recorded specific conductivity range in Hooghly estuary was 177–40,000 μS cm^{-1}, whereas slightly higher range of 205–43,300 μS cm^{-1} was recorded during 2011–2012. Specific conductivity, an indicator of dissolved ions in water, signifies the mixing process influenced by tides and the magnitude of intrusion of saline water vis-a-vis freshwater influx into the estuary. Reduction of specific conductivity of water with monsoon rain was reported in large Indian rivers like R. Brahmaputra (Manna and Sarkar, 2008). Nandy et al. (1983) reported a sp. conductivity range of 143–43,538 μS cm^{-1} in Hooghly estuary. Similar specific conductivity value of 40,400 μS cm^{-1} was reported by Nath (1998) from Fraserganj.

Total alkalinity

Lower range of alkalinity (66–140 mg l^{-1} during 2010–2011 and 80–174 mg l^{-1} in 2011–2012) was recorded during our study in Hooghly estuary (Figures S15 and S16). As in our observation, Nath (1998) noted higher total alkalinity in freshwater and gradient zone and recorded a range of 103–139 mg l^{-1}. As salinity increased, total alkalinity was observed to decrease (Ray, 1981). Post-monsoon was characterized by significantly higher total alkalinity values especially in freshwater and gradient zones in our study. Before construction of Farakka barrage, Basu (1965) reported a total alkalinity range of 176–232 mg l^{-1} in Hooghly estuary. A significant decrease in total alkalinity in post-Farakka barrage period (40–195 mg l^{-1}) was reported by Nandy et al. (1983) as compared to that in pre-Farakka barrage period (102–357 mg l^{-1}) as reported by Bose (1956). Lal (1990) also noted similar results during post-Farakka barrage period (75.85–146.66 mg l^{-1}).

Total hardness

A wide range of 60–5000 mg l^{-1} of total hardness during 2010–2011 and 70–5300 mg l^{-1} in 2011–2012 was recorded during our study in Hooghly estuary (Figures S17 and S18). Hardness of estuarine waters is the result of the mixing between hard saline water from sea and softer freshwater discharge from upstream. The measured values of hardness marked a sharp increase in gradient and marine zones from the values registered in the freshwater zone. Pre-Farakka status of total hardness of Hooghly estuary was not available in the literature. However, post-Farakka scenario of total hardness along with calcium and magnesium was reported by Nath (1998) and Nath et al. (2004). Calcium–magnesium ratio was observed to be reversed, then progressing from freshwater to marine zone and may also be used to understand salinity pattern of Hooghly estuary.

Salinity

Significantly different values of salinities are generally observed at gradient and marine zone sampling centres between flood tide and ebb tide in a single day (Basu and Ghosh, 1970). Hence, graphs of spatio-temporal variation of salinity observed during 2010–2012 were plotted using mean salinity value along with standard deviation (Figures 2 and 3). Salinity is the most important parameter effectively controlling distribution of fishes and other aquatic organism in Hooghly estuary. Based on salinity, Hooghly estuary was demarcated into zones both in pre- and post-Farakka barrage period by researchers. During pre-Farakka barrage period, due to lack of freshwater discharge, freshwater zone was small, stretching about 110 km from Nabadwip to Nawabganj-Barrackpore. A salinity value 0.004–0.20 ppt (sometimes even up to 1.16 ppt) was recorded at Barrackpore by David (1954) during pre-Farakka barrage period. However, increased freshwater inflow by water diversion through Farakka barrage changed the entire salinity scenario of the Hooghly estuary. Similar range of salinity that was observed by David (1954) at Barrackpore–Nawabganj region may now be found beyond Godakhali–Uluberia region, about 60 km downstream. Nandy et al. (1983) suggested the need for redefining of zones in Hooghly estuary considering the effect of Farakka barrage discharge. Lal (1990) mentioned about 45 km shifting of freshwater zone limit from Konnagar (22°41′58″N, 88°21′41″E) to Uluberia (22°28′02″N, 88°07′10″E) in his study of the impact of Farakka barrage freshwater discharge.

