Applied Biological Research 21(3): 235-244; (2019)
DOI: 10.5958/0974-4517.2019.00030.2

BIOASSESSMENT OF RIVER GANGA IN UTTARAKHAND STRETCH (INDIA) USING BENTHIC MACRO-INVERTEBRATES AS BIOINDICATOR

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(Received 20 May, 2019; accepted 11 November, 2019)

ABSTRACT

The sedentary lives of macro-invertebrates enable them to act as continuous monitor of water quality of freshwater bodies. Some specific families of benthic macro-invertebrate fauna belonging particularly to the Order Ephemeroptera, Trichoptera, Plecoptera, Hemiptera, Coleoptera, Diptera, Molllusca, Crustacea, Odonata, Hirudinea, Oligochaeta, Polychaeta and Planaria have been recognized as bioindicator of water quality by Biological Monitoring Working Party (BMWP). The present study was carried out to explore the taxonomic richness of macro-zoobenthos found in various habitats and biological water quality of river Ganga in Uttarakhand stretch of India at 3 locations *viz*., Haridwar barrage, Jagjeetpur sewage treatment plant (STP) upstream and downstream. The samples were collected twice a year to elucidate seasonal variation in taxa occurrence. A total of 1,560 individuals belonging to 32 families and 12 taxonomic orders were recorded. Biological water quality at Haridwar barrage was found to be clean in both the seasons. Direct discharge of untreated sewage from Jagjeetpur STP had profound effect on the biota of river and lead to community replacement at downstream of discharge. Dominant Ephemeroptera colonies were replaced by Diptera family Chironomidae at this location and thereby showed decline in biological water quality.

Keywords: Bioindicators, biological water quality, benthic macro-invertebrates, saprobity, taxonomic richness

INTRODUCTION

The Ganga is one of the prime rivers of India. It originates as 'Bhagirathi' from Gangotri glaciers in the Himalayas at an elevation of about 7010 m in Uttarkashi district of Uttarakhand (India) and flows through a total length of about 2525 km up to its outfall into the Bay of Bengal through the former main course of Bhagirathi-Hooghly. The river water is used for drinking purpose, power generation, irrigation, fish production and religious pilgrimages. Presently, it is under constant threat of pollution by municipal and industrial waste, disposal of dead bodies, deforestation, excessive use of fertilizers and pesticides, bathing and religious pilgrimages.

The water quality of river Ganga is constantly monitored at various locations based on the physicochemical and bacterial parameters including biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), temperature, pH, total coliforms, faecal coliforms, etc. which provide momentary account of water quality i.e. the water quality that prevails at that particular time of monitoring. Biological monitoring, on the other hand, has much longer dimension

since the aquatic biota can be affected by chemical and/or hydrological events that may have lasted only a few days, some months or even years before monitoring was carried out (Akolkar *et al*., 2017a).

A systematic method of collecting qualitative and quantitative information about the environment by physicochemical and biological methods is called environmental monitoring. Biomonitoring is an ecological exercise where various kinds of biota called bioindicators are considered in ascertaining the extent of pollution in a water body (Sharma and Sharma, 2010). A bioindicator is an organism (or part of an organism or a community of organisms) that furnishes the information on the quality of environment or a part of environment (Markert *et al*., 2003). An ideal indicator, therefore, should have the characteristics of: a) taxonomic soundness (easy to be recognized by non-specialist); b) wide or cosmopolitan distribution; c) low mobility (local indication); d) well-known ecological characteristics; e) numerical abundance; f) suitability for laboratory experiments; g) high sensitivity to environmental stressor(s); and h) high ability for quantification and standardization (Füreder and Reynolds, 2003). Benthic macro-invertebrates serve as biological indicators of water quality as they are ubiquitous in nature and cover wide habitat and area. A large number of species cover a wide spectrum of pollution and pollutants; while sedentary lives of macro-invertebrates allow elucidation of temporal changes (continuous monitoring). The present study was aimed to explore the taxonomic richness of benthic macro-invertebrates and biological water quality of river Ganga in Uttarakhand (India).

