Channel Controlled Foraminiferal Distribution off Bakkhali, West Bengal, India

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ABSTRACT: Study area is situated 8 km south of the Bakkhali Island, west Bengal of India and its subaqueous environment influenced by the fluvial processes such as Hooghly River in west and its distributary like Muri Ganga in the centre and Saptamukhi River in the east. To understand the submarine behavior of these channels and associated meiobenthos, total of 28 sediment samples have been studied in detail. The study reveal that a total of fifteen species of recent benthic foraminifera belonging to 13 genera under 11 families were present and their distribution mainly controlled by channel morphology and sediment character. Based on the distribution of these benthic foraminiferal species, two assemblages have been identified. First assemblage, observed within the Hooghly and Muri Ganga channel, where salinity is comparatively low and sediment is mainly dominated by silt and clay. The most dominating benthic foraminifers of this assemblage are *Ammobaculites agglutinans, Cribrostomoides jeffreysii* and *Asterorotalia trispinosa.* Whereas, second assemblage mainly comprise of *A. trispinosa, Ammonia beccarii, Asterorotalia* spp., *Elphidium excavatum, Elphidium crispum* and *Ammonia tepida* noticed over the sand bars and adjoining shallow area.

Keywords: channel morphology, Muri Ganga, Hooghly, sand bar

INTRODUCTION

Delta is considered as the most significant depositional regime with continuously modifying environmental setup by the fluvial and tidal activity that control subaqueous conditions mainly salinity, temperature, dissolved oxygen and nature of the sea bed sediment (Murray, 1991; Sen Gupta, 1999; Chakrabarti, 2005; Gautam, 2010; Bianchi, 2013). Similarly, east coast of India have unique geomorphological and ecological setup with varied range of meiobenthos. These meiobenthos were studied extensively especially for their taxonomic and ecology in the Indian estuaries by Rao and Rao, 1974; Reddy and Rao, 1984; Chaudhuri and Choudhuri, 1994; Jayaraju and Reddy, 1995; Kathal, 2002; Hameed and Achyuthan, 2011; Susanta and Tridip, 2018. As like, other estuary along the east coast of India, Sundarban delta receives inadequate attention even after having larger scope of benthic foraminiferal variation particularly off Bakkhali. Previous studies were mainly focused on the marsh, mud flat and tidal channels in the inner part of the delta (Sabyasachi *et al.,* 1996; Gautam, 2010; Ghosh *et al.,* 2014; Tripathi *et al.,* 2017a; 2017b; Tripathi *et al.*, 2018). However, no such study is undertaken in the open sea especially in the submarine channels off Bakkhali. Keeping in view, the present study has been carried out to understand the geomorphic behaviour of the submarine channels and its associated ecological scenario of the meiobenthos.

METHODS

The study area is situated off Bakkhali between the latitude 21°27'; 21°33'N and longitude 88°10'; 88°20' E in West Bengal, India. There are three major channels flowing north-south direction within the study area. The Western boundary is marked by river Hooghly, the eastern boundary demarcated as river Saptamukhi and Muri Ganga River passing through the central part of the area having orientation of NNW-SSE. All these channels carry fresh water from the main trunk channel (Resmi *et al.,* 2017). It is also seen that the Muri Ganga River which used to flow along western part of Jambudwip has changed its course gradually towards east by the year 1990 as compared to year 1975 (Sengupta *et al.,* 2016). By year 2000, the incision has become so deep that much of the western boundary of Frasergunj was affected and ultimately this river took a NNE-SSW turn after merging with the Saptamukhi.

Bathymetric survey carried out in these submarine areas onboard a mechanized boat with portable Echo sounder and DGPS. Van Veen grab sampler and Niskin water sampler were used for collecting 27 grab sediment samples and 11 water samples (Figure 1). Physical parameters of each samples were measured

