Arabian Journal of Geosciences (2022) 15:1124
https://doi.org/10.1007/s12517-022-10392-z

ORIGINAL PAPER

Interaction among macrobenthic molluscan diversity of river Ganga and ecological variables by using multivariate indices

Shreya Roy[1] · Canciyal Johnson[1] · Nitish Kumar Tiwari[1] · Subhadeep Das Gupta[1] · Basanta Kumar Das[1]

Received: 13 September 2021 / Accepted: 26 May 2022

Abstract

Ganga river is one of the important water bodies harbouring different aquatic communities especially sedentary benthic organisms. We determined several macrobenthic molluscan faunas including 24 species comprising of 18 gastropods and 6 bivalves. The maximum species diversity with a value of 2.08 was recorded during monsoon, whereas the species richness was found to be highest (0.809) during winter. To determine the correlation between the physicochemical parameters of water, sediment and macrobenthic organisms, we have employed the canonical correspondence analysis (CCA) for middle, lower and estuarine stretches of river Ganga. The water CCA components, CCA1 and CCA2, explained 48.64%, 47.01%, 45.11% ($p = 0.568$, 0.019 and 0.417) and 18.11%, 26%, 23.9% ($p = 0.98$, 0.292 and 0.978) between the environmental parameters and macrobenthos correlation, respectively. Similarly, the CCA components for soil showed a percentage of 41.82%, 41.58%, 24.73% in CCA1 ($p = 0.156$, 0.026 and 0.922) and the CCA2 revealed a percentage value of 24.23%, 25.58%, 23.59% ($p =$ 0.446, 0.174 and 0.488) of the mentioned parameters. The present study explored a dual relationship between the organisms and environmental factors according to their abundance and distribution pattern.

Keywords Mollusca · River Ganga · Ecological parameters

Introduction

Freshwater ecosystems act as source and sink for those chemicals which are biologically important and operate as phosphorus, carbon, nitrogen, sulphur and silicon cycles (Fisher 1982). Macrobenthic organisms, inhabitants of the sediment, play an important role in maintaining the nutrient content of the soil as well as water for better primary production. It also helps in maintaining nutrient cycles for trace elements, radionuclides and xenobiotics (Jones and Bowser 1978). To understand well about a particular habitat and its importance, it is recommended to study a group of inhabitant organisms rather than studying an individual species (Rao 1991). Several studies have been conducted on the chief importance of the benthic macroinvertebrates in the lotic ecosystem (Sharma et al. 2011; Gupta et al. 2015; Liu et al. 2017; Chi et al. 2018). To provide a congenial niche for an ideal aquatic biota, a lotic body requires certain criteria based on richness, composition, relative abundance of a species (either individual or in the group) and their ecological engagement with co-organisms (Gupta et al. 2015). Within the macrobenthic invertebrates, the molluscs play an important role in water biomonitoring and maintaining the health and integrity of the aquatic ecosystem. To understand well about temporal population dynamics and community alterations, it is required to investigate species specific interaction with the abiotic environment affected by endogenous and exogenous factors covering the core of ecology and evolution process (Higgins et al. 1997; Belyea and Lancaster 1999; Stenseth et al. 1999; Lundberg et al. 2000). The presence and abundance of many molluscan species like *Filopaludina bengalensis* provide relevant information on the status of the physico-chemical condition of water (Gupta et al. 2015). India, the land of rivers, produced a large number of publications based on the benthic community including lakes, wetlands and ponds but recent evidence on spatio-temporal variation, distribution and composition of the benthic molluscan fauna in relation to environmental factors is inadequate. Therefore, the objective of the present

Responsible Editor: Amjad Kallel

✉ Basanta Kumar Das
basantakumard@gmail.com

[1] ICAR-Central Inland Fisheries Research Institute, Barrackpore, Kolkata 700120, India

Table 1 The zonation and sediment characteristics of the study area

Zones	Stations/stretch	Characteristics
Middle	Buxar, Patna and Bhagalpur	Plain freshwater riverine stretch with no tidal influence
Lower	Farakka, Jangipur, Berhampur, Balagarh and Tribeni	Lower freshwater zone with medium tidal influence at the stations between Tribeni and Balagarh
Estuarine	Godakhali, Diamond Harbour and Fraserganj	Estuarine zone with high tidal amplitude

study is to assess the present status of macrobenthic molluscan diversity and to correlate with the environmental variables along the middle, lower and estuarine stretches of river Ganga for effective biomonitoring and aquatic resource management.

Materials and methods

Study area

The sampling was carried out in 11 stations along the middle, lower and estuarine stretches of river Ganga from Buxar to Fraserganj depicted in Table 1. The sampling stations with their geographical coordinates and landscapes are represented in Table 2. Figure 1 denotes site map of the study area.

Sampling layout

Samples used in this study were collected in a quarterly manner comprising of pre-monsoon (March–May), monsoon (June–August), post-monsoon (September–November) and winter (December to February) throughout the year from April 2017 to April 2019. The four seasons considered in this study was designated following the guidelines of the Indian Meteorological Department (IMD), Mausam Bhavan, New Delhi, India.

Ecological study

Water samples were collected from 50–60 cm depth, using a standard water sampler—'Ruttner water sampler' and transferred immediately into designated polyethylene bottles. Water pH was measured in situ by using a portable digital pH metre (HANNA Instruments, Inc.). After collection, water samples were brought to the laboratory in controlled temperature condition at 4 °C in insulated box. Biological oxygen demand (BOD) of the samples was analysed by using the standard protocol from American Public Health Association (APHA 2017). The nutrients such as total nitrogen (TN), total phosphate (TP), silicate (SiO_4-Si) and total chlorophyll (TC) (acetone extraction

Table 2 Geographical coordinates of sampling sites and their geographical landscape

Stations	Abb.	Coordinates	Geographical landscape
Buxar	Bux	83.97775° E; 25.56471° N	Kotwanarayanpur Ghat is a localized well-maintained ghat with ritualistic and spiritual practices.
Patna	Pat	85.13756° E; 25.59409° N	Localized ghat with muddy clayed bottom locally called Gai Ghat.
Bhagalpur	Bha	86.98243° E; 25.3478° N	Barari Ghat is not a well-used ghat but influenced by ritualistic and industrial activities.
Farakka	Far	87.90896° E; 24.80067° N	A localized non-ghat area called Taltala Ghat is used for different local activities and mostly fishing along with household activities.
Jangipur	Jan	88.10301°E; 24.45265°N	Local ghat with fewer anthropogenic activity only used for fishing. The ghat is locally called Jangipur Ferry Ghat.
Berhampur/Rejinagar	Beh	88.26793°E; 24.09883° N	Locally build ghat with clayed bottom sediment used for washing and other household activities.
Balagarh	Bal	88.46461° E; 23.11886° N	Ghat is used for fishing activities. Localized ghat is called Milangar Ghat.
Tribeni	Tri	88.4025° E; 22.98671° N	Localized ghat for fishing activities.
Godakhali	God	88.14256° E; 22.39321° N	Non-polluted and non-cemented ghat with clayed bottom, used for fishing activities by the locals and bathing and washing purpose.
Diamond Harbour	DH	88.20229° E; 22.19873° N	Few fishing activities taking place with not a properly built ghat locally called Harar Khal.
Fraserganj	Fra	88.25829°E; 21.58249° N	Fishing Harbour Jetty with trawlers and sandy bottom sediments, commonly large mechanized boats are parked/docked here.

