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Community structure of benthic macroinvertebrate fauna of river Ichamati, India

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Abstract: Benthic macroinvertebrate communities are frequently applied as indicators of aquatic ecosystem health as many species are responsive to pollution and abrupt changes in their surroundings. The qualities of benthic invertebrate communities greatly depend on habitat conditions. Thus the diversity in benthic community varies with different habitat conditions. This investigation on the structure of the benthic invertebrate communities was conducted on river Ichamati, a trans-boundary river between India and Bangladesh to assess the cumulative effects of water quality on the aquatic biota. The study period extended from February 2011 to January 2014 at three sites from Majdiah to Hasanabad (in West Bengal, India) a stretch of 124km. A total of 23 macrobenthic species belonging to three phyla, five classes and nine orders were identified. Fifteen species of benthic invertebrates belonging to Mollusca, three species under Annelida and five species under Arthropoda were found. The highest abundance density (3633.33 indiv.m^{-2}) and species richness (18 species) were recorded up-stream (Majdiah) where marginal habitats covered by macrophytes were significantly higher than at other sites. Both the organic carbon (4.41±1.11) and organic matter (7.48±1.56) of soil at this site were the maximum thus influencing the richness of benthic macroinvertebrate communities. Hydrological variables, viz, dissolved oxygen, pH, alkalinity; hardness, salinity, nutrients, calcium, and magnesium were studied to determine their influences on the benthic community in the upper, middle- and down-streams of the river, respectively. Shannon's diversity index (0.95–2.07; 0.00–0.72; 0.00–0.64), dominance index (0.57–0.86; 0.00–0.44; 0.00–0.44), evenness index (0.72–0.95; 0.61–1.00; 0.00–1.00), Margalef index (0.72–2.23; 0.00–1.32; 0.00-0.28) of the upper, middle- and down-streams were calculated. Benthic macroinvertebrate density was correlated with hydrological variables which indicated that the abiotic factors had either direct or inverse influence on the richness and abundance; however, the abiotic factors did not correlate identically in all three sites.

Keywords: Diversity indices, hydrological variables, macrophytes, species richness.

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Author Contribution: AB & IS: fieldwork, data analysis and manuscript draft preparation. SR & SD: overall supervision of research work, editing and final manuscript preparation.

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INTRODUCTION

Benthic macroinvertebrates are sedentary or sessile aquatic fauna that exist in the bottom substrates of their habitats (Lenat et al. 1981; Victor & Ogbeibu 1985; Rosenberg & Resh 1993; Idowu & Ugwumba 2005) at least for a part of their life cycle. The benthic fauna perform a key role in nutrient cycling and are also used as food for other aquatic animals (Lind 1979; Milbrink 1983; Jana & Manna 1995). Further they play a critical role as a link in the aquatic food chain affecting bio-geochemical processes in the sediment (Wetzel 2001; Heck et al. 2003; Pokorny´ & Kveˇt 2004; Idowu & Ugwnmba 2005). Benthic invertebrates are difficult to sample especially in deep subsurface sediments. Thus, the species richness and functional importance of freshwater benthic invertebrates usually goes unnoticed until unpredicted changes occur in the ecosystems. Besides these organisms are used as bio-indicators as they frequently respond to pollution stress (Stanford & Spacie 1994; Gamlath & Wijeyartne 1997; Ikomi et al. 2005). The community structure of benthic macroinvertebrates is influenced by the physico-chemical parameters of the water body (Timm et al. 2001; Johnson et al. 2004; Kagalou et al. 2006; Celik et al. 2010). Examination of parameters like richness, diversity, abundance, evenness and community composition are essential to determine the natural or anthropogenic changes with time (Mittermeier & Mittermeier 1997; Dudgeon et al. 2006; Srivastava 2007; Strayer & Dudgeon 2010; Jun et al. 2016). In riverine ecosystem macrobenthic invertebrates show an uneven distribution (Timms 2006).

River Ichamati ('Icha' - fish and 'moti' - pearl), is one of the important trans-boundary rivers between Bangladesh and India, has variable biological, physical and chemical characteristics due to its irregular discharge pattern, diverse habitat arising out of abiotic and anthropogenic activities and both brackish and freshwater characters. Presently, this river is facing various environmental constraints due to siltation, discharge of organic debris from human settlements, production of macrophytic biomass, lack of sanitation and over-fishing (Das et al. 2012). Thus, it is ever more important to preserve the biodiversity of aquatic flora and fauna in this river to lower the risk of sudden unwanted consequences. A number of studies on macrobenthic community structure and hydrochemistry of various water-bodies are well documented (Degani et al. 1992; Jana & Manna 1995; Mancini et al. 2004; Moretti & Callisto 2005; Dolbeth et al. 2007; Sharma & Dhanze 2012; Basu et al. 2013; Mishra & Nautiyal 2013, 2017; Nautiyal & Mishra 2013; Nautiyal et al. 2017).

To the best of our knowledge, information on macrobenthic fauna of river Ichamati is unavailable so far. This encouraged us to undertake the present study on the river to ascertain: (i) the structure and composition of the benthic macroinvertebrate species, (ii) the environmental factors (natural as well as anthropogenic) responsible for the community patterns, (iii) the present ecological status of the river and (iv) determine the quality of water by using benthic fauna to establish the pollution level of the river to create a base line data.

MATERIALS AND METHODS

Description of the study area

The river Ichamati is among the important trans-boundary rivers sharing the boundaries between Bangladesh and India. River Mathabhanga originates from the right bank of Padma at Munshigunj in Kustia District, Bangladesh. It bifurcates near Majhdia (Nadia District, West Bengal, India) creating two rivers, Ichamati and Churni. River Ichamati traverses a course of about 216km and finally discharges into the river Kalindi at Hasnabad in the district of North 24 Parganas and ultimately finds its way into the Bay of Bengal near Moore Island as a part of Kalindi-Raimangal estuary in the deltaic southern part of West Bengal. After about a 19.5km long journey in India it re-enters Bangladesh. It crosses the border again near Duttafulia in Nadia District (West Bengal, India). After a further 21km, it falls into the Bay of Bengal in Bangladesh near Hasnabad and Taki.

The stream at its origin is narrow and shallow clogged by macrophytes such as *Eicchornia, Pistia, Lemna and Alternanthera*. The middle and down reaches of the river are now facing problems due to siltation, high fluvial allochthonus discharges from the river banks, discharge of organic debris from the human settlements along the river, all domestic works such as bathing, washing clothes, utensils, bathing of cattle, lack of sanitation practices, boat ferry, immersion of idols during festivals etc.

The study period extended from February, 2011 to January, 2014 at three sites from Majdiah to Hasanabad (in West Bengal, India) a stretch of 124km. The locations of the sites chosen were (1) near the origin (Majdiah; up-stream, site I), (2) middle part of the stretch (Tetulia; middle-stream, site II), finally Hasanabad (down-stream, site III) before it reaches river Kalindi in the south

(Mondal & Bandyopadhyay 2016).

Locations and characteristics of the sites

Locations of the sites (I, II and III) are marked in Images 1, 2. Physiological and geographical characteristics of the three sites are given in Table 1.

Sampling methods

Water samples were collected from two sampling points (140m apart) in each site in 1 L clean plastic containers between 06:00–08:00 hr during February 2011 to January 2014 twice a month and transported to the laboratory for chemical analyses.

Water temperature was recorded using mercury glass thermometer (0–60 ^{0}C). Electrical conductivity, total dissolved solids (TDS) and pH were measured by ELICO Ion analyzer (Model: PE 138, India). All other water quality variables such as dissolved oxygen (DO), free carbon dioxide, total alkalinity, total hardness, calcium, magnesium, phosphate, nitrate, salinity and transparency, organic matter and organic carbon were monitored following standard protocol, American Public Health Association (APHA) (2005).