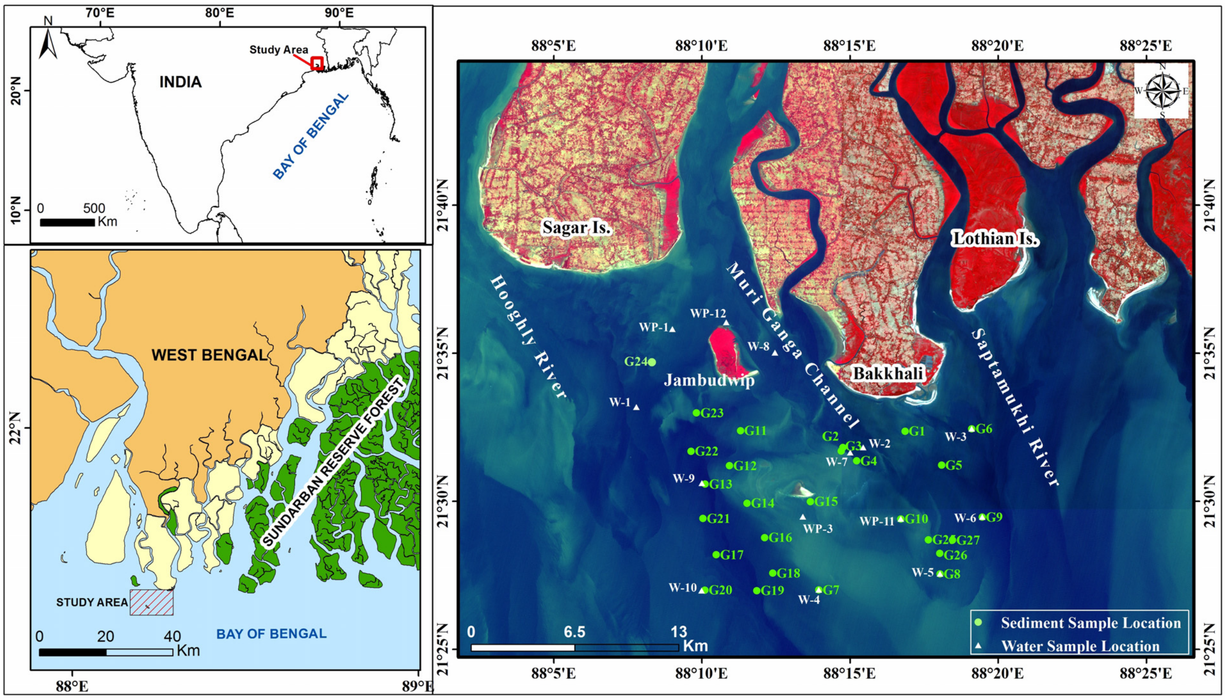

Figure 1. Sample location map of the survey area, off Bakkhali, Sundarban.

onboard such salinity, conductivity, pH and temperature by using chemical analytical kit Multiline F/SET-3. Simultaneously, few selected sediment samples of top 2 cm were than treated with Rose Bengal solution for live foraminiferal distribution. Other studied such as foraminifera and granulometric studies were performed at the laboratory.

For study of foraminifera, 20 g sediment samples were dried and these dry sediment samples were treated with 6% H_2O_2 and allowed to be soaked for 24hrs and then these samples were wet sieved through 230 ASTM (E-11). The portion of washed residue was air dried and weighed for total coarse fraction weight. Later total fraction was taken for assessing the nature and occurrence of microfauna under stereo zoom microscope for detailed taxonomic characterization (Loeblich and Tappan, 1988; Murray, 2006). These microfaunas were picked up and kept individually in foraminiferal tray on the basis of their shape, test composition and apertural opening. Simultaneously, granulometric analysis was performed following the standard operating procedures developed for granulometric study (Folk, 1966; Shepard, 1954).

RESULTS

The depositional environment in the study area is affected by the high rate of tidal energy influx and fluvial input. Channel in the western margin is offshore part of river Hooghly and eastern margin channel is marked as river Saptamukhi. However central part channel marked as river Muri Ganga. Average depth and width of this recorded channel is 5-10 m and 3-3.5 km respectively. The river Muri Ganga and Saptamukhi is separated by a narrow linear ridge-like feature trending NW-SE in the offshore region (Figure 2). The mid-channel shoal in the offshore region between the rivers Hooghly and Muri Ganga is almost flat and emerged above the water surface during the low tide time. The shoals are made of silt to coarse grained sand whereas the channel beds are covered by loose silty clay to clayey silt. During survey, samples were collected from these geomorphic domains for assessing the nature and occurrence of microfauna following the taxonomic characterization of Loeblich and Tappan (1988); Murray, 2006. A total of fifteen species of recent benthic foraminifera belonging to 13 genera and 11 families were identified that dominated by *A. agglutinans, C. jeffreysii, A. trispinosa, A. beccarii, E. crispum* and *A. tepida* (Table 1). It is also observed that 40% of the samples are devoid of benthic foraminifera. Based on the statistical count data, Simpson's Diversity Index (SDI) was measured taking in account the number of species present as well as the relative abundance of each species. As species richness and evenness increases diversity also increases, respectively. The value of SDI ranges from 0 to 1, where 1 represent infinite diversity and 0 represent no diversity. So SDI values for the sample stations range from 0 to 0.89 and for the whole area it was found to be 0.47.

