Influence of water quality on the diversity of macroinvertebrates in the Mandakini River in India

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ABSTRACT

This research work was carried out from July 2018 to June 2019. WQI method was utilized to examine the seasonal changes in water quality that can indicate the potential use of water in the future. Water samples were tested from three locations along the Mandakini River. Fourteen physical and chemical parameters were analyzed. All water quality parameters were inside the admissible furthest reaches of the WHO for drinking water except turbidity, especially in the monsoon season. Twelve taxa of macroinvertebrates (Philopotamus sp., Laphophlebia sp., Isoperla sp., Diploperla sp., Tabanus sp., Hydropsyche sp., Baetis sp., Glossosoma sp., Heptagenia sp., Ephemerella sp., Psephenus sp., and Protandrous sp.) were identified in the Mandakini River. The fundamental goal of this investigation was to evaluate the seasonal effects on benthic macroinvertebrate diversity from the physicochemical variables of the Mandakini River. The study also affirmed that tourist-generated waste disposal and poisonous and dangerous chemicals from farming are the key components liable for the deterioration of water quality during the monsoon season.

Key words | canonical correspondence analysis, macroinvertebrates, Mandakini River, tributaries, WQI

HIGHLIGHTS

- Seasonal benthic macroinvertebrate diversity along with water quality was studied.
- Factors influencing the freshwater diversity were also studied and represented.
- CCA was also calculated for all the sampling sites by using PAST software.
- Network of various streams and rivulets showing a dendritic drainage pattern.
- Water quality impacted macroinvertebrate was also studied.

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doi: 10.2166/ws.2021.020
GRAPHICAL ABSTRACT

ABBREVIATIONS

WQI  Water Quality Index  
CCA  Canonical Correspondence Analysis  
WHO  World Health Organization  
BIS  Bureau of Indian Standards  
CPCB  Central Pollution Control Board  
ICMR  Indian Council of Medical Research  
TDS  Total Dissolved Solids  
DO  Dissolved Oxygen  
Free CO₂  Free Carbon Dioxide  
AT  Air Temperature  
WT  Water Temperature  
WV  Water Velocity  
EC  Electrical Conductivity  
TH  Total Hardness

INTRODUCTION

The Like-Minded Megadiversity Countries are the richest 
sources of biodiversity (Kumar & Sharma 2018). India is 
one among the 18 megadiversity nations (Behera et al. 
2019). The Garhwal Himalaya is a store of the rich and extra-
ordinary diversity of aquatic animals (Nautiyal & Thapliyal 
2011). Freshwater biodiversity is an essential feature for the 
proper functioning of the fluvial system and to ensure its 
resistance and resilience against natural and anthropogenic 
stressors (Bellard et al. 2012). A riverine biological system is a 
necessary and significant segment of the freshwater environ-
ment, wherein the mountain fluvial environment is 
uncommon just as explicit in all conditions. The density 
and influence of biological factors in freshwater ecosystems 
differ significantly from non-biological factors. Every species 
has its explicit boundaries of physiology, biochemistry, and 
genetics with the effective divergence of physicochemical 
attributes of an ecosystem in due course of time (Wetzel & 
Likens 2000).

An increase in the human population exerts pressure on 
the environment and its assets. The growing level of urbaniz-
ation, industrialization, agribusiness modernization, and 
expansion in traffic require exact information with respect 
to the water quality of an aquatic body, as people are gener-
ally relying upon waterways for their standard activities. 
Expanded contamination level in streams is a central point 
of contention, as these waterways give water for consump-
tion (Kazi et al. 2009). The WQI technique has been 
utilized to assess the wellbeing of a water body for human 
consumption. Specifically, water quality assessment indi-
cates the degree of consistency with the principles
suggested for drinking water by the WHO, BIS, CPCB, and ICMR. The biophysical diversity of an aquatic ecosystem increases with latitudinal and longitudinal gradients in geology and climate. Hence, it is essential to study the aquatic diversity of macroinvertebrates in response to the physicochemical characteristics for ensuring potable water of good quality (Ntislidou et al. 2018). The CCA strategy has been implemented to compute the effect of physicochemical factors on the seasonal diversity of macroinvertebrates (Kumari & Sharma 2018; Kumar et al. 2020b).

Only a few attempts have been made so far on the various conditions of Mandakini River, which encompass the contribution of Joshi et al. (2001) on landslides in Mandakini River Valley; Kumar et al. (2010) on the physicochemical and bacterial assessment of the river; Rawat et al. (2013) on landslide hazard zonation; Benthwal et al. (2018) on water purity; Goswami & Singh (2018) on the functioning of the river ecosystem; and Tamta & Joshi (2019) on geomorphic and topographic studies. However, no detailed endeavor has been made with respect to the investigation of benthic macroinvertebrate variation in the Mandakini River. The current study provides the baseline information about the macroinvertebrate diversity and nature of water of the Mandakini River to scientists working in comparable fields. The current study was done with the following objectives: (i) water quality index assessment; (ii) assessment of benthic macroinvertebrate variety in connection with physicochemical factors; (iii) factors influencing the aquatic diversity.