Again, there are difference of salinity between spring tide and neap tide in a lunar cycle of 15 days. An intensive study was conducted by Nath and De (1998) at Falta (a gradient zone sampling centre, 80 km from sea mouth, between Godakhali and

Table 1. Salinity (ppt) of selected sampling stations in pre- and post-Farakka barrage period.

Distance (km)	0	36.5	56.3	75.6	95.7	127.1	169	188.4	212.1	295.9	
Year of study	Fraserganj	Kakdwip	Kulpi/ Nischintapur	Diamond Harbour	Falta/ Geokhali	Uluberia/ Godakhali	Calcutta/ Dakhineswar	Barrackpore/ Nawabganj	Tribeni	Nabadwip	Reference
Pre-Farakka barrage period											
	Marine zone			Gradient zone				Freshwater zone			
1953–55	—	1.6–30		23	0.5–19	0.5–19	0.5–5	Trace-2	Trace	Trace	Bose, 1956
1960–61	—	1.5–32.8		—	20.2	12.0	—	0.2	—	—	Shetty et al., 1963
—	—	—	—	—	—	7.0	1.0	0.2	0.2	—	Basu et al., 1970
Farakka barrage commissioning on 21 April 1975											
Post-Farakka barrage period											
	Marine zone		Gradient zone			Freshwater zone					
1975–76		3.2–29.24		—	10.21	0.379	—	Traces	—	—	Nandy et al., 1983
1976–77		2.5–18.0		—	0.975	0.118	—	Traces	—	—	
1986–87		18.6			3.84			0.04		0.03	Chakrabarti and Chattopadhyay, 1989
1986	19.79–28.57	—		0.02–1.85							Lal, 1990
1993–94				0.18–4.08						0.01–0.06	Chakraborty et al., 1995
1993–97	21.1–25.4			0.15–1.42	0.06–0.13					0.04–0.06	Nath, 1998; Nath and De, 1998
2010–11	17.54–28.07	5.43–25.54	—	0.38–1.60	—	0.05–0.06	0.06	0.05	0.05	0.05	Present study
2011–12	9.12–30.38	0.77–15.09	0.19–8.71	0.19–2.86	—	0.05–0.07	0.06	0.05	0.05	0.05	Present study

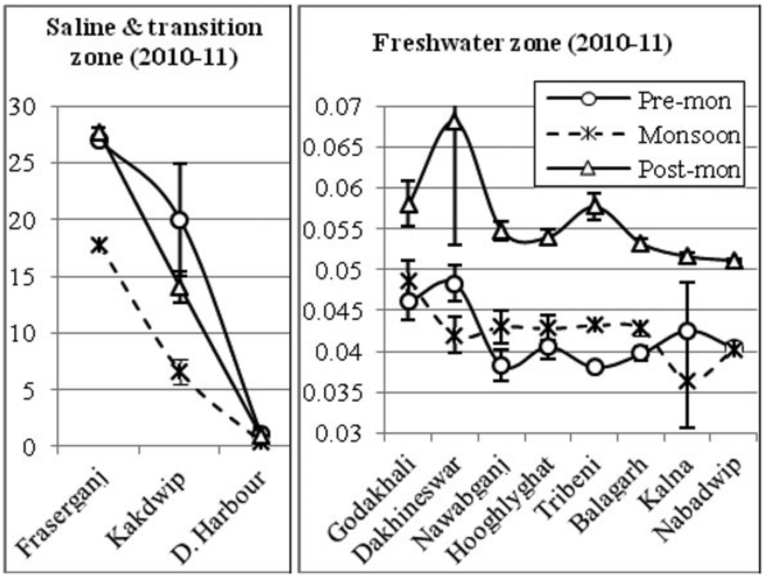

Figure 2. Salinity (ppt) during 2010–2011.

