



Bioassessment of Mandakini River with the help of aquatic macroinvertebrates in the vicinity of Kedarnath Wildlife Sanctuary

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Abstract

Increasing advancement in development activities in the Indian Himalayan region in tandem with changing climate is influencing the ecological patterns of rivers. Thus, the present study investigates the effect of various degrees of anthropogenic stresses and possible implication of thermal dynamics of river water on the macroinvertebrate community in the Mandakini River, which flows in the vicinity of Kedarnath Wildlife Sanctuary of Chamoli district, Uttarakhand. The main objective was to study the community structure of macroinvertebrates in the Mandakini River and to calculate the effect of anthropogenic stresses on the macroinvertebrate community, particularly on Ephemeroptera, Plecoptera, and Trichoptera. The study was carried out in 10 spatially located sampling stations, and the frequency of sampling was divided into pre- and post-monsoon season (May and November 2017). Based on the degree of anthropogenic stresses, sampling locations were divided into least (Sonprayag), medium (Ukhimath), and high disturbed (Rudraprayag) sites. A total of 3257 individuals belonging to 7 orders and 21 families were found in both the sampling season. Diptera and Trichoptera were dominant orders in both the seasons, whereas Baetidae (Ephemeroptera), Hydropsychidae, Leptoceridae (Trichoptera) and Chironomidae (Diptera) were dominant families. Shannon diversity index varies from 2.048 to 2.25 in the least disturbed site (Sonprayag), 0.186–2.446 in medium disturbance (Ukhimath), and 1.362–2.271 in the highly disturbed site (Rudraprayag) in both the sampling season. Quantification of the EPT index shows a negative trend with an increase in anthropogenic stress, and it was least in Rudraprayag as compared to the other two sites. Result of one-way ANOVA shows a significant difference in diversity between pre- and post-monsoon season ($p < 0.05$). Analyzing the research gaps, it is recommended to have long-term ecological monitoring of high altitude and glacier-fed rivers and streams to obtain robust information regarding the dynamics of the riverine ecosystem in Garhwal Himalayas.

Keywords Aquatic macroinvertebrates · EPT · Himalaya · Mandakini · Kedarnath Wildlife Sanctuary

Introduction

Garhwal Himalayas boasts of its exotic beauty and serenity because of its beatific landscapes and rivers flowing across it. However, with the advancement of the Anthropocene age, every vulnerable ecosystem is influenced by it, especially the aquatic ecosystem. Aquatic macroinvertebrates, which act as a river sentinels, are sensitive to such changes and are used worldwide for evaluating the impact of climate change and anthropogenic stresses. Majority of rivers in Garhwal region are glacier-fed and vary in their ecological

composition with distance from glaciers, their biodiversity decreases as compared to non-glacial rivers as temperature of the former is influenced by the amount of snowmelt and local climatic regimes, whereas latter is more diverse due to less fluctuation in temperature and discharge (Milner et al. 2001). Subsequent studies have been conducted in Southern Alps and Italian glacier-fed streams to quantify the effect of glacier retreat in the macroinvertebrate community (Jacobsen et al. 2014; Hotaling et al. 2017; Scotti et al. 2018). The characteristic feature of glacier-fed rivers and streams is their fluctuation in average monsoonal discharge, daily discharge, temperature, and riparian sediments like cobbles and boulders (Lencioni 2018). Change in land-use and human activities are important factors influencing the macroinvertebrate community (Meyer and Turner 1992), whereas changes in the climatic conditions might be the result of