MATERIALS AND METHODS

Site description

The present study was conducted on river Ganga in Uttarakhand state (India). Three sampling stations *viz*., Haridwar barrage, Jagjeetpur STP upstream and Jagjeetpur STP downstream were selected to study the diversity and taxonomic richness of benthic macroinvertebrates in summer (April, 2017) and winter (February, 2018) seasons of year 2017-18. Geographical locations of sampling stations (Fig. 1) were: Haridwar barrage (at Bhimgauda barrage, first gate of Upper Ganga canal 29.95854° N and 78.17847° E), Jagjeetpur STP upstream (upstream Jagjeetpur STP drain outlet, 29.899040° N and 78.141413° E) and Jagjeetpur STP downstream (near Ajeetpur village, 29.887070° N and 78.139573° E).

Fig. 1: Map of river Ganges at Haridwar barrage and sampling locations

Benthic macro-invertebrate collection, sorting and preservation

The sampling procedure was equivalently distributed over all the possible aquatic habitats including the bed substrate (stones, sand or mud), macrophytes (floating, submerged, emerged), immersed roots of overhanging trees and all other natural or artificial substrates, floating or submerged in the water. In Uttarakhand, benthic macro-invertebrates sampling involved lifting and brushing of stones as the substratum is mainly composed of boulders, cobbles and pebbles. The small stones were picked up randomly and swiftly from the river and the organisms were collected by brushing off or using soft forceps pins; whereas fauna from the large rocks, lying under water, was collected by brushing off directly into the net placed firmly on to the stream bed. Samples were sieved using 600 µ mesh size round sieve (International Standard ISO 10870:2012). The organisms were collected in 250 mL reagent grade plastic bottle and preserved in 4% formalin. Preserved samples were brought to the Bioscience Division, CPCB, New Delhi for further identification.

Identification of benthic macro-invertebrates

As broad taxonomic classifications are acceptable when empirical relationships involving benthic macro-invertebrates are to be developed, the fauna was identified up to the family level using stereo-zoom microscope. The distribution of different families was calculated on percentage basis. Mollusca, Crustacea and Annelida were identified using the taxonomic key developed by Nessemann *et al*. (2007). Ephemeroptera, Trichoptera, Plecoptera, Hemiptera, Coleoptera, Diptera, Odonata and Planaria taxa were identified using the reference keys of Zwart and Trivedi (1995), Jessup *et al*. (2003), Graf *et al*. (2006) and Akolkar *et al*. (2017b).

Biological water quality assessment

Biological water quality was assessed by using 2 indices: saprobic score and diversity score using bio-assessment field protocol as developed by CPBC, New Delhi (India) in Indo-Dutch project. Saprobic score is a measure of taxonomic composition whereas diversity score is a measure of taxonomic richness of riverine ecosystem. Each taxonomic family is given a score on the scale of 1 to 10 by BMWP (Biological Monitoring Working Party). Saprobic and diversity scores were calculated after the identification of benthic macroinvertebrates. Further, biological water quality of all the three locations of Uttarakhand was determined using Biological Water Quality Criteria (BWQC) (Source: Central Pollution Control Board) which is based on the range of saprobic and diversity score values as under:

Saprobic score (range)	Diversity score (range)	Water quality	Water quality class	Indicator colour
≥ 7.0	0.2-1.0	Clean	A	Blue
6-7	0.5-1.0	Slight Pollution	B	Light Blue
3-6	0.3-0.9	Moderate Pollution	C	Green
2-5	0.4 –Less	Heavy Pollution	D	Orange
0-2	0-0.2	Severe Pollution	E	Red

Physicochemical parameters

Physicochemical parameters *viz*., dissolved oxygen (DO), water temperature and flow were recorded at the time of sample collection. Dissolved oxygen was estimated using the standards methods of water and wastewater analysis (APHA, 2000). Water temperature was measured using a calibrated thermometer. Water flow (m sec^{-1}) was estimated by measuring the time taken by floating object (plastic ball) over a set distance of 10 m (approx.).