**THE STUDY AREA**

The Garhwal Himalayan region of Uttarakhand is situated between the latitudes 29° 26’ N to 30° 28’ N and longitudes 77° 49’ E to 80° 06’ E covering an extent of 30,090 km². This extent is the unceasing home of ice sheets, high pinacles, hanging valleys, and steep gullies. Mandakini River is a significant, perseverance, snow-fed feeder of Alaknanda River. The altitudinal gradient of the river is quite high. Inside the stretch of 90 km, the falling surface is from 6,664 m to 675 m above msl. The entire basin of the river reflects an outstanding network of 26 streams and rivulets of different measurements delightfully demonstrating a dendritic drainage pattern. These tributaries are either spring-fed or snow-fed in nature (Table 1). These tributaries bring and dump a large amount of sediments, rocks, and gravel that are responsible for the transparency, turbidity, pH, and various other important physicochemical parameters. The origin source of these tributaries varies from a height of 4,690 m above msl to 1,240 m above msl. Each and every glacier and valley is the origin source of one basin. The surface area of the basin including that of Mandakini River itself and its tributaries is spread over 165 km². Three water sampling locations (S₁, S₂, and S₃) were selected for the collection and detailed determination of water samples (Figure 1).

**MATERIALS AND METHODS**

**Water sampling**

Three water testing destinations were perceived and examined along the Mandakini River to assess the physicochemical factors and WQI for the duration of 12 months (July 2018 to June 2019). Aside from these two investigations, the physiography of the study area and benthic macroinvertebrate diversity were also recorded. Site S₁ was identified as Agastyamuni (782 m above msl), which was located at latitude 30° 23’ 37” N and longitude 79° 01’ 45” E; S₂ was recognized as Tilwara (706 m above msl), which was located at latitude 30° 20’ 36” N and longitude 78° 58’ 25” E. However, S₃ was recognized as Rudraprayag (633 m above msl before the confluence with the Alaknanda River), which was located at latitude 30° 17’ 18” N and longitude 78° 58’ 46” E. During the research work, water samples were gathered from all predetermined sites of the waterway from a depth of 10 cm by plunging spotless and contamination-free containers in the morning. A few of the physicochemical factors (pH, AT, WT, transparency, WV, turbidity, free CO₂ and DO) were investigated at the water testing destinations; later the sterilized sample bottles were filled with water samples and those bottles were placed in a dark, airtight container filled with ice. The container was moved to the examination research center at the Department for additional assessment of leftover parameters within 4–5 hours of sample collection.

All samples of water gathered from the waterway had experienced the research center strategy to assess 16
physicochemical factors by utilizing the system accessible in APHA (2012). The air and water temperature were recorded by utilizing a precise thermometer. The pH was estimated at the site utilizing the versatile pH meter of Electronics India (model no. 7011). DO was estimated utilizing the modified Winkler’s iodometric strategy at the testing site. Conductivity, TDS, alkalinity, hardness, chlorides, nitrates, sulphates, and phosphates were observed inside the laboratory (APHA 2012). TDS was likewise estimated by utilizing the multiparameter analyzer. Free CO₂, absolute alkalinity, absolute hardness, and chlorides were estimated by using the protocols accessible in APHA (2012). The spectrophotometric strategy (Systronic UV–Vis Spectrophotometer: model no. 117) was utilized to estimate the concentration of nitrates at 410 nm, sulphates at 420 nm, and phosphates at 690 nm of wavelength. The digital turbidity meter of Electronics India (model no. 331) was utilized to measure the concentration of turbidity in the river water.

**WQI**

WQI is a novel measure made to combine various water quality norms suggested by various health organizations into a specific number by normalizing all the surveyed

### Table 1 | Drainage pattern of fluvial system of Mandakini River, Garhwal Himalaya

| S. No. | Tributary | Origin | Nature | Confluence with Mandakini | Total length (km) | Basin area (km²) | % of Mandakini Basin |
|--------|-----------|--------|--------|---------------------------|------------------|-----------------|-------------------|
| 1      | Laster Gad | Kinkhola Khal (3,390 m) | Spring-fed | Tilwara (676 m) | 38 | 293.62 | 17.96 |
| 2      | Son Ganga | Patiyari Dhar (4,590 m) | Snow-fed | Sonprayag (1,648 m) | – | 122.77 | 7.50 |
| 3      | Madhmaheshwar Ganga | Nandi Kund (4,390 m) | Snow-fed | Okhimath (1,059 m) | 29 | 432.50 | 26.44 |
| 4      | Kali Ganga | Kaleun Bank (4,690 m) | Snow-fed | Narayan Koti (1,150 m) | 25 | 149.62 | – |
| 5      | Mandani Ganga | Mandani Bank (4,080 m) | Snow-fed | Kaliganga (1,490 m) | – | – | – |
| 6      | Damar Gad | Bajrangi Peak (3,525 m) | Spring-fed | Damar (950 m) | 21 | 91.59 | – |
| 7      | Kakra Gad | Ragsi Dhar | Spring-fed | Kakra (1,000 m) | – | 73.17 | – |
| 8      | Kyunja Gad | – | Spring-fed | Chandrapuri (827 m) | 12 | 62.8 | – |
| 9      | Rawan Ganga | Dhayya Peak | Spring-fed | Kundchatti (1,040 m) | 9 | 30.4 | – |
| 10     | Lan Gadhera | Bangri Dhar (2,700 m) | Spring-fed | Hati (760 m) | 11 | 30.0 | – |
| 11     | Chaka Gadhera | Bangri Dhar (2,485 m) | Spring-fed | Chaka (750 m) | 9 | 29.6 | – |
| 12     | Saur Gad | Dala Dhar (2,400 m) | Spring-fed | Silli (737 m) | 13 | 29.0 | 1.8 |
| 13     | Gabri Gad | Tangurchi Dhar (3,100 m) | Spring-fed | Rail (1,390 m) | 7 | 19.51 | – |
| 14     | Pati Gad | Chaunri (3,500 m) | Snow-fed | Sitapur (1,620 m) | 8.0 | 19.33 | – |
| 15     | Sauri Gadhera | Kartik Swami Peak (2,325 m) | Snow-fed | Suri (755 m) | 6.0 | 11.83 | – |
| 16     | Kaldungi Nala | North Slope of Tangurchi (2,280 m) | Snow-fed | Rampur (1,550 m) | 6.5 | 8.41 | – |
| 17     | Sari Gadhera | – (2,000 m) | Snow-fed | Downstream Rampur | – | 7.67 | – |
| 18     | Matihana Gadhera | – (1,240 m) | Snow-fed | Matihana (670 m) | 3.75 | 5.91 | – |
| 19     | Devalgarh Gadhera | Dob-Bhaunsal (2,000 m) | Snow-fed | Agastyamuni (752 m) | 3.25 | 4.54 | – |
| 20     | Tarwari Gadhera | Dungri (1,680 m) | Snow-fed | Tilwara (625 m) | – | 4.52 | – |
| 21     | Byung Gad | Dhayya (3,000 m) | Snow-fed | Khumera (1,150 m) | 6.75 | 16.25 | – |
| 22     | Kanda Gadhera | – (1,920 m) | Snow-fed | Kanda (670 m) | 6.0 | 10.0 | – |
| 23     | Ratanpur Gadhera | Near Ghengar (1,640 m) | Snow-fed | Ratanpur (660 m) | 4.25 | 7.0 | – |
| 24     | Bheri Gadhera | Rangsi Dhar (2,400 m) | Snow-fed | Bheri | 5.25 | 6.0 | – |
| 25     | Bangar Gadhera | Durga Dhar (1,650 m) | Snow-fed | Rampur (687 m) | 3.25 | 5.81 | – |
| 26     | Ranyasu Gadhera | Bamsu Dhar (1,745 m) | Snow-fed | Pali (830 m) | 3.75 | 4.35 | – |
Figure 1 | Location map of the sampling sites along the Mandakini River.
factors. To analyze the WQI of all the sampling sites of the Mandakini River, a total of 12 parameters whose permissible limit has been given either by WHO or BIS were identified and evaluated (Prati et al. 1971). A value utilized for each and every physicochemical factor was the standard value of all the three recognized sampling areas. The ‘water quality guidelines’ chosen and recommended by the WHO/BIS have been utilized to compute the WQI value of the Mandakini River. The computation of WQI involves the following steps:

**First step**

A weight \( AW_i \) has been allocated to each physicochemical factor ranging from 1 to 4 based on collective expert opinions taken from published literature on similar aspects available in the public domain (Sharma & Kumar 2017; Kumar et al. 2018; Kumar & Sharma 2019; Rawat et al. 2020a, 2020b). Normal values for the weight of all physicochemical characteristics are given in Table 2 (1: least important; 4: most important).

**Second step**

The following formula was applied to evaluate the relative weight \( RW \):

\[
RW = \frac{AW_i}{\sum_{i=1}^{n} AW_i}
\]  

(1)

Here, \( RW \) = relative weight, \( AW \) = assigned weight of each environmental factor, \( n \) = complete number of assessed factors. The assessed relative weight \( RW \) estimations of each environmental factor appear in Table 3.

**Third step**

The quality rating scale \( Q_i \) for the surveyed environmental factors barring pH and DO was allotted after dividing the determined amount in water by its tolerable limit endorsed for drinking water by WHO/BIS, and then the resultant was multiplied by 100:

\[
Q_i = \frac{C_i}{S_i} \times 100
\]  

(2)

However, the following formula was applied to compute the quality rating for pH and DO:

\[
Q_{\text{pH}, \text{DO}} = \frac{C_i - V_i}{S_i - V_i} \times 100
\]  

(3)
Here, $Q_i =$ quality rating, $C_i =$ value of a specific environmental factor obtained after investigations at the department, $S_i =$ value of the physicochemical factor suggested by the health organizations for drinking water, $V_i =$ optimal value (pH: 7.0; DO: 14.6).

Equations (2) and (3) confirm that $Q_i = 0$ when a contaminant is totally inadequate in the water sample and $Q_i = 100$ when the estimation of the physicochemical factor is identical to its recommended value. The $Q_i$ value indicates the contamination level (Kumar et al. 2018).

Fourth step

In conclusion, to compute the WQI value, the sub-indices ($S_i$) were first assessed for each physicochemical factor, and later by implementing the following equations:

\[ S_i = RW \times Q_i \] (4)

\[ WQI = \sum_{i=1}^{n} S_i \] (5)

The estimation of determined WQI for water quality could be classified as $<50 = $ excellent; $50–100 = $ good; $100–200 = $ poor; $200–300 = $ very poor; $>300 = $ unsuitable for human utilization (Chaudhary et al. 2018; Kumar & Sharma 2018; Rana et al. 2018; Deep et al. 2020).

Analysis of benthic macro-biota (Macroinvertebrates)

The Surber sampler (0.50 mm mesh net) was carefully utilized for the benthic macroinvertebrate collection in three replicates by colonizing the bottom substrates and by hand-picking from boulders and stones at all the three sites. Samples were collected from the entire river stretch covering each sampling site. Then 4% formalin was used to preserve the collected samples until further identification in the laboratory. Qualitative analysis was made possible by following the standard methodology given by Needham & Needham (1962) and Wallace et al. (1991) and the standard keys of the Freshwater Biological Association (UK) for surveying the structure of community and macroinvertebrate variety. An Olympus CX21i-TR-LED (Trinocular Version) Microscope equipped with MIPS (Micro Image Projection System) was used for macroinvertebrate identification.

Statistical treatment

The software Microsoft Excel 2013 was utilized to ascertain the minimum, maximum, mean, and standard deviation for all sites (Kumar et al. 2020a). The Shannon–Wiener diversity index method was implemented for the recorded data set of benthic macroinvertebrates. The species relative abundance was utilized to calculate the diversity index ($H$). This method also calculates the species richness and abundance. However, CCA was also calculated for all the sites by using the statistical software Paleontological Statistics (PAST). CCA is a multivariate method that has been adopted for graphical representation. It was also applied to elucidate the relationships between biological samples and their environment.

RESULTS AND DISCUSSION

Physicochemical factors

Physicochemical factors of water were evaluated for a period of one year (July 2018 to June 2019) (Tables 4–6). The variation in mean air temperature was found to be lowest (15.5°C) in winters and highest (29.07°C) in monsoon. The fluctuation in mean water temperature was noticed to be a minimum of 9.33°C in winters and a maximum of 18.17°C in monsoon. Rawat et al. (2018) announced analogous outcomes for water and air temperature. The water and air temperatures straightforwardly correspond to one another. Turbidity represents water clarity. Turbidity and power of dissipated light are straightforwardly relative to one another. The estimation of turbidity was noticed to be a minimum of 14.25 NTU in winters and a maximum of 18.17°C in monsoon. Tsering et al. (2019) and Patang et al. (2018) recorded it from 4.34 NTU to 47.3 NTU. However,
| Physicochemical parameters | Monsoon (Jul–Sep) | Autumn (Oct–Nov) | Winter (Dec–Mar) | Summer (Apr–Jun) |
|----------------------------|-------------------|------------------|------------------|------------------|
| AT (°C)                    | 23.7 ± 2.07       | 17.1 ± 2.26      | 12.1 ± 2.60      | 21.7 ± 3.40      |
| WT (°C)                    | 12.5 ± 1.68       | 10.2 ± 0.64      | 8.4 ± 1.22       | 15.4 ± 1.74      |
| Turbidity (NTU)            | 211.93 ± 51.36    | 19.05 ± 8.98     | 14.25 ± 5.42     | 75.3 ± 23.25     |
| WV (m/s)                   | 0.71 ± 0.03       | 0.47 ± 0.04      | 0.35 ± 0.07      | 0.57 ± 0.06      |
| Transparency (m)           | 1.06 ± 0.20       | 1.93 ± 0.35      | 2.75 ± 0.15      | 1.91 ± 0.36      |
| TDS (mg/l)                 | 151.67 ± 4.51     | 97 ± 9.90        | 84.5 ± 10.47     | 130.3 ± 5.54     |
| EC (μS/cm)                 | 0.139 ± 0.01      | 0.102 ± 0.01     | 0.096 ± 0.01     | 0.119 ± 0.01     |
| DO (mg/l)                  | 7.8 ± 0.40        | 9.3 ± 0.42       | 9.25 ± 0.41      | 8.07 ± 0.61      |
| Free CO₂ (mg/l)            | 6.6 ± 1.09        | 3.3 ± 1.56       | 3.3 ± 1.27       | 7.33 ± 2.54      |
| Chlorides (mg/l)           | 16.57 ± 0.82      | 12.78 ± 2.01     | 10.30 ± 1.36     | 13.73 ± 0.82     |
| TH (mg/l)                  | 49.33 ± 4.16      | 32 ± 2.83        | 26.5 ± 1.91      | 37.33 ± 6.11     |
| Phosphates (mg/l)          | 0.54 ± 0.02       | 0.230 ± 0.02     | 0.196 ± 0.01     | 0.41 ± 0.05      |
| Nitrates (mg/l)            | 0.67 ± 0.04       | 0.329 ± 0.03     | 0.306 ± 0.02     | 0.44 ± 0.04      |
| Sulphates (mg/l)           | 2.11 ± 0.15       | 1.487 ± 0.03     | 1.421 ± 0.05     | 1.74 ± 0.09      |
| WQI                        | 437.88            | 57.03            | 47.91            | 175.76           |
Table 5 | Physicochemical parameters (minimum, maximum, X ± SD) recorded at Tilwara (site S2) on the Mandakini River, Garhwal Himalaya

| Physicochemical parameters | Min | Max | X ± SD | Min | Max | X ± SD | Min | Max | X ± SD | Min | Max | X ± SD |
|-----------------------------|-----|-----|--------|-----|-----|--------|-----|-----|--------|-----|-----|--------|
| AT (°C)                     | 25.8| 30.2| 28.03 ±2.20 | 21.5| 23.1| 22.3 ±1.13 | 15.2| 20.3| 17.83 ±2.09 | 23.9| 29.1| 26.47 ±2.60 |
| WT (°C)                     | 15.4| 19.1| 17.37 ±1.86 | 12.3| 13.1| 12.7 ±0.57 | 9.2 | 13.3| 10.73 ±1.81 | 15.1| 18.4| 16.6 ±1.67  |
| Turbidity (NTU)             | 171.5| 291.7| 225.43 ±61.04 | 13.3| 29.7| 21.5 ±11.60 | 9.1 | 23.3| 15.83 ±6.23 | 57.1| 101.1| 78.23 ±22.05 |
| WV (m/s)                    | 0.83| 0.91| 0.87 ±0.04 | 0.42| 0.73| 0.58 ±0.22 | 0.33| 0.53| 0.43 ±0.09 | 0.59| 0.77| 0.68 ±0.09  |
| Transparency (m)            | 0.91| 1.31| 1.12 ±0.20 | 1.75| 2.25| 2.0 ±0.35 | 2.53| 2.96| 2.81 ±0.19 | 1.63| 2.17| 1.88 ±0.27  |
| TDS (mg.l⁻¹)                | 154 | 169 | 161.33 ±7.51 | 105 | 120 | 112.5 ±10.61 | 95  | 120 | 103.5 ±11.56 | 135 | 151 | 143.0 ±8.0   |
| EC (μS/cm)                  | 0.134| 0.158| 0.15 ±0.01 | 0.101| 0.119| 0.11 ±0.01 | 0.102| 0.127| 0.114 ±0.01 | 0.131| 0.145| 0.138 ±0.01 |
| pH                          | 7.76| 7.95| 7.87 ±0.10 | 7.11| 7.18| 7.15 ±0.05 | 7.25| 7.70| 7.53 ±0.20 | 7.79| 7.88| 7.85 ±0.05  |
| DO (mg.l⁻¹)                 | 7.2 | 7.8 | 7.47 ±0.31 | 8 | 8.4 | 8.2 ±0.28 | 8.6 | 9.4 | 9.05 ±0.34 | 7.6 | 8.6 | 8.07 ±0.50  |
| Free CO₂ (mg.l⁻¹)           | 8.8 | 8.8 | 8.8 ±0.00 | 4.4 | 6.6 | 5.5 ±1.56 | 4.4 | 4.4 | 4.4 ±0.00 | 6.6 | 8.8 | 7.35 ±1.27  |
| Alkalinity (mg.l⁻¹)         | 80 | 90 | 86.67 ±5.77 | 60 | 65 | 62.5 ±3.54 | 55 | 65 | 58.75 ±4.79 | 65 | 85 | 75.0 ±10.0   |
| Chlorides (mg.l⁻¹)          | 15.62| 17.04| 16.57 ±0.82 | 15.62| 15.62| 15.62 ±0.00 | 9.94| 12.78| 11.01 ±1.36 | 14.2| 15.62| 14.67 ±0.82 |
| TH (mg.l⁻¹)                 | 46 | 54 | 50.0 ±4.0 | 32 | 36 | 34.0 ±2.83 | 28 | 34 | 30.0 ±2.83 | 34 | 42 | 38.0 ±4.0   |
| Phosphates (mg.l⁻¹)         | 0.497| 0.591| 0.538 ±0.05 | 0.225| 0.248| 0.237 ±0.02 | 0.193| 0.223| 0.208 ±0.01 | 0.379| 0.471| 0.415 ±0.05 |
| Nitrates (mg.l⁻¹)           | 0.631| 0.719| 0.677 ±0.04 | 0.321| 0.352| 0.337 ±0.02 | 0.291| 0.337| 0.307 ±0.02 | 0.393| 0.488| 0.439 ±0.05 |
| Sulphates (mg.l⁻¹)          | 1.954| 2.231| 2.128 ±0.15 | 1.487| 1.528| 1.508 ±0.03 | 1.403| 1.477| 1.444 ±0.03 | 1.686| 1.864| 1.766 ±0.09 |
| WQI                         | 464.94| 63.15| 51.91 | 182.91 |
| Physicochemical parameters | Monsoon (Jul-Sep) | Autumn (Oct-Nov) | Winter (Dec-Mar) | Summer (Apr-Jun) |
|----------------------------|-------------------|------------------|-----------------|-----------------|
| AT (°C)                    | 26.5              | 29.07 ± 2.50     | 22.13 ± 1.34    | 20.03 ± 1.21    |
| WT (°C)                    | 16.6              | 18.17 ± 1.60     | 12.35 ± 1.06    | 10.75 ± 1.55    |
| Turbidity (NTU)            | 183.5             | 234.77 ± 60.64   | 24.4 ± 12.87    | 16.83 ± 6.17    |
| WV (m/s)                   | 0.89              | 0.93 ± 0.04      | 0.72 ± 0.13     | 0.49 ± 0.07     |
| Transparency (m)           | 1.22              | 1.58 ± 0.34      | 2.14 ± 0.31     | 3.22 ± 0.14     |
| TDS (mg.l⁻¹)               | 184               | 195.0 ± 9.85     | 155.0 ± 14.14   | 127.0 ± 18.67   |
| EC (μS/cm)                 | 0.154             | 0.168 ± 0.01     | 0.113 ± 0.02    | 0.12 ± 0.01     |
| pH                         | 7.84              | 7.92 ± 0.07      | 7.33 ± 0.06     | 7.58 ± 0.18     |
| DO (mg.l⁻¹)                | 7.6               | 7.67 ± 0.12      | 8.5 ± 0.42      | 9.0 ± 0.23      |
| Free CO₂ (mg.l⁻¹)          | 8.8               | 10.27 ± 1.27     | 5.5 ± 1.56      | 5.5 ± 1.27      |
| Alkalinity (mg.l⁻¹)        | 85                | 91.67 ± 7.64     | 70.0 ± 7.07     | 62.5 ± 6.45     |
| Chlorides (mg.l⁻¹)         | 15.62             | 17.04 ± 1.42     | 14.91 ± 1.0     | 12.78 ± 1.16    |
| TH (mg.l⁻¹)                | 52                | 56.0 ± 4.0       | 38.0 ± 2.83     | 31.0 ± 3.46     |
| Phosphates (mg.l⁻¹)        | 0.497             | 0.540 ± 0.05     | 0.245 ± 0.02    | 0.217 ± 0.02    |
| Nitrates (mg.l⁻¹)          | 0.647             | 0.690 ± 0.04     | 0.346 ± 0.02    | 0.316 ± 0.02    |
| Sulphates (mg.l⁻¹)         | 1.969             | 2.147 ± 0.15     | 1.512 ± 0.03    | 1.453 ± 0.03    |
| WQI                        | 483.81            | 71.41            | 57.26           | 192.69          |
Sharma et al. (2018) recorded it from 12.15 NTU to 625.23 NTU. A river's velocity is controlled by different significant variables, including the shape, and the proportion of the incline of the water channel, the water volume that a stream conveys, and the friction extent caused by harsh edges inside the riverbed. It was observed to be from 0.41 m/s to 0.93 m/s.

Penetration of light decides the water transparency. Microscopic river biodiversity, disintegrated soil, suspended residue, and synthetic compounds are generally liable for turbidity. The transparency was noticed from 1.06 m to 3.22 m. Sharma et al. (2018) recorded 0.03 m to 0.65 m for the Bhagirathi River. The estimation of TDS was noticed from 97.0 mg.l$^{-1}$ to 195.0 mg.l$^{-1}$. Precipitation and domesticated animals close to the water body are liable for a high measure of TDS. Tsering et al. (2019), Patang et al. (2018) and Seth et al. (2014) recorded the range of TDS to be between 16 mg.l$^{-1}$ and 621 mg.l$^{-1}$. The ability of water to transfer an electric current observed through the conductivity of water is connected to the TDS. It was noticed from 0.104 $\mu$S/cm to 0.168 $\mu$S/cm. The pH is the crucial and critical trademark to assess the well-being status of water and furthermore speaks to its contamination level. It was noticed from 7.15 to 7.95. The previously acknowledged pH range demonstrated the somewhat basic or alkaline quality of water within the investigation time-frame. An almost comparative range of pH was noticed by Tsering et al. (2019) and Patang et al. (2018).

DO is considered as an immediate marker of quality evaluation. The water temperature and DO concentration are inversely proportional to each other. DO was reported to be from 7.47 mg.l$^{-1}$ to 9.5 mg.l$^{-1}$. WHO/BIS suggested the standard estimation of DO in drinking water is more than 5.0 mg.l$^{-1}$. Similar observations were recorded by Patang et al. (2018) and Bisht et al. (2018). Free CO$_2$ is always estimated at the site. High free CO$_2$ in water indicates a high measure of contamination level. It was noticed to be between 3.5 mg.l$^{-1}$ and 10.27 mg.l$^{-1}$. Free CO$_2$ level was less than the accepted value suggested (250 mg.l$^{-1}$) by the health organizations for drinking water. Total alkalinity was observed to be from 46.25 mg.l$^{-1}$ to 91.67 mg.l$^{-1}$. Seth et al. (2014) noticed it to be between 57 mg.l$^{-1}$ and 461 mg.l$^{-1}$ for the rivers. Chlorides were recorded to be between 10.30 mg.l$^{-1}$ and 17.04 mg.l$^{-1}$. Seth et al. (2014) noticed it to be from 10.2 mg.l$^{-1}$ to 40.3 mg.l$^{-1}$. The stones in the encompassing of an aquatic body are to a great extent the source of hardness. Hardness was noticed to be from 26.5 mg.l$^{-1}$ to 56.0 mg.l$^{-1}$. It was less than the accepted value suggested (200 mg.l$^{-1}$) by the health organizations. Seth et al. (2014) noticed it to be from 70 mg.l$^{-1}$ to 570 mg.l$^{-1}$.

Phosphates additionally demonstrate the eutrophic status of an aquatic body and decide the contamination level. The range of phosphates was noticed to be from 0.196 mg.l$^{-1}$ to 0.540 mg.l$^{-1}$. If the level of phosphates in a water body turns out to be excessively high, it hastens thick algal and aquatic plant growth. Nitrites decide if an aquatic body is eutrophic or not. The fluctuation in nitrates was noticed to be from 0.506 mg.l$^{-1}$ to 0.690 mg.l$^{-1}$. Sulphates can be found in almost all water assets. It is a vital factor to conclude the contamination level in an aquatic body. The fluctuation in the sulphates was noticed to be from 1.421 mg.l$^{-1}$ to 2.218 mg.l$^{-1}$. Patang et al. (2018) noticed the fluctuation in phosphates to be from 0.26 mg.l$^{-1}$ to 0.60 mg.l$^{-1}$; nitrates from 0.12 mg.l$^{-1}$ to 0.47 mg.l$^{-1}$; and sulphates from 4 mg.l$^{-1}$ to 61 mg.l$^{-1}$.

**WQI**

WQI is an approach used to gather various physicochemical factors and their concentration in a particular measure that indicates the water quality of the Mandakini River. Here, the WQI value has been calculated season-wise. Hence the calculated value of WQI for site S$_1$ ranged from 47.91 to 437.88 (Table 4); for S$_2$ from 51.91 to 464.94 (Table 5); and for site S$_3$ from 57.26 to 483.81 (Table 6). All major water quality parameters except turbidity lay within the limit of WHO/BIS recommended for water for drinking purposes by humans. Due to high turbidity in the river water, it is not fit for human consumption without proper treatment, especially in the monsoon period. The water quality was excellent in winters. It was of good quality in autumns and poor or unsuitable during the summers. The 26 tributaries showing the drainage pattern in Table 1 are also responsible for the unsuitable water quality, especially during the monsoon season.

**Aquatic macroinvertebrates diversity**

The numerical counting method was used for quantitative estimation, i.e. individuals per m$^2$ (ind.m$^{-2}$). A sum of 12
taxa of five major groups were recorded within the duration of research (Tables 7–9; Figure 2). Monthly fluctuations in the macroinvertebrates density showed that at S1 the highest density (305 ind·m\(^{-2}\)) was recorded during the winters while the lowest (190 ind·m\(^{-2}\)) was recorded in the monsoon period. At site S2, it was recorded from 148 ind·m\(^{-2}\) to 264 ind·m\(^{-2}\), whereas at S3 the highest density (326 ind·m\(^{-2}\)) was noticed during winters and the lowest (226 ind·m\(^{-2}\)) during the monsoon. The density of Ephemeroptera was recorded from 41 ind·m\(^{-2}\) to 121 ind·m\(^{-2}\) at S1; 23 ind·m\(^{-2}\) to 86 ind·m\(^{-2}\) at S2; and 51 ind·m\(^{-2}\) to 131 ind·m\(^{-2}\) at S3. Ephemeroptera was indicated by four taxa (Baetis sp., Ephemerella sp., Heptagenia sp. and Laptophlebia sp.). The Coleoptera density was recorded from 15 ind·m\(^{-2}\) to 35 ind·m\(^{-2}\) at S1; 11 ind·m\(^{-2}\) to 37 ind·m\(^{-2}\) at S2; and 16 ind·m\(^{-2}\) to 36 ind·m\(^{-2}\) at S3. Coleoptera was represented by a single taxon (Psephenus sp.). The density of Trichoptera was recorded from 25 ind·m\(^{-2}\) to 88 ind·m\(^{-2}\) at S1; 20 ind·m\(^{-2}\) to 76 ind·m\(^{-2}\) at S2; and 29 ind·m\(^{-2}\) to 90 ind·m\(^{-2}\) at S3. Trichoptera was characterized by three taxa (Glossosoma sp., Hydropsyche sp. and Philopotamus sp.). The Diptera density was recorded from 25 ind·m\(^{-2}\) to 73 ind·m\(^{-2}\) at S1; 23 ind·m\(^{-2}\) to 60 ind·m\(^{-2}\) at S2; and 30 ind·m\(^{-2}\) to 76 ind·m\(^{-2}\) at S3. Diptera was characterized by two taxa (Protaenius sp. and Tabanus sp.). The Plecoptera density was recorded from 20 ind·m\(^{-2}\) to 36 ind·m\(^{-2}\) at S1; 18 ind·m\(^{-2}\) to 42 ind·m\(^{-2}\) at S2; and 20 ind·m\(^{-2}\) to 44 ind·m\(^{-2}\) at S3. Plecoptera was characterized by two taxa (Isoperla sp. and Diploperla sp.).

Table 7 | Average (avg ± SD values) seasonal spatial qualitative and quantitative distribution of macroinvertebrates at site S1 (Agasthyamunni)

| Macroinvertebrates | S1 Monsoon (Jul-Sep) | | S1 Autumn (Oct-Nov) | | S1 Winter (Dec-Mar) | | S1 Summer (Apr-Jun) |
|--------------------|---------------------|---|--------------------|---|--------------------|---|
|                    | Min | Max | X ± SD | Min | Max | X ± SD | Min | Max | X ± SD | Min | Max | X ± SD |
| EPHIMEROPTERA      |     |     |        |     |     |        |     |     |        |     |     |        |
| Baetis             | 20  | 34  | 25.3 ± 7.6 | 40  | 45  | 42.5 ± 3.5 | 42  | 52  | 47.8 ± 4.2 | 29  | 39  | 33.3 ± 5.1 |
| Ephemerella        | 11  | 17  | 13.7 ± 3.1 | 19  | 21  | 20 ± 1.4  | 22  | 28  | 24.8 ± 2.5 | 14  | 19  | 16.7 ± 2.5 |
| Heptagenia         | 10  | 13  | 11.3 ± 1.5 | 16  | 20  | 18 ± 2.8  | 23  | 28  | 25 ± 2.4  | 13  | 20  | 16.7 ± 3.5 |
| Laptophlebia       | 0   | 3   | 1.7 ± 1.5  | 5   | 7   | 6 ± 1.4   | 8   | 13  | 10.8 ± 2.2 | 1   | 5   | 3 ± 2.0   |
| Total              | 41  | 67  | 52 ± 13.5  | 80  | 93  | 86.5 ± 9.2 | 95  | 121 | 108.3 ± 10.6 | 57  | 83  | 69.7 ± 13.0 |
| COLEOPTERA         |     |     |        |     |     |        |     |     |        |     |     |        |
| Psephenus          | 15  | 21  | 17.7 ± 3.1 | 25  | 28  | 26.5 ± 2.1 | 29  | 35  | 31.5 ± 2.6 | 19  | 24  | 21.3 ± 2.5 |
| TRICHOPTERA        |     |     |        |     |     |        |     |     |        |     |     |        |
| Glossosoma         | 12  | 21  | 15.7 ± 4.7 | 24  | 29  | 26.5 ± 3.5 | 30  | 36  | 32.8 ± 2.5 | 17  | 26  | 21.7 ± 4.5 |
| Hydropsyche        | 13  | 23  | 17.7 ± 5.0 | 32  | 35  | 33.5 ± 2.1 | 35  | 42  | 38.8 ± 3.0 | 21  | 31  | 25.7 ± 5.0 |
| Philopotamus       | 0   | 2   | 0.7 ± 1.2  | 4   | 6   | 5 ± 1.4   | 4   | 10  | 7.3 ± 2.5  | 1   | 2   | 1.7 ± 0.6  |
| Total              | 25  | 46  | 34 ± 10.8  | 60  | 70  | 65 ± 7.1  | 69  | 88  | 78.8 ± 7.8 | 39  | 59  | 49 ± 10.0  |
| DIPTERA            |     |     |        |     |     |        |     |     |        |     |     |        |
| Protaenius         | 32  | 38  | 34.3 ± 3.2 | 22  | 27  | 24.5 ± 3.5 | 12  | 17  | 14.8 ± 2.2 | 19  | 29  | 23.7 ± 5.0 |
| Tabanus             | 31  | 35  | 32.7 ± 2.1 | 24  | 28  | 26 ± 2.8  | 11  | 17  | 13.8 ± 2.5 | 15  | 25  | 20.3 ± 5.0 |
| Total              | 64  | 73  | 67 ± 5.2  | 46  | 55  | 50.5 ± 6.4 | 25  | 34  | 28.5 ± 4.0 | 34  | 54  | 44 ± 10.0  |
| PLECOPTERA         |     |     |        |     |     |        |     |     |        |     |     |        |
| Isoperla           | 12  | 17  | 14.7 ± 2.5 | 10  | 11  | 10.5 ± 0.7 | 10  | 15  | 12.5 ± 2.1 | 7   | 12  | 9.3 ± 2.5 |
| Diploperla         | 16  | 19  | 17.3 ± 1.5 | 12  | 15  | 13.5 ± 2.1 | 15  | 20  | 17.5 ± 2.1 | 11  | 15  | 13 ± 2.0   |
| Total              | 28  | 36  | 32 ± 4.0  | 23  | 25  | 24 ± 1.4  | 25  | 35  | 30 ± 4.2  | 20  | 27  | 22.3 ± 4.0 |
| GRAND TOTAL        | 190 | 226 | 202.7 ± 20.2 | 243 | 262 | 252.5 ± 13.4 | 247 | 305 | 277 ± 23.9 | 196 | 220 | 206.3 ± 12.3 |
CCA was assessed by putting 12 critical macroinvertebrate taxa in correlation with 15 physicochemical environmental factors that were distinguished in the Mandakini River (S1 to S3). The percentage eigenvalue of the first two axes was explained up to 96.94%, where the value for axis 1 was 90.49% and the value for axis 2 was 6.45% correlation explained. *Philopotamus* sp., *Laptophlebia* sp., *Heptagenia* sp. and *Hydropsyche* sp. were significantly positively correlated at axis 1, while, *Tendipus* sp., *Tabanus* sp. and *Isoperla* sp. were significantly negatively correlated at axis 1. Dissolved oxygen and transparency showed a positive correlation at axis 1 and other parameters were negatively correlated at the same axis. *Isoperla* sp., *Diploperla* sp., *Laptophlebia* sp. and *Philopotamus* sp. were significantly positively correlated at axis 2, while, *Tendipus* sp., *Hydropsyche* sp. and *Tabanus* sp. were significantly negatively correlated at axis 2. Chloride represented a significant negative correlation at axis 2 and EC showed a significant positive correlation at axis 2 (Figure 3).

**Diversity index**

The Shannon–Wiener Index value for aquatic macroinvertebrates was reported to be the maximum (4.179) in July and minimum (0.758) during February at S1. It was reported to be the maximum (3.720) in January and minimum (3.165) in July at S2. However, it was reported to be the maximum (3.833) in May and minimum (3.350) in June at S3 (Table 10). This index value signifies the scale of water
If the diversity index is more prominent than (>4), it implies the water is clear and safe; if the diversity index is somewhere in the range of 3 and 4, it implies the water is somewhat contaminated; diversity indices from 2 to 3 imply the water is moderately polluted. If the value is less than 2, it implies the water is extremely contaminated or polluted (Shanthala et al. 2013).

FACTORS INFLUENCING THE AQUATIC DIVