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Abundance & distribution of aquatic benthic macro-invertebrate families of river Ganga and correlation with environmental parameters

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Abstract Bio-monitoring freshwater bodies using macro-invertebrates is an excellent way to detect biological water quality. Organic contamination in aquatic settings is well indicated by benthic macro-invertebrates. The use of macro-invertebrates to bio-monitor freshwater bodies is an effective method for determining biological water quality. Benthic macro-invertebrates are excellent indicators of organic pollution in aquatic environments. In the present study, the distribution of pollution-sensitive and pollution-tolerant families of benthic macro-invertebrates from 33 different locations along the Ganga River in Uttarakhand, Uttar Pradesh, Bihar, and West Bengal was studied. Benthic macro-invertebrates collected from different studied locations were identified up to family level and it was observed that a total of 15 pollution-sensitive families belong to four taxonomic orders, while eight pollution-tolerant families come from two taxonomic orders. Several moderately tolerant families have also been observed, but in this paper the distribution of only pollution-sensitive and pollution-tolerant families is presented as they reflect the extreme states of organic pollution. In the majority of locations, the pollution-sensitive Ephemeroptera family Ameletidae predominated. Likewise, the pollution-tolerant families Chironomidae (order—Diptera) and Naididae (order—Oligochaeta) dominated the Ganga River locations. Besides, the relationship between macro-invertebrate diversity and physicochemical factors (pH, water temperature, and dissolved oxygen) was investigated, and 3D surface distribution maps were displayed for qualitative interpretation. The correlation coefficients for all parameters were found to be positive. Macro-invertebrate pollution indices for bio-monitoring are based on community impacts and assist in evaluating the success of action plans to prevent industrial and anthropogenic pollution that contributes to the Ganga.

Keywords Bio-monitoring · Taxonomy · Benthic macro-invertebrates · Pearson correlation

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Introduction

Water quality is assessed using a variety of factors, including physicochemical and biological changes. Physicochemical measures may analyze short-term accounts of information about a water body's status, but they are useless in presenting a comprehensive picture of riverine health (USEPA, 2005). On the other hand, biological measures help in assessing an overall waterbody and broad state of health (Karr, 1999). According to Karr and Chu (1999), biological monitoring is "measuring and evaluating the condition of a living system, or biota." It is time-consuming to "detect changes in living systems, specifically changes caused by humans apart from natural changes." Thus, bio-assessment is one-of-a-kind evaluation of stream ecosystems essential for long-term bio-monitoring projects. The biological surveillance of benthic macro-invertebrate (BMI) communities living in freshwater bodies is known as bio-monitoring. Lower trophic level organisms, such as algae or benthic macro-invertebrates, and upper trophic level species, such as fish, are biological indicators, also known as bio-criteria.

Interestingly, due to their limited habitat, greater diversity, and less mobility, the distribution of benthic macro-invertebrates is critical and the most preferred group in monitoring biological water quality. Furthermore, they have a long-life cycle, allowing researchers to study the long-term effects of pollution on aquatic habitats (Kenney et al., 2009). Macro-invertebrate fauna is used to assess the functional status of rivers/streams in different parts of the world, including North America and Europe (Mishra & Nautiyal, 2013). Several studies have emphasized the importance of using benthic macro-invertebrates for monitoring purposes to back up the results obtained for physical and chemical variables (Masese et al., 2009, 2013; Minaya et al., 2013; Raburu et al., 2009). Because of their abundance and ubiquitous nature, these organisms are good biological indicators of water quality, providing a wide range of noticeable responses to environmental changes (Turkmen and Kazanci, 2010; Wallace and Anderson, 1995).

The Ephemeroptera, Plecoptera, and Trichoptera (EPT) group of sensitive taxa indicates a healthy stream (Barbour et al., 1999; Bonada et al., 2006a, b; Karr, 1999; Rosenberg & Resh, 1993). They are commonly known as "Mayfly," "Stone fly," and "Caddisfly," respectively. They tend to require high amount of dissolved oxygen. Their larvae can be found in habitats such as rocks, plants, and leaf litter in standing or fast flowing streams. In many lotic systems, the EPT group is often dominant and quite common (Barber-James et al., 2008; Wiggins, 1996). It also plays a crucial function in degrading organic materials and transmission of matter and energy in food webs (Hauer & Resh, 2017). As a result, it plays an essential role in the riverine systems (Principe et al., 2019).

Some macro-invertebrates, such as leeches and red worms, can survive in low-quality water (oxygen-depleting environment), deteriorating water quality. Some invertebrates, such as Diptera (Syrphidae, Chironomidae) and Oligochaetes (Naididae, Tubifiscidae) have adaptations such as "red pigment," a cuticle layer on their skin, and siphon-like structures that enable them to survive in a low amount of aquatic oxygen.

In this study, the abundance and distribution of these groups of organisms in the river Ganga have been evaluated and discussed. The Ganga River flows through five states: Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal, covering a distance of 2525 km, Haridwar, to Diamond Harbour, West Bengal. The river water quality is deteriorating along the stretch due to various types of domestic and industrial pollution. The Ganga stretch is heavily polluted because of wastewater discharge from various sources. Therefore, the current study was carried out to monitor the impact of organic pollution on the river ecosystem by studying the biodiversity of pollution-sensitive and pollution-tolerant families of aquatic insects such as macro-invertebrates collected from 33 selected locations along the Ganga's main channel from 2017 to 2020. To better understand the seasonal impact of macro-invertebrate populations, the study was conducted twice a year, during the pre-monsoon/summer season (April to June) and the post-monsoon/winter season (November to February). However, several moderately tolerant families have also been observed, but this paper is focused on the distribution of pollution-sensitive and pollution-tolerant families and relationship with between physicochemical parameters.