Benthic invertebrates were collected twice a month with a specialized box sampler having a dimension of 15 x 15 cm which can penetrate a maximum depth of 15cm (Paul & Nandi 2003). The samples were sieved with No. 40 mesh (pore size: 0.420mm) (Jana & Manna, 1995; Tagliapietra & Sigovini 2010). Considering the depth of the down-stream, desired samples were collected with the help of local fishermen. Collected organisms were preserved in 4% formalin. Benthic macroinvertebrate were then identified following Michael (1977) for the phylum Annelida, Barnes et al. (1988) and Rao (1989) for the phylum Mollusca whereas Arthropoda by the Zoological Survey of India, Kolkata, India. Benthic macroinvertebrates were quantitatively analysed by individual counting of each taxon and expressed in individuals/m^2.

Taxonomic indices was subjected to univariate analyses for studying the benthic community structure using Margalef's richness index, Margalef (1968) for species richness (counts the number of different species in a community), Pielou's Evenness index (Pielou 1966) for species evenness (quantifies the relative abundance of species present in a community), Shannon-Weiner index (Shannon & Weiner 1964) for species diversity (reflects the types of species present in a particular area at a particular time) and Simpson's Dominance Index (Simpson 1949) for dominancy (quantifies the dominancy sharing species in a community). The

Image 1. Course of river Ichamati (Source: Nishat et al. 2014)

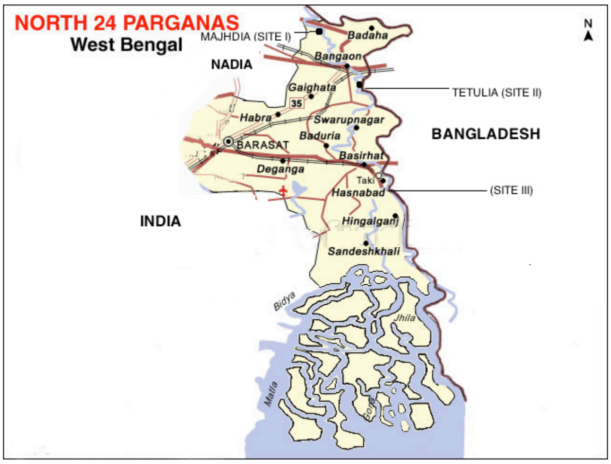

Image 2 . Location of sites (I), (II) and (III) of river Ichamati. (Source: North 24 Parganas Dist Police 2013)

data were computed using Paleontological Statistical software (PAST version 3.15). Pearson correlation (r) was applied to analyse the relationship between the benthic macroinvertebrates density and hydrological variables. The graphs were plotted with MS Excel Software.

RESULTS

The range and average of all water parameters were recorded in Table 2. In the Ichamati, 23 benthic macroinvertebrate species were found from all the samples collected from upper-, middle- and down-streams (Table 3). Of these, up-stream was the richest with species (18) followed by middle-stream (5) and down-stream (2). The maximum density (individual m^{-2}) was found in the following sequence, i.e., up- > middle- > down- streams. Fig. 1 showed the monthly variations of total benthic macroinvertebrate community in three different sites of Ichamati. Benthic macroinvertebrate community was available throughout the year up-stream with peaks in the months of June and September (Fig. 1). Down- and middle-streams showed similar trends where the communities gradually increased from October and reached the maximum in May (Fig. 1). In down-stream, during monsoons (June–September) it was not possible to find and collect any benthic macroinvertebrate samples due to the dangerous rise in water levels and the highly turbulent character of the water. Perhaps, due to the same reason a low concentration of benthic macroinvertebrate was found mid-stream during the monsoons.

The results are presented separately for all three different study sites as follows:

(A) At upper reaches of Ichamati

In the upper-stream, 13 species of Mollusca belonging to class Gastropoda (three orders) and class Bivalvia (one order) dominated the community followed by Annelida (2 orders) and Arthropoda (one order). The population of benthic invertebrates was dominated mainly by three taxa of Mollusca: namely, *Bellamya bengalensis* Lamarck 1822, *Bellamya dissimilis* Muller, 1774 and *Gyraulus convexiusculus* Hutton, 1849 (Table 3). The abundance of *B. bengalensis* increased to maximum density (322.22) in the pre-monsoon period then its population declined. In comparison, the *B. dissimilis* after attaining its population peak in pre-monsoons (255.54) drastically declined in the post-monsoon period (33.33). *B. crassa* was completely absent in pre-monsoon periods. On the other hand, species like *Segmentina* in monsoon and pre-monsoon periods and *Melanoides* in the monsoons were completely absent. *Brotia* and *Bythinia* were found in all seasons (Table 4).

During the investigation, one Bivalvia taxa (*Lamellidens marginalis* Lamarck 1819) was found exclusively in the pre-monsoons. Hutton 1849 found maximum *Gyraulus convexiusculus* (411.10) in the monsoons was another dominant species among Mollusca (Table 4). Further, two species of phylum Annelida (*Glyphidrilus tuberosus* Stephenson, 1916 and *Pheretima posthuma* Kinberg, 1867) could be detected both in monsoon and post-

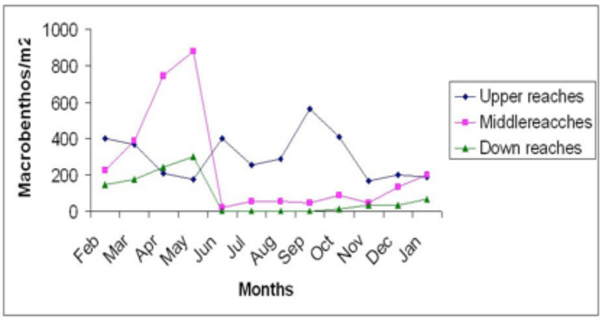

Figure 1. Variations of macrobenthic density in Ichamati

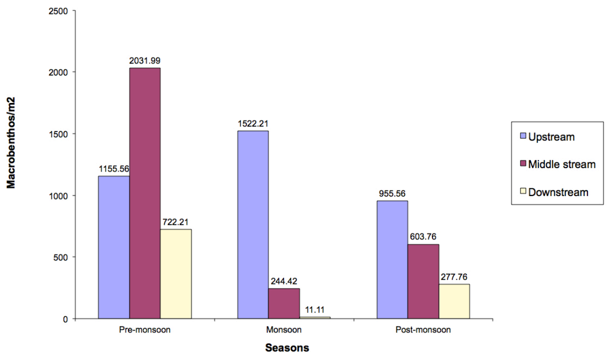

Figure 2. Seasonal variations of macrobenthic abundances in Ichamati at three different sites.

Table 1. Geographical and physical characteristics of three sites of river Ichamati

	Characteristics	Up-stream	Middle-stream	Down-stream
1	Geographical location	23.42049^{0}N & 88.72759^{0}E	22.78593^{0}N & 88.85843^{0}E	22.57190^{0}N, 88.91355^{0}E
2	Depth of river (m) Summer Monsoon	1.0–1.5 1.5–2.0	1.5–3.0 2.5–4.0	8.0–9.0 not measured
3	Width of river (m)	100.00	250.00	400.00
4	Substrate combination	clay, silt, and mud	sine sand, silt, small amount of mud with small pebbles	sand and silt, small amount of mud and gravels
5	Vegetation	aquatic plant present	absent	Absent
6	Land use type Right bank Left bank	none extensive agriculture	village, agriculture, bheri culture, brick kiln	urbanisation, town, bridge construction
7	Anthropogenic interferences	fishing	domestic activities, cattle farming, crematorium, fishing	domestic activities, ferry boat, idol immersion, fishing, sewerage
8	Flow of river	stagnant to gentle	strong	very strong