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the natural process (Parmesan and Yohe 2003). On the one hand, anthropogenic disturbances and land-use patterns are affecting rivers and streams (Carvalho and Tejerina-Garro 2015) and on the other hand meteorological phenomenon such as air temperature and precipitation which has strong correlation with climate change is affecting the temperature and velocity of the same (McGregor et al. 1995; Karl 2003; Milner et al. 2001; Li et al. 2018; Lencioni 2018). An interesting study done in Taizi river at China predicts the cumulative effect of land use and climate change on EPT (Ephemeroptera, Plecoptera, and Trichoptera) indices with structural equation model and Bayesian network, and the results showed that land-use change due to anthropogenic pressure indicated greater effect on their population than climate change (Li et al. 2018). Predictions have been made in European countries that with an increase in glacier retreat by recent climate change will result in shift macroinvertebrates community and the same has been supported by the study of Lods-Crozet et al. (2001) in which the colonization of *Diamesa* spp. of order Chironomidae has been observed in European Glacier-fed streams. Similarly, the Mandakini River, which is one of the glacier-fed rivers of the Garhwal Himalayan region, is also facing constant stress in past decades due to the retreat of Chorabari glacier which might be due to the cumulative effect of climate change and anthropogenic pressure. Increasing population pressure in the Mandakini River is one of the major factors for river water deterioration. According to the 2011 census, there is a percentage increase of 6.58% of the population observed from the 2001 census as compared to the 2011 census. Thus, multiple factors are influencing the riverine ecosystem of selected locations, which is further affecting the ecological status of the Mandakini River. Cumulative impact of direct and indirect anthropogenic stress in form of greenhouse gas emissions and increase in developmental activities are changing the microclimate regimes which might be an addition to retreating glacier (McGregor et al. 1995; Boon 1988; Brittain and Saltveit 1989), and aquatic macroinvertebrates are the potential indicator of such changes. Their presence and absence reveal the ecological status and water quality of the particular aquatic ecosystem. As glacier-fed rivers, lakes, and streams in the Himalayan region constitute the majority of available freshwater in the world; hence, their monitoring, management, and conservation are essential for long-term sustenance of water resources. Previous studies have been done in India to quantify water quality and its relation to macroinvertebrates. Checklists of orders Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, and Odonata have been developed by the Zoological Survey of India, focusing mainly on their morphological identification (Sivaramakrishnan et al. 2014; Sharma and Chandra 2009; Chandra et al. 2017). In southern India, assessment of the water quality of rivers and streams of Kudremukh National

Park and North Kannada using aquatic macroinvertebrates has been studied (Sivaramakrishnan et al. 1992). In the Garhwal region, studies have been conducted to understand the macroinvertebrate assemblage concerning different forests type, elevation gradient, stream orders, and latitudinal and longitudinal gradient (Mishra 2007, 2012; Mishra and Nautiyal 2011, 2013; Nautiyal et al. 2004). Fragmented studies have been done in the Himalayan region due to the time and geographical constraints, and the gaps have been recognized in the literature review. Although previous studies done on Mandakini River investigate the distribution pattern of aquatic macroinvertebrate near snowline (Semwal and Nautiyal 2009) and dynamics of aquatic insects in different locations of Mandakini River (Goswami and Singh 2017), the effect of anthropogenic pressure on macroinvertebrates has yet not been studied. Hence, it is important to know how macroinvertebrates respond to various degrees of anthropogenic pressures and climatic variations. Thus, the main objective of the study was (1) to quantify the macroinvertebrate assemblage in different locations of Mandakini River in pre- and post-monsoon season, (2) to quantify the changes in EPT percentage with respect to anthropogenic disturbances and (3) changes in diversity of macroinvertebrates in response to anthropogenic disturbances in both the sampling seasons.

Methods

The Mandakini River is situated near the Kedarnath Wildlife Sanctuary and owes its origin to the Chorabari Glacier (3895 m) located in the Uttarakhand district of Rudraprayag. It is one of the sacred rivers of Uttarakhand as it covers the area of the shrine of Kedarnath and is of great religious significance to people all over the world. The altitude of the catchment area varies from 3507 to 6917 m above mean sea level (Kansal et al. 2014).

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12 m³/s observed from June to September with the mean monthly daily rainfall of 120–150 mm (Fig. 1).

Criteria of site selection

We did a reconnaissance survey in the towns and villages of Kedarnath wildlife sanctuary situated in the bank of River Mandakini. Based on the degree of anthropogenic disturbances, we divided these towns into three categories, namely (1) least disturbed or undisturbed site, (2) medium disturbed sites and (3) maximum disturbed sites as mentioned in Table 1. Approximate distance from human habitation was recorded which ranged from 0 to 5 km.

Data collection and sampling technique

Macroinvertebrates were collected from 10 spatially located sampling sites. Sampling time was divided into pre-monsoon (May 2017) and post-monsoon season (November 2017).