Materials and methods

Monitoring locations

Benthic macro- invertebrates' samples were collected from 33 main streams of the Ganga from Haridwar

Table 1 List of sampling locations with coordinates

Serial no.	River Ganga locations	Latitude	Longitude
1	Haridwar Barrage	29.971247	78.1842
2	Jagjeetpur U/S	29.89904	78.141413
3	Jagjeetpur D/S	29.87853	78.144199
4	Madhya Ganga Barrage	29.373889	78.040833
5	Anupshahr	28.36534	78.278355
6	Narora	28.194925	78.403008
7	Kacchla Ghat, Badaun	27.930736	78.857806
8	Ghatia Ghat, Farrukhabad	27.398415	79.62751
9	Kannauj D/S	27.010681	79.986332
10	Bithoor	26.616412	80.273932
11	Ganga Barrage U/S Kanpur	26.50724	80.31745
12	Shukla Ganj, Kanpur	26.46756	80.374147
13	Jajmau, Kanpur	26.4325	80.4177778
14	Deorighat, Kanpur	26.378141	80.490793
15	Asni Village, Fatehpur	26.057378	80.906673
16	Prayagraj U/S	25.437923	81.885484
17	Prayagraj D/S	25.345649	81.921228
18	Sirsa, Tamas D/S	25.2677	82.093031
19	Varanasi U/S	25.25574	83.027717
20	Varanasi D/S	25.322414	83.03452
21	Rajwari A/C Gomti	25.537372	83.199939
22	Digha Ghat, Patna	25.65331	85.093393
23	Gandhi Ghat	25.622066	85.17114
24	Malsalami	25.595747	85.244144
25	Fatuha	25.509544	85.318221
26	Balighat Bridge, Jangipur	24.48266	88.056343
27	Beharampore U/S	24.099475	88.245433
28	Behrampore D/S	24.062227	88.228161
29	Srirampore D/S	22.71929	88.364127
30	Belgharia	22.670503	88.360044
31	Ballykhal	22.653221	88.350386
32	Howrah Bridge	22.582878	88.348287
33	Garden Reach	22.549211	88.295512

Barrage (Uttarakhand) to Diamond Harbour (West Bengal). The coordinates of sample collection sites are listed in Table 1. In this study, water samples were collected for analysis of physico-chemical parameters. The temperature was recorded using an LCD portable Digital Multi-Stem thermometer and water pH was determined using a pH meter (pH tester 2, Oakton). Dissolved oxygen (DO) was measured by the Strickland and Parsons (1972) methodology in the selected sites.

Sample collection and preservation

The dry season was considered to be essential for the collection of macro-invertebrates in the present study because it accounts for a significant part of the year (9 months) compared to the rainy season (3 months) from July to September (Unni, 1996; Vombatkere, 2005). The dry season extends from October to June; however, the sampling was restricted to only the above-said period. Benthic macro-invertebrates were collected by following the standard procedures mentioned in International Standard ISO 10870:2012. The stones were lifted randomly in the Uttarakhand stretch, where the river bed was made up of boulders and cobbles. The samples were picked up using soft forceps or brushed off into the white tray, while in the case of pebbles and gravels, D-Net/hand net (ISO designed) was placed firmly on the stream bed against the flow. The stream bed was disturbed by foot, and the organisms were collected into the net. After this, the collected material was washed using a sieve (recommended mesh size 0.6 mm as per ISO), and macro-invertebrates were collected into plastic bottles containing formalin (4%). In Uttar Pradesh, Bihar, and West Bengal, where the river bed consists of clay, sand, and silt, samples were collected by the shovel and Eckman Berge sampler and then washed through a sieve (600-µm pore size) by river water. After washing, macro-invertebrates were transferred by forceps into the tray. The samples in the tray were preserved in 4% formalin and transferred to the laboratory for species identification.

Taxonomic identification

The broad taxonomic classifications are acceptable when observed relationships involving benthic macro-invertebrates are identified (Agrawal et al., 2019). The fauna was identified up to the family level using a stereo zoom microscope (Leica Model no. M80) and a taxonomic key developed by Nessemann et al. (2007), Zwart and Trivedi (1995a, b), and Akolkar et al. (2017).

Statistical analysis

Pearson correlation and one-way ANOVA were employed for ecological parameters (water temperature, pH, and DO) recorded in selected sampling sites to understand the relationship between the macro-invertebrate ecosystem using a statistical software package (SPSS ver. 21). A 3D surface model in Surfer version 8 was used to depict the spatial variations in pollution-sensitive and pollution-tolerant areas utilizing the species distribution data and georelation data (GPS points) (Golden software Inc.). A palette of colors was chosen based on the distribution level.

Results and discussion

The present study was conducted to investigate the diversity and distribution of benthic macro-invertebrates along the Ganga River stretch in four states: Uttarakhand, Uttar Pradesh, Bihar, and West Bengal. Water ecological parameters influence benthic fauna's distribution, abundance, and diversity (Greenstreet et al., 2007; Henning and Kröncke, 2005). Food availability, recruitment, hydrographic conditions, and sediment stability are the critical variables controlling the benthic community structure in a tropical regime (Gaonkar et al., 2013). Descriptive statistics on three ecological parameters and benthic macro-invertebrates were collected and analyzed for the 33 selected Ganga locations. The ANOVA revealed that the environmental variables in the chosen locations varied significantly in different zones (Table 2). During the monitoring period, the water temperature ranged between 14 and 35 °C and gradually increased from Uttarakhand to West Bengal (Fig. 3c), with significant differences ($P < 0.05$). According to the present study, water temperatures were higher at several of West Bengal's lower regimes, and the return of industrially used water into the river could be the cause. Aquatic insects generally require temperatures ranging from 0 to about 50 °C for metabolism, growth, emergence, and reproduction, whereas it is not much required for food availability (Anderson & Cummins, 1979). Such temperature distribution variability in the study area has previously been reported (Mondal et al., 2015).