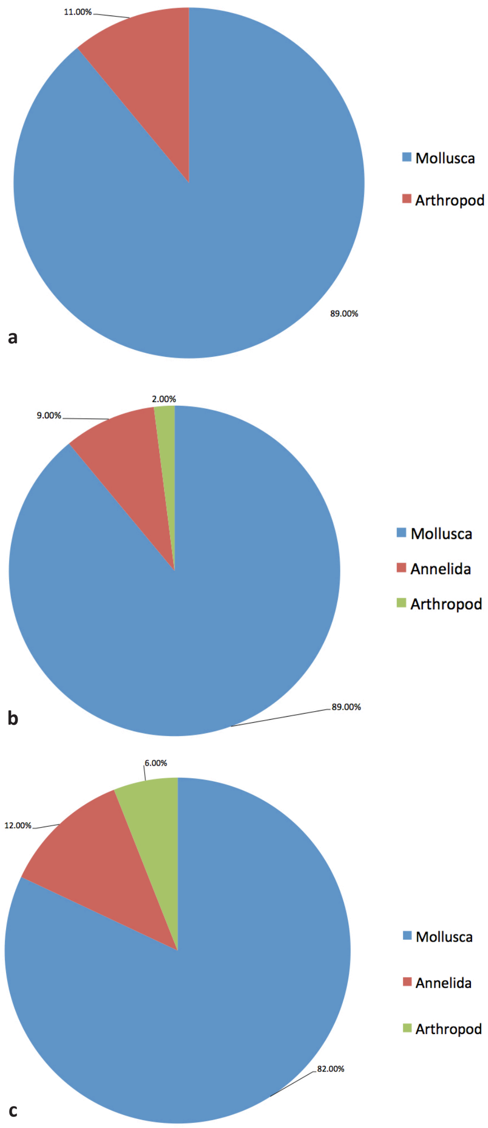

Figure 3. a, b, c - show the community structures of the benthic invertebrates of Ichamati at upper-, middle- and down-reaches, respectively.

Table 2. Limnological variables in Ichamati

Limnological Parameters	Upper reaches	Middle reaches	Down reaches
pH	7.10–8.50 (7.86 ± 0.15)	7.10–8.30 (7.51 ± 0.13)	7.10–8.75 (7.67 ± 0.15)
[a]TDS (ppt)	141.00–353.90 (232.06 ± 19.61)	0.18–14.75 (4.43 ± 1.55)	1.70–17.11 (7.55 ± 1.63)
Water Temperature (°C)	16.50–31.00 (25.21 ± 1.52)	18.00–32.00 (26.67 ± 1.29)	18.6–32.20 (28.21 ± 4.08)
Water Transparency (cm)	17.70–70.00 (37.79 ± 4.93)	5.95–27.50 (13.75 ± 1.64)	4.20–12.75 (7.82 ± 0.79)
Dissolved Oxygen (ppm)	3.40–6.24 (4.50 ± 0.23)	4.02–14.20 (8.31 ± 0.88)	4.00–8.10 (5.61 ± 0.28)
Free [b]CO_2 (ppm)	4.00–12.00 (7.5 ± 0.65)	0.00–8.65 (3.05± 2.61)	0.00–8.00 (3.33 ± 0.83)
Phosphate (ppm)	0.40–0.72 (0.55± 0.02)	0.40–1.46 (0.62 ± 0.09)	0.40–1.40 (0.81 ± 0.09)
Nitrate (ppm)	0.35–0.90 (0.68 ± 0.04)	0.40–2.50 (1.03 ± 0.19)	0.30–1.00 (0.75 ± 0.05)
Total Alkalinity (ppm)	52.80–108.00 (78.21 ± 3.98)	32.00–183.86 (75.24 ± 14.43)	46.60–73.20 (59.75 ± 2.48)
Total Hardness (ppm)	90.00–490.00 (270.27 ± 31.17)	165.30–2772.50 (750.64 ± 242.22)	380.00–3053.00 (1444.34 ± 289.32)
Calcium (ppm)	29.26–86.25 (52.54 ± 5.17)	31.20–532.26 (166.41 ± 54.93)	45.90–308.30 (125.82 ± 23.15)
Magnesium (ppm)	4.14–53.31 (28.66 ± 4.61)	12.80–352.50 (81.85 ± 28.18)	56.05–618.01 (285.81 ± 61.08)
Salinity (ppt)	0.03–0.04 (0.03 ± 0.0005)	0.03–0.47 (0.16 ± 0.05)	0.07–0.48 (0.24 ± 0.04)
Organic Carbon (mg/g)	0.73–11.56 (4.41 ± 1.11)	0.13–6.12 (2.90 ± 0.52)	1.15–6.9 (4.09 ± 0.59)
Organic Matter (mg/g)	1.19–19.56 (7.48 ± 1.56)	0.22–10.52 (4.94 ± 0.9)	1.95–11.73 (3.95 ± 0.78)

[a]TDS = Total dissolved solids, [b]CO_2= Carbon dioxide

monsoon periods. Interestingly, *Sartoriana spingera* Wood-Mason, 1871, was the only Arthropoda found up-stream during the monsoon period (Table 4).

The benthic macroinvertebrate community (Fig. 3a) was dominated by molluscans (82.35%) followed by annelids (11.76%), and arthropods (5.88%) (Fig. 3a). The data on analysis revealed that benthic macroinvertebrate abundance was the highest in post-monsoons followed by pre-monsoon and monsoon periods.

Maximum species diversity (1.79) and Simpson's dominance index (0.79) were recorded in the monsoon period and minimum species diversity (1.58) and dominance index (0.75) in the pre-monsoons. Species richness, i.e., Margalef's index was found to be the maximum during monsoons and minimum in the pre-monsoon period. Pielou's evenness index was found to vary from 0.81 to 0.87 (Table 5).

Water temperature, transparency, free CO_2, salinity, organic carbon, TDS and nutrients were positively correlated with the benthic macroinvertebrate abundance (Table 6). Dissolved oxygen and total alkalinity, two important parameters were negatively correlated with benthic macroinvertebrate density. These water parameters were additionally correlated individually with density of Gastropoda, Bivalvia, Annelida and Arthropoda (Table 7) in up-stream only.

(B) At middle reaches of Ichamati

The benthic macroinvertebrate community was dominated by Mollusca (88.43%) followed by Arthropoda (9.26%) and Annelida (2.31%) (Fig. 3b). Arthropoda *Metapograpsus latifrons* White, 1847 was found maximum (166.66) in post-monsoon whereas *Scylla serrata* Forsskål, 1775 was found only during the

Table 3. Distribution of benthic invertebrates in Ichamati

Benthic invertebrates		Up-stream	Middle-stream	Down-stream
Phylum: I Mollusca Class: I Gastropoda Order: I Mesogastropoda	1. *Brotia costula* Rafinesque, 1833	+	-	-
	2. *Bithynia cerameopoma* Benson, 1830	+	-	-
	3. *Bellamya bengalensis* Lamarck, 1822	+	-	-
	4. *Bellamya dissimilis* Muller, 1774	+	-	-
	5. *Bellamya crassa* Benson, 1836	+	-	-
	6. *Segmentina calatha* Benson, 1850	+	-	-
	7. *Melanoides tuberculata* Muller, 1774	+	-	-
	8. *Gabbia orcula* Frauenfeld, 1862	+	-	-
Order: II Basommatophora	9. *Pseudosuccinea luteola* (Lamarck, 1799)	+	-	-
	10. *Pseudosuccinea acuminate* (Lamarck, 1799)	+	-	-
	11. *Gyraulus convexiusculus* Hutton, 1849	+	-	-
	12. *Indoplanorbis exustus* Deshayes, 1834	+	-	-
Order: III Megagastropoda	13. *Pila globosa* Swainson, 1822	+	+	-
Class: II Bivalvia Order: I Eulamellibranchiata Family: Unionidae	14. *Lamallidens marginalis* Lamarck, 1819	+	-	-
Order: II Mytiloida Family: I Mytilidae	15. *Modiolus striatules* Hanley, 1843	+	+	-
Phylum: II Annelida Class:I Oligochaeta Order :I Ophisthophora	16. *Pheretima postuma* Kinberg, 1867	+	-	-
Order: II Haplotaxida Class: II Polychaeta Order: I Phyllodocida	17. *Glyphidrilus tuberosus* Stephenson, 1916	+	-	-
	18. *Neanthes* sp. Frey & Leuckart, 1847	-	+	-
Phylum: III Arthropoda Subphylum: I Crustacea Order: I Decapoda Family:I Portunidae	19. *Scylla tranquebarica* Fabricius, 1798	-	-	+
	20. *Scylla serrata* Forsskål, 1775	-	+	-
Family: II Gecarcinucidae	21. *Sartoriana spinigera* Wood-Mason, 1871	+	-	-
Family:II Grapsidae	22. *Metapograpsus latifrons* White, 1847	-	+	-
Family: III Ocypodidae	23. *Ocypode macrocera* H. Milne Edwards, 1837	-	-	+

monsoons (Table 4). Only one Annelida, i.e., *Neanthes* was found maximum during pre-monsoons and declined at the onset of the monsoon. *Pila globosa* Swainson 1822, the Gastropoda were identified during monsoon and post-monsoon periods. One bivalvian species, *Modiolus* was recorded in maximum density (1965.33) during pre-monsoons (Table 4). Diversity index and dominance index recorded were the maximum in the monsoons and minimum in the pre-monsoons (Table 5). Evenness index and richness index was found to be maximum in the post-monsoon period.