Diamond Harbour) to see the impact of spring tide (bore tide) and neap tide on different physico-chemical parameters. Previous studies in Hooghly estuary indicated only one salinity peak during pre-monsoon months of March–June both in pre- and post-Farakka barrage period (Lal, 1990). Mukhopadhyay and Saigal (1986) demonstrated that the distribution of a diatom, *Coscinodiscus granii* could serve as a bioindicator for trends in the salinity regime in Hooghly estuary. Change in zonation based on salinity in pre- and post-Farakka barrage period are given in Table 1.

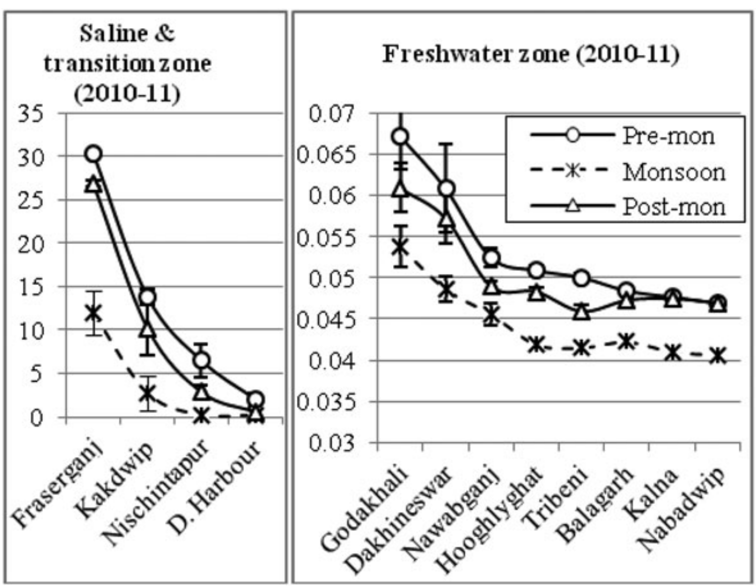

Figure 3. Salinity (ppt) during 2011–2012.

Impact of monsoon flow on salinity based zonation

Hierarchical Clustering techniques were employed for grouping of sites based on the hydrochemical distance measure. Higher monsoon inflow decreased salinity to a great extent with a drastic alternation in established zonation. The gradient zone tended to develop more or less similar characteristics to that of freshwater zone (Figures 4 and 5). As a result many freshwater fishes were observed to shift downwards during monsoon months.

Nutrients

All three available nutrients viz. nitrate, phosphate and silicate showed a decreasing trend from freshwater to gradient to marine zones, indicating higher nutrient utilization rate in lower estuary i.e. gradient and marine zone. Similar decreasing trend of all nutrients (nitrate, phosphate and silicate) from freshwater to marine zone was observed by Nath (1998) during his study in Hooghly estuary. Sulphate, an important nutrient in saline zone of the estuary, however, showed increasing trend from freshwater to marine zone, quite similar to the salinity gradient.

Nitrate-N

Our study recorded a similar range of 0.03–0.49 mg l^{-1} with higher values in freshwater zone during monsoon season (Figures S20 and S21). Lal (1990) reported rich nutrient status in Hooghly estuary with 0.05–0.25 mg l^{-1} NO_3-N. Similar higher nitrate in Hooghly estuary during monsoon was reported by Kundu et al. (1996). The nitrate distribution pattern indicated possible allochthonus input source in freshwater zone along with surface run-off especially during monsoon months.

Phosphate-P

In our study in Hooghly estuary, phosphate also showed higher values during monsoon in most occasions, signifying its loading through surface run-off (Figures S22 and S23). Significantly higher PO_4-P was recorded at Diamond Harbour and Nischintapur during monsoon. This may be due to loading through River Rupnarayana, the tributary joined just above Diamond Harbour sampling point. Phosphate is often considered to be the most critical parameter controlling aquatic productivity. However, due to its rapid utilization in a tropical country like India, it is very difficult to understand the distribution or availability of this important nutrient. Higher phosphate-P (0.38–0.56 mg l^{-1}) was reported by Lal (1990) in Hooghly estuary.