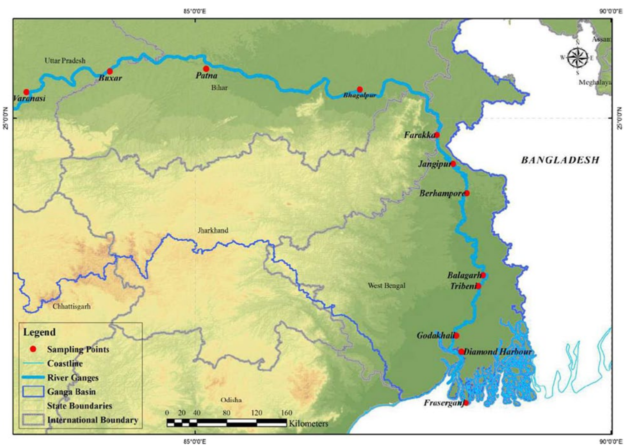


Fig. 1 Map showing the location of the sampling site from Buxar to Fraserganj across river Ganga

method) were analysed by using standard recommendations and protocol as described in APHA (2017). Total hardness (TH) from the samples was measured by titrimetric method (APHA 2017). To determine the sediment quality, samples were collected using Peterson grab (15.2 cm × 15.2 cm). Soil pH was measured using portable pH metre (HANNA Instruments, Inc.) and parameters such as available nitrogen (AN), phosphorus pentoxide (P_2O_5), soil organic carbon (OC), calcium carbonate ($CaCO_3$) and soil texture: sand, silt and clay were assessed according to the standard methods and protocol Jackson (1964) and Piper (1966).

Sample processing and preservation

For biota analysis, the soil samples were collected by scooping the grab inside the bottom sediment using Peterson grab mentioned earlier. Samples, just after collection, were transferred into a plastic bucket and mixed with ample amount of water till evenness. The soil samples were then sieved (200 μm mesh size) without losing the macrobenthos. The sieved materials were then transferred into polyethylene bottles (Tarson, India) and preserved in 4% formalin until further analysis.

Sample identification and assessment

For taxonomic identification, the specimens were sorted and identified up to the genus or the species level using taxonomic keys (Needham 1957; Edmondson 1959; Rao 1989). Numerical abundance of the samples was performed using a quantitative analysis by simple counting and then converting it to a square metre area (Welch 1948).

$$N = \frac{O}{A} \times S \times 10,000$$

where:

N no. of macrobenthic organisms/m^2

O no. of organisms counted

A area of a sampler/m^2

S no. of samples collected at each station

The relative abundance (RA) of different species was calculated according to the standard protocol (Mahajan and Fatima 2017).

$$Relative\ Abundance\ (RA) = \frac{Total\ no.of\ species}{Total\ no.of\ individual\ species\ recorded} \times 100$$

Data analysis

Samples collected during study seasons were analysed for species richness, numerical abundance and dominance. The diversity indices, viz., Shannon-Weiner diversity (H') (Shannon-Weiner, 1949); Margalef richness (d') (Margalef, 1958); evenness index (J') (Pielou, 1977); Simpson dominance (D) and Simpson diversity (1-D) (Simpson, 1949), were computed by using Paleontological Statistics (PAST, version 4.2) programme (Hammer et al. 2001). Karl Pearson's correlation coefficient test was performed by using IBM-SPSS software version 22. The PAST 4.02 software was employed to implement permutation multivariate analysis (PERMANOVA), cluster analysis and the canonical correspondence analysis (CCA) to examine the empirical relationship between environmental factors and macrobenthic species with respect to four seasons corresponding to the sampling sites with the help of Paleontological Statistics (PAST, version 4.2). We evaluated similarity among sites and seasons with cluster analysis, using paired group Bray-Curtis methods. Bray-Curtis is considered a better distance metric when measuring such a heterogeneous gradient as studied here (McCune and Grace 2002). For this analysis, the numbers of macrobenthic molluscan organisms of each species were considered. Prior to multivariate analysis, Shapiro-Wilk test for

Table 3 Ecological parameters of eleven stations of river Ganga from Buxar to Fraserganj represented by range (max–min) and mean in parentheses during 2017 to 2019

		Buxar	Patna	Bhagalpur	Farakka	Jangipur	Berhampur	Balagarh	Tribeni	Godakhali	D. Harbour	Fraserganj
Water	pH	7.4–8.4	8.32–7.6	8.3–7.6	7.4–8.57	7.6–8.7	7.5–8.52	7.4–8.67	7.3–8.87	7.7–8.22	7.9–8.3	7.95–8.37
		(7.9)	(8.08)	(8.05)	(8.05)	(8.2)	(8.1)	(8.1)	(8.1)	(7.9)	(8.1)	(8.2)
	BOD (mg/l)	0.98–1.8	0.6–1.5	0.8–1.2	0.4–0.8	0.4–0.9	0.1–0.9	0.4–1.4	1.1–2	0.4–0.8	0.7–1.5	0.43–3.9
		(1.3)	(1.02)	(1)	(0.5)	(0.6)	(0.5)	(0.8)	(1.4)	(0.5)	(1.1)	(1.3)
	TH (mg/l)	98–179.3	103–160	111–192	86–144	141–85	91–144	91–188	62–201	108–212	110–1213.3	3675–7033.3
		(145.8)	(138.75)	(153)	(108.6)	(102.07)	(126.9)	(140.5)	(124.4)	(147.5)	(663.07)	(5152.07)
	TP (mg/l)	0.062–0.24	0.05–0.12	0.11–0.45	0.03–0.26	0.02–0.16	0.04–0.14	0.03–0.08	0.04–0.06	0.03–0.23	0.04–0.14	0.02–0.13
		(0.1)	(0.1)	(0.2)	(0.1)	(0.07)	(0.09)	(0.05)	(0.05)	(0.1)	(0.09)	(0.07)
	SiO_4-Si (mg/l)	2.4–7.98	4.178–9.09	4.8–8.7	8–10.2	6.34–8.68	6.06–8.34	6.6–7.64	6.59–8.16	5.29–8.61	3.71–7.04	2.47–4.9
		(5.8)	(7.2)	(6.9)	(9.1)	(7.5)	(7.03)	(7.2)	(7.3)	(7.06)	(6.00)	(4.09)
	TN (mg/l)	0.63–0.98	0.514–1.12	0.89–1.68	0.45–2.18	0.34–1.4	0.5–0.93	0.51–0.8	0.29–1	0.47–2.49	0.36–1.46	0.33–0.8
		(0.7)	(0.8)	(1.2)	(1.01)	(0.9)	(0.6)	(0.6)	(0.5)	(1.2)	(0.7)	(0.5)
	TC (mg/l)	3.26–8.33	3.4–8.74	2.24–11.62	1.73–6.53	2.74–5.36	3.49–24.26	11.17–21.01	7.49–52.9	5.25–32.75	2.38–19.58	3.24–19.3
		(6.2)	(5.6)	(6.3)	(4.1)	(4.3)	(10.2)	(14.8)	(20.5)	(16.6)	(12.8)	(12.9)
Sediment	pH	7.4–8.36	8.2–8.59	7.8–8.33	7.84–8.34	8.06–8.23	8.03–8.48	8.02–8.26	8.02–8.22	8.06–8.3	7.97–8.31	7.79–8.25
		(7.9)	(8.41)	(8)	(8.09)	(8.1)	(8.2)	(8.1)	(8.1)	(8.2)	(8.1)	(7.9)
	AN (mg/100 g)	11.48–16.8	3.64–7.28	6.15–18.2	10.73–14.28	11.53–5.04	15.96–3.21	6.56–18.48	7.21–21.84	3.05–10.92	6.96–14	7.28–13.03
		(12.8)	(5.98)	(10.7)	(12.03)	(7.6)	(8.7)	(11.74)	(12.1)	(7.3)	(9.5)	(7.9)
	P_2O_5 (mg/100 g)	2.85–6.84	2.06–5.41	2.4–5.13	2.09–5.06	1.12–5.17	1.91–5.23	2.4–11.94	3.11–11.9	1.92–5.11	2.53–6.03	3.2–16.06
		(4.3)	(3.3)	(3.6)	(3.5)	(3.06)	(3.4)	(5.7)	(6.06)	(3.3)	(4.02)	(7.5)
	OC (mg/100 g)	0.36–0.52	0.24–0.36	0.28–0.58	0.49–0.78	0.27–0.55	0.15–0.48	0.19–0.75	0.75–0.53	0.37–0.69	0.35–0.89	0.39–0.93
		(0.4)	(0.3)	(0.5)	(0.6)	(0.3)	(0.3)	(0.5)	(0.6)	(0.4)	(0.6)	(0.7)
	$CaCO_3$ (mg/100 g)	24.1–3.25	4.5–12	4.52–13.83	5.75–13.25	2.35–11.25	6.52–11.33	7.5–9	5.7–13.5	4.22–10.75	2.37–9.75	3.95–9.5
		10.3	(9.02)	(8.1)	(9.6)	(7.8)	(9.03)	(8.2)	(10.9)	(8.04)	(6.5)	(6.8)
	Sand (%)	72.25–89	85.5–99	60–77.5	48–67.5	37–85.66	76.33–94.25	50–88	56.5–75.5	55.5–89	46.5–77.5	67.5–76
		(79.1)	(77.5)	(71.1)	(54.5)	(67.8)	(86.1)	(68.08)	(68)	(70.6)	(63)	(70.9)
	Silt (%)	6.5–20.75	0.5–7	13.5–17.25	18.75–33.25	15.83–25	17.33–2.5	5.75–33.5	14–30	6.33–30.5	11.25–31.5	15–25.5
		(14.6)	(4.1)	(15.2)	(26.9)	(17.3)	(7.8)	(21.7)	(20.3)	(19.3)	(21.3)	(19.7)
	Clay (%)	4.5–8.5	0.5–7.5	9–22.75	13.75–22	6.75–20	3–7.5	5.33–16.5	9.25–13.5	4.66–14	11.25–27	7–16
		(6.1)	(3.9)	(13.6)	(18.5)	(10.5)	(5.02)	(10.1)	(11.6)	(9.9)	(16.8)	(9.7)