The pH ranged from 6 to 9.08, indicating that the water was weakly acidic to alkaline (Fig. 3b). The acidic pH recorded in Uttar Pradesh's midstream during the post-monsoon season could be due to industrial effluent discharge into river water, which causes the acidic nature of the water (Singh et al., 2018). The mean dissolved oxygen levels ranged from 0.4 to 14.6 mg/L (Fig. 3a). These three indicators (pH, DO, temperature) varied consistently along the river, with the highest values in Uttar Pradesh middle region and significant differences between the upstream and midstream regions ($P < 0.05$). High positive correlations were found between water temperature, pH, and DO, indicating that DO increases significantly as pH and water temperature increased. The strong correlation between water temperature and DO indicated that water temperature significantly impacted water quality.

Table 2 ANOVA testing differences in species distribution patterns among stations

ANOVA						
		Sum of squares	df	Mean square	*F*	Significance
Haridwar Barrage	Between groups	18.022	6	3.004	.079	.997
	Within groups	416.823	11	37.893		
	Total	434.845	17			
Jagjeetpur U/S	Between groups	25.019	6	4.170	.108	.994
	Within groups	425.044	11	38.640		
	Total	450.063	17			
Jagjeetpur D/S	Between groups	21.632	6	3.605	.048	.999
	Within groups	757.882	10	75.788		
	Total	779.515	16			
Madhya Ganga Barrage	Between groups	115.725	6	19.287	.159	.983
	Within groups	1333.962	11	121.269		
	Total	1449.687	17			
Anupshahr	Between groups	130.476	6	21.746	.203	.970
	Within groups	1390.892	13	106.992		
	Total	1521.368	19			
Narora	Between groups	240.256	6	40.043	.393	.870
	Within groups	1323.753	13	101.827		
	Total	1564.009	19			
Kacchla Ghat, Badaun	Between groups	98.263	6	16.377	.165	.982
	Within groups	1385.746	14	98.982		
	Total	1484.008	20			
Ghatia Ghat, Farrukhabad	Between groups	133.230	6	22.205	.254	.949
	Within groups	1134.252	13	87.250		
	Total	1267.482	19			
Kannauj D/S	Between groups	181.044	6	30.174	.306	.922
	Within groups	1182.540	12	98.545		
	Total	1363.584	18			
Bithoor	Between groups	162.895	6	27.149	.224	.961
	Within groups	1334.066	11	121.279		
	Total	1496.961	17			
Ganga Barrage U/S Kanpur	Between groups	166.328	6	27.721	.235	.956
	Within groups	1300.348	11	118.213		
	Total	1466.676	17			
Shukla Ganj, Kanpur	Between groups	97.086	5	19.417	.136	.980
	Within groups	1284.305	9	142.701		
	Total	1381.391	14			
Deorighat, Kanpur	Between groups	265.906	6	44.318	.324	.911
	Within groups	1504.772	11	136.797		
	Total	1770.679	17			
Jajmau, Kanpur	Between groups	137.440	5	27.488	.269	.920
	Within groups	1022.213	10	102.221		
	Total	1159.654	15			
Asni Village, Fatehpur	Between groups	87.431	6	14.572	.136	.989
	Within groups	1286.339	12	107.195		
	Total	1373.770	18			

Table 2 (continued)

ANOVA						
		Sum of squares	df	Mean square	*F*	Significance
Sirsa, Tamas D/S	Between groups	94.272	6	15.712	.133	.990
	Within groups	1653.500	14	118.107		
	Total	1747.772	20			
Prayagraj D/S	Between groups	220.571	6	36.762	.333	.907
	Within groups	1433.957	13	110.304		
	Total	1654.527	19			
Prayagraj U/S	Between groups	55.733	6	9.289	.064	.998
	Within groups	1597.598	11	145.236		
	Total	1653.331	17			
Varanasi U/S	Between groups	42.596	6	7.099	.058	.999
	Within groups	1354.080	11	123.098		
	Total	1396.676	17			
Varanasi D/S	Between groups	30.957	5	6.191	.041	.999
	Within groups	1664.078	11	151.280		
	Total	1695.035	16			
Rajwari A/C Gomti	Between groups	59.058	6	9.843	.066	.998
	Within groups	1649.560	11	149.960		
	Total	1708.618	17			
Digha Ghat, Patna	Between groups	48.624	6	8.104	.063	.999
	Within groups	1803.057	14	128.790		
	Total	1851.682	20			
Fatuha	Between groups	60.070	6	10.012	.076	.998
	Within groups	1846.708	14	131.908		
	Total	1906.778	20			
Malsalami	Between groups	38.933	6	6.489	.054	.999
	Within groups	1679.467	14	119.962		
	Total	1718.400	20			
Gandhi Ghat	Between groups	41.073	6	6.845	.050	.999
	Within groups	1914.532	14	136.752		
	Total	1955.605	20			
Balighat Bridge, Jangipur	Between groups	53.974	3	17.991	.086	.966
	Within groups	1465.383	7	209.340		
	Total	1519.357	10			
Beharampore U/S	Between groups	1.067	3	.356	.002	1.000
	Within groups	1252.035	8	156.504		
	Total	1253.102	11			
Behrampore D/S	Between groups	5.172	3	1.724	.010	.999
	Within groups	1418.658	8	177.332		
	Total	1423.831	11			
Srirampore D/S	Between groups	17.872	3	5.957	.028	.993
	Within groups	1686.057	8	210.757		
	Total	1703.929	11			
Belgharia	Between groups	3.183	3	1.061	.006	.999
	Within groups	1453.033	8	181.629		
	Total	1456.216	11			

Table 2 (continued)

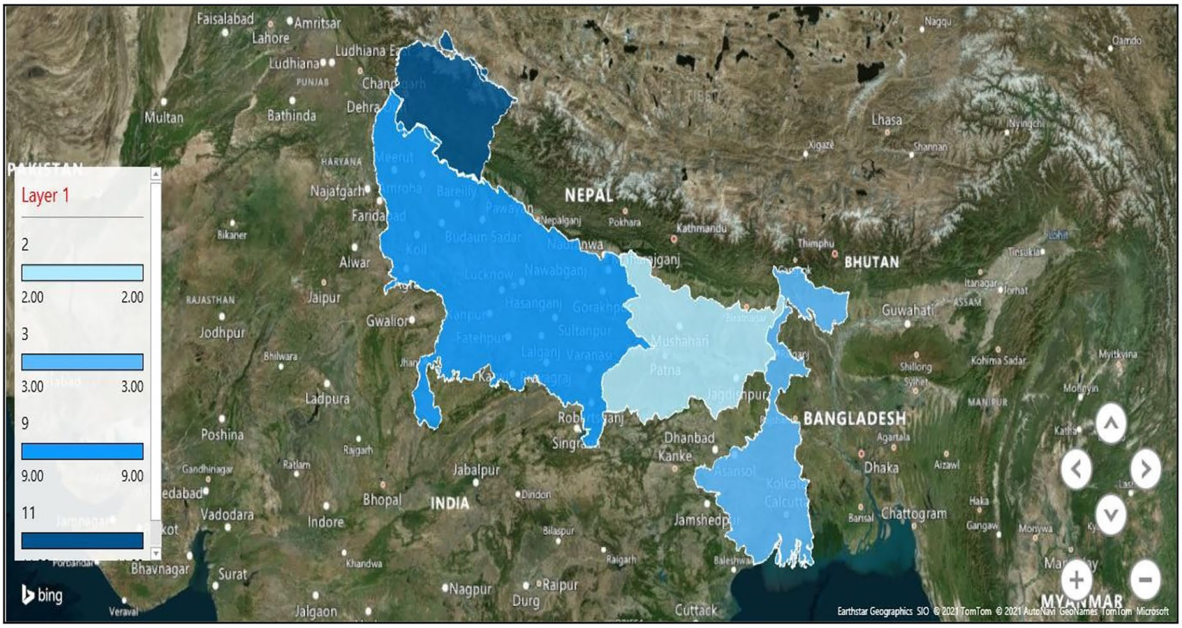
ANOVA						
		Sum of squares	df	Mean square	*F*	Significance
Ballykhal	Between groups	12.406	3	4.135	.022	.995
	Within groups	1511.501	8	188.938		
	Total	1523.907	11			
Howrah Bridge	Between groups	6.862	3	2.287	.015	.997
	Within groups	1222.985	8	152.873		
	Total	1229.846	11			
Garden Reach	Between groups	5.987	3	1.996	.010	.998
	Within groups	1526.215	8	190.777		
	Total	1532.202	11			

Collected macro-invertebrates were identified up to a family level and arranged according to their tolerance for organic pollution. The distribution map (Fig. 1a, b) and 3D surface model (Fig. 2a, b) of pollution-sensitive and pollution-tolerant families along the Ganga River in Uttarakhand, Uttar Pradesh, Bihar, and West Bengal from 2017 to 2020 show evident spatial variation between the families and abundance of sensitive and tolerant families.

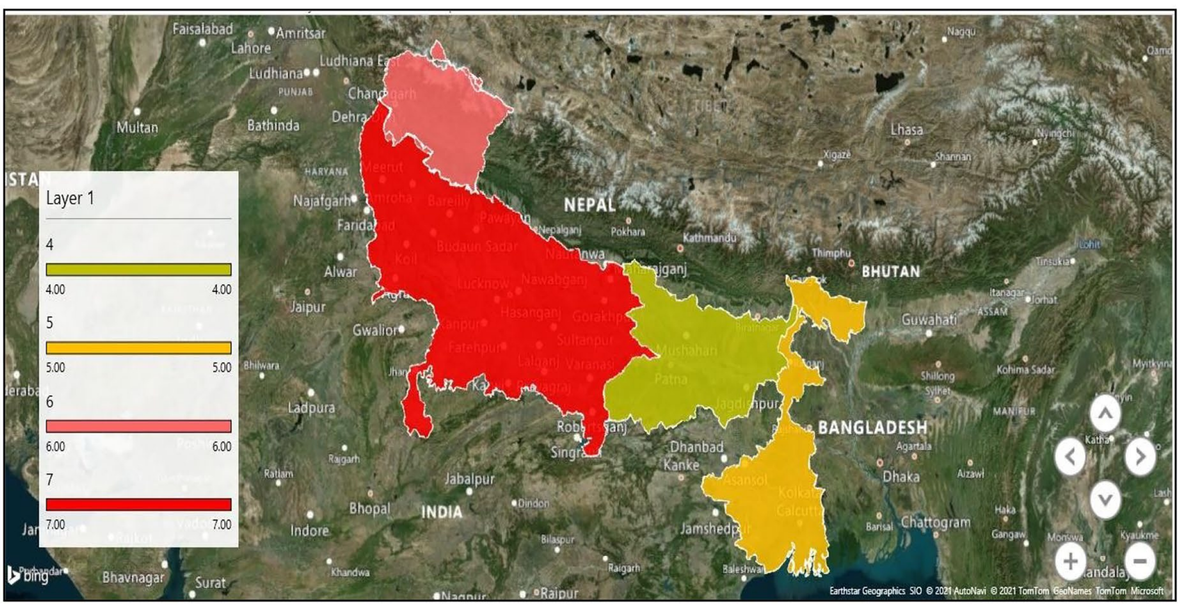
Figures 5 and 6 show the % abundance of pollution-sensitive and pollution-tolerant families observed in the stretch of river Ganga during 2017–2020. A total of 15 pollution-sensitive families from 04 taxonomic orders and 08 pollution-tolerant families from 02 taxonomic orders have been observed in the Ganga River Basin study sites in Uttarakhand, Uttar Pradesh, Bihar, and West Bengal). The highest number of pollution-sensitive families (18) are observed at 03 locations in Uttarakhand and highest number of pollution-tolerant families (45) are observed at 17 locations in the Uttar Pradesh stretch (Fig. 4).

Pollution-sensitive families belonging to the taxonomic orders Ephemeroptera, Plecoptera, Trichoptera, and Coleoptera, namely, Heptagenidae, Siphloneuridae, Leptophlebidae, Ephemeridae, Ameletidae, Neoephemeridae, Ephemerilidae, Aphelocheridae, Glossosomatidae, Leptoceridae, and Brachycentridae, were found in the upper stretches of river Ganga (Haridwar Barrage and Jagjeetpur STP D/s), where dissolved oxygen levels range between 8.85 mg/L and 11.7 mg/L, which is higher in upper stretches in comparison to lower stretch, providing an oxygen-rich environment for the survival of these organisms. The family Ameletidae, order Ephemeroptera dominated the pollutant-sensitive taxonomic groups of benthic macro-invertebrates (class Insecta) at all the studied locations and found to be 38.8% abundant followed by Heptagenidae (21%), Siphloneuridae (13.8%), Leptophlebidae (9.6%), and Aphelocheridae (6.8%) (Fig. 5). Insects from this group, specifically present in a lotic environment, are found to be good swimmers due to the energy requirement to swim against the water current. Families such as Ameletidae can swim as rapid bursts, whereas most lotic insects swim by crawling or displacement. The Ephemeroptera are residents of oxygen-rich environment and thus, reflect clean water quality, as stated by Emere and Nasiru (2009) and Tonapi (1980). A study carried out by Kumar (2014) has also observed the presence of Ephemeroptera in oxygen-rich environment, i.e., the glacial-fed Goriganga River in the Kumaun Himalaya.

Some physiological features such as flattening body and smooth-streamlined dorsum support many rheophilic (current-loving) insects, e.g., heptageniid mayflies, perlid stoneflies, and psephenid beetles. Also, the lateral positioning of the legs of several mayflies and stoneflies enable their body to reduce their dragging and increases friction with the substrate. Similarly, in the case of some caddisflies, e.g., Glossosomatidae, the shape of the case is advantageous as it modifies turbulent flow to a laminar sublayer. According to the research done by Mishra et al. (2013), Ephemeroptera, Trichoptera, Diptera, Plecoptera, and Coleopterans account for more than 80% of the benthic macro-invertebrate community in higher elevation rivers. A similar study done by Khanna and Bhutiani (2005) shows that Ephemeroptera (30.52 percent) and Lepidoptera (25.07 percent) were the



(a)



(b)

Fig. 1 (**a**) Spatial distribution of pollution-sensitive families. (**b**) Spatial distribution of pollution-tolerant families

major taxonomic groups present in the Ganga River from Rishikesh to Haridwar. Besides, other orders, viz., Odonata, Zygoptera, Trichoptera, Hemiptera, Coleoptera, Diptera, Gastropoda, and Annelida, were also present. Nautiyal et al. (2004) also described the abundance of benthic macro-invertebrate fauna of Uttarakhand and found that most insect taxa belonged to the orders Trichoptera and Ephemeroptera.

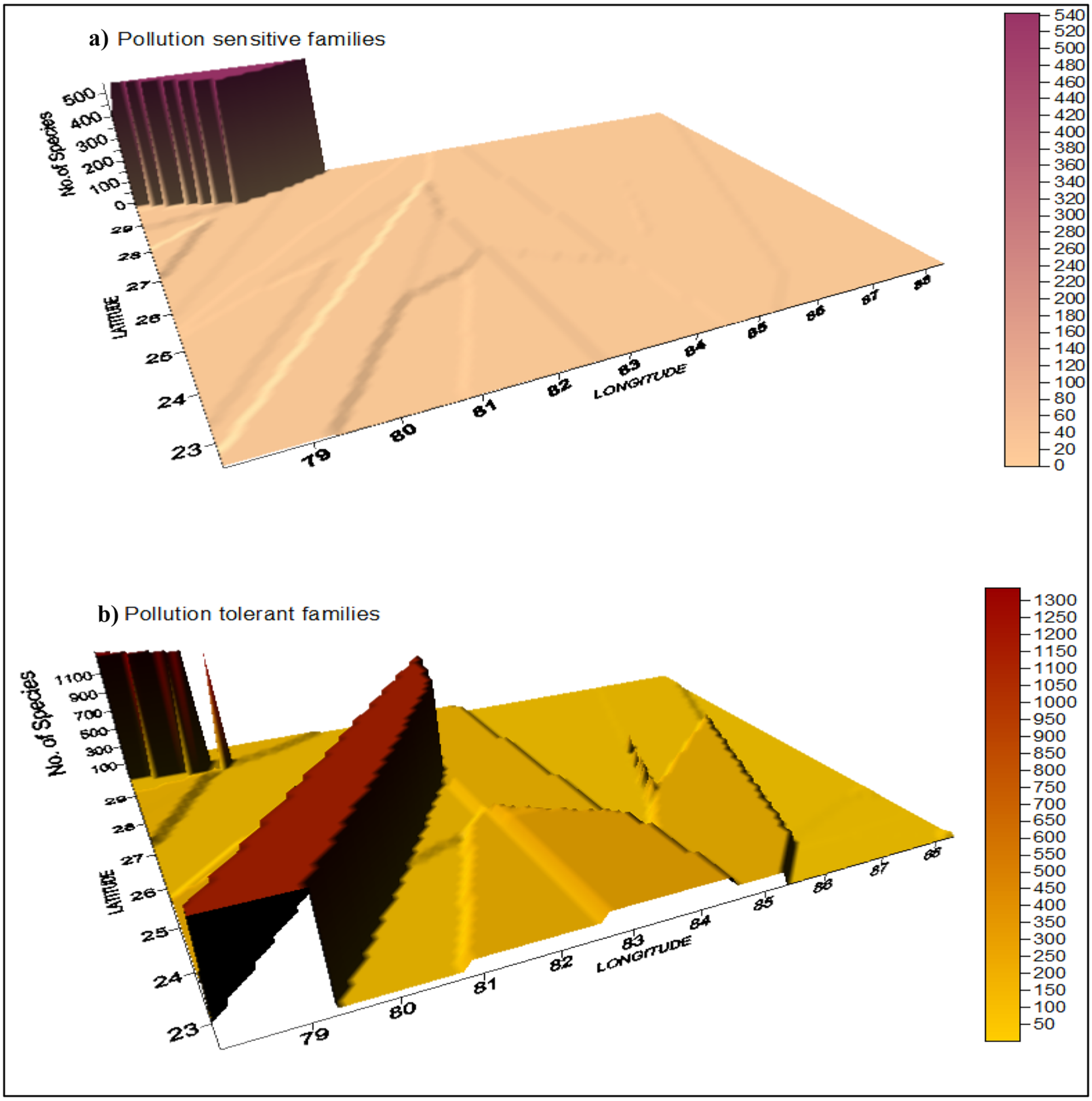


Fig. 2 3D surface map of distribution of macro-invertebrate diversity of (**a**) pollution-sensitive and (**b**) pollution-tolerant families in Gangetic River

On the other hand, at Jagjeetpur STP D/S, no pollution-sensitive families were discovered. The discharge of partially treated wastewater from STP into the Ganga River possibly causes the diminishing of sensitive families at this location. It is supported by the relatively low dissolved oxygen levels (2.9 to 9.6 mg/L).

At the 18 sites of the Uttar Pradesh stretch, nine pollution-sensitive families were identified, namely, Heptagenidae, Siphloneuridae, Leptohyphidae, Ameletidae,

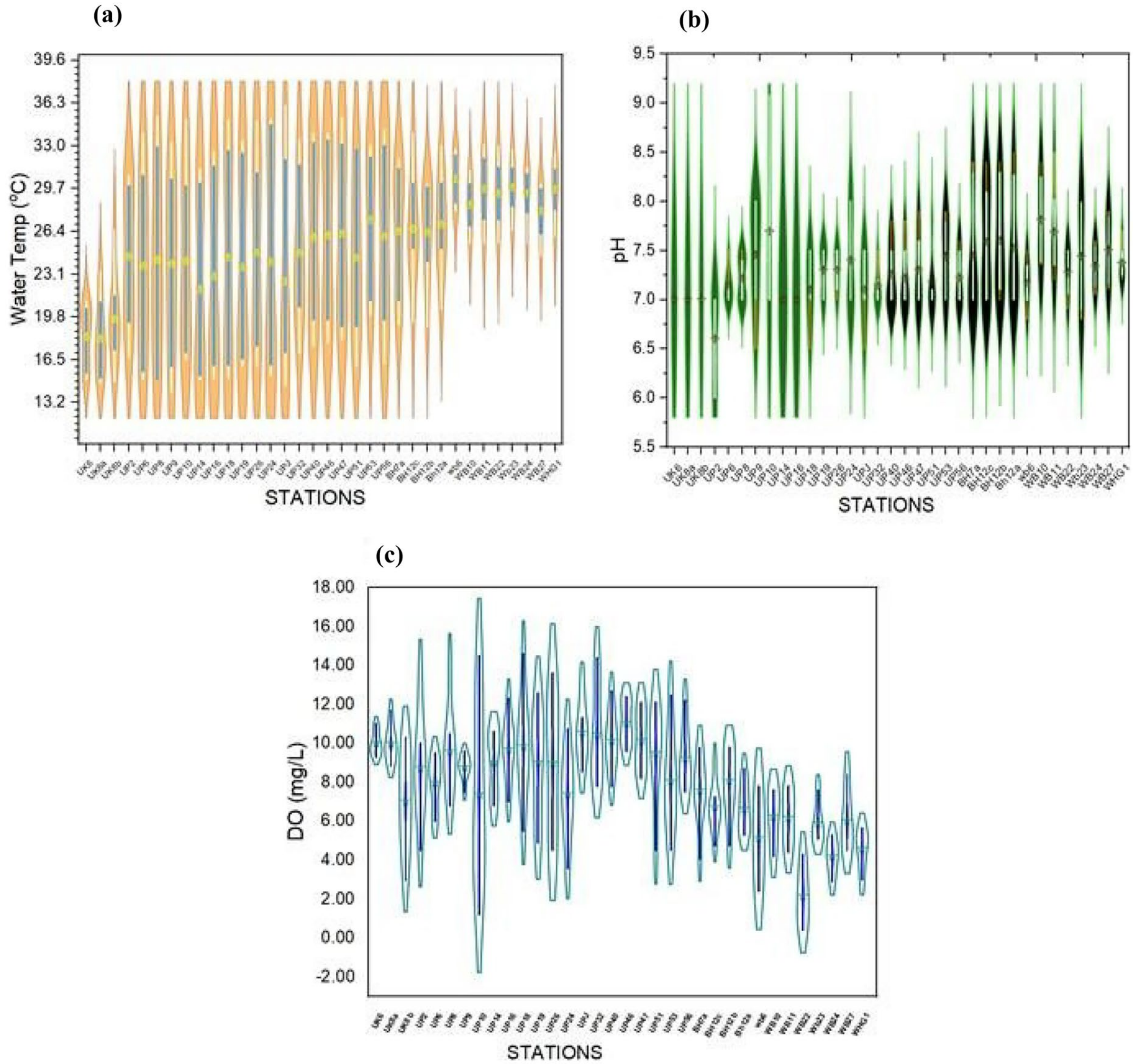


Fig. 3 Violin plots (envelope) and box plots (within) showing the distribution of (**a**) dissolved oxygen, (**b**) pH, and (**c**) water temperature in Gangetic River water within the study region

Neoephemeridae, Chloroperlidae, Perlodidae, and Lepidosomatidae. Brachycentridae, another sensitive family, was discovered at the Madhya Ganga Barrage. Siphloneuridae and Perlodidae were found in Asni Village, Fatehpur; Chloroperlidae in Ganga Barrage, U/S Kanpur; and Lepidosomatidae in Prayagraj D/S (Fig. 4). Family Ameletidae was the most abundant (56.8%) in Uttar Pradesh stretch. Other abundant families were Brachycentridae (10.8%), Perlodidae (8.1), Siphloneuridae (8.1%), and Heptagenidae (5.4%) (Fig. 5). Overall dissolved oxygen levels in Uttar Pradesh ranged from 3.5 to 14.4 mg/L. Three pollution-sensitive families were observed in Asni village, Fatehpur, linked to the high DO range (7.8 to

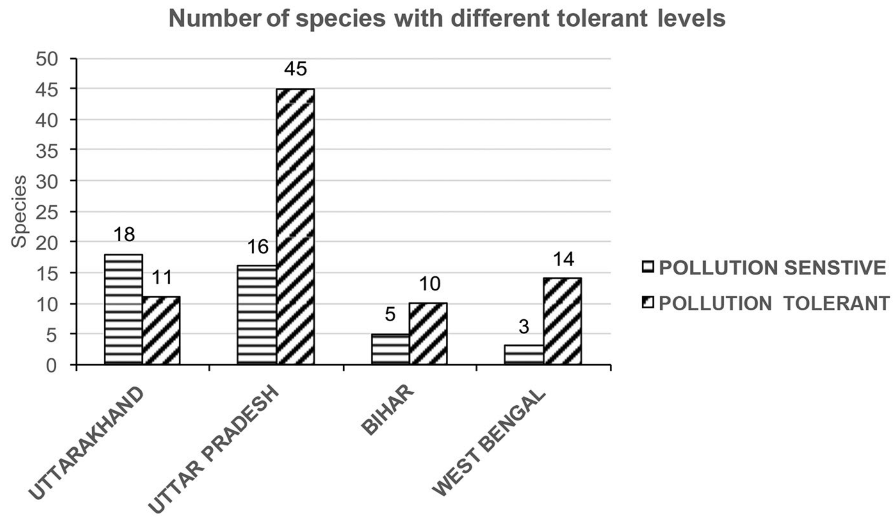


Fig. 4 Number of pollution-sensitive and pollution-tolerant species distributed in the Ganga River

14.4 mg/L). Interestingly, at downstream locations of Uttar Pradesh (Ghatia Ghat [Farrukhabad], Bithoor, Shukla Ganj [Kanpur], Jajmau [Kanpur], Deorighat [Kanpur], Varanasi U/S and D/S), no pollution-sensitive families were observed. It might be due to an increase in organic pollution load and habitat destruction due to increased human activities. At total 04 locations of Bihar and West Bengal locations, two (Ephemerilidae [0.96%] and Ephemeridae [0.24%]) pollution-sensitive families were recorded while in West Bengal pollution-sensitive families were not recorded during the study period (Fig. 5). DO was in the range of 4.1 to 9.8 in Bihar and from 0.4 to 8.4 in West Bengal.

Organic matter enrichment from domestic effluents, waste from livestock breeding, and industrial and mining enterprises, which are discharged directly or indirectly into the river channel, frequently affect the heterogeneity of river habitats along the river course, increasing nutrient input. This leads to the growth of families which are tolerant to biodegradable organic matter. Therefore, percentage abundance of pollution-tolerant families collected from 2017 to 2020 from Uttarakhand, Uttar Pradesh, Bihar, and West Bengal was studied and presented in Fig. 6. Family Chironomidae, order Diptera was found to be most abundant at the majority of the locations, followed by family Naididae (order Oligochaeta) except

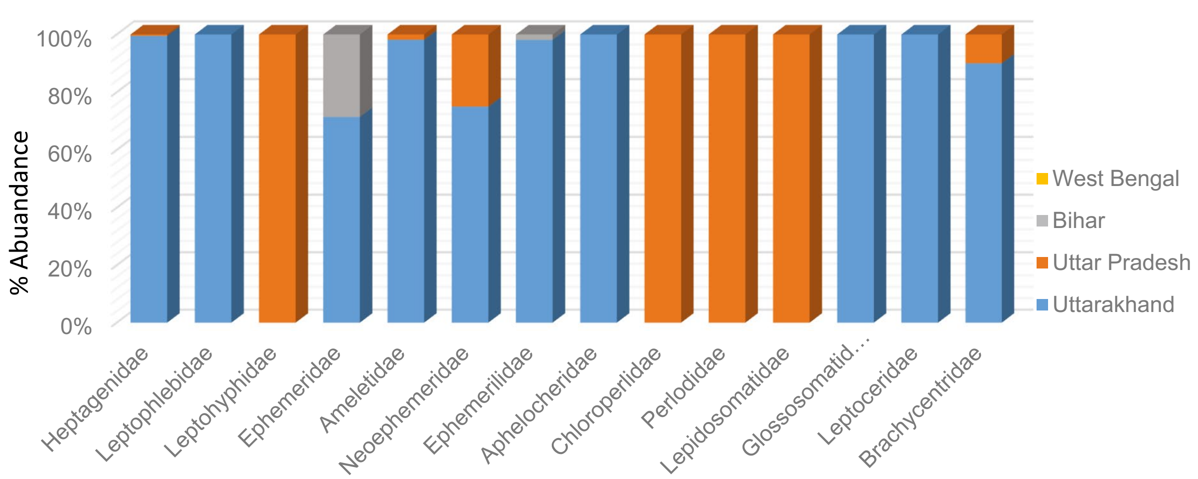


Fig. 5 Percentage abundance of pollution-sensitive families in the stretch of river Ganga

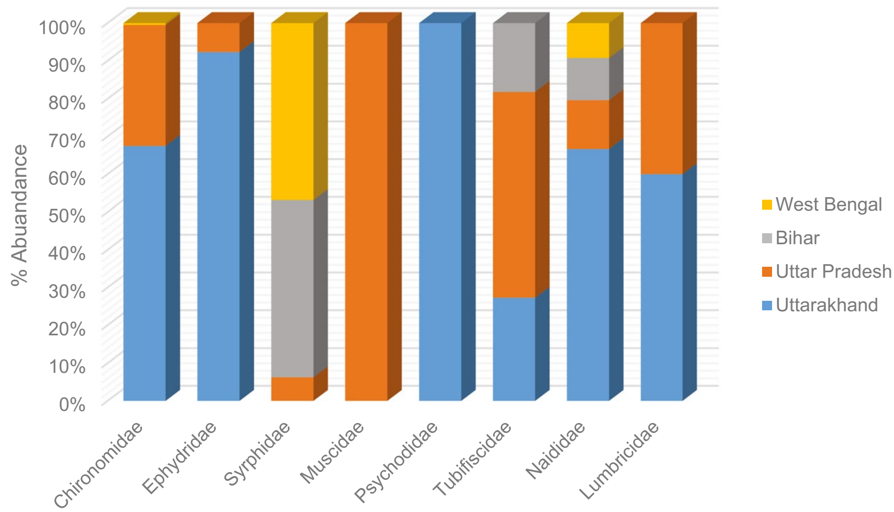


Fig. 6 Percentage abundance of pollution-tolerant families in the stretch of river Ganga

at two West Bengal locations, i.e., Behrampore D/S and Belgharia.

In Uttarakhand, six pollution-tolerant families from the orders Diptera, Polychaeta, and Oligochaeta, namely, Chironomidae, Ephydridae, Psychodidae, Tubifiscidae, Naididae, and Lumbricidae, were found in three different locations. However, these families were less abundant at these locations.

In Uttar Pradesh, seven families (Chironomidae, Ephydridae, Syrphidae, Muscidae, Tubifiscidae, Naididae, and Lumbricidae) were discovered. Four families (Chironomidae, Syrphidae, Tubifiscidae, and Naididae) were observed in West Bengal and, similarly, 05 families (Chironomidae, Ephydridae, Syrphidae, Tubifiscidae, Naididae, and Lumbricidae) were found in Bihar. Presence of oligochaete supports the fact that they increase in number with an increase in organic matter and, therefore, replace the other less tolerant benthic fauna (Schenková & Helesic, 2006).

Conclusion

The study concludes that the Ganga River offers a habitat for diversified macro-invertebrate fauna, including groups that are sensitive to pollution, somewhat tolerant, and tolerant. However, the distribution and variety of pollution-sensitive and pollution-tolerant families have been explored in this research. The highest concentration of pollution-sensitive households was identified in Haridwar Barrage and U/S of Jagjeetpur, Uttarakhand, whereas the highest concentration of tolerant families was located in Asni village (Fatehpur), Uttar Pradesh, and Gandhi Ghat, Bihar. A gradual loss of pollution-sensitive communities is visible in the stretch of the Ganga River, causing a change in community composition; however, presence of pollution sensitive families in Uttar Pradesh indicates the improvement in Biological water quality. Further, restrictions on human activities such as mass bathing and cattle wading would be beneficial in maintaining the river substratum, diversity, structure and function stability of aquatic ecosystems.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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