RESULTS AND DISCUSSION

A total of 1560 individuals belonging to 34 families and 12 taxonomic orders were recorded at the

Table 1: Distribution of taxonomic families of micro-invertebrates at selected sampling locations of river Ganga in Uttarakhand

Families	Haridwar Barrage		Jagjeetpur STP u/s		Jagjeetpur STP d/s		Total
	April, 2017	Feb., 2018	April, 2017	Feb., 2018	April, 2017	Feb., 2018	
Heptagenidae	64	70	02	19	00	00	155
Baetidae	03	00	00	00	00	00	3
Hydroptilidae	01	14	07	01	06	00	29
Ceratopoganidae	23	00	00	00	00	00	23
Ephemerilidae	28	07	00	00	00	00	35
Chironomidae	01	54	04	48	126	260	493
Siphloneuridae	65	03	63	00	00	00	131
Leptophlebidae	01	90	00	00	00	00	91
Leptoceridae	01	00	00	01	00	00	2
Planorbidae	06	00	09	04	00	00	19
Hydropsychidae	26	53	57	55	57	00	248
Glossiphonidae	03	00	10	00	17	00	30
Brachycentridae	01	00	00	00	00	00	1
Neoephemeridae	01	00	00	00	00	00	1
Caenidae	01	51	01	08	00	00	61
Gomphidae	01	00	01	01	00	00	3
Physidae	01	00	10	00	00	51	62
Aphelocheridae	00	00	64	00	00	00	64
Isonychiidae	00	00	01	00	00	00	1
Tipulidae	00	00	02	00	00	00	2
Limonidae	00	03	00	01	00	00	4
Unionidae	00	01	00	00	00	00	1
Culicidae	00	01	00	03	00	08	12
Ameletidae	00	10	00	42	00	00	52
Ephemeridae	00	03	00	01	00	00	4
Corrydelidae	00	01	00	00	00	00	1
Potamidae	00	01	00	00	00	00	1
Belastomatidae	00	00	00	01	00	00	1
Hydrophilidae larva	00	00	00	01	00	00	1
Dytiscidae larva	00	00	00	03	00	00	3
Duggesidae	00	00	00	07	00	00	7
Salifidae	00	00	00	00	00	01	1
Naididae	00	00	00	00	00	12	12
Simulidae	00	00	00	06	00	00	6
Total	227	362	231	202	206	332	1560

three sampling sites during summer and winter seasons (Table 1). At Haridwar barrage, pre-monsoon sampling revealed 17 benthic macroinvertebrate families comprising of 12 families from order Ephemeroptera, 1 from Diptera, 2 from Mollusca and 1 each from Hirudinea and Odonata. Families Heptagenidae (28.19%) and Siphloneuridae (28.6%) were dominant at this location (Fig. 2). Post-monsoon sampling revealed the presence of 15 families of which 10 families belonged to Ephemeroptera order, 3 families to Diptera and 1 each to Crustacea, Coleoptera and Mollusca. In this phase, family Leptophlebidae (24.86%) was dominant, followed by Siphloneuridae (19.34%), Chironomidae (14.92%), Hydropsychidae (14.64%) and Caenidae (14.08%).

At Jagjeetpur STP upstream, 13 macro-invertebrate families were observed in pre-monsoon samples comprising of 6 families from Ephemeroptera, 2 from Diptera, 1 each from Odonata and Coleoptera and 2 from Mollusca. Of these families, Hydropsychidae, Siphloneuridae and Aphelocheridae were abundant with 24.7, 27.3 and 27.7% dominance, respectively (Fig. 3a). On the same