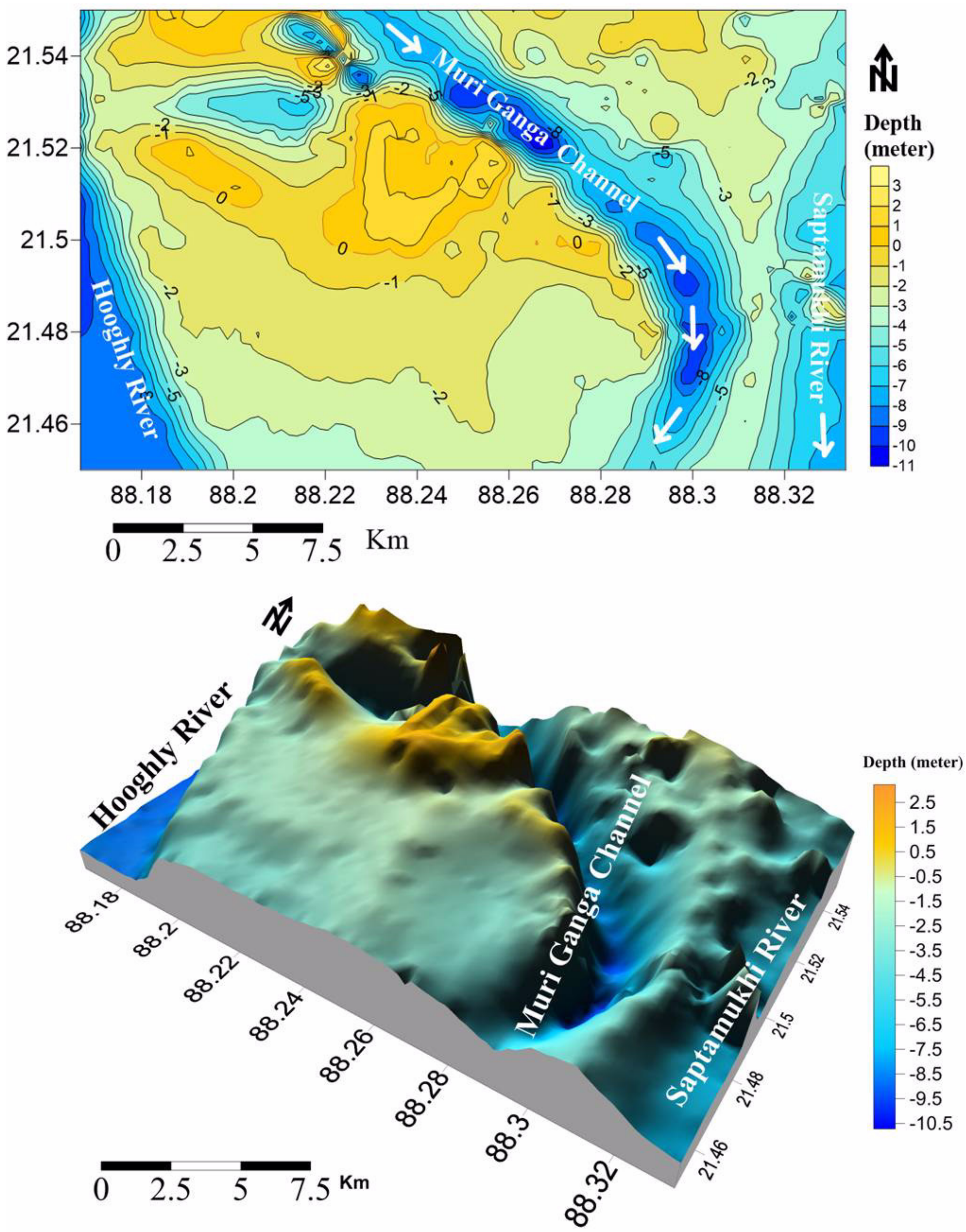

Figure 2. 2D and 3D Bathymetry contour map of the survey area, off Bakkhali, Sundarban.

The correlation coefficient matrix analysis was also performed along with the SDI in-order to understand the correlation between the different species of benthic foraminifera with physical parameters of sea water (salinity, conductivity and pH) and also with grain size (Table 2). In the correlation matrix, *A. tepida* shows a very strong positive correlation with *Elphidium* spp., *A. trispinosa*, *Pararotalia* spp., *Pseudononion*, *Triloculina* spp., and with clay. Moreover, *A. tepida* also showing moderate negative correlation with sand and at same time *A. trispinosa* is exhibiting strong significant positive correlation with *Pararotalia* spp., *Triloculina* spp., *A. beccarii, Elphidium* spp., and *Elphidium advenum*. *A. agglutinans* shows significant positive correlation with *C. jeffreysii, Cribononion* sp*., Elphidium* spp. *E. advenum, Triloculina* spp., and also with clay (Table 2). However, *E. advenum* is showing a strong positive correlation with *Triloculina* spp., *Nonion* spp., *Pararotalia* spp. and it also having moderate positive correlation with *C. jeffrevsii*, clay and silt. Further, *Cribononion* and *Nonion* spp., is showing very strong positive correlation with *C. jeffreysii*, *Pseudononion* and *A. agglutinans*. Temperature, salinity, conductivity and pH do not have any major effect over distribution of these benthic foraminifera present in the sediment. But close

Table 1. Percentage wise distribution of benthic foraminifera, off Bakkhali

Foraminifera & Ostracoda (%)	Sample No	G-01	G-02	G-03	G-04	G-05	G-06	G-07	G-08	G-09	G-10	G-11	G-12	G-13	G-14	G-15	G-16	G-17	G-18	G-19	G-20	G-21	G-22	G-23	G-24	G-25	G-26	G-27
	Water Depth	3.6	9	0	1	5.1	6.1	5.6	7.4	7.7	4.4	4.1	3.4	12	5.8	3.3	5.6	13	6.5	7.3	11.2	11	12	11	8	2.2	11	8.6
	Sediment Type	Fine sand				ZS	CZ	Fine sand										CZ	Fine sand		CZ	ZC	Fine sand				Silt	SZ
A.tepida		0	30	0	0	0	22	25	0	8	8	20	0	0	22	0	40	3	0	0	3	23	0	50	25	20	8	20
A. trispinosa		0	30	0	0	0	31	0	0	38	15	30	0	0	22	0	30	7	0	0	10	0	0	33	38	40	6	60
Elphidium spp.,		0	0	0	0	0	8	0	0	8	8	0	0	0	0	0	0	3	0	0	3	8	0	6	13	10	4	0
E. crispum		0	0	0	0	0	0	0	0	0	8	0	0	0	11	0	0	0	0	0	3	0	0	0	0	10	0	0
E. advenum		0	0	0	0	0	6	0	0	8	8	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	4	0
Pararotalia spp.,		0	20	0	0	0	11	0	0	15	15	20	0	0	11	0	30	0	0	0	3	0	0	0	0	0	0	20
A. beccarii		0	0	0	0	0	0	25	0	23	0	10	0	0	22	0	0	0	0	0	3	0	0	11	25	20	0	0
Nonion spp.		0	0	0	0	0	8	50	0	0	8	10	0	0	0	0	0	3	0	0	3	0	0	0	0	0	20	0
Pseudo Nonion		0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0
Triloculina spp .,		0	0	0	0	0	11	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammobaculites spp.,		0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	38	0	0	45	42	0	0	0	0	24	0
Cribononion spp.,		0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	10	0
Melonis spp.,		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
Cribrostomoides jeffreysii		0	0	0	0	0	0	0	0	0	8	0	0	0	11	0	0	14	0	0	10	15	0	0	0	0	25	0
Cibicides spp.,		0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
Planktic foraminifera		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	3	8	0	0	0	0	0	0
Ostrocods		0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CZ- Clayey Silt	ZS- Silty Sand	SZ- Sandy S	ZC- Silty Clay																									

Table 2. Correlation table showing relationship between benthic foraminifera and environmental conditions (sediments, pH, salinity, temperature).