Silicate-silica

Decreasing trend of silicate from freshwater to marine zone was observed during our study (Figure S24 and S25). Significantly low silicate-silica was recorded in some occasions especially during pre-monsoon period. In general, inverse relationship exists between salinity and silicate in estuaries indicating that silicate is mainly controlled by freshwater discharge. Similar decreasing trend of silicate from freshwater zone to marine zone of Hooghly estuary was reported by Nandy et al. (1983). Sarma et al. (1993) observed highly significant inverse correlation of silicate and salinity in Godavari River estuary.

Statistical analysis of hydrological data

Sampling sites were divided into zones based on salinity during non-monsoon months (Figure 4) to examine statistical significance of data across zones. Results of ANOVA are given in Table 2. As expected, water temperature and dissolved gases like oxygen and free CO_2 significantly vary across seasons. Water depth varied significantly across sites and zones. Significant variation in transparency was observed across seasons. Total alkalinity also varied significantly across seasons. Salinity and its related parameters like specific conductivity and total hardness significantly vary across zones. Interestingly, available nutrients like nitrate, phosphate and silicate were observed to vary significantly across seasons and zones.

Changed hydrological regime vis-à-vis distribution and abundance of aquatic communities

Hooghly estuary has undergone alterations with regard to freshwater discharge (Parua, 2010) vis-à-vis salinity and its associated aquatic communities including fish species distribution during the last few centuries. In the early part of 19th century, Kolkata region was basically freshwater in nature as evidenced by fish species recorded from this region of Hooghly River by Hamilton (1822). But,

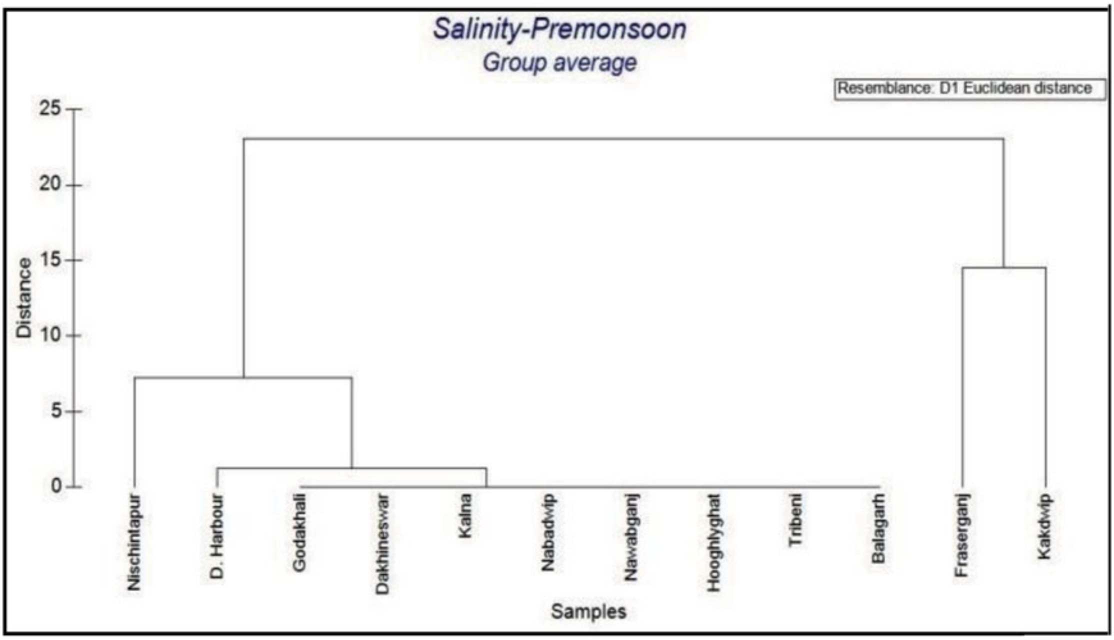

Figure 4. Distinct cluster of freshwater, gradient and marine zone during pre-monsoon. (Color figure available online.)

due to rapid siltation and severely reduced freshwater inflow during early part of the 20th century, the Calcutta region was totally brackish water in nature as indicated in the publications of Hora (1943) and Prashad (1937) and others. Hora (1943) mentioned about a probable bottom salt wedge in Hooghly estuary that may be responsible for supporting of euryhaline fish species in zone I (Barrackpore region) in pre-Farakka barrage period. However, intensive studies by David (1954) and Ghosh (2008) around Barrackpore area provide an insight in understanding the impact of Farakka barrage discharge. Just before the start of Farakka barrage, Menon et al. (1972) predicted the replacement of estuarine forms by freshwater forms especially in zone I (Nabadwip to Barrackpore) due to discharge from Farakka barrage. Shifting of salinity based zonation can also be verified by the availability of fish species. Increased freshwater inflow changed fish assemblage pattern to a great extent in the entire estuary, especially in freshwater region resulted in shifting of saline-water fish species closer to mouth. Previous studies are very few to delineate large scale changes of fish availability or distribution pattern in entire Hooghly estuary. Detailed stationwise distribution of fish species is not available in entire stretch in pre- or post-Farakka barrage period. Only zone wise fish species availability is reported from time to time. Hence, it is difficult to understand the distance of shifting of a particular fish species in Hooghly estuary due to Farakka barrage discharge. Many euryhaline fish species which were recorded in upper estuarine zone (Nabadwip to Barrackpore) in pre-Farakka barrage period have now shifted downwards to an extent of at least 60–100 km. Some species like *Polynemus paradiseus* are still encountered in freshwater zone but with highly reduced abundance. Table S2 and S3 depicts the post-Farakka barrage period production of selected euryhaline fish as compared to pre-Farakka period to understand the impact of Farakka barrage. From a study in 12 km stretch in Barrackpore-Nawabganj area, Ghosh (2008) reported that as many as 29 fish species out of 82 fish species reported by David (1954) from the same area of Barrackpore-Nawabganj stretch were affected by changed hydrological regime. Just before initiation of Farakka barrage, Menon et al. (1972) prepared a list of 57 estuarine fish species predictably most likely to be disturbed due to altered hydrological regime with higher freshwater inflow. Again, in changed hydrological regime, many of those euryhaline species with distinct decline on catch in zone I and II, tended to increase significantly in the marine zone catch (Nandy et al., 1983). For example, production of *Polynemus paradiseus*, a

Table 2. Significance of different hydrological parameters of Hooghly estuary.

Water parameters	Across seasons R-Square value	Across seasons p-value	Across zones R-Square value	Across zones p-value	Across sites R-Square value	Across sites p-value
Water temperature	0.929	<0.001*	0.002	0.932	0.008	0.999
Water depth	0.047	0.202	0.774	<0.001*	0.839	<0.001*
Transparency	0.328	<0.001*	0.050	0.183	0.096	0.858
Sp. conductivity	0.023	0.472	0.756	<0.001*	0.879	<0.001*
Water pH	0.032	0.339	0.011	0.687	0.034	0.998
Free CO_2	0.334	<0.001*	0.041	0.254	0.185	0.321
Dissolved oxygen	0.667	<0.001*	0.047	0.208	0.079	0.930
Total alkalinity	0.663	<0.001*	0.041	0.254	0.083	0.913
Total hardness	0.033	0.334	0.690	<0.001*	0.824	<0.001*
Salinity	0.022	0.481	0.759	<0.001*	0.880	<0.001*
Available nitrate	0.229	<0.001*	0.344	<0.001*	0.441	<0.001*
Available phosphate	0.196	<0.001*	0.208	<0.001*	0.311	0.018
Available silicate	0.270	<0.001*	0.146	0.006*	0.176	0.372

*Significant (p value < 0.01).

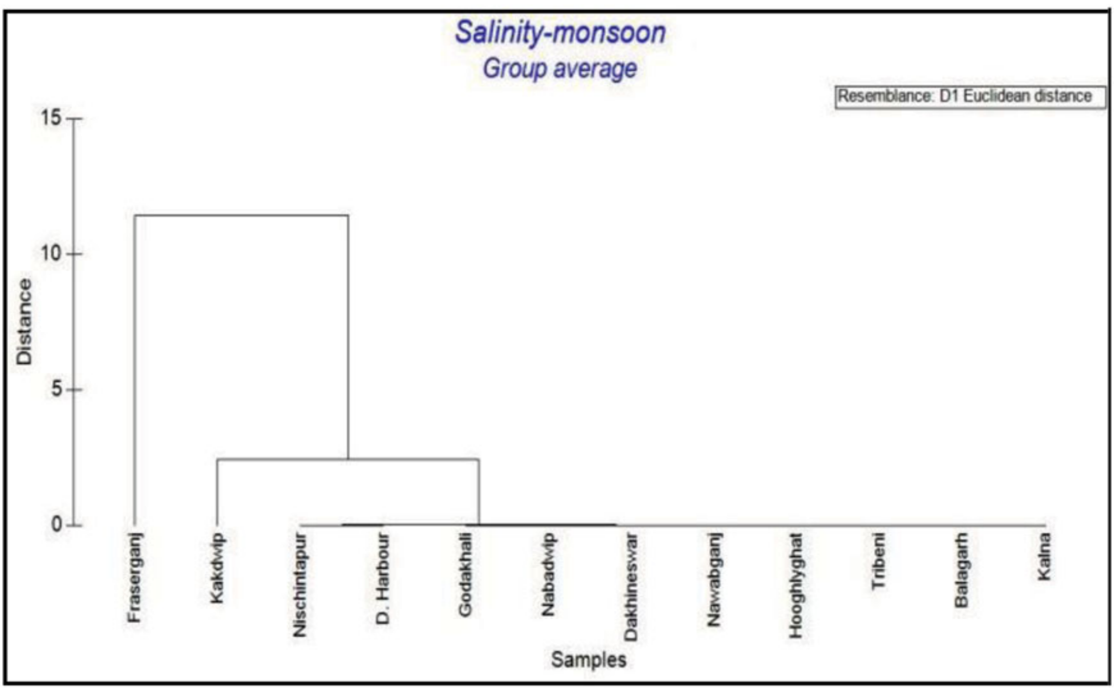

Figure 5. Monsoon inflow to club gradient zone sampling centres with freshwater zone. (Color figure available online.)

prized fish in Hooghly estuary, though decreased in zone I (from 5.7 t in 1966–1974 to 3.8 t 1984–1994), increased significantly in gradient and marine zones (Mukhopadhyay et al., 1995).

Some other euryhaline fish species which seem to have disappeared from zone I are *Plotosus cannius*, *Mystus gulio, Thryssa* sp. (hamiltonii, purava), *Caranx* sp. etc. as reported by David (1954) from Barrackpore region in pre-Farakka barrage period. Many freshwater fish species which were reported only from zone I during pre-Farakka barrage period are now available in much lower areas of the estuary. For example, species like *Apocryptes bato*, *Goniolosa manminna*, *Labeo* sp., *Notopterus notopterus*, *Nundus nandus*, *Puntius* sp., etc. are available in Godakhali-Uluberia region signifying at least 60 km shifting of freshwater zone towards estuary mouth. A detailed account of distribution of fish species in different sampling centres in freshwater zone of Hooghly estuary is described by Roshith et al. (submitted).

Change in salinity regime has a visible impact on distribution and abundance of aquatic communities like plankton. Plankton population apparently improved 3–5 times immediately after construction of Farakka barrage as reported by Nandy et al. (1983). Gopalakrishnan (1971) reported on the ubiquity of brackishwater diatom, *Coscinodiscus granii* in entire Hooghly estuary during pre-Farakka barrage period, whereas their distribution was significantly shifted downstream during post-Farakka barrage period (Mukhopadhyay and Saigal, 1986).

Conclusions

This study builds up a clear scenario about the present ecosystem health status of the entire Hooghly estuary with respect to fisheries under the present hydrological regime. Distribution of aquatic organisms in the estuary may be better analyzed and interpreted based on the vital information from the present study. Knowledge about the time scale changes of water quality, especially salinity, in the entire Hooghly estuary and its associated fishes will be helpful in formulating future management strategies for this important estuary.

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