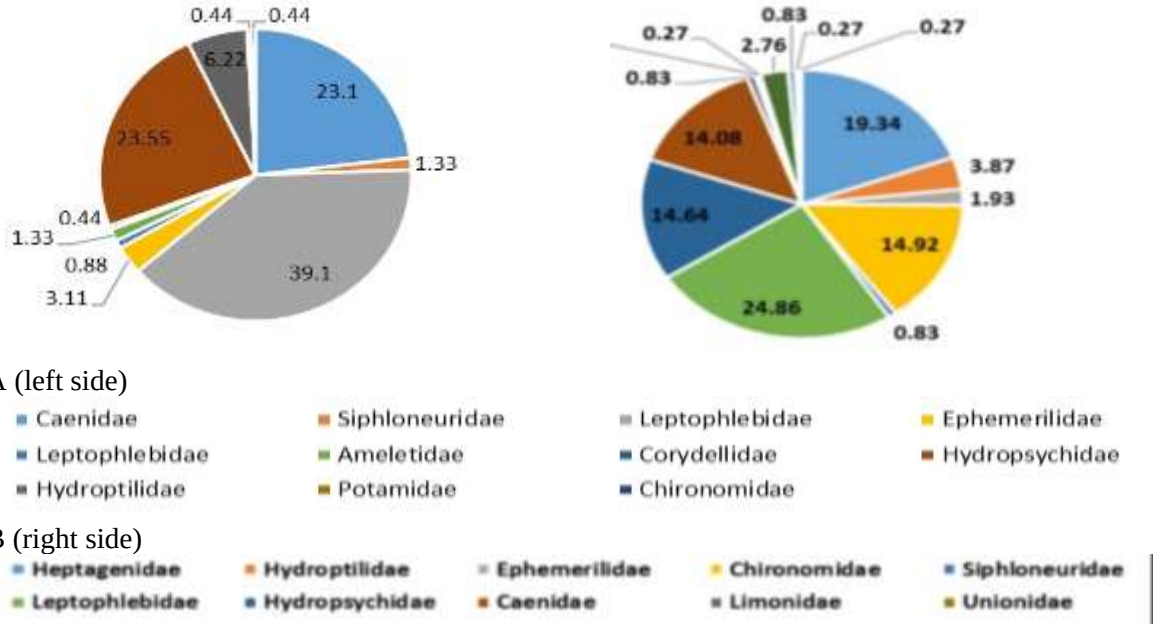

Fig. 2: Dominance (%) of taxonomic families at Haridwar barrage; (left side) pre-monsoon; (right side) post-monsoon

location in post-monsoon season 15 families were found which belonged to Ephemeroptera (7), Diptera (4), Hemiptera (1), Planaria (1), Odonata (1) and Mollsuca (1). Comparatively, in summer season the occurrence of Chironomidae enhanced from 1.73 to 23.76% whereas other dominant families Hydropsychidae and Ameletidae showed 27.2 and 20.8% dominance, respectively (Fig. 3b). Mishra *et al.* (2013) studied distributional patterns of benthic macro-invertebrate fauna in glacier-fed rivers of Indian Himalaya and reported the dominance of family Heptageniidae (Ephemeroptera) in

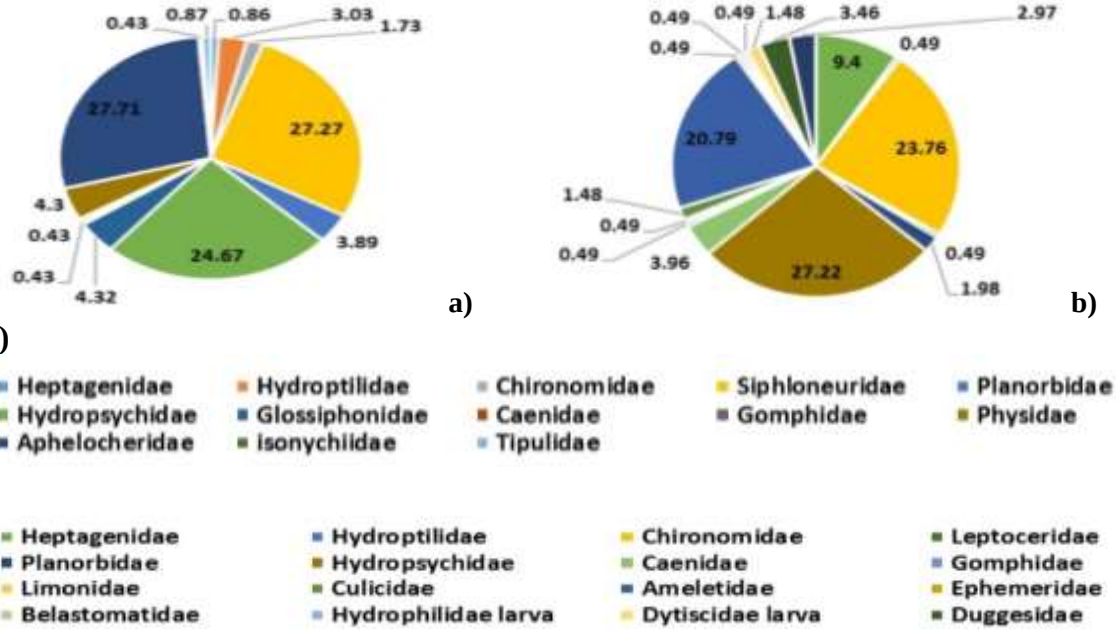

Fig. 3: Dominance (%) of taxonomic families of micro-invertebrates at Haridwar STP upstream; a) pre-monsoon, b) post-monsoon

river Chandra and Bhaga or in combination with Chironomidae (Diptera) in similar proportions in river Chenab or Diptera alone in river Miyar, Leptoceridae in combination with Limnephilidae in Alaknanada at Tapovan and Heptageniidae and Baetidae in Alaknanada at Mana. They found partial similarity between Mandakini and Alaknanda by virtue of abundant Limnephilidae and Bhagirathi was characterized by abundance of Philopotamidae. Karrouch *et al*. (2017) reported highest numbers of Ephemeroptera taxa at upstream location of Boufekrane river in Morocco and complete absence at the downstream location of anthropogenic activities. Huh (2019) investigated the community analysis and water quality of benthic macro-invertebrates at Gwangseok stream, Jinhae city in Korea and reported 781 individuals belonged to 19 species, 14 families, 8 orders, 5 classes and 3 phyla.

At Jagjeetpur STP downstream, four benthic macroinvertebrates families *viz*., Hydroptilidae, Chirono-midae, Hydropsychidae and Glossiphonidae were recorded in pre-monsoon sampling (Fig. 4a). A sharp increase in Chironomidae abundance (61.61%) at this location may be attributed to the direct discharge of untreated sewage from STP outlet to the mainstream of river Ganga.

Hydropsychidae, Glossi-phonidae and Hydroptilidae showed 7.66, 8.25 and 2.92% occurrence (Fig. 4a). In post-monsoon samples a total of 5 families were encountered which comprised of taxa Diptera, Mollusca, Oligochaeta and Hirudinea. Oligochaetes (3.61%) were present in post-monsoon sampling at this location only. However, Chironomidae family was most abundant in this season with 78.31% dominance. Physidae, Culicidae and Salifidae were present with 15.36, 2.31 and 0.3% dominance (Fig. 4b). Boyle and Fraleigh (2003) reported that a high density of oligochaetes is a good indicator of organic pollution. Martin *et al*. (2008) reported increased densities of Oligochaeta specifically *Limnodrillus hoffmeisteri* in an urban stream in southeast Brazil which served as an indication of organic pollution. Li *et al.* (2010) reported Chironomidae family as the most tolerant group. Karrouch *et al.* (2017) studied the impact of anthropogenic activities on the distribution and biodiversity of benthic macro-invertebrates and consequently on water quality of Boufekrane river (Mekens) and reported significantly higher number of microbenthic taxa, overall richness indices and diversity indices at upstream location as compared to that of downstream location. They reported the dominance of 126 taxa at upstream while only 26 taxa were found at downstream locations.

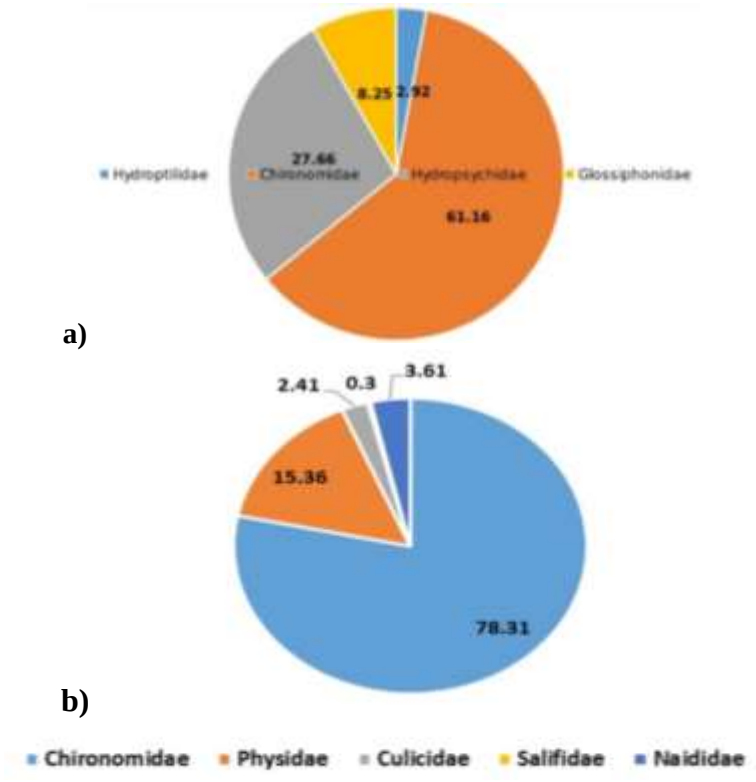

Fig. 4: Dominance (%) of taxonomic families of micro-invertebrates at Haridwar STP downstream; a) pre-monsoon (b) post-monsoon

Riverbed substratum is of utmost importance because it allows the selective colonization of benthic macroinvertebrates thereby determines the overall taxonomic structure of a location. In present study, the riverbed substratum mainly composed of boulders, cobbles, pebbles and gravels at all the

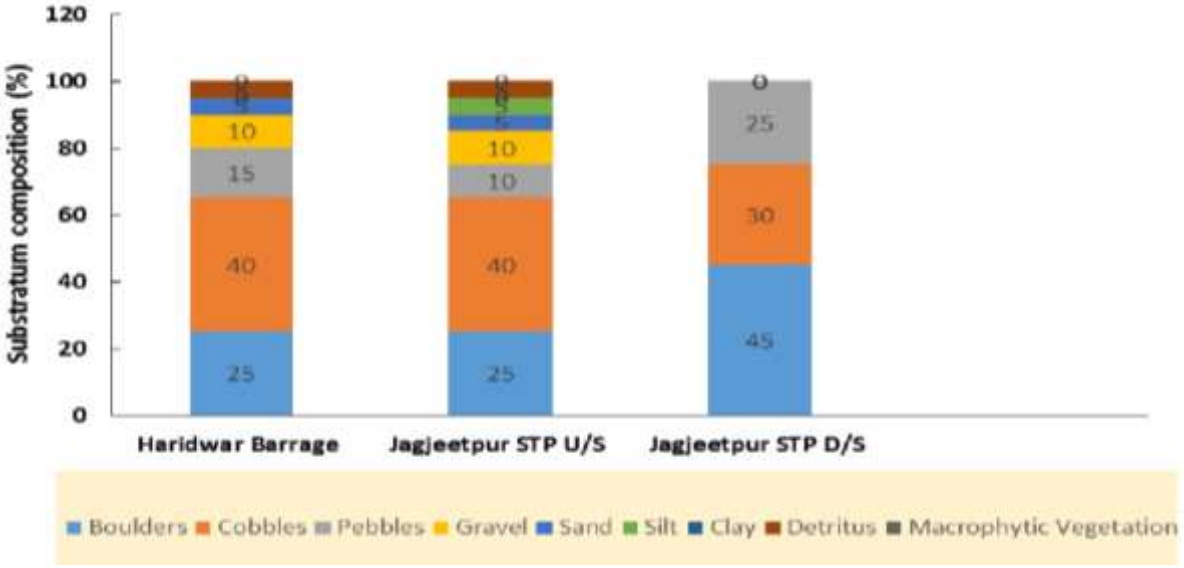

Fig. 5: Composition of riverbed substratum of Ganga at Haridwar Uttarakhand (India)

selected locations and thus is suitable for the colonization of Ephemeroptera, Trichoptera and Plecoptera. Substratum at Haridwar barrage composed of 25% boulders, 40% cobbles, 15% pebbles, 10% gravels and 5% each of sand and detritus. At Jagjeetpur STP upstream, river bed composed of 25% boulders, 40% cobbles, 10% pebbles, 10% gravels and 5% each of sand, silt, detritus whereas at Jagjeetpur STP downstream substratum composed of 45% boulders, 30% cobbles and 25% pebbles (Fig. 5). Kumar (2014) studied the qualitative and quantitative abundance of aquatic entomofauna in glacial fed mountainous Goriganga river of Kumaun Himalaya Uttarakhand (India) and reported that aquatic insects were generally found concealed under stones, gravel and rocks. Most specifically, stone flies (Plecoptera) were present in the riffles and Odonata (dragon flies) and Coleoptera (water beetles) in slow and stagnant conditions. Others such as mayflies (Ephemeroptera), Caddisflies (Trichoptera) and trueflies (Diptera) were common to both the habitats. Kubendran *et al*. (2017) reported most species of Baetidae family such as *Baetis acceptus, B. conservatus, B. frequentus, Indobaetis michaelohubbardi, Labiobaetis geminatus, L. pulchellum, L. soldani, L. jacobusi,* and *L. vera* were predominantly associated with pebbles substrates, but *L. geminatus, L. pulchellum, L. soldani* and *Nigrobaetis paramakalyani* were predominantly associated with grasses, two species *Chopralla ceylonensis* and *C. similis* were primarily attached with rocks and two species, namely *Cloeon bimaculatum* and *Procloeon regularum* were found in pool litter substrate.

The temperature of river water was almost constant at 21°C in pre-monsoon phase and dropped down by approximately 2°C in the following monsoon at all the locations (Table 2). Decrease in water temperature may be attributed to changes in weather conditions. Water flow was observed to be 0.43, 0.97 and 1.01 m sec^{-1} in pre-monsoon season, whereas values were 0.18, 0.91 and 0.83 m sec^{-1} in post-monsoon at Haridwar barrage, Jagjeetpur STP upstream and Jagjeetpur STP downstream, respectively. In pre-monsoon phase, DO at Haridwar barrage and Jagjeetpur STP upstream was 9.3 and 8.85, respectively; whereas at Jagjeetpur STP downstream the value observed

Table 2: Physico-chemical parameters at selected locations of river Ganga in Uttarakhand

Location	Water temperature (˚C)		Flow (m sec^{-1})		Dissolved oxygen (mg L^{-1})	
	April, 2017	Feb., 2018	April, 2017	Feb., 2018	April, 2017	Feb., 2018
Haridwar Barrage	21.0	19.0	0.43	0.18	9.3	9.7
Jagjeetpur STP upstream	21.0	17.7	0.97	0.91	8.85	11.7
Jagjeetpur STP downstream	21.5	19.4	1.01	0.83	4.7	6.2

Table 3: Biology water quality of selected locations of river Ganga in Uttarakhand (India)

Location name	Month of sampling	Diversity score	Saprobic score	Biological water quality	Biological water quality class
Haridwar	April, 2017	0.60	7.16	Clean	A
Barrage	February, 2018	0.66	7.25	Clean	A
Jagjeetpur	April, 2017	0.64	6.21	Slight Pollution	B
STP U/S	February, 2018	0.77	5.94	Moderate Pollution	C
Jagjeetpur	April, 2017	0.48	5.75	Moderate Pollution	C
STP D/S	February, 2018	0.28	2.28	Heavy Pollution	D

were 4.7 only. Post-monsoon phase revealed a similar trend in DO content at all locations. The respective diversity and saprobic scores at Haridwar barrage were 0.60 and 7.16 in pre-monsoon and 0.66 and 7.25 in post-monsoon sampling; thus, belonged to clean biological water quality (BWQC) class A in both the seasons.

At Jagjeetpur STP upstream, the diversity and saprobic scores in pre-monsoon sampling were 0.64 and 6.21, thereby belonged to slight pollution category (BWQC; class B) while in post-monsoon sampling the saprobic score decreased to 5.94 and consequently the biological water quality decline to moderate pollution (BWQC; class C) level. Biological water quality at Jagjeetpur STP downstream was found to be moderate Polluted (BWQC; class C) in pre-monsoon and heavily polluted (BWQC; class D) [Table 3].

High DO values at Haridwar Barrage and Jagjeetpur STP upstream in both the seasons supports the dominance of pollution sensitive families of order Ephemeroptera and Hemiptera depicting the clean water quality. The complete elimination of pollution sensitive taxa and colonization of pollution tolerant families belonging to the order Coleoptera (saprobic index - 6.0), Diptera (saprobic index - 2.0), Hirudinea (saprobic index - 3.0) and Oligochaeta (saprobic index - 1.0) is correlated with the low DO content of 4.7 and 6.2 in pre- and post-monsoon sampling, respectively, and decline in water quality. Abundance of Chironomidae at this location is clear indicator of organic (sewage) pollution. Duran and Akyildiz (2011) evaluated the benthic macroinvertebrate fauna and water quality of Suleymanli lake (Buldan-Denizli) in Turkey and reported that the benthic macroinvertebrate richness and diversity of Suleymanli lake were moderate but the number of individuals were high. Zeybek *et al*. (2014) studied the use of BMWP and ASPT indices for the evaluation of water quality according to macroinvertebrates in Değirmendere Stream (Isparta, Turkey) and reported that the water quality of Değirmendere stream was unpolluted or slightly polluted according to the physicochemical data and the different versions of BMWP and ASPT. Deo *et al.* (2016) studied the diversity of benthic macroinvertebrates in four seasonal tributaries of river Narmada in the central zone (India) and reported the occurrence of 30 taxa from 8 sampling stations with major taxonomic composition of phylum arthropoda (63%) and moderate pollution at all stations using Shannon-Wiener diversity index. Patang *et al*. (2018) studied benthic macroinvertebrates diversity as bioindicator of water quality of rivers in east Kalimantan (Indonesia) and based on the values of average score per taxon (ASPT) & the national sanitation foundation - water quality index (NSF-WQI), categorized Karang Mumus river as polluted with *Chironomus* sp. and *Melanoides tuberculata* as codominant taxa, Jembayan river as doubtful or moderate quality containing *M. tuberculata* and *A. parvula* as codominant taxa and Pampang river as the cleanest river with Odonata and Baetidae families as codominant taxa.

Conclusion: A total of 1560 individuals belonging to 32 families in dominance order: Hydropschyidae (248) > Heptagenidae (155) > Siphloneuridae (131) > Leptophlebidae (91) > Aphelocheridae (64) ~ Physidae (62) ~ Caenidae (61) > Ameletidae (52) were recorded. Individuals of other families were less sparsely distributed constituting about 13% of total benthic population.

The observance of organisms with saprobic index - 10 belonging mainly to Ephemeroptera families (Heptagenidae, Siphloneuridae, Leptophlebidae and Ameletidae) and Hemiptera family (Aphelocheridae) indicated clean water quality at 2 locations i.e. Haridwar barrage and Jagjeetpur STP upstream. An abundance of Chironomidae taxa (493) at Jagjeetpur STP downstream in both the seasons was due to the direct discharge of untreated sewage into the mainstream of river Ganga from STP resulting in sharp decline in dissolved oxygen from 8.85 to 4.7 and 11.7 to 6.2 in both the seasons i.e. pre-monsoon and post-monsoon respectively. The biological water quality at Jagjeetpur STP downstream may improve in future after completion of project for upgrading the existing STP capacity from 27 MLD to 55MLD.

Acknowledgement: The authors are thankful to the Central Pollution Control Board, Head Office, New Delhi (India) for providing all the facilities for conducting this research. The support received from the Uttarakhand Environment Protection & Pollution Control Board (UEPPCB), Dehradun and Regional Directorate, CPCB, Roorkee is also acknowledged. The financial assistance received from Rejuvenation of River Ganga project and National Mission for Clean Ganga (NMCG) is gratefully acknowledged.

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