Table 4 Correlation table representing the relationship between ecological parameters of water and sediment along the river from Buxar to Fraserganj

		WpH	BOD	TH	TP	SiO4-Si	TN	TC	SpH	AN	P2O5	OC	CaCO3	Sand	Silt	Clay
Water	WpH															
	BOD	−0.066														
	TH	0.112	0.101													
	TP	−0.027	0.003	−0.120												
	SiO4-Si	0.049	−0.216	**−0.536****	0.183											
	TN	0.047	−0.204	−0.220	0.084	0.126										
	TC	−0.157	−0.119	0.103	0.051	−0.051	**−0.309***									
Sediment	SpH	−0.226	0.045	**−0.311***	−0.148	**0.383***	0.118	−0.023								
	AN	**0.397****	0.031	0.031	−0.041	−0.048	0.219	−0.082	**−0.303***							
	P2O5	0.008	0.166	**0.395****	−0.221	−0.288	−0.084	−0.005	−0.145	0.129						
	OC	0.037	0.017	**0.467****	0.105	−0.209	**−0.302***	0.252	**−0.635****	0.092	**0.341***					
	CaCO3	0.109	0.074	−0.111	**0.347***	0.174	0.057	−0.111	0.037	0.133	−0.079	−0.078				
	Sand	**0.421****	−0.014	−0.020	0.080	−0.062	0.032	−0.156	0.223	−0.125	0.032	**−0.387****	0.204			
	Silt	**−0.430****	0.078	0.105	−0.145	−0.021	−0.192	0.227	−0.285	0.049	0.071	**0.480****	−0.101	**−0.898****		
	Clay	−0.243	−0.009	−0.058	0.067	0.110	0.119	0.080	−0.177	0.214	−0.062	**0.380***	−0.208	**−0.882****	**0.676****	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed) normality was carried and data were found significant for multivariate analysis through SPSS.

Results

Physico-chemical parameters

The ecological parameters of the river in eleven stations showed an optimum range throughout the study period (Table 3). Table 4 depicts the correlation coefficients among the ecological parameters studied. The water and soil pH showed an alkaline range (8.22–8.87) at all sampling sites. The nutrient parameters studied using water and sediment samples were found to be within the optimum range. Nutrient richness was recorded maximum at Buxar, Bhagalpur, Farakka and Fraserganj. Pearson's correlation coefficient values indicated that there is a significant relationship ($p < 0.05$) between the samples examined for ecological parameters. Values obtained showed a moderate positive relation between WpH, AN and sand while showing a negative correlation with silt. TH indicated a strong negative relation with SiO_4-Si and SpH, whereas it showed a positive correlation with P_2O_5 and OC. The calcium content of the sediment sample revealed a positive relation with TP. TN indicated a strong negative correlation between TC and OC. A negative correlation was found between soil pH vs AN and OC, while P_2O_5 indicated a positive correlation with OC. Soil texture showed dual correlation with OC, indicating a negative correlation with sand and a positive correlation with silt and clay.

Relative abundance

The present study documented 24 species under the phylum Mollusca, of which, 18 species belongs to class Gastropoda, and 6 are from class Bivalvia. The gastropods and bivalves are comprised of 9 families, namely, Thiaridae, Viviparidae, Planorbidae, Lymnaeidae, Neritidae, Potamididae, Ampullariidae, Unionidae and Cyrenidae. *Filopaludina bengalensis*, *Lymnaea acuminata*, *Brotia costula*, *Assiminea francesiae* and *Parreysia favidens* were found to be the most dominant species along the stretch. *Filopaludina bengalensis* (family—Viviparidae) accounted for 9.58% at Patna followed by 6.29% at Farakka of the total sampling performed. The maximum abundance of *Filopaludina bengalensis* was calculated at Buxar to Bhagalpur. *Lymnaea acuminata* (family Lymnaeidae) contributed 2.66% to the sampling population at Farakka, while *Brotia costula* (family Pachychilidae) consisted of 1.32% and 1.56% at Farakka and Jangipur, respectively. *Assiminea francesiae* (family Assimineidae), a familiar species found in low saline zone (Godakhali and Diamond Harbour), contributed to 5.59% and 4.21%, respectively. A significant abundance of some partially dominated gastropods belonging to the family Thiaridae like *Tarebia granifera* and *Melanoides tuberculata* was found across the middle stretch. At Farakka, we found *Parreysia favidens* (family Unionidae) to be the most dominated bivalve which represented 2.39% of the total sampling population. Among the other dominated bivalves, *Corbicula striatella* belonging to the family Cyrenidae were recorded. Based on our sampling, it can be concluded that in river Ganga, the series of dominant molluscan families are like Thiaridae > Viviparidae > Assimineidae > Pachychilidae > Lymnaeidae > Unionidae > Cyrenidae > Bithyniidae. Figure 2 represents the relative abundance of gastropods (a) and bivalves (b) of the different sampling stations.

According to the relative abundance, the association of the macrobenthic community was broadly designated to four distinct colours in Tables 5 and 6 (for gastropod species and bivalve species, respectively). Starting from the highest to the lowest abundance, we assigned violet first, followed by green, yellow and blue, respectively.

Diversity indices

In Fig. 3, we presented the diversity indices of macrobenthic fauna during four seasons (a) and the station-wise variance (b). The Shannon index (*H*) ranged from 1.49 to 2.08 during pre-monsoon and monsoon sampling. Pre-monsoon showed the highest dominance value (*D*) of 0.38, while the lowest value (0.19) was observed during the monsoon. Evenness index value (J') among the sampled species ranged between 0.23 and 0.62 during pre-monsoon and monsoon. Species richness was calculated by using Margalef index (d') and found the maximum during monsoon (1.80) followed by winter (0.8).

The highest dominance value (*D*) was recorded at Godakhali (0.99) whereas the lowest was recorded at Fraserganj (0.22). The Simpson dominance and the Shannon diversity index were found to be maximum at Fraserganj and Patna with a value of 0.77 and 1.73, respectively, at the species level. The values were recorded minimum at Tribeni (0.29) and Godakhali (0.02). The values obtained using Evenness index (J') were recorded a maximum at Fraserganj (0.69) and a minimum at Jangipur (0.28) which implies an even distribution among the available species.