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1	*A. tepida*	1																					
2	*A. trispinosa*	0.58	1																				
3	*Elphidium* spp.	0.87	0.61	1																			
4	*E. crispum*	0.13	0.43	0.28	1																		
5	*E. advenum*	0.41	0.61	0.57	-0.11	1																	
6	*Pararotalia* spp.	0.5	0.82	0.37	0.2	0.46	1																
7	*A. beccarri*	0.19	0.53	0.16	0.74	-0.1	0.36	1															
8	*Nonion* spp.	0.35	0.49	0.44	0.05	0.68	0.4	0	1														
9	*Pseudononion*	0.52	0.29	0.45	0.32	-0.15	0.44	0.32	0.19	1													
10	*Triloculina* spp.	0.53	0.7	0.54	-0.05	0.73	0.66	-0.11	0.38	-0.08	1												
11	*A. agglutinans*	0.45	0.2	0.67	0.39	0.17	0.08	0.11	0.34	0.68	-0.06	1											
12	*Cribononion* spp.	0.08	0.17	0.27	0.28	0.27	0.04	0.07	0.81	0.25	-0.07	0.5	1										
13	*Melonis* spp.	-0.01	0.07	0.16	-0.08	0.42	-0.1	-0.1	0.11	-0.07	-0.04	0.37	-0.06	1									
14	*C. jeffrevsii*	0.46	0.11	0.62	0.23	0.33	-0.03	0.02	0.62	0.47	-0.09	0.86	0.72	0.35	1								
15	*Cibicides* spp.	0.03	0.28	0.27	0.63	-0.1	0.24	0.29	0.18	0.57	-0.05	0.68	0.51	-0.04	0.38	1							
16	pH	0.11	0.09	0.06	0.02	0.05	0.12	0.05	0.1	0.07	0.04	0.04	0.06	-0.02	0.07	0	1						
17	Salinity	0.21	0.14	0.2	0.21	0.06	0.18	0.19	0.13	0.35	-0.02	0.32	0.09	0.17	0.29	0.16	0.66	1					
18	Conductivity	0.21	0.14	0.2	0.2	0.07	0.19	0.18	0.13	0.34	-0.02	0.31	0.09	0.16	0.28	0.15	0.69	1	1				
19	Temperature	0.13	0.19	0.21	0.1	0.18	0.24	-0.06	0.07	0.18	0.22	0.25	-0.01	0.22	0.13	0.19	-0.09	0.29	0.28	1			
20	Sand %	-0.59	-0.41	-0.77	-0.12	-0.59	-0.23	0.09	-0.64	-0.39	-0.36	-0.77	-0.53	-0.38	-0.79	-0.36	-0.13	-0.26	-0.26	-0.27	1		
21	Silt %	0.48	0.4	0.67	0.11	0.59	0.23	-0.1	0.68	0.31	0.35	0.68	0.59	0.34	0.74	0.36	0.14	0.23	0.23	0.24	-0.98	1	
22	Clay %	0.72	0.38	0.87	0.11	0.54	0.22	-0.08	0.49	0.49	0.35	0.84	0.37	0.43	0.81	0.33	0.1	0.29	0.29	0.28	-0.93	0.85	1

examination of the samples shows that *A. agglutinans, C. jeffreysii* and *Pseudononion* represent very moderate to low positive correlation with salinity and conductivity. Correlation between silt and clay fractions shows a very strong positive correlation with the benthic forams such as *A. agglutinans, C. jeffreysii, A. tepida* and *Elphidium* spp. However, sand shows a significantly negative relation with all the benthic foraminifers except *A. beccarii* (Table 2).

In support with correlation coefficient matrix analysis, principal component analysis (PCA) was also carried out to understand the relation between different foraminiferal species. Factor analysis generated a three factor model, which accounts for 66% of the total variance in the data. Factor-1 accounts for 39% of variance and Factor-2 and 3 accounts for about 13.5% of variance. Factor-1 vs Factor-3 analysis shows clear association of two assemblages (Group A and Group B). Group A represents benthic foraminifers such as *A. agglutinans, C. jeffreysii, Nonion* spp., *E. advenum* and *Cribononion* in the first assemblage. While second Group B dominated by *A. trispinosa*, *A. beccarii, Pararotalia* spp., *Pseudononion*, *Triloculina* spp., *A. tepida* and *E. crispum* (Figure 3). Group B have close

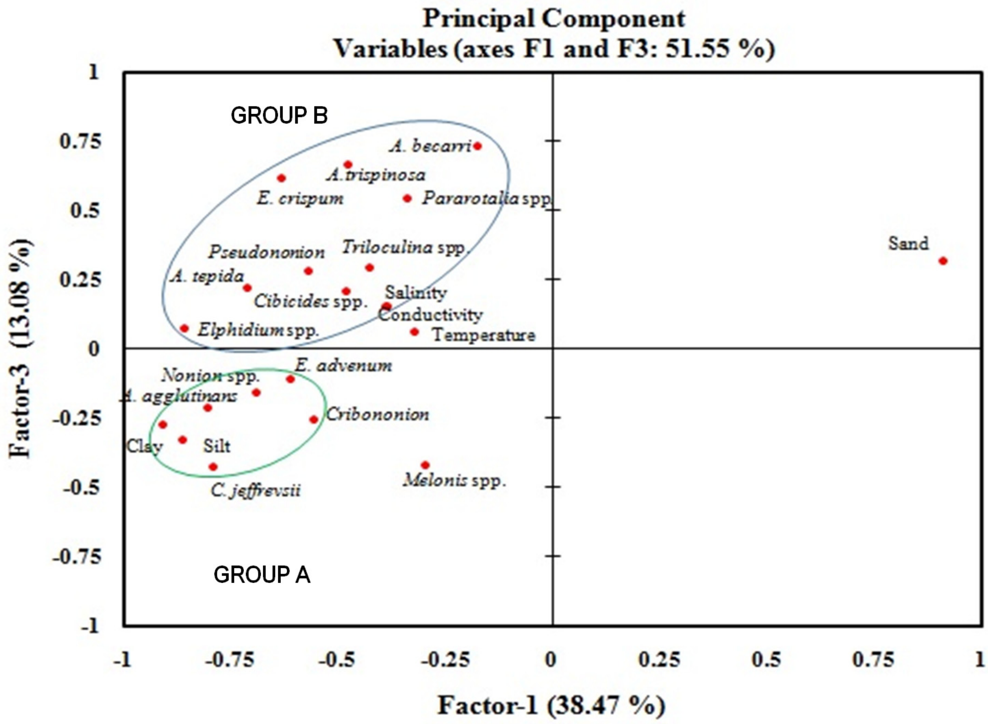

Figure 3. Principal component factor analysis representing two assemblages Group A and Group B, off Bakkhali, Sundarban.

association with salinity and conductivity compare to the Group A. Other component which controlling the distribution of benthic species has been discussed in detailed below.

Physical parameter of sea water

Seawater samples were also collected from 10 stations at different depths for detailed monitoring of the environmental parameter (Figure 1) such as temperature, salinity, conductivity and pH. The pH value in the study area varies from 8.3 to 8. 88 and having general NW-SE trend (Figure 4). The salinity in the area varies from 17.5 to 23.6‰ with an average of 20.67‰. In the channel part salinity shows a very low trend of around 17.5‰ within the Hooghly channel, (W-1, Figure 5) and around 18.1‰ at Muri Ganaga Channel (W-2, Figure 5). Vertical salinity gradient in most of the samples indicate an increase of salinity from surface to bottom by the factor of 0.5 ‰. Moreover, conductivity value varies from and 28.3 to 37.4 ms/cm (Figure 6) and their distribution pattern follow the general N-S trend of the major channels (Figure 6).

Sediment and associated foraminiferal distribution

Granulometric analysis of 27 grab sediment samples revealed that the study area is dominated by sand (70.37%), clayey silt (14.81%), silty sand (3.7%), sandy silt (3.7%), silt (3.7%), and silty clay (3.7%). Along with this, foraminiferal study was also performed, in which terrigenous content is dominating over the biogenic content. Here the terrigenous content varies from 98% to 100%. Within the biogenic content, benthic foraminifers are one of the major constituents over planktonic foraminifera and ostracods. Since, benthic foraminiferal assemblages provide the detailed ecology of bottom sediments and to understand this, a few sediment samples were treated with Rose Bengal solution. Study reveals that sediment is mainly dominated by living benthic foraminiferal species of around 50% to 70%. The observed living benthic foraminifers are *A. trispinosa*, *C. jeffreysii, A. agglutinans, A. tepida* and *Nonion* spp., (Plate I).

Based on the foraminiferal counts, two distinct assemblages have been identified (Figure 7). First assemblage Group A, observed within the Hooghly and Muri Ganga channel with the presence of. *A. agglutinans* and *C. jeffreysii* followed by *A. trispinosa* and *Nonion* spp., in the silty and clayey area. However, in the second assemblage Group B, *A. trispinosa, A. beccarii*, *Asterorotalia sp., E. crispum, Pararotalia* and *Triloculina* spp., are the most dominating species getting over the shallower part where silt and sand as a major component. Apart from this, few other forms which are common in both the assemblages are *A. tepida, Elphidium* spp., *E. excavatum, E. advenum*, *Nonion* spp., *Pseudononion* spp., *Melonis* spp., and planktonic foraminifera along with some ostracods (Plate I).

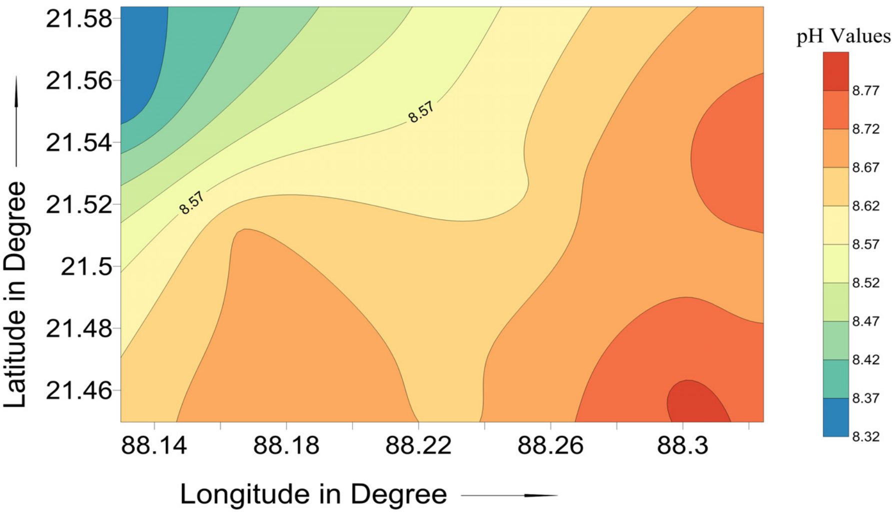

Figure 4. Spatial variation of pH values in water samples.

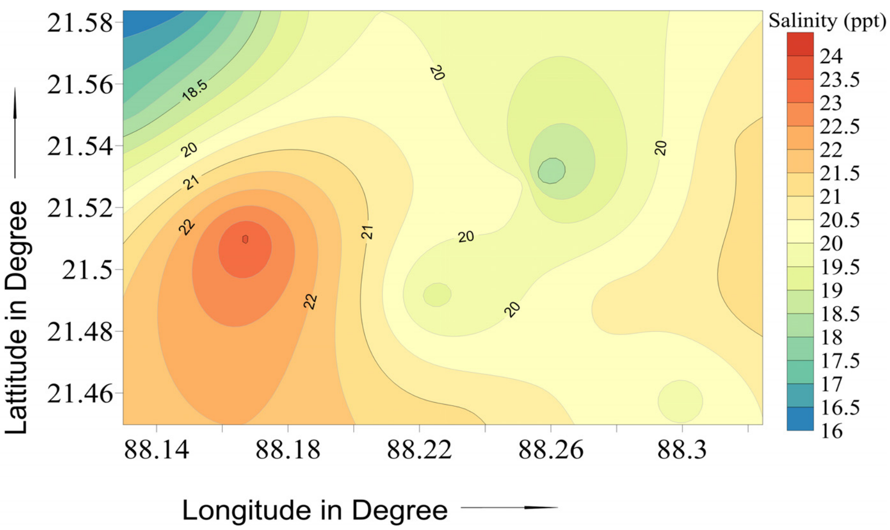

Figure 5. Spatial variation of salinity values in water samples

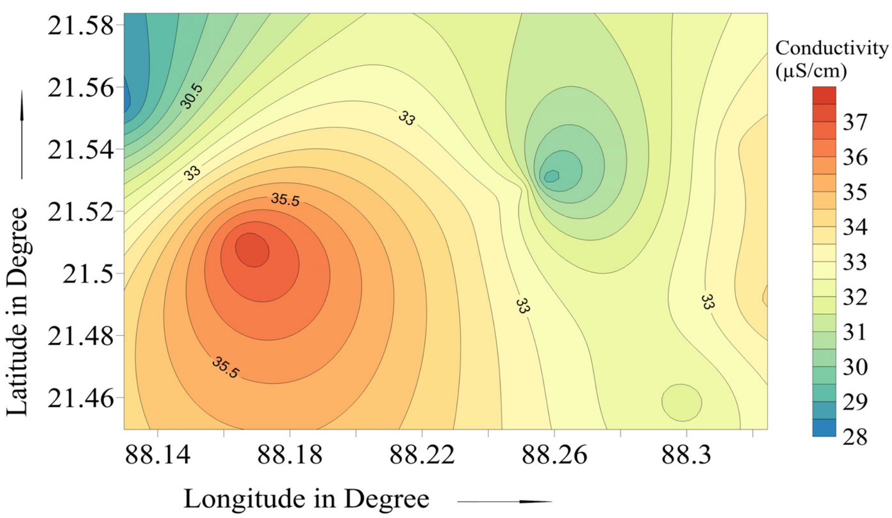

Figure 6. Spatial variation of electrical conductivity in water samples.

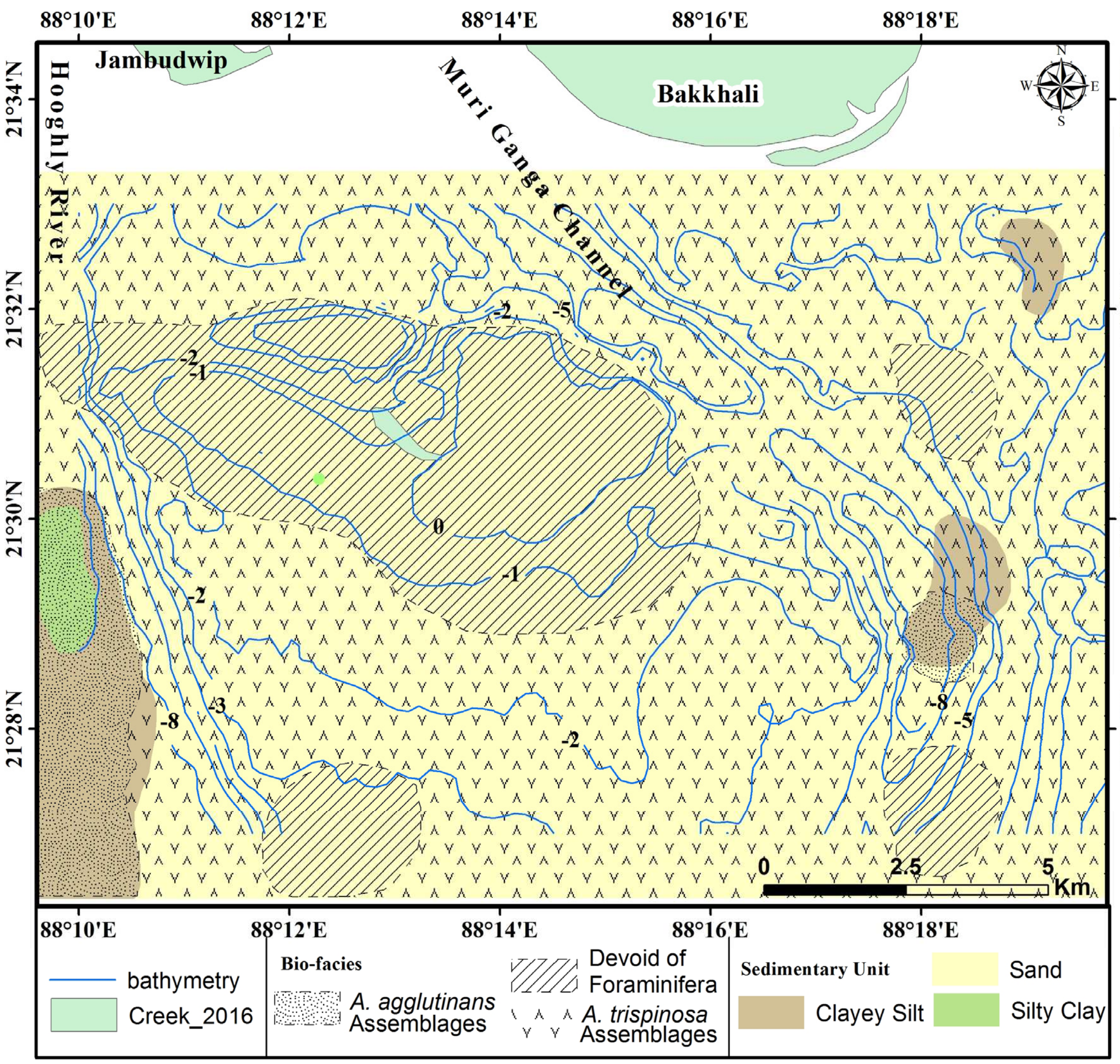

Figure 7. Benthic foraminifer's Bio-facies map of the study area off Bakkhali.

DISCUSSION

The sample from the Hooghly channel (Figure 1) show high concentration of foraminifera which accounts for 54% of total foraminiferal distribution compare to Muri Ganga channel sediment accounts for about 36% of total foraminiferal distribution. Moreover only 10% of foraminifera are found in the shallower region especially over sandy area (Table 1). This clearly points that geomorphology is providing favourable ecological setup for the prolific growth and occurrence of the selective benthic foraminifera such as *A. trispinosa*, *C. jeffreysii, A. agglutinans, A. tepida* and *Nonion* spp. However, physico-chemical parameter such as salinity, nutrients and turbidity current is also playing a vital role for controlling the abundance and distribution of these benthic foraminifera. It is also found that some species mainly *A. agglutinans* and *C. jeffreysii* are strictly opportunistic and occurring in great abundance in the channel where silt and silty clay as major component providing highly favourable condition and become scarce when conditions are unfavorable mainly in the shallower part where fine sand as a major component. Similar observation noticed in the study of Sabyasachi *et al.,* 1996 and Tripathi *et al.,* 2017b, they found that *C. jeffreysii* is occurring in the low salinity environment along with very fine sand and silt in the upper regime of the channels. Moreover other forms such as *A. trispinosa*, *Elphidium* spp., *A. tepida* and *Nonion* spp., occupying shallower region of the study area where sand as foremost component, same observation also recorded in the Gautam, 2010 study from the Bakkhali beach sediment. Above findings are also supported by the SDI analysis; here overall diversity index of the area is under moderately good as the SDI is 0.45, although it varies from station to station, which means ecology is favourable for the growth and abundance of benthic foraminifera at particular sample station rather than the whole area.

These observations very well observed in the 40% samples which are devoid of foraminifera, this might be due to the very shallower area which not providing enough time during high tide for total submergence and also due to presence of unstable channel margins (Figure 1). All above combined factors have created hostile environment for the development and growth of bottom ecology particularly for 40% of the samples. To support this observation, correlation coefficient matrix analysis and PCA was performed, which reveal that the environment of individual species is unique and these are mainly controlled by the current pattern, sediment characteristic and salinity. Subsequently PCA of the fauna also revealed two distinct assemblages (Group A and Group B), which are mainly controlled by its unique congenial ecological setup (Table 3). One assemblage (Group A) observed within the Hooghly and Muri Ganga channels have close association with each other like *Ammobaculites* spp., and *C. jeffreysii* and also have positive relation with clay and silt (Figure 3). When silt and clay increases, the content of these benthic foraminifera were also increases along with *Nonion* spp., *Cribononion* and *E. advenum* (Table 1). This implies that the sea bed material and channel current playing a major role compare to salinity and pH, matching with view of Tripathi *et al.,* 2017b. Ryan, 1969 and Nigam, 1984 were also reported the favourable growth of *Ammobaculites* within the temperature and salinity range between 20˚C to 25˚C and 13‰ to 23‰ and this observation is supporting with the present study. Other than these physical parameters of water, organic matter is also a major constituent which are transported by the river channels and facilitating congenial environment for the populace growth of *Ammobaculites* (Scott *et al.,* 1979; Albani *et al.,* 1991; Debenay *et al.,* 2000). Along with the organic matter, *Ammobaculites* also preferring silty and clayey environment both in form of suspension as well as on the bottom of the channel is very well matching with view of Ryan, 1969; Kraft and Margules, 1971. Similar observation is also recorded through PCA and correlation matrix analysis which shows that their association is more influenced by silty clay and clayey silt sediments rather than salinity. Second assemblage (Group B) is mainly dominating in the shallow water regime which mostly comprises of the fine sand and robust benthic foraminifers test (Figure 3), indicating relatively high energy and turbulent environment (Murray, 1991, Ghosh *et al.,* 2014). Therefore, the presence of *Asterorotalia* with two to three spines in this group supports above energy condition (Ghosh, 1966). According to him, spines facilitated the species to be more buoyant, possibly just above the sediment water interface which is corroborated with the PCA Analysis. PCA indicate that Group B show direct correlation with physical parameters such as salinity and conductivity, whereas Group A shows an affinity towards sediment characteristic rather than salinity and conductivity.

Table 3. Foraminiferal assemblages and their ecological characteristic and environment, off Bakkhali.

No	Assemblage	Observed foraminifera association	Ecological characteristic	Environment
1	A	*A. agglutinans, C. Jeffreysii, A. trispinosa. Nonion* spp., and *A. tepida*	Submarine channels of Hooghly and Muri Ganga dominated by the silty and clayey area	Turbidity channel with suspended silt and clay
2	B	*A. trispinosa, A. beccarii, E. crispum, A. tepida, Pararotalia, Triloculina* spp., *E. advenum, E. excavatum, Nonion spp.*, *Pseudononion* spp.,	Shallower depth dominated by sandy and silty material	Relatively high energy and turbulent environment

CONCLUSION

Based on the above discussion it can be concluded that the ecology of the study area is mainly affected by the diurnal tidal variation and sediment carried by the submarine river of Hooghly and Muri Ganga. Presence of *A. agglutinans* and *C. jeffreysii* in assemblage A, is mainly depends upon the channels sediment (silt and clay) that carried in form of suspension. Moreover the presence of *A. trispinosa, E. crispum, A. beccarii, Pararotalia* and *Triloculina* spp., in assemblage B in the shallower area supports the relatively high energy and turbulent bottom environmental condition. So, overall distribution of foraminifers in the study area is mainly controlled by the submarine channels and overall geomorphology.

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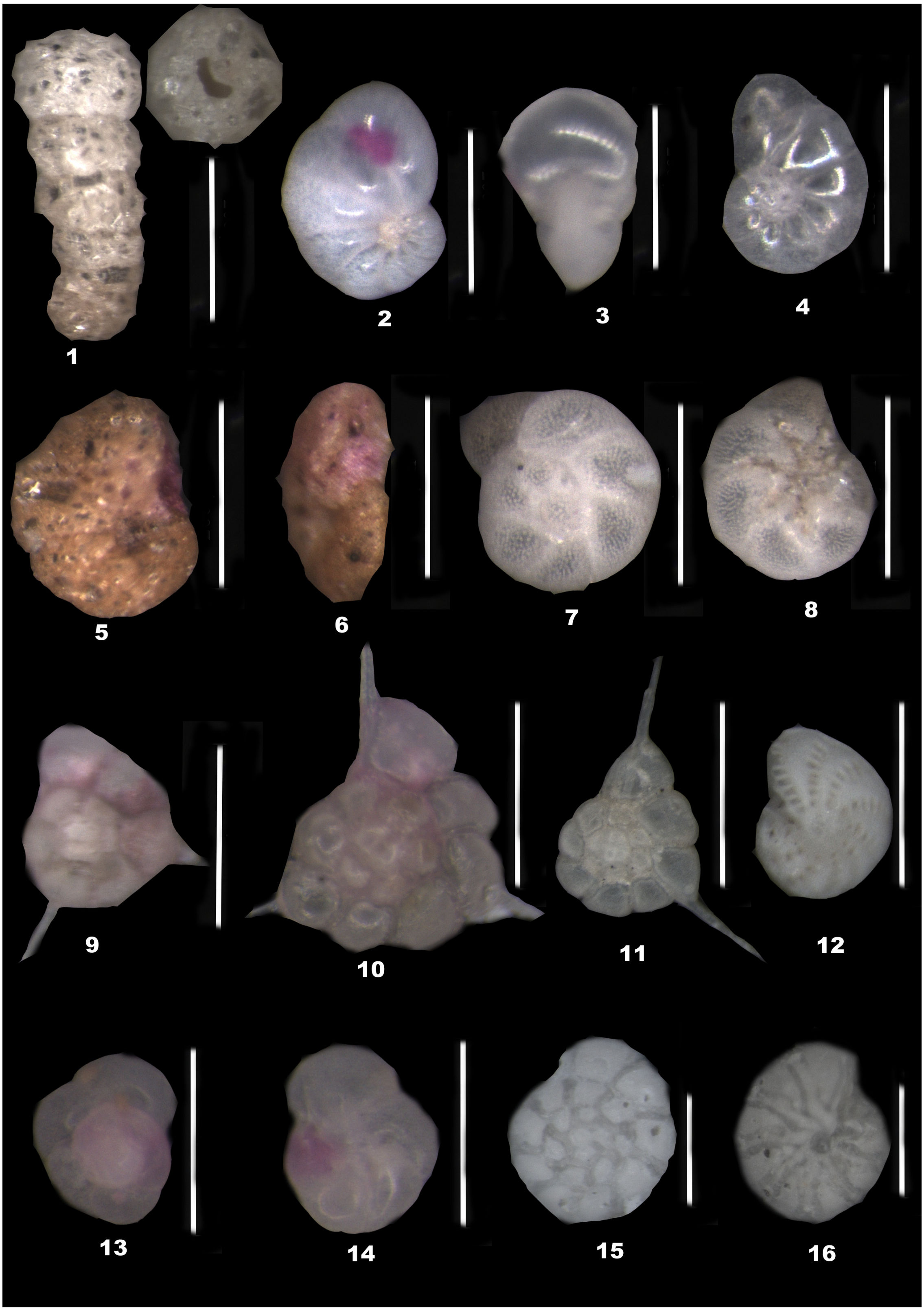

Plate I. Photomicrograph of the most dominant benthonic foraminifers of the study area, scale bar = 200µm 1) *Ammobaculites agglutinans*; 2 & 3) *Nonionella atlantica;* 4) *Nonion depressulum;* 5 &6) *Cribrostomoides jeffreysii*; 7&8) *Ammonia tepida;* 9-11) *Asterorotalia trispinosa*; 12) *Elphidium advenum* 13 &14) *Ammonia tepida;* 15 & 16) *Ammonia beccarii,*