In the middle-stream, all the water and soil parameters except DO, free CO_2 and phosphate were positively correlated with benthic macroinvertebrate density (Table 6).

(C) At down reaches of Ichamati

The benthic macroinvertebrate community (Fig. 3c) was dominated by Mollusca (89.01%) followed by Arthropoda (10.99%; Fig. 3c). Two species of Arthropoda, *Ocypode sp.* were absent in the monsoons but were present in pre- and post-monsoon periods (Table 4). *Scylla tranquebarica* was minimum (11.11) in the monsoons, but found in the other two seasons. One bivalvian species *Modiolus* was maximum (711.10) during pre-monsoons (Table 4). All the taxonomic indices determined (Table 5) were found to have maximum values in post-monsoon and minimum in monsoon periods.

In down-stream, total alkalinity, phosphate, organic carbon and organic matter were negatively correlated with benthic macroinvertebrate density, the rest of the parameters were positively correlated (Table 6).

DISCUSSION

The glory of river Ichamati has faded a lot with time. Ichamati now faces problems like forcible land occupation, weed infestation, different environment hazards due to lack of sanitation facilities, encroachment, ground water contamination etc. Destruction of aquatic flora and fauna in the river is the most serious problem regarding the ecosystem.

The important factors that affect the abundance of benthic macroinvertebrate fauna in a given community include the hydro-biology of water, substrate of occupants and food availability (Olenin 1997; Nelson & Lieberman 2002; Carlisle et al. 2007; Coleman et al. 2007; Li et al. 2012; Basu et al. 2013).

The pH of water of all three sites indicated the alkaline nature of the water; the pH of the up-stream was the highest (7.86 ± 0.15) compared to the two other sites. The richness of diversity of benthic macroinvertebrates was found maximum in up-stream due probably to the alkaline nature and shallow depth of the river. Simpson et al. (1985), Feldman & Connor (1992) and Baldigo et al. (2009) also found that the site with the higher pH had a higher diversity of benthic macroinvertebrates.

Benthic macroinvertebrates density was negatively correlated with DO level as they could survive in poor DO conditions. In this study the low dissolved oxygen content observed in up-stream water might be due to the high organic matter decomposition from macrophyte vegetation and also bottom type which contained high percentage of mud (Sandin 2003; Williams & Gormally 2009; Jiang et al. 2010; Schultz & Dibble 2012; Zybek et al.2012). The high DO contents in middle- and down-streams were attributed to non-vegetation and strong water current characteristics of these two sites (Soszka 1975; Cogerino et al. 1995).

The low density of benthic macroinvertebrate was observed during the present study in all three sites particularly in middle- and down- streams. The species richness of benthic macroinvertebrate were found to be the highest in up-stream probably due to suitable habitat conditions, organically enriched soft bottom (Ingole et al. 2002), slow water current, shallow depth (Roy & Gupta 2010), bottom substrate (muddy and clayey) and the presence of macrophytes in marginal water (Kumar et al. 2013; Tall et al. 2016).

Molluscans were mostly associated with very low oxygen and lentic ecosystems (Spyra 2010). The up-stream of Ichamati was enriched with molluscan density (13 species). The water in this region was motionless and had a shallow substratum with decomposed organic matter which facilitated the molluscans growth, especially Gastropoda (Principe & Corrigliano 2006; Zybek et al. 2012). The lowest concentrations of salinity, hardness and alkalinity of water may have enhanced the abundance of species in the up-stream, hence these parameters showed the negative correlations with benthic macroinvertebrate densities. This was

Table 4. Average density of benthic macroinvertebrates in up-, middle- and down- streams of Ichamati

A. Up-stream I. Molluscs (Individuals/m^2)	**Pre-monsoon**	**Monsoon**	**Post-monsoon**
Brotia costula	66.66	88.88	88.88
Bythinia cerameopoma	44.44	144.44	199.99
Pseudosuccinea acuminata	55.55	11.11	11.11
Pseudosuccinea luteola	111.10	11.11	44.44
Gyraulus convexiusculus	44.44	411.1	77.77
Bellamya bengalensis	322.22	233.32	233.31
Bellamya dissimilis	255.54	233.32	33.33
Bellamya crassa	0	77.77	33.33
Segmentina calatha	0	0	22.22
Melanoides tuberculata	0	0	55.55
Lamellidens marginalis	11.11	0	0
Indoplanorbis exustus	144.44	88.88	0
Gabbia orcula	88.88	44.44	66.67
Pila globosa	11.11	22.22	11.11
II. Annelids (Individuals/m^2)			
Glyphidrilus tuberosus	0	11.11	22.22
Pheretima postuma	0	88.88	55.55
III. Arthropods (Individuals/m^2)			
Sartoriana spinigera	0	55.55	0
B. Middle-stream			
I. Molluscs (Individuals/m^2)			
Pila globosa	0	144.43	66.66
Modiolus striatules	1965.33	0	370.44
II. Annelids (Individuals/m^2)			
Neanthes sp.	44.44	22.22	0
III. Arthropods (Individuals/m^2)			
Scylla serrata	0	44.44	0
Metapograpsus latifrons	0	55.55	166.66
C. Down-stream			
I. Molluscs (Individuals/m^2)			
Modiolus striatules	711.10	0	188.88
II. Arthropods (Individuals/m^2)			
Ocypode sp.	33.33	0	55.55
Scylla transquebarica	55.55	11.11	44.44

Table 5. Taxonomic indices of benthic macroinvertebrate community in river Ichamati

Seasons	Dominance index			Shannon's diversity index			Evenness index			Margalef's index		
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Pre-monsoon	0.75	0.02	0.44	1.58	0.05	0.07	0.87	0.90	0.42	1.52	0.03	0.04
Monsoon	0.79	0.17	0.00	1.79	0.26	0.00	0.79	0.92	0.25	1.94	0.12	0.00
Post-monsoon	0.77	0.11	0.17	1.64	0.19	0.27	0.81	0.96	0.93	1.80	0.35	0.12

Table 6. Correlation among limnological parameters and benthic macroinvertebrate density.