Multivariate analysis of macrobenthic molluscan community structure

Paired group Bray-Curtis analysis was carried out to determine the macrobenthic molluscan composition and abundance at 11 stations of river Ganga, based on the clusters formed with at least 50–90% similarity in the hierarchical cluster analysis (Fig. 4a). The cluster analysis showed a distinct deviation in the abundance of the macrobenthic fauna

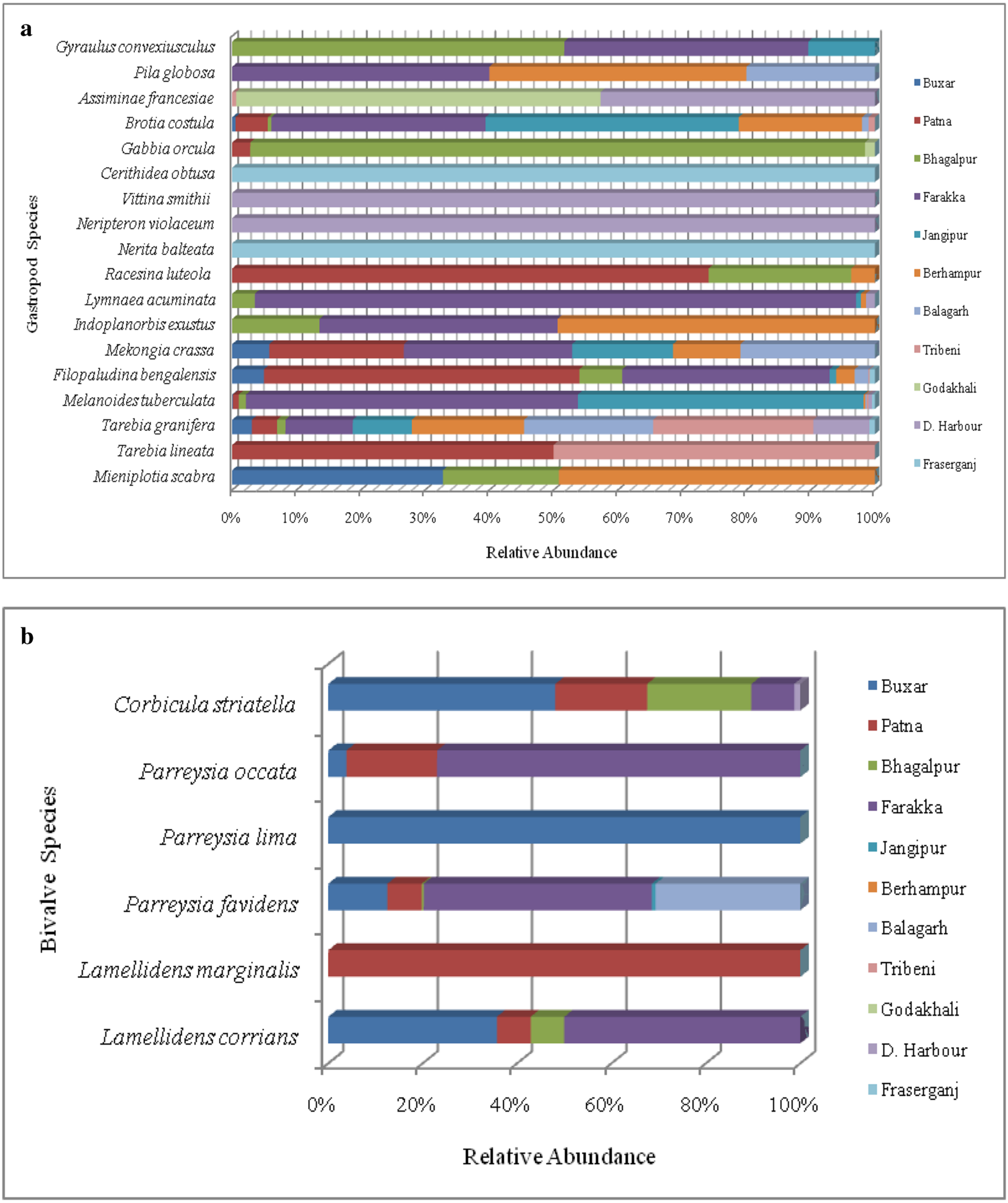


Fig. 2 Relative abundance of 24 species of macrobenthic molluscan fauna along the Ganga river, where **a** depicts 18 gastropod species and **b** depicts 6 bivalve species from Buxar to Fraserganj

Table 5 List of gastropod species showing relative abundance at different stretch along river Ganga

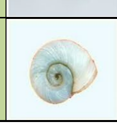
Class	Species	Species Image	Buxar	Patna	Bhagalpur	Farakka	Jangipur	Berhampur	Balagarh	Tribeni	Godakhali	D. Harbour	Fraserganj
CLASS – GASTROPODA	*Mieniplotia scabra*												
	Tarebia lineata												
	Tarebia granifera												
	Melanoides tuberculata												
	Filopaludina bengalensis												
	Mekongia crassa												
	Indoplanorbis exustus												
	Lymnaea acuminata												
	Racesina luteola												
	Nerita balteata												
	Neritina violaceum												
	Vittina smithi												
	Cerithidea obtusa												
	Gabbia orcula												
	Brotia costula												
	Assiminea francesiae												
	Pila globosa												
	Gyraulus convexiusculus												

Table 6 List of bivalve species showing relative abundance at different stretch along river Ganga

	Species	Species Image	Buxar	Patna	Bhagalpur	Farakka	Jangipur	Berhampur	Balagarh	Tribeni	Godakhali	D. Harbour	Fraserganj
CLASS - BIVALVIA	*Lamelliden scorrians*		blue	blue	blue	blue							
	Lamellidens marginalis			blue									
	Parreysia favidens		yellow	yellow	blue	green	blue		green				
	Parreysia lima	NA	blue										
	Parreysia occata		blue	blue		yellow							
	Corbicula striatella		yellow	yellow	yellow	blue						blue	

(purple) - having the highest percentage of existing organisms (very high)
(green) - considered to be a considerable high amount (high)
(yellow) - considered to be a medium range of organisms found (medium)
(blue) - considered to be the lowest abundance found (low)

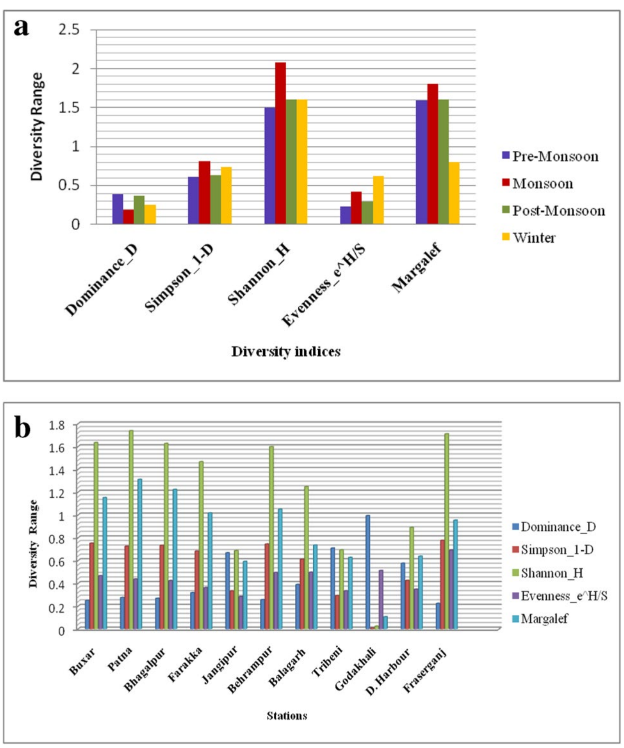


Fig. 3 Mean of the molluscan diversity indices for 2 years showing **a** the seasonal variations among the species and **b** the variations in the diversity estimated station-wise

which was observed at Farakka and Fraserganj, where the diversity was reported to be maximum. The cluster formed at Jangipur and Berhampur; Bhagalpur, Patna and Buxar; Tribeni and Godakhali showed clustering of 50–70%, and had a close similarity with the species abundance. The seasonal variation among the species was highly distinctive during pre-monsoon when analysed through cluster analysis (Fig. 4b). In cophenetic correlation was observed 0.90, which signifies the suitability of both the data to comprehend the analysis. The PERMANOVA data was interpreted and found that there has been a significant '*p*' value (<0.05). There was not much significant seasonal difference observed, but a distinct station-wise significant difference of 0.001 was observed.