Each sampling site had ten subplots, consisting of five riffles and five pools. A total of 100 sampling points was extensively searched for 1 min each in 100-m reach of the river, and each sampling plot was of 1 × 1 m² dimensions. “Hand-picking method” was adopted over the conventional method of “kick sampling” because most of the riparian bed of Mandakini River is composed of cobbles and boulders. Substrates were picked up quickly to collect the relatively fast swimmers (Flotemersch et al. 2017; Hill et al. 2016). The dominant substratum subsamples were pooled to get composite samples. The depth of the sampling point was noticed with the help of a 12-inch metal scale. The temperature was measured by a handheld digital pH temperature meter. After collection, macroinvertebrates were dislodged into 300 µm sieve net tucked in the bucket and again picked by tweezers meticulously for the average of 2 h and preserved in 70% ethanol (Singh and Nautiyal 1990) and brought to laboratory at Wildlife Institute of India, Dehradun, for identification up to family level with the aid of inverted microscope. Macroinvertebrates were identified with the help of keys mentioned

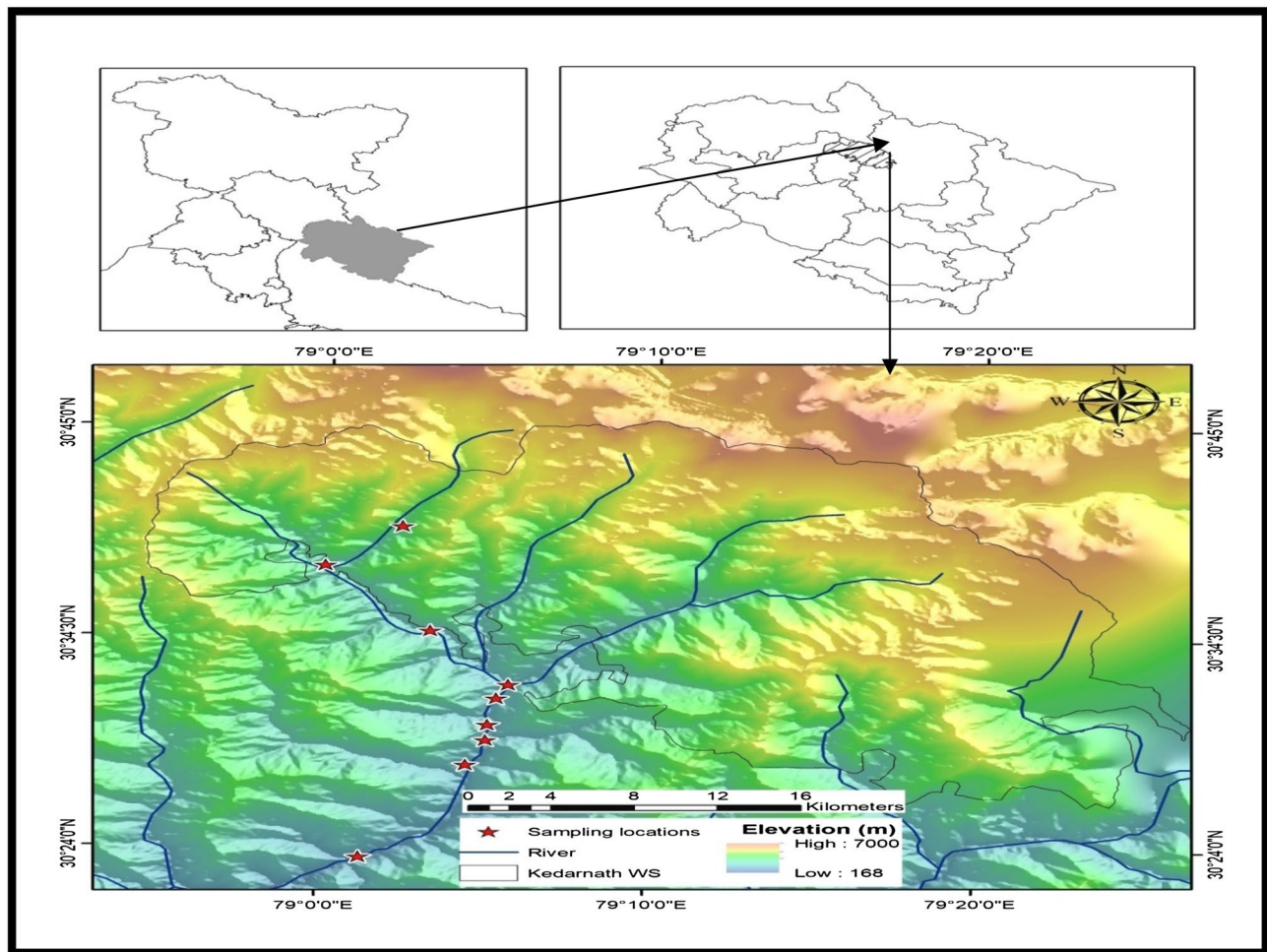


Fig. 1 Map of the sampling sites in Mandakini River, Rudraprayag Uttarakhand, India