	Limnological parameters	Up-stream	Middle-stream	Down-stream
Macro-benthos density/m^2	Water temperature (^{0}C)	0.33[a]	0.02	0.62
	Water transparency (cm)	0.07	-0.03	-0.55
	pH	-0.05	0.78[c]	0.12
	Dissolved Oxygen (ppm)	-0.17[a]	-0.24[a]	0.00
	Free [d]CO_2 (ppm)	0.10[a]	-0.17[a]	-0.24[b]
	Total alkalinity (ppm)	-0.02	0.85[c]	-0.37[a]
	Total hardness(ppm)	-0.01	0.95[c]	0.48[a]
	Calcium (ppm)	-0.16[a]	0.95[c]	0.55[b]
	Magnesium (ppm)	0.06	0.86	0.47
	Phosphate (ppm)	0.29[a]	-0.08	-0.37[a]
	Nitrate (ppm)	0.17[a]	0.55[b]	0.05
	Salinity (ppt)	0.06	0.93[c]	0.50[b]
	[e]EC (ms)	-0.32	0.91	-0.67
	[f]TDS (ppt)	0.23	0.90	0.53
	Organic carbon (mg/g)	0.47[a]	0.48[a]	-0.30[a]
	Organic matter (mg/g)	0.47[a]	0.48[a]	-0.03

[a] = 5% level of significance; [b] =1% level of significance; [c] = 0.1% level of significance, [d] = carbon dioxide, [e] = electrical conductivity, [f] = total dissolved solids

Table 7. Correlation among limnological parameters and benthic macroinvertebrates density at up-stream.

Limnological parameters	Gastropoda	Bivalvia	Annelida	Arthropoda
Water temperature (^{0}C)	0.95[c]	0.34[a]	-0.14[a]	0.64[b]
Water transparency (cm)	-0.58[b]	-0.84[c]	0.70[c]	-0.05
pH	0.85[c]	0.47[a]	0.65[b]	-0.99[c]
Dissolved Oxygen (ppm)	-0.38[a]	-0.90[c]	-0.97[c]	0.82[c]
Total alkalinity (ppm)	0.96[c]	0.33[a]	-0.13[a]	0.65[b]
Total hardness (ppm)	-0.88[c]	0.43[a]	-0.61[b]	-0.99[c]
Calcium (ppm)	-0.98[c]	-0.24[a]	0.03	-0.72[c]
Magnesium (ppm)	-0.51[a]	-0.88[c]	0.77[c]	0.04
Phosphate (ppm)	0.99[c]	0.08	0.13[a]	0.82[c]
Nitrate (ppm)	0.97[c]	-0.17[a]	0.37[a]	0.94[c]
Salinity (ppt)	0.05	1	-0.98[c]	-0.5[a]
[d]EC (ms)	-0.98[c]	-0.23[a]	0.02	-0.72[c]
[e]TDS (ppt)	-0.99[c]	-0.14[a]	-0.07	-0.79[c]
Organic carbon (mg/g)	0.87[c]	-0.45[a]	0.63[b]	0.99[c]
Organic matter (mg/g)	0.86[c]	-0.45[a]	0.63[b]	0.99[c]

[a] = 5% level of significance; [b] =1% level of significance; [c] = 0.1% level of significance, [d] = electrical conductivity, [e] = total dissolved solids

further substantiated by the observation of Brucet et al. (2012). Two oligochaetes, *Pheretima posthuma* and *Glyphidrilus tuberosus* were present up-stream due to their preference for organically enriched polluted water bodies with low oxygen content, also noted by Barquin & Beath (2011). This was further corroborated by the negative correlation with dissolved oxygen, total hardness, total alkalinity and positive correlation with nutrients, organic carbon and organic matter (Table 6). *Pheretima,* though a terrestrial species, was found during monsoon and post-monsoon periods when the riverbank was flooded. Possibly because of inundation, they were found within 1m inside the river from the edge during these periods; however, Brraich & Kaur (2017) very recently described the abundance of *Pheretima* in 'Wetland of National Importance', the Nangal wetland which came into existence with the construction of a barrage on the River Satluj, Punjab, India.

Gyraulus convexiusculus was found in all seasons in the upper reaches of Ichamati. A similar observation was reported on macroinvertebrates communities by Fisher & Williams (2006) and Spyra & Strzelec (2013) where *Gyraulus* sp. was found in all seasons.

During pre-monsoon and monsoon periods, the maximum species diversity was noted in the upper reaches. Jana & Manna (1995), Khalua et al. (2008) and Roy et al. (2008) also demonstrated the benthic abundance during these periods. Benthic macroinvertebrate density was high during both pre-monsoon and monsoon periods which may be attributed to the availability of appropriately nutrient-rich water and soft and organically rich bottom soil. Similar studies were reported by Beauchard et al. (2003) on African rivers and Li et al. (2012) on stream macroinvertebrates.

In this study the positive correlation between nutrients and organic matter with benthic macroinvertebrate density supports the observation. It was interesting to note that species like *Segmentina*, *Melanoides* and *Lamellidens*, were not found during the monsoons, probably due to increased water levels and a relatively strong water current to unsettle the bottom substrate on which these species were attached (Koperski 2011). In this study it was observed that the species richness of freshwater Gastropoda depended on the type of bottom substrate and the richness of aquatic macrophytes (Lodge 1985; Perez 2004; Spyra 2010). The density of Gastropoda was positively correlated with phosphate, nitrate, total alkalinity, TDS, pH, organic carbon and organic matter (Table 6) and supported by Pip (1987) and Williams & Gormally (2009).

In middle-stream, a very low species diversity comprising of two species of Mollusca (with one Gastropoda and one Bivalvia) and only one Polychaeta (*Neanthes sp*.) were observed. Polychaetes preferred fine to medium type of sandy bottom with moderate abundance of admixtures of silt and clay (Al-khayat 2005). The middle-stream had a very similar bottom type. Molluscan diversity was meager probably due to the high flow of river water and a particular bottom type (sand and clay). The Benthic macroinvertebrates experienced threats by the changes in its habitats associated with pollution and siltation. Moreover, the poor growth of bottom fauna could be associated with frequent water level fluctuations. The dependence of benthic macroinvertebrate fauna on a number of factors such as physical nature of the substratum, depth, nutritive contents, degree of stability and oxygen concentration of the water body (Barbour et al. 1999; Merz & Chan 2005; Braccia & Voshell 2006) was reflected by the findings of this investigation that in middle-stream - substratum, depth, nutrition and oxygen concentrations were not congenial for benthic macroinvertebrate diversity to flourish. This was supported further by the negative correlation between density and phosphate as well as oxygen concentrations studied. Presence of *Pila globosa* (Gastropoda) and *Neanthes sp.* (Polychaeta) indicated the freshness of the water (Perez 2004). Benthic macroinvertebrate in middle reaches were observed in the highest concentration level during pre-monsoons probably due to the maximum occurrence of *Modiolus sp*. (Bivalvia). It was likely that the species utilized the elevated concentration of calcium in the water during pre-monsoons contributing to the increase in the benthic macroinvertebrate density.

Meager existence of benthic macroinvertebrate diversity in down-stream might be related to the depth of water, soaring water current, increased siltation, anthropogenic disturbances and unstable substratum (as noted by the studies of Kroncke & Reiss (2010), Xu et al. (2014). Absence of macrobenthos during monsoons was probably due to high turbulence and depth of water in the down-stream. Moreover, increased anthropogenic activities (organic debris from adjoining localities, ferry boats across the river, immersion of idols, domestic daily activities, river bank occupation by factories like brick kilns etc.) at this station caused substratum instability of macrobenthic community (Leprieur et al. 2008). The destructive effects of anthropogenic activities on different estuarine communities were recorded by Patricio & Marquis (2006); Dolbeth et al. (2007); Geetha et al. (2010). The presence or absence of benthic macroinvertebrates could be a good indicator of both chronic and episodic impact of human disturbances to river conditions (Hellawell 1986; Stanford & Spacie 1994; Pinel-Alloul et al. 1996; Gamlath & Wijeyaratne 1997). The plausible reasons for the complete absence of benthos at this site might be dominated by the silt in the sediment (Cloern 2001; Bode & Varela 2006).

Hydrological conditions such as extreme hard water and salinity alteration (due to freshwater inflow during monsoons) and food availability were major factors affecting the community dynamics of benthic invertebrates (Brucet et al. 2012).

Water temperature showed a positive correlation with benthos density. During the pre-monsoon period (summer: March–June) density of benthic macroinvertebrates were higher than the post-monsoon period (winter: November–December) in all three sites presumably indicating that the temperature had a positive influence on the benthic macroinvertebrate community as noted by Hauer & Hill (1996) and Sharma & Rawat (2009).

Water transparency was positively correlated with the benthic invertebrates as also noted by Basu et al. (2013). A significant positive correlation was found between organic carbon content of soil, organic matter and benthic invertebrate density. The presence of aquatic vegetation in the study area supported the availability of more organic matter (Bath et al. 1999; Rosenberg 2001; Mikulyuk et al. 2011; Basu et al. 2013).

Community structure index is a measurement for two distinct aspects of biological community: (i) number of taxa (richness) and (ii) distribution of individuals among taxa (evenness). Diversity indices depend on the quality and availability of habitat (Barbour et al. 1999). Mason (1996) set diversity index <1 for highly polluted, 1–3 for moderately polluted and >4 for unpolluted water bodies. In up-stream the diversity index (Table 5) indicated moderately polluted water and the presence of a rich habitat. In middle- and down- streams the diversity index indicated more polluted water than up-stream. In this study, the evenness indices of all three sites indicated that the taxa identified were consistently distributed (Table 5) in all sites.

The results pointed out that benthic macroinvertebrate diversity was very poor in middle- and down- streams but had a moderate population in up-stream. Structure of macrobenthic population was mainly driven by seasonal variations, depth of water, water current, habitat type, riverbed characteristics and influence of anthropogenic interferences. The macrophyte vegetated marginal habitats supported greater species richness and abundance (up-stream) than non-vegetated habitats (middle- and down-streams). The Mollusca could be regarded as a bio-indicator species thus indicated a good water condition of the river. It was evident from the investigations that the seasonal changes in the hydrological parameters influenced the community structure of the benthic invertebrates in river Ichamati.

REFERENCES

Al-Khayat, J.A. (2005). Some macrobenthic invertebrates in the Qatari waters, *Arabian Gulf. Qatar University Science Bulletin* 25: 126–136.

APHA (2005). *Standard Methods for the Examination of Water and Waste Water - 21st Edition*. American Public Health Association, Washington, D.C.

Baldigo, B.P., G.B. Lawrence, R.W. Bode, H.A. Simonin, K.M. Roy & A.J. Smith (2009). Impacts of acidification on macroinvertebrate communities in streams of the western Adirondack mountains, New York, USA. *Ecological Indictors* 9(2): 226–239; http://doi.org/10.1016/j.ecolind.2008.04.004

Barbour, M.T., J. Gerritsen, B.D. Snyder & J.B. Stribling (1999). *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macro invertebrates and Fish - 2nd Edition*. EPA 841-B-99-002, U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Barnes, R.S.K., P. Callow & P.J.W. Olive (1988). *The invertebrates: A New Synthesis.* Blackwell Scientific Publications, Oxford, 582pp.

Barquin, J. & R.G. Beath (2011). Down-stream changes in spring-fed stream invertebrate communities: the effect of increased temperature range. *Journal of limnology* 70(1): 134–146; http://doi.org/10.3274/JL11-70-S1-10

Basu, A., S. Sengupta, S. Dutta, A. Saha, P. Ghosh & S. Roy (2013). Studies on macreobenthic organisms in relation to water parameters at east Calcutta wetlands. *Journal of Environmental Biology* 34: 733–737.

Bath, K.S., H. Kaur & S.S. Dhillon (1999). Correlation of Molluscs with physico-chemical factors at Harike Reservoir (Punjab). *Indian Journal of Environmental Science* 3: 159–163.

Beauchard, O., J. Gagneur & S. Brosse (2003). Macroinvertebrate richness patterns in North African streams. *Journal of Biogeography* 30: 1821–1833.

Bode, A.-O.M.T. & M. Varela (2006). Phytoplankton and macrophytes contributions littoral food webs in the Galician upwelling estimated from stable isotopes. *Marine Ecology Progress Series* 318: 89–102.

Braccia, A. & J.R. Voshell (2006). Environmental factors accounting for benthic macroinvertebrate assemblage structure at the sample scale in streams subjected to a gradient of cattle grazing. *Hydrobiologia* 573: 55–73.

Brraich, O.S. & R. Kaur (2017). Temporal composition and distribution of benthic macroinvertebrates in wetlands. *Current Science* 112(1): 116–125; http://doi.org/10.18520/cs/v112/i01/116-125

Brucet, S., D. Boix, L.W. Nathansen, X.D. Quintana, E. Jensen, D. Balayla, M. Meerhoff & E. Jeppesen (2012). Effects of temperature, salinity and fish in structuring the macroinvertebrate community in shallow lakes: implications for effects of climate change. *PLoS ONE* 7(2): e30877; http://doi.org/10.1371/journal.pone.0030877

Carlisle, D., M.R. Meador, S.R. Moulton & P.M. Ruhi (2007). Estimation and application of indicator value for common macro-invertebrates. *Ecological Indicator* 7: 22–33; http://doi.org/10.1016/j.ecolind.2005.09.005

Celik, K., N. Akbulut, A. Akbulut & D. Ozatli (2010). Macro zoobenthos of lake Uluabat, Turkey, related to some physical and chemical parameters. *Pan-American Journal of Aquatic Sciences* 5(4): 520–529.

Cloern, J.E. (2001). Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series* 210: 223–253.

Cogerino, I., B. Cellot & M. Bournaud (1995). Microhabitat diversity and associated macroinvertebrates in aquatic banks of a large European river. *Hydrobiologia* 304: 103–115.

Coleman, N., W. Cuff, J. Moverley, A.S.H. Gason & S. Heislers (2007). Depth, sediment type, biogeography and high species richness in shallow-water benthos. *Marine and Freshwater Research* 58(3): 293–305; http://doi.org/10.1071/MF06098

Das, M.K., M. Naskar, M.L. Mondal, P.K. Srivastava , S. Dey & A. Rej (2012). Influence of ecological factors on the patterns of fish species richness in tropical Indian rivers. *Acta Ichthyologica Et Piscatoria* 42(1): 47–58; http://doi.org/10.3750/AIP2011.42.1.06

Degani, G., G.N. Herbest, R. Ortal, H.J. Bromley, P. Levanon, H. Glazman & Y. Regev (1992). Faunal relationships to abiotic factors along the river Dan in northern Israel. *Hydrobiologia* 246: 69–82.

Dolbeth, M.C., P.G. Ferreira, S.M. Verdelhos, T.D. Raffaelli & M.A. Pardel (2007). Anthropogenic and natural effects on a macrobenthic esturiane community over a 10 year period. *Marine Pollution Bulletin* 54: 576–585.

Dudgeon, D., A.H. Arthington, M.O. Gessner, Z. Kawabata, D.J. Knowler, C. Lévêque, R.J. Naiman, A.H. Prieur-Richard, D. Soto, M.L. Stiassny & C.A. Sullivan (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological reviews of the Cambridge Philosophical Society* 81(2): 163–182; http://doi.org/10.1017/S1464793105006950

Feldman, R.S. & E.F. Connor (1992). The relationship between pH and community structure of invertebrates in streams of the Shenandoah National Park, Virginia, U.S.A. *Freshwater Biology* 27(2): 261–276; http://doi.org/10.1111/j.1365-2427.1992.tb00538.x

Fisher, M.R. & W.P. Williams (2006). A feasibility study to monitor the macroinvertebrate diversity of the River Nile using three sampling methods. *Hydrobiologia* 56:137–147; http://doi.org/10.1007/s10750-005-1262-6

Gamlath, G.A.R .K. & M.J.S. Wijeyaratne (1997). Indicator organisms of environmental condition in a lotic water body in Srilanka. *Srilanka Journal of Aquatic Sciences* 2: 121–129.

Geetha, P.N., T.A. Thasneem & S.B. Nandan (2010). Macrobenthos and its relation to ecosystem dynamics in the Cochin estuary. Lake 2010: Wetlands, Biodiversity and Climate Change. Indian Institute of Science, Bangalore, India. 22nd–24th December, 1–12 pp.

Hauer, F.R. & W.R. Hill (1996). Temperature, light and oxygenn, pp. 103–117. In: Hauer, F.R. & G.A. Lamberti (eds.). *Methods in Stream Ecology - 2rd Edition*. San Diego, Academic Press, 877pp.

Heck, K.I., G. Hays & R.J. Orth (2003). Critical evaluation ofthe nursery role hypothesis for seagrass meadows. *Marine Ecology Progress Series* 253: 123–136.

Hellawell, J.M. (1986). *Biological Indicators of Freshwater Pollution and Environmental Management*. Elsevier Applied Sciences Publishers, London, New York, 546pp.

Idowu, E.O. & A.A.A. Ugwumba (2005). Physical, chemical and benthic faunal characteristics of a southern Nigeria reservoir. *The Zoologist* 3: 15–25.

Ikomi, R.B, F.O. Arimoro & O.K. Odihirin (2005). Composition, distribution and abundance of macroinvetebrates of the upper reaches of River Ethiope, Delta State, Nigeria. *The Zoologist* 3: 68–81.

Ingole B., N. Rodriguez & Z.A. Ansari (2002). Macro benthic communities of the coastal waters of Dabhol, West coast of India. *Indian Journal of Marine Sciences* 31(2): 93–99.

Nishat, B., S.K. Chakraborty, M.E. Hasan & A.J.M.Z. Rahman (2014). *Rivers Beyond Borders: India Bangladesh Trans-boundary River Atlas. Ecosystems for Life: A Bangladesh-India Initiative*, IUCN, International Union for Conservation of Nature, Drik publication, Dhaka, Bangladesh, xx+152pp.

Jana, B.B. & A.K. Manna (1995). Seasonal changes of benthic invertebrates in two tropical fish ponds. *Journal of Freshwater Biology* 7(2): 129–136.

Jiang, X.M., J. Xiong, J.J.W. Qiu, J.M. Wu, J.W. Wang & Z.C. Xie (2010). Structure of macroinvertebrate communities in relation to environmental variables in a subtropical Asian river system. *International Review of Hydrobiology* 95: 42–57.

Johnson, R.K., W. Goedkoop & L. Sandin (2004). Spatial scale and ecological relationships between the macroinvertebrate communities of stony habitats of streams and lakes. *Freshwater Biology* 49: 1179–1194.

Jun, Y.C., N.Y. Kim, S.H. Kim, Y.S. Park, D.S. Kong & S.J. Hwang (2016). Spatial distribution of benthic macroinvertebrate assemblages in relation to environmental variables in Korean Nationwide Streams. *Water* 8: 27; http://doi.org/10.3390/w8010027

Kagalou, I., G. Economidis, I. Leonardos & C. Papaloukas (2006). Assessment of a Mediterranean shallow lentic ecosystem (Lake Pamvotis, Greece) using benthic community diversity: Response to environmental parameters. *Limnologica* 36: 269–278.

Khalua, R.K., G. Chakravarty & S.K. Chakraborty (2008). *Community Structure of Macrobenthic Mollusks of Three Contrasting Intertidal Belts of Midnapur Coast, West Bengal, India*. Zoological Research in Human Welfare, Published-Director, Zoological Survey of India, Kolkata, 484pp.

Kroncke, I & H. Reiss (2010). Influence of macrofauna long-term natural variability on benthic indices used in ecological quality assessment. *Marine Pollution Bulletin* 60(1): 58–68.

Koperski, P. (2011). Diversity of freshwater macrobenthos and its use in biological assessment: a critical review of current applications. *Environmental Review* 19: 16–31; http://doi.org/10.1139/A10-023

Kumar, R., H. Nesewann, G. Sharma, T. Li-Chun, A.K. Prabhakar & S.P. Roy (2013). Community structure of macrobenthic invertebrates in the river Ganga in Bihar, India. *Aquatic Ecoystem, Health and Management* 16(4): 385–394.

Lenat, D.R., D.L.S. Penrose & K.W. Eagles (1981). Variable effects of Sediment addition on stream benthos. *Hydrobiologia* 79: 187–194.

Leprieur, F., O. Beauchard, S. Blanchet, T. Oberdorff & S. Brosse (2008). Fish invasions in the world's river systems: when natural processes are blurred by human activities. *PLoS biology* 6(12): e28: http://doi.org/10.1371/journal.pbio.0060028

Li, F., N. Chung, M.J. Bae, Y.S. Kwon & Y.S. Park (2012). Relationships between stream macroinvertebrates and environmental variables at multiple spatial scales. *Freshwater Biology* 57: 2107–2124.

Lind, O.T. (1979). *Handbook of Common Method in limnology 2nd Edition*, The C.V. Mosby Company, St. Louis, USA, 136–145pp.

Lodge, D.M. (1985). Macrophyte-gastropod associations: observations and experiments on macrophyte choice by gastropods. *Freshwater Biology* 15: 695–708.

Mancini, L., P. Formichetti, J.G. Morgana, L.Tancioni, A.M. D'Angelo, P. P.Danieli, E. Pierdominici, M. Iaconelli & P. Andreani (2004). Analysis of macrobenthic communities in the river basins of Central Italy. *Limnetica* 23(3–4): 199–208.

Margalef, R. (1968). *Perspectives in Ecological Theory*. University of Chicago Press, Chicago, USA.

Mason, C.F. (1996). *Biology of Freshwater Pollution*. *3rd Edition*. Longman, England, 356pp.

Merz, J.R. & L.K.O. Chan (2005). Effects of gravel augmentation on macroinvertebrate assemblages in a regulated California river. *River Research and Applications* 21: 61–74; http://doi.org/10.1002/rra.819

Michael, Q. (1977). *Invertebrates of Streams and Rivers: A Key to Identification*. Edward Arnold Publishers Ltd., London, 84pp.

Milbrink, G. (1983). An improved environmental index based on the relative abundance of Oligochaeta species. *Hydrobiology* 102: 89–97; http://doi.org/10.1007/BF00006072

Mikulyuk, A., S. Sharma, S.V. Egeren, E. Erdmann, M.E. Nault & J. Hauxwell (2011). The relative role of environmental, spatial, and land-use patterns in explaining aquatic macrophyte community composition. *Canadian Journal of Fisheries and Aquatic Sciences* 68: 1778–1789.

Mishra, A.S. & P. Nautiyal (2013). Functional composition of benthic macroinvertebrate fauna in the plateau rivers, Bundelkhand, central India. *Journal of Threatened Taxa* 5(13): 4752–4758; http://doi.org/10.11609/JoTT.o3226.4752-8

Mishra, A.S. & P. Nautiyal (2017). Canonical correspondence analysis for determining distributional patterns of benthic macroinvertebrate fauna in the lotic ecosystem. *Indian Journal of Ecology* 44(4): 697–705.

Mittermeier, R.A. & C.G. Mittermeier (1997). Megadiversity: earth's biologically wealthiest nation, pp 1–140. In: McAllister, D.E., A.L. Hamilton & B. Harvery (eds.). *Global Freshwater Biodiversity - Vol. 11.* Sea Wind, Cemex, Mexico City.

Mondal, I. & J. Bandyopadhyay (2016). Physicochemical Analysis of Ichamati River and Estimation of Soil Parameters using Geospatial Technology. *Journal of The Institution of Engineers (India): Series E* 97(2): 151–158; http://doi.org/10.1007/s40034-016-0086-4

Moretti, M.S. & M. Callisto (2005). Biomonitoring of benthic macro invertebrates in the middle Doce river watershed. *Acta Limnologica Brasiliensia* 17(3): 267–281.

Nautiyal, P. & A.S. Mishra (2013). Variations in benthic macroinvertebratefauna as indicator of land use in the Ken River, central India. *Journal of Threatened Taxa* 5(7): 4096–4105; http://doi.org/10.11609/JoTT.o3211.4096-105

Nautiyal, P., A. S. Mishra, J. Verma & A. Agrawal (2017). River ecosystems of the Central Highland ecoregion: Spatial distribution of benthic flora and fauna in the Plateau rivers (tributaries of the Yamuna and Ganga) in Central India. *Aquatic Ecosystem Health & Management* 20(1–2): 43–58; http://doi.org/10.1080/14634988.2017.1296324

Nelson, S.M. & D.M. Lieberman (2002). The influence of flow and other environmental factor on benthic invertebrates in the Sacramento River, USA. *Hydrobiologia* 489: 117–129.

North 24 Parganas Dist Police (2013). Know Your Police Station. Retrieved May 13, 2018, from http://n24pgspolice.in/home/police-station.php .

Olenin, S. (1997). Benthic zonation of the Eastern Gotland Basin. *Netherlands Journal of Aquatic Ecology* 30: 265–282; http://doi.org/10.1007/BF02085871

Patricio, J. & A.R. Marquis (2006). Mass balanced models of the food web in three areas along gradient eutrophication in three areas along gradient eutrophication symptoms in the South arm of the Mondege estuary (Portugal). *Ecological Modeling* 197: 21–34; http://doi.org/10.1016/j.ecolmodel.2006.03.008

Paul, S. & N.C. Nandi (2003). Studies on intertidal macrobenthos of Hugli River in and around Calcutta in relation to water and soil conditions. *Records of the Zoological Survey of India, Kolkata*. Occasional Paper No. 213: 1–135.

Perez, K.E. (2004). *Planorbidae*, pp. 40–43. In: Perez K.E., S.A.

Clark & C. Lydeard (eds.). *Freshwater Gastropod, Identification Workshop "Showing your Shells" A Primer to Freshwater Gastropod Identification*. Freshwater Mollusk Conservation Society, University of Alabama,Tuscaloosa, Alabama.

Pielou, E.C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13: 131–144; http://doi.org/10.1016/0022-5193(66)90013-0

Pinel-Alloul, B., G.Methot, L. Lapierre & A. Willsie (1996). Macrobenthic community as a biological indicator of ecological and toxicological factors in Lake Saint-Francois (Quebec). *Environmental Pollution* 91: 65–87.

Pip, E. (1987). Species richness of freshwater gastropod communities in Central North America. *Journal of Molluscan Studies* 53(2): 163–170.

Pokorny´, J. & J. Kveˇt (2004). Aquatic plants and lake ecosystems, pp. 309–340. In: O'Sullivan, P.E. & C.S. Reynolds (eds.). *The Lakes Handbook*, *Vol. 1.* Limnology and Limnetic Ecology. Blackwell, Malden, Massachusetts.

Principe, R.E. & M.C. Corrigliano (2006). Benthic, drifting and marginal macroinvertebrate assemblages in a low land river: temporal and spatial variations and Size structure. *Hydrobiologia* 553(1): 303–317.

Rao, N.V.S. (1989). *HandBook. Freshwater Molluscs of India*. Zoological Survey of India, Kolkata, India.

Rosenberg, D.M. & V.H. Resh (1993). *Freshwater Biomonitoring and Benthic Macroinvertebrates.* Chapman and Hall, New York. 488pp.

Rosenberg, R. (2001). Marine benthic faunal successional stages and related sedimentary activity. *Scientia Marina* 65: 107–119; http://doi.org/10.3989/scimar.2001.65s2107

Roy, M., A. Dey, S. Banerjee & N.C. Nandi (2008). Molluscan macrobenthic diversity of brackishwater wetlands in West Bengal. *Zoological Research in Human Welfare*. Zoological Survey of India, Kolkata, 25–34pp.

Roy, S. & A. Gupta (2010). Molluscan diversity in river Barak and its tributaries, Assam, India. *Assam University Journal of Science and Technology: Biological and Environmental Science* 5(1): 109–113.

Sandin, L. (2003). Benthic macroinvertebrates in Swedish streams: Community structure, taxon richness, and environmental relations. *Ecography* 26: 269–282.

Schultz, R. & E. Dibble (2012). Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits. *Hydrobiologia* 84(1): 1–14; http://doi.org/10.1007/s10750-011-0978-8

Shannon, C.F. & W. Weiner (1964). *The Mathematical Theory of Communications.* The University of Illinois Press, Urbana, USA.

Sharma, I. & R. Dhanze (2012). Evaluation of macrobenthic fauna in hill stream environment of western Himalaya, India. *Journal of Threatened Taxa* 4(9): 2875–2882; http://doi.org/10.11609/JoTT.o2725.2875-82

Sharma, R.C. & J.S. Rawat (2009). Monitoring of aquatic macroinvertebrates as bioindicator for assessing the health of wetlands: A case study in the central Himalayas, India. *Ecological Indicators* 9: 118–128.

Simpson, E.H. (1949). Measurement of diversity. *Nature* 16: 688

Simpson K.W., R.W. Bode & J.R. Colquhoun (1985)**.** The macroinvertebrate fauna of an acid-stressed headwater stream system in the Adirondack Mountains, New York. *Freshwater Biology* 15: 673–681.

Soszka, G.J. (1975). Ecological relationships between invertebrates and submerged macrophytes in the lake littoral. *Ekologia Polska* 23: 393–415.

Spyra, A. (2010). Environmental factors influencing the occurrence of freshwater snails in woodland water bodies. *Biologia* 65(4): 697–703; http://doi.org/10.2478/s11756-010-0063-1

Spyra, A. & M.l. Strzelec (2013). Occurrence and morphological variability of Gyraulus crista (Gastropoda: Pulmonata: Planorbidae) on different types of substratum in woodland ponds. *Biologia* 68(4): 679–686; http://doi.org/10.2478/s11756-013-0197-z

Srivastava, V.K. (2007). River ecology in India: present status and future research strategy for management and conservation. *Proceedings of the Indian National Science Academy* 73(4): 255–269.

Stanford, L.L. & A. Spacie (1994). *Biological Monitoring of Aquatic System*. CRC Press, London, 400pp.

Strayer, D.L. & D. Dudgeon (2010). Freshwater biodiversity conservation: recent progress and future challenges. *Journal of the North American Benthological Society* 29(1): 344–358; http://doi.org/10.1899/08-171.1

Tagliapietra, D. & M. Sigovini (2010). Benthic fauna: collection and identification of macrobenthic invertebrates. *NEAR Curriculum in Natural Environmental Science, Terre et Environnement* 88: 253–261.

Tall, L., A. Armellin, B. Pinel-Alloul, G. Méthot & C. Hudon (2016). Effects of hydrological regime, landscape features, and environment on macroinvertebrates in St. Lawrence River wetlands. *Hydrobiologia* 778(1): 221–241.

Timm, H., M. Ivsk & T. Mols (2001). Response of macroinvertebrates and water quality to long-term decrease in organic pollution in some Estonian streams during 1990–1998. *Hydrobiologia* 464: 153–164.

Timms, B.V. (2006). A study of the benthic communities of twenty lakes in the South Island, New Zealand. *Freshwater Biology* 12: 123–138.

Victor, R. & A.E. Ogbeibu (1985). Macrobenthic invertebrates of a stream flowing through farmland in Southern Nigeria. *Environmental Pollution (Series A)* 39: 339–349.

Wetzel, R.G. (2001). *Limnology: Lake and River Ecosystems, 3rd Edition*. Academic Press, San Diego, California.

Williams, C.D. & M.J. Gormally (2009). Spatio-temporal and environmental gradient effects on Mollusc communities in a unique wetland habitat (Turloughs). *Wetlands* 29(3): 854–865; http://doi.org/10.1672/08-185.1

Xu, M., Z. Wang, X. Duan & B. Pan (2014). Effects of pollution on macroinvertebrates and water quality bioassessment. *Hydrobiologia* 729(1): 247–259.

Zeybek, M., H. Kalyoncu & Ö.O. Ertan (2012). Species composition and distribution of Mollusca in relation to water quality. *Turkish Journal of Fisheries and Aquatic Sciences* 12: 719–727; http://doi.org/10.4194/1303-2712-v12_3_21

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