Relationship of the macroinvertebrates with the environmental parameters

To perform a comparative study for understanding the relationship between macrobenthic community and environmental attributes (both water and sediment parameters), canonical correspondence analysis (CCA) was used in the present study, and the results were depicted in Fig. 5 (water) and Fig. 6 (sediment). The sampling data from all stations and environmental parameters were taken into account while creating CCA plot.

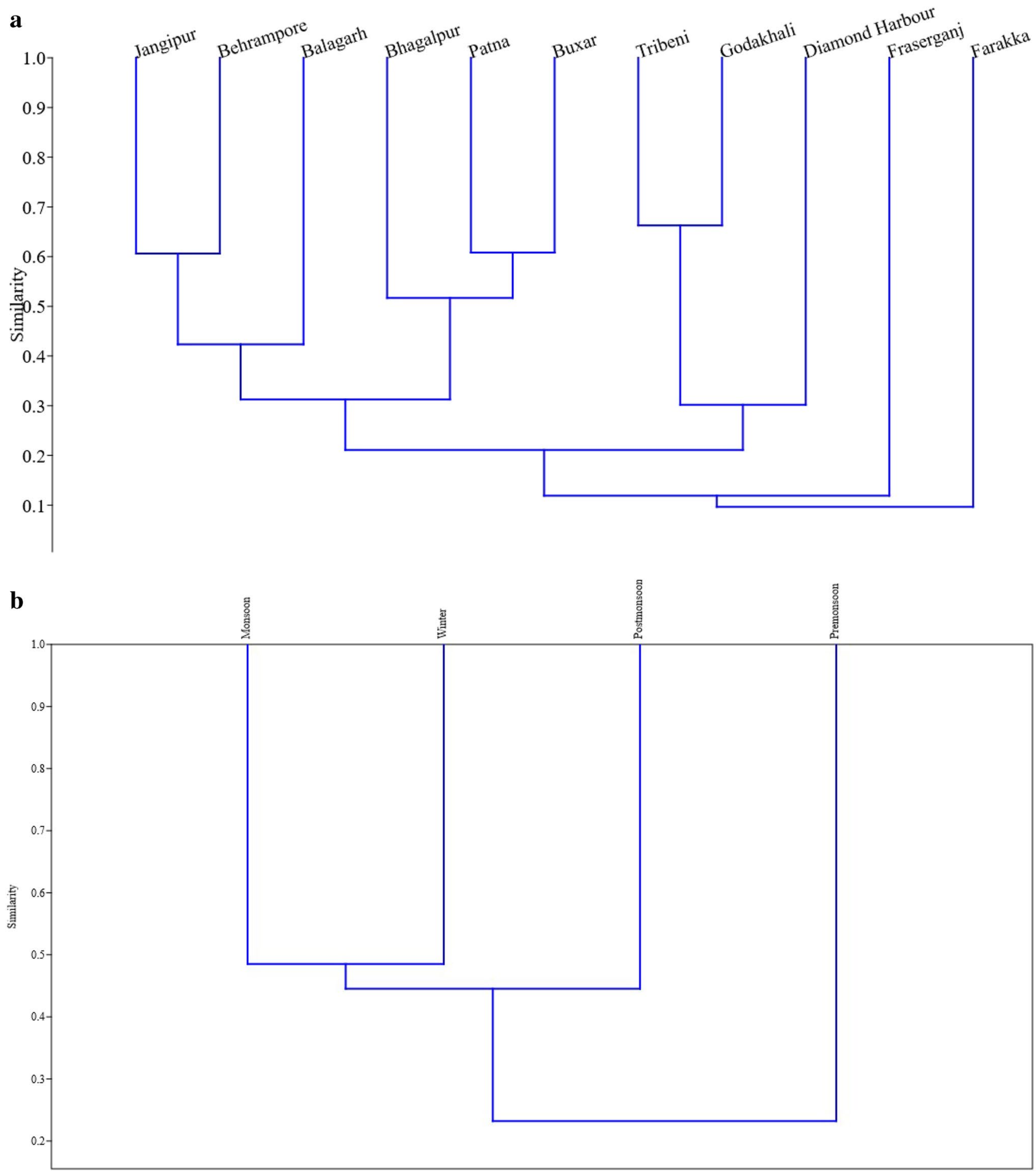


Fig. 4 **a** Dendrogram of the similarity cluster analysis based on species abundance and richness for 11 sampling sites in river Ganga, using Bray-Curtis distance. **b** Dendrogram based on similarity cluster analysis using Bray-Curtis distance showing the similarity between species abundance and richness during seasonal variation in river Ganga. **c** Non-metric multidimensional scaling (NMDS) of spatial-seasonal variation in macrobenthic molluscan communities based on abundance data

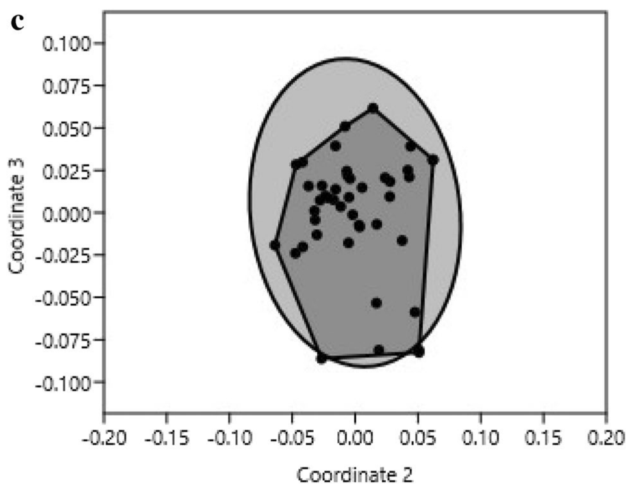


Fig. 4 (continued)

The first two component of CCA explained 66.75% of the total variation of the CCA model (Fig. 5a). The biplot of the first two component of the CCA indicated that BOD and silicate influenced the abundance of *T. granifera*, *T. lineate*, *M. crassa*, *L. corrianus*, *P. occata*, *R. luteola*, *L. marginalis* and *C. striatella*. The abundance of *I. exustus*, *L. accuminata*, *G. orcula* and *M. tuberculata* was influenced by the variation of total phosphorus and total chlorophyll. Total nitrogen influenced the abundance of *P. lima* and *F. bengalensis*.

Figure 5b has been configured using the CCA data obtained from the samples collected from Farakka and Tribeni, revealed a total percentage of 73.01. Unlike middle stretch, the lower stretch showed a greater affinity between macrobenthic species like gastropods (*P. globosa*, *M. tuberculata*, *F. bengalensis*, *B. costula*, *M. scabra* and *M. crassa*) and bivalves (*L. corrianus*, *P. occata* and *P. favidens*) with the variables like TP, TN, pH and SiO_4-Si. From the data analysed, we found that TC positively influences *R. luteola* and *A. francesiae*.

In the estuarine stretch, values obtained from CCA represented 69.01% of variance depicted in Fig. 5c. The vectors like BOD, TN and SiO_4-Si showed positive affinity in the attributes with gastropods (*L. acuminata*, *T. granifera*, *T. lineate*, *N. violaceum* and *M. tuberculata*) and bivalve (*C. striatella*). TP influenced *A. francesiae* positively while TH showed affinity towards with the available organisms (*B. costula*, *F. bengalensis*, *V. smithii* and *C. obtusa*).

Like water, relationship between sediment parameters and the macrobenthic species has also been evaluated by using CCA to comprehend their association. Both axes explained a total percentage of 66.05 in Fig. 6a. *F. bengalensis* was observed to be influenced by all the aforesaid sediment parameters. AN, P_2O_5 and pH influence *C. striatella*, *T. granifera*, *T. lineate*, *B. costula*, *P. favidens* and *M. scabra*. The macrobenthic assemblage is strongly influenced by OC, $CaCO_3$, pH, sand, clay and AN.

Samples from lower stretch and their CCA analysis using multiple soil variables have been shown in Fig. 6b (67.16%). Sand and pH are the two influencing parameters that are positively correlated with gastropods (*F. bengalensis*, *G. convexiusculus*, *M. crassa*, *B. costula*, *P. globosa* and *I. exustus*) and bivalves (*C. striatella*, *P. favidens* and *P. lima*). *L. acuminata*, *M. tuberculata* and *G. orcula* were positively influenced by clay.

Data represented in Fig. 6c denotes 48.32%. Silt and pH influenced *M. tuberculata*, *C. striatella*, *G. orcula*, *C. obtusa* and *V. smithii* in a positive manner. OC, AN and P_2O_5 showed affinity towards *N. violaceum*, *A. francesiae*, *F. bengalensis* and *B. costula*. A positive affinity with silt and $CaCO_3$ and macroorganisms (*M. scabra* and *N. balteata*) has been established in the biplot.

Discussion

The present study of macrobenthic diversity in the middle and lower stretches of river Ganga showed the congregation and richness of the sedentary organisms in correlation to the environmental parameters. Earlier, the ecological traits of river Ganga in 43 different stations from Gangotri to the Bay of Bengal were recorded by Central Inland Fisheries Research Institute (CIFRI) during 1995 and 1996 and reported (Sinha et al. 1998). Another study showed that the abundance of benthic population along river Ganga was dominated by *Filopaludina bengalensis*, *Melanoides tuberculata* and *Mieniplotia scabra* among gastropods and *Lamellidens corrianus* and *Lamellidens marginalis* among bivalves (Vass et al. 2010) which is quite relevant to our observations apart from the fact that the present findings showed reduced abundance (258 inds/m^2) of *Mieniplotia scabra* across the river. These benthic organisms are very important in the aquatic niche and are responsible for maintaining the aquatic biota. The pH values of soil and water were found to be alkaline which might contribute to the growth and development of the molluscan species. Earlier studies showed that the alkalinity of water along with the cumulative effect of calcium content and macrophytic vegetation contributed to the enhancement of species richness (Tonapi 1980; Garg et al. 2009). However, in the present study, the species diversity was recorded maximum during the monsoon period as the season is considered to be the breeding season of the molluscs. Khan (2003) reported the annual cycle of breeding of *Gyraulus convexiusculus* and *Filopaludina bengalensis* and observed that the peak was reached during the monsoon. Among the riverine macrobenthic fauna, molluscan species are considered to be a good source of protein to the riparian

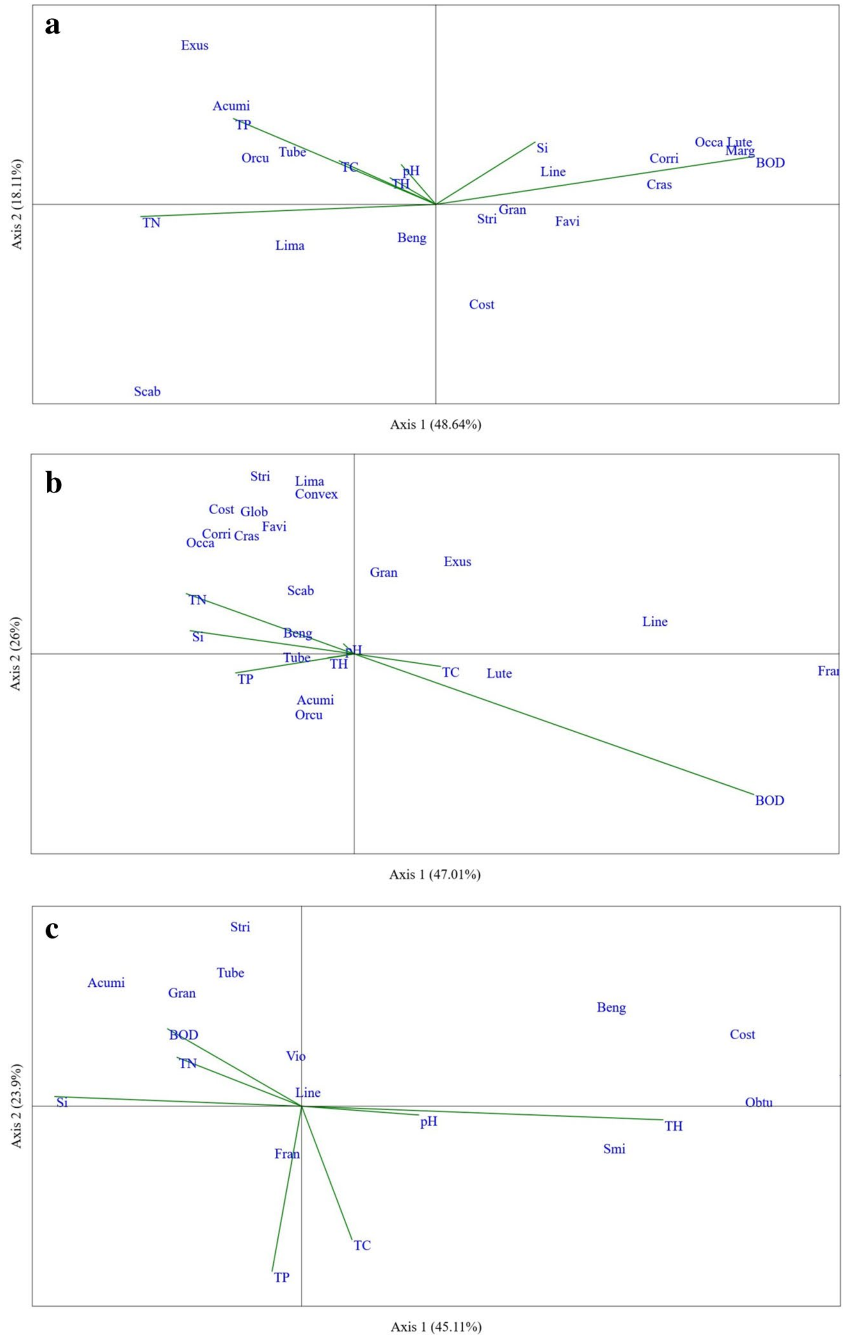


Fig. 5 **a** CCA biplot was analysed for the middle stretch of river Ganga showing a relationship between macrobenthic species and water quality parameters from Buxar to Bhagalpur. **b** CCA biplot showing the macrobenthic species influenced by the water quality parameters in the lower stretch of river Ganga from Farakka to Tribeni. **c** CCA biplot for estuarine stretch of river Ganga (Godakhali to Fraserganj) plotted between the macrobenthic species and water quality parameters

community and also add a socio-economic value which is very important (Wagle et al. 2018).

The sampling sites at different stretches of Ganga confirm the availability and number of the existing molluscs as evidenced by the relative abundance study. The arrangement and assemblage of the Gangetic macrobenthic organisms living in the sediment play an important role in the enhancement of nutrients in the soil. In the aquatic community, macrobenthic organisms play an important role by involving their biochemical coordination with minerals, mixing of sediments, oxygen influx in the bottom substratum, organic matter enrichment and nutrient cycling (Lind 1979). The amount of nutrients released by the sediment is dependent on the mineralization capacity of the benthic community (Newrkla and Gunatilaka 1982). Unlike *Lymnaea* sp. which showed an annual variation in the river at Masi, the other zoobenthos showed monthly, seasonal and annual variations with a higher percentage of abundance in summer followed by winter but decreased abundance was observed during monsoon due to high water velocity and other physical factors of the river (Pathani and Upadhyay 2006). According to our findings, *Lymnaea* sp. showed a spatio-temporal

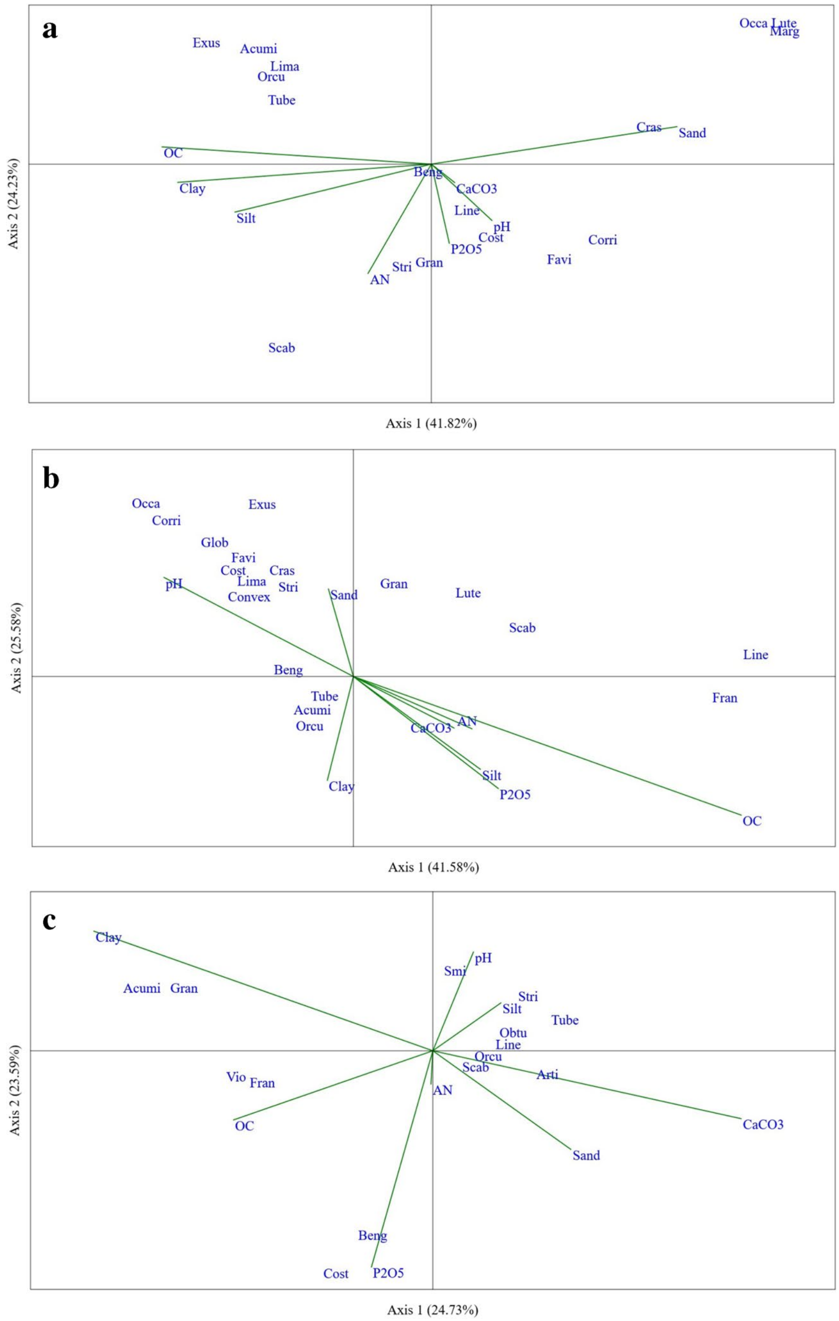


Fig. 6 **a** CCA was plotted for the middle stretch of river Ganga from Buxar to Bhagalpur showing a relationship between the macrobenthic species and soil quality parameters. **b** CCA biplot was analysed for the lower stretch of river Ganga from Farakka to Tribeni showing the macrobenthic species and influencing soil parameters. **c** Biplot analysis of CCA was plotted from Godakhali to Fraserganj (estuarine stretch) of river Ganga showing the relationship between the macrobenthic species and soil parameters

variation in the river Ganga with the maximum availability during the pre-monsoon period at Farakka. During this period, the average total hardness of the river water showed a constant positive relation with molluscan species. There is ample evidence that showed the involvement of total hardness in the growth promotion of the molluscan species (Garg et al. 2009). Higher calcium (Ca^{++}) concentration has been reported to promote the growth of the molluscan species in a fish pond at Jammu (Dutta and Malhotra 1986). The distribution and the availability of macrobenthic organisms depend upon various factors like water current along with the organic contents, amount of sedimentation, toxicity and contamination of the sediment beds (Pearson 1970). In Patna, the faunal feature of Ganga is found to be similar to the largest European rivers like Rhine, Main and Oder (Nesemann et al. 2011). Instead of the presence of multiple factors affecting the distribution of molluscan species, we, in this study, have found that the three dominating gastropods, *Filopaludina bengalensis*, *Melanoides tuberculata* and *Assiminea francesiae*, are prevalent in the three stretches of river Ganga, which might play a distinct role in harmonizing aquatic ecosystem. Among others, *Tarebia granifera*, *Melanoides tuberculata*, *Mekongia crassa* and *Brotia costula* were found to be the most dominant species in the freshwater zone (Buxar to Tribeni), whereas *Assiminea francesiae* is found to be the dominant gastropod in the lower freshwater zone, especially in the estuarine zone (Godakhali and Diamond Harbour). Among the bivalves, *Parreysia favidens* is found to be relatively dominant at Farakka and Balagarh. Based on the seasonal variation found in the sampling sites, the physicochemical properties of the river Ganga play an important role in relation to the macrobenthic fauna. From the correlation between the physicochemical properties of the river and the molluscan species, it is well understood that the water parameters induce the growth of the planktons which in turn acts as a nutritional source for the benthic filter feeders, indirectly causing an improvement of the water quality. Simultaneously, organic carbon, available nitrogen, $CaCO_3$ and P_2O_5 enhanced the nutritional value of the soil. A precise and proportionate correlation has been observed between total chlorophyll and the gastropods (*Melanoides tuberculata*, *Racesina luteola*, *Indoplanorbis exustus*, *Lymnaea acuminata*, *Assiminea francesiae* and *Gabbia orcula*). Our data is being supported by a very recent finding (Lorencová and Horsák 2019) which showed that chlorophyll-a is the best parameter to assess the molluscan richness. The present study showed that phosphate derivative in water is positively correlated with *Indoplanorbis exustus*, *Melanoides tuberculata*, *Assiminea francesiae*, *Lymnaea acuminata*, *Racesina luteola* and *Gabbia orcula*, whereas the derivative from sediment showed a similar correlation with *Filopaludina bengalensis*, *Corbicula striatella*, *Tarebia granifera* and *Brotia costula*. The data provided in the present study is in accordance with an earlier report which showed that the parameters do not affect the abundance of the molluscan population (Garg et al. 2009). The molluscan density might be altered by soil organic carbon content (Garg et al. 2009). It has been reported that soft organic rich sediments act as a growing platform for molluscan species (Syed et al. 2012), likewise from the present study, it can be stated that in the middle stretch, a positive correlation exists between soil organic carbon and the gastropod community (*Indoplanorbis exustus*, *Lymnaea acuminata*, *Melanoides tuberculata*, *Gabbia orcula* and *Parreysia lima*). The study based on soil texture showed that the sediment particle size affects the distribution pattern of the molluscan community greatly (Wijeyaratne and Bellanthudawa 2018). It has been well established that the rehabilitation process of the molluscan community was greatly influenced by the removal of riparian flora, infiltration of effluents, grazing habit of the cattle and finally domestic runoff (Meena et al. 2019). Our findings reconstruct the theory that the majority of soil and water parameters help to maintain the major macrobenthic community of river Ganga and are corroborated with the findings from the earlier studies (Vass et al. 2010). However, in a study from Harike reservoir, Punjab, it has been observed that variations in the molluscan community were slightly modified involving different parameters (Bath et al. 1999). The study reported that an increase in the organic carbon content of soil directly influenced the abundance of molluscan community, whereas we, in the present study, found that a negative correlation exists between gastropods (*Neripteron violaceum* and *Assiminea francesiae*) and soil organic carbon in the estuarine region (Diamond Harbour and Fraserganj). This might be attributed due to several anthropogenic activities, sewage disposal including chemical, thermal and industrial effluents, accumulation of disposed organic loads, agricultural washouts, etc. Benthic communities are well-known critical living creatures that offer better management in maintaining a healthy and balanced ecosystem. Therefore, the community should be reinforced in the ecosystem which will eventually help them their better survival. We, in the present study, observed (1) the variability of the biomonitoring species; (2) the species played a significant role in the improvement of the sediment quality during the study duration; and (3) are positively correlated with the relative abundance throughout the stretch during different seasons.

Conclusion

The abundance of macrobenthic gastropods and bivalves and their correlation with the ecophysiological variables represent the good health and improved quality of the Ganga river. In the present study, the interrelationship between the ecological parameters (silicate, biological oxygen demand, total nitrogen and pH) and zoobenthic organisms showed highly positive correlationship. The plantation of various factories along the river banks promotes the dumping of the industrial waste directly into the river, leading to the deterioration of ecological parameters of the water thereby affecting the abundance and distribution pattern of the macrobenthic population. To protect the riverine health, we thus have to maintain a balance with the ecological indices and the macrobenthic organisms.

Acknowledgements The authors are grateful to National Mission for Clean Ganga for providing us the platform to perform the experiments and carry out the research activities and also to ICAR-Central Inland Fisheries Research Institute for providing us with all the research support and facilities.

Author contribution The experiment was designed by Dr. Basanta Kumar Das, Director, ICAR-Central Inland Fisheries Research Institute and P.I. of NMCG Project. Field data were collected and analysed by Shreya Roy, Canciyal Johnson, Nitish Kumar Tiwari and Subhadeep Das Gupta. Statistical analysis was analysed by Shreya Roy. Data interpretation by Dr. Basanta Kumar Das, Shreya Roy and Canciyal Johnson. The manuscript was prepared and edited by all the authors.

Data availability The experimental data generated or analysed in the present study are available from the corresponding author on request.

Declarations

Conflict of interest The authors declare no competing interests.

References

APHA (2017) In: Baird, R.B., Eaton, A.D., Rice, E.W., Clesceri, L.S. (Eds.), Standard methods for the examination of water and wastewater. American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF) 23: 1–1546

Bath KS, Kaur H, Dhillon SS (1999) Correlation of molluscs with physico-chemical factors at Harike Reservoir (Punjab). Indian J Environ Sci 3(2):159–163

Belyea LR, Lancaster J (1999) Assembly rules within a contingent ecology. Oikos 86:402–416

Chi S, Wei C, Zheng J, Hu J, Li M, Hu J (2018) Distribution patterns of macroinvertebrate communities in a Chinese floodgate-regulated river and their relationships with river longitudinal connectivity. Sci Total Environ 631:765–777

Dutta SPS, Malhotra YR (1986) Seasonal variations in the macrobenthic fauna of Gadigarh stream (Miran Sahib) Jammu. Indian J Ecol 13(1):138–145

Edmondson, W.T (1959) Freshwater biology. John Wiley and Sons Inc., New York: 1248

Fisher JB (1982) Effects of macrobenthos on the chemical diagenesis of freshwater sediments. In Animal-sediment relations (177–218). Springer, Boston, MA

Garg RK, Rao RJ, Saksena DN (2009) Correlation of molluscan diversity with physico-chemical characteristics of water of Ramsagar reservoir, India. Intl J Biodivers Conserv 1(6):202–207

Gupta K, Nandy A, Banerjee K, Talapatra SN (2015) Biomonitoring of river Ganga bank by identifying mollusc species as an indicator. Intl Lett Nat Sci 37:71–77

Hammer Ø, Harper DA, Ryan PD (2001) PAST: paleontological statistics software package for education and data analysis. Palaeontol Electron 4(1):9

Higgins K, Hastings A, Sarvela JN, Botsford LW (1997) Stochastic dynamics and deterministic skeletons: population behavior of Dungeness crab. Science 276(5317):1431–1435

Jackson ML (1964) Soil chemical analysis, Prentice Hall Inc4, 448

Jones BF, Bowser CJ (1978) The mineralogy and related chemistry of lake sediments. In Lakes: 179–235

Khan RA (2003) Population dynamics and biology of aquatic gastropod, *Gyraulus convexiusculus* (Hutton) in a small pond. Rec Zool Surv India 101(Part 3–4):25–37

Lind OT (1979) Handbook of common method in limnology. The C.V. Mosby Company 2: 136–145

Liu X, Cao Y, Xue T, Wu R, Zhou YU, Zhou C, Zanatta DT, Ouyang S, Wu X (2017) Genetic structure and diversity of *Nodularia douglasiae* (Bivalvia: Unionida) from the middle and lower Yangtze River drainage. PLoS One 12(12):e0189737

Lorencová E, Horsák M (2019) Environmental drivers of mollusc assemblage diversity in a system of lowland lentic habitats. Hydrobiologia 836(1):49–64

Lundberg P, Ranta E, Ripa J, Kaitala V (2000) Population variability in space and time. Trends Ecol Evol 15(11):460–464

Mahajan M, Fatima S (2017) Frequency, abundance and density of plant species by list count quadrat method. Intl J Multidisc Res 3(7):1–8

McCune B, JBGrace (2002) Analysis of ecological communities. MjM Software Design, Gleneden Beach, Oregon.

Meena DK, Lianthuamluaia L, Mishal P, Swain HS, Naskar BK, Saha S, Sandhya KM, Kumari S, Tayung T, Sarkar UK, Das BK (2019) Assemblage patterns and community structure of macro-zoobenthos and temporal dynamics of eco-physiological indices of two wetlands, in lower gangetic plains under varying ecological regimes: a tool for wetland management. Ecol Eng 130:1–10

Needham JG (1957) A guide to the study freshwater biology with special reference of aquatic insects and other invertebrates animals and phytoplankton, Comstock Publishing Company Inc 4: 1–88

Nesemann H, Sharma G, Sinha R (2011) Benthic macro-invertebrate fauna and "marine elements" sensu Annandale (1922) highlight the valuable dolphin habitat of river Ganga in Bihar-India. Taprobanica: The Journal of Asian Biodiversity 3(1)

Newrkla P, Gunatilaka A (1982) Benthic community metabolism of three Austrian pre-alpine lakes of different tropic conditions and its oxygen dependency. Hydrobiologia 92:531–536

Pathani SS, Upadhyay KK (2006) An inventory on zooplankton, zoobenthos and fish fauna in the river Ram Ganga (W) of Uttaranchal, India. ENVIS Bulletin 14(2):37–46

Pearson TH (1970) The benthic ecology of Loch Linnhe and Loch Eil, a sea–loch system on the west coast of Scotland. The physical environment and distribution of the macrobenthic fauna. Journal of Experimental Marine Biology and Ecology5: 1–34

Piper CS (1966) Soil and plant analysis, Hans. Publisher Bombay. Asian Ed: 368–374

Rao NS (1989) Handbook, freshwater molluscs of India. Zool Surv India 9:1–411

Rao RJ (1991) Studies on biodiversity in the Chambal river. Report submitted to Government of India:1–220.

Sharma KK, Langer S, Sharma R (2011) Water quality and macrobenthic invertebrate fauna of Behlol Nullah, Jammu (J&K). The Ecoscan 5(3&4):111–115

Sinha M, De DK, Jha BC (1998) Management of fisheries in open water system and extension methods. Central Inland Fish Res Inst Bulletin No 87: 1 – 153

Stenseth NC, Bjørnstadf ON, Falck W, Fromentin JM, Gjøsieter J, Gray JS (1999) Dynamics of coastal cod populations: intra-and intercohort density dependence and stochastic processes. Proc R Soc Lond Ser B Biol Sci 266(1429):1645–1654

Syed A, Mir MF, Syed I, Mir AM, Ahangar IA (2012) Macrozoobenthic community as biological indicators of pollution in river Jhelum. Kashmir Univ J Environ Res Technol 2(4):273–279

Tonapi GT (1980) Fresh water animals of India an ecological approach Oxford and IBH. Publishing Company, New Delhi: 431

Vass KK, Mondal SK, Samanta S, Suresh VR, Katiha PK (2010) The environment and fishery status of the River Ganges. Aquat Ecosyst Health Manag 13(4):385–394

Wagle SK, Jha A, Gautam A (2018) Diversity of edible aquatic mollusk and their nutritional contribution in selected Terai districts of Nepal. Narayan Prasad Pandit: 31–50

Welch PS (1948) Limnological methods. Mcgraw Hill Book Company: 381

Wijeyaratne WDN, Bellanthudawa BA (2018) Abundance-biomass comparison approach to assess the environmental stressors in Diyawannawa wetland in monsoonal and non-monsoonal seasons. Sri Lanka J Aqu Sci: 23(2)