Table 1 Macroinvertebrate sampling location in different areas of Mandakini River

Site	Location	(N= 10/site)	Disturbances	Distance from human habitation (approx.)	Substrate type	Depth of collection (inch)
1	Sonprayag	Upstream of Gaurikund (2205 m)	Undisturbed	1–2 km	Cobbles and stones	5.2–8.9
2	Sonprayag	Confluence of Mandakini and Sonprayag (1712 m)	Channel alteration/Mass bathing during pilgrimage	0.4–0.7 km	Cobbles, stones and silt	3.4–7.8
3	Sonprayag	Kalimath (1321 m)	Occasional landslides	< 5 km	Cobbles, stones and silt	3.4–9.3
4	Sonprayag	Confluence of Madmaheshwar Ganga and Mandakini (1108 m)	Undisturbed	< 5 km	Cobbles, stones and silt	4.4–6.7
5	Ukhimath	Upper reaches of Ukhimath Dam (1054 m)	Road construction and channel alteration	4–5 km	Cobbles and stones	2.3–7.9
6	Ukhimath	Kund (1018)	Muck disposal and sand mining	3–4 km	Cobbles and stones	4.4–6.7
7	Ukhimath	Kakda (986 m)	Muck disposal, sand mining and channel alteration	< 5 km	Cobbles and stones	5.3–6.8
8	Rudraprayag	Bhiri (930 m)	Sewage sludge disposal, ash sediments, channel alteration	0.5–0.1 km	Cobbles and stones	3.3–5.6
9	Rudraprayag	Agastyamuni (772 m)	Agricultural runoff, sewage sludge disposal, muck disposal and road construction	0.2–0.3 km	Cobbles and stones	6.4–9.9
10	Rudraprayag	Rudraprayag Town (Tilwara) (635 m)	Agricultural runoff, sewage sludge disposal, muck disposal and road construction	0.2–0.3 km	Cobbles and stones	4.9–7.8

in technical reports, research papers (Subramanian and Sivaramkrishnan 2007; Rana et al. 2017; Chandra 2018). Based on the sensitivity of taxa percentage Ephemeroptera, Plecoptera and Trichoptera were calculated (Hilsenhoff 1982; Cummins and Wilzbach 1985; Crawford and Lenat 1989; Plafkin et al. 1989; Scotti et al. 2018).

Statistical analysis

Shannon diversity index was calculated using software PAST (3.2). Percentage Ephemeroptera, Plecoptera and Trichoptera (EPT) were calculated using guidelines of Rapid Bioassessment protocol. One-way ANOVA was conducted in XLSTAT (2018) software to find the significant difference between the two seasons.

Result and discussion

Community structure of aquatic macroinvertebrates

A total of 7 orders and 21 families and 3214 individuals have been found in pre- and post-monsoon season in different sampling locations of the Mandakini River. A list of aquatic macroinvertebrates found in pre- and post-monsoon season is tabulated in Tables 2 and 3. During pre-monsoon

season, Limnephilidae, Leptoceridae, Hydropsychidae, Glossosomatidae, Limoniidae, and Chironomidae were dominant families, whereas in post-monsoon season, Baetidae, Ephemerellidae, Ameletidae, Hydropsychidae, Chironomidae, and Hydrachnid were dominant. Trichoptera (Caddisflies) and Diptera (True Flies) were more abundant order in pre-monsoon, whereas Ephemeroptera and Diptera were more abundant during post-monsoon. According to the zonal distribution of macroinvertebrates among the categorized sites, Limnephilidae, Leptoceridae, Hydropsychidae, Branchycentridae, Glossosomatidae, Limoniidae, and Chironomidae were dominant in Sonprayag area (site 1–4) where forest composition comprised of *Quercus* spp. and *Pinus* spp. One of the important families found in the confluence of Mandakini and Madmaheshwar Ganga was Blephariceridae (*Horaria* sp.) belonging to order Diptera, which is one of the rarest insects studied and found in the region. Similar specimens of the same were recorded from Chamba and Dalhousie of Himachal Pradesh (Tonnoir 1930). At the Ukhimath region, Philopotamidae, Leptoceridae, Glossosomatidae, Simuliidae, and Chironomidae were dominant families. Water penny belonging to the Psephenidae family was found in the lower reaches of Ukhimath at the junction of Khakhra gad and Mandakini River. The area comprises of dense mixed forests where *Pinus* spp. were dominant vegetation. At Rudraprayag region (site 7–10), the

Table 2 Macroinvertebrates community composition during pre-monsoon season (May 2017)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Baetidae	+	+	+	+	-	-	-	-	-	-
Ephemerellidae	+	+	+	+	+	+	+	+	+	+
Ameletidae	-	-	-	-	-	-	-	-	-	-
Heptageniidae	+	+	+	+	+	+	+	-	-	-
Perlidae	+	+	+	+	+	+	-	-	-	-
Capniidae	-	-	-	-	-	-	-	-	-	-
Nemouridae	+	+	+	-	-	-	-	-	-	-
Rhyacophilidae	-	-	-	-	-	-	-	-	-	-
Limnephilidae	+	+	+	+	+	+	+	+	-	-
Philopotamidae	+	+	+	-	+	-	-	-	-	-
Leptoceridae	+	+	+	+	+	+	+	+	-	-
Hydropsychidae	+	+	+	+	+	+	+	-	-	-
Branchycentridae	+	+	+	+	+	+	-	-	-	-
Glossosomatidae	+	+	+	+	+	+	+	+	-	-
Blephariceridae	-	-	-	-	-	-	-	-	-	-
Limoniinae	+	+	+	+	+	+	+	+	+	+
Simuliidae	-	-	-	+	+	+	+	+	+	+
Anthricidae	-	-	-	-	-	-	-	-	-	-
Chironomidae	+	+	+	+	+	+	+	+	+	+
Gyrinidae	-	-	-	-	-	-	-	-	-	-
Psephenidae	-	-	-	-	-	+	+	+	-	-
Libellulidae	-	+	+	-	-	-	-	-	-	-
Hydrachnidia	-	-	-	-	-	-	-	-	-	-

Table 3 Macroinvertebrates composition during post-monsoon season (November 2017)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Baetidae	+	+	+	+	+	+	+	+	+	+
Ephemerellidae	+	+	+	+	+	+	+	+	+	+
Ameletidae	-	+	+	-	+	-	+	-	-	-
Heptageniidae	+	-	+	+	+	+	+	+	+	-
Perlidae	-	+	-	-	+	-	-	+	-	-
Capniidae	+	+	-	-	-	-	-	-	-	-
Nemouridae	-	-	-	-	-	-	-	-	-	-
Rhyacophilidae	+	-	+	-	+	+	-	-	+	-
Limnephilidae	-	-	-	-	-	-	-	-	-	-
Philopotamidae	-	-	+	+	-	+	-	+	+	-
Leptoceridae	-	-	-	-	-	-	-	-	-	-
Hydropsychidae	+	+	+	+	+	+	+	+	+	+
Branchycentridae	-	+	-	+	-	+	-	-	+	+
Glossosomatidae	+	+	+	+	+	+	+	+	-	-
Blephariceridae	-	-	+	-	-	-	-	-	-	-
Limoniinae	+	+	+	+	+	+	+	+	+	+
Simuliidae	-	+	+	+	+	+	+	+	+	+
Anthricidae	+	-	-	+	-	+	-	-	+	-
Chironomidae	+	+	+	+	+	+	+	+	+	+
Gyrinidae	-	-	-	-	-	-	-	+	+	+
Psephenidae	-	-	-	-	-	-	+	+	+	+
Libellulidae	-	+	+	-	-	-	-	-	-	-
Hydrachnidia	+	-	-	-	-	+	+	+	+	+

dominant families were Limoniidae, Simuliidae, and Chironomidae belonging to order Diptera. The number of macroinvertebrates in all the sites was found more in the post-monsoon season ($n = 1814$) as compared to pre-monsoon season ($n = 1400$). Similar results were obtained at Kund to the confluence of Mandakini and Alaknanda (Goswami and Singh 2017). It is deduced from the above statement that the macroinvertebrates community thrives well during the winter season.

%EPT variation to anthropogenic disturbances

The biotic index was calculated based on the presence and absence of EPT (Ephemeroptera, Plecoptera, and Trichoptera), and the results indicated that the EPT percentage was higher in the area of minimum disturbances (Sonprayag) and the lowest in the area of maximum disturbance (Rudraprayag) (Figs. 2, 3). The percentage of pollution intolerant taxa in both the sampling season was highest in Rudraprayag (high disturbance). Order Ephemeroptera, Plecoptera, and Trichoptera thrive well in the undisturbed

area where the water is well oxygenated and surrounded by riparian forests are known as “specialists.” On the contrary, at medium disturbed sites, the diversity of benthic fauna was maximum and the reason could be due to moderate anthropogenic stress in which specialists could not survive and thus give generalists the opportunity to diversify (He et al. 2018). The fundamental concept behind the biotic index is based on the fact that most genera are sensitive to organic pollution (Rosenbery and Resh 1993; Fierro et al. 2017; Wan Abdul Ghani et al. 2018). During the pre-monsoon season (May 2017), the percentage EPT values range from 69.18 to 82.6% at a minimum disturbed site (Sonprayag), 51.44 to 64.18% at a medium disturbed site (Ukhimath) and 11.44 to 44.62% at the maximum disturbed site (Rudraprayag). Similar results were obtained for the post-monsoon season, where the EPT abundance ranged from 69.18 to 82.6% at least disturbed site, 40.54 to 64.41% at medium disturbed sites, and 12.8 to 20.61% at maximum impaired sites. It can, therefore, be deduced from the above results that the abundance of EPT could vary with seasonal fluctuations and anthropogenic disturbances. The maximum disturbed

Fig. 2 Variation in %EPT during pre-monsoon season (May, 2017)

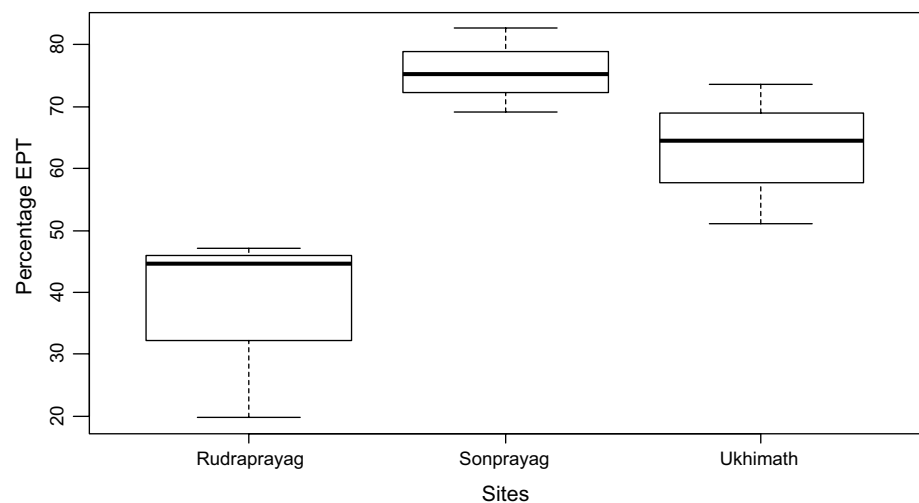
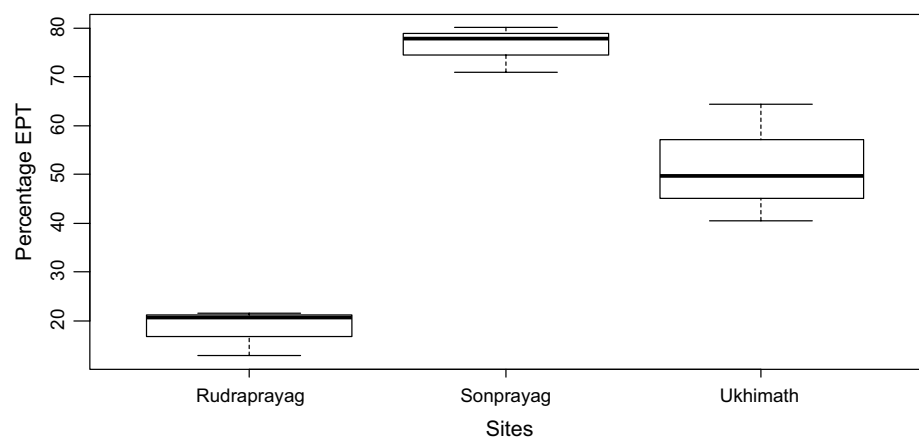


Fig. 3 Variation in %EPT during post-monsoon season (November 2017)



sites (Rudraprayag) had the least abundance of EPTs and a high number of Diptera. As a result, an area with higher anthropogenic disturbances (Rudraprayag) had poor water quality compared to medium (Ukhimath) and minimum disturbance (Sonprayag) area. Decreasing EPT with an increase in disturbance can be explained by the study conducted by Poulton et al. (2015) at Upper Blue River where the macroinvertebrate community is responding to longitudinal changes on the stream condition and loss of EPT was observed at the downstream of the river where the wastewater discharge is high as compared to upstream where there is low or no disturbance. The pattern of land use also plays an important role in structuring the benthic macroinvertebrate population, and thus its impact can be seen in the benthic fauna of these specific landforms if there is an intrusion in the surrounding riparian zone through emission loads (Kasangki et al. 2006, 2008, Li et al.). Variation in water quality due to natural or human-induced intervention also affects the macroinvertebrates community as EPT thrives best on the higher levels of dissolved oxygen and very susceptible to the slightest variation in dissolved oxygen. Physical disturbance such as alteration of channels, sand mining and muck disposal, construction of artificial reservoirs, decomposition of riparian forests and chemical alterations such as dumping of solid and liquid waste and agricultural runoff usually affect macroinvertebrate communities near the watershed and tell a lot about the health of the water body, as the less susceptible species to changes in water quality will vanish from that region (Holt and Miller 2011). They, therefore, serve as an excellent bioindicator of water chemistry changes.

Change in the diversity of macroinvertebrates in response to anthropogenic intervention

During the pre-monsoon season, the Shannon diversity index varied from 2.048 to 2.137 in the least disturbed sites, 0.186 to 2.245 in medium disturbed sites, and 1.362 to 1.597 in maximum disturbed sites. During the

post-monsoon season, the Shannon diversity index ranges between 2.084 and 2.254 at least disturbed sites, 2.245 and 2.446 at medium disturbed sites, and 1.794 and 2.274 at maximum disturbed sites (Fig. 4). Spatial distribution of aquatic macroinvertebrates vis-à-vis their Shannon diversity index was found to be maximum in the moderately disturbed site in both pre- and post-monsoon season in comparison with least and maximum disturbed area. The proportion of specialists to generalists was higher in the Sonprayag area (minimum disturbed), roughly equal in moderately disturbed sites (Ukhimath), and minimum (Rudraprayag) in high anthropogenic disturbances. The reason for such a pattern might be taxonomic groups; EPT is susceptible to the disturbance and changes in stream environment, allowing more tolerant groups to replace them. Consequently, the community assemblage of macroinvertebrates becomes more homogeneous at the disturbed area (Sanchez et al. 2010; He et al. 2018). Other reasons for such fluctuation might be high rainfall, high temperature affecting dissolved oxygen levels, high water velocity in addition to anthropogenic interventions. It is also observed that during pre-monsoon, the disturbance across the lower reaches of the Mandakini River increases due to high tourist influx, which further results in high discharge from nearby localities. These results are consistent with the study conducted by Mehler et al. (2014), at Walker River in the Great Basin Desert, Nevada wherein values of Shannon–Wiener Index (H'), Margelef's diversity index (DMG) and the Pielou index (J) varied both spatially and temporally and benthic macroinvertebrates communities changed downstream toward depauperate assemblages with a few dominant taxa. However, increased loads of nutrients and other pollutants from agricultural and urban lands are among the dominant stressors that can lead to sharp changes in benthic community structure often associated with land use (De Moor 1992; Cuffney et al. 2000; Cross et al. 2006; Aera et al. 2019).

Fig. 4 Shannon diversity (H') during pre-monsoon (PRM) and post-monsoon season (POM) (May–November 2017)

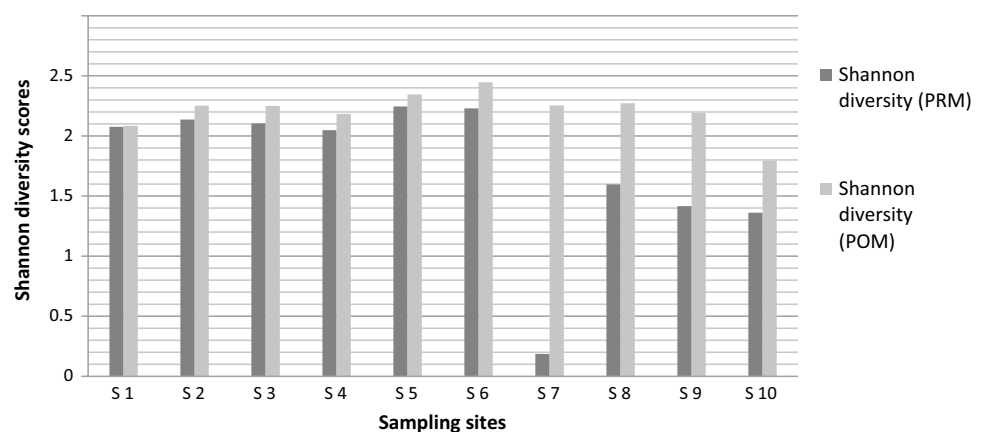


Table 4 Result of one-way ANOVA

Source of variation	SS	df	MS	F	p value	F crit
Between groups	1.09170	1	1.091706	4.977091	0.038645	4.413873
Within groups	3.94823	18	0.219346			
Total	5.03993	19				

Results from one-way ANOVA

One-way ANOVA was performed on macroinvertebrates diversity to test whether there is any significant difference seasonally in the diversity of aquatic macroinvertebrates. A null and alternate hypothesis was tested to confirm that the diversity of aquatic macroinvertebrates in both pre and post-monsoon season is the same or different. From the ANOVA result, the value of F calculated (4.977) was found to be higher than F critical (4.413), and based on this result, we were able to reject the null hypothesis and accept the alternative hypothesis (Table 4). Further, the p value (0.038) was found to be less than 0.05, which indicated the level of significance. This result clearly shows that there is a significant difference in the diversity of macroinvertebrates in both the season (i.e., pre-monsoon, and post-monsoon). However, results show that the value of $p < 0.05$ and F critical value less than the F calculated value rejecting the null hypothesis. This result indicates the significant difference between the diversity of aquatic macroinvertebrates in pre- and post-monsoon season. Results tabulated in Table 1 clearly show that the ratio of the absence of macroinvertebrates families in pre-monsoon is higher than that of post-monsoon. Also, in Fig. 4, the difference in the diversity indices at the disturbed sites (Site 7, Site 8, Site 9, Site 10) is higher as compared to the other sites, and the diversity index is low in pre-monsoon as compared to post-monsoon season (Righi et al. 2010). The reason for such fluctuation is that during summers (pre-monsoon), the river velocity, temperature, rainfall, and anthropogenic activities are higher as compared to post-monsoon. High temperature is inversely proportional to the dissolved oxygen (Connolly et al. 2004; Buckup et al. 2007; Walczyńska and Sobczyk 2017), which might result in a decrease in the diversity of macroinvertebrates in that region. The results correlate with the studies wherein the anthropogenic and other environmental factors are responsible for the statistically significant difference in macroinvertebrates assemblage seasonally (Kang and King 2013; Sartori et al. 2014; Goswami and Singh 2017; Roy and Homechaudhuri 2017; Verdura et al. 2019; Xue et al. 2019).

Conclusion

It can be concluded from the above study that the composition of benthic macroinvertebrate varies with the land-use pattern and seasonal changes that affect the hydrology of the Mandakini River.

Analysis of results obtained from the %EPT index and Shannon diversity indices indicates that compromised water quality at lower Mandakini (Rudraprayag) is due to high anthropogenic disturbance. Selected sites of Ukhimath need proper management and risk analysis to prevent the further impairment of these areas. Results also reveal the statistically significant difference in the diversity of aquatic macroinvertebrates in pre- and post-monsoon, which might indicate the need for proper redressal mechanism for pre-monsoon when the exposures of anthropogenic influences are high. A high negative correlation of anthropogenic interruptions with the EPT index serves as a model of bioassessment studies in Himalayan Rivers. However, long-term ecological monitoring of high altitude rivers is necessary to quantify climate change effects on benthic fauna. Mandakini River serves as a lifeline for endemic flora and fauna of Kedarnath Wildlife Sanctuary; thus, it is essential to conserve its sanctity.

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Compliance with ethical standards

Conflict of interest We declare that we have no conflict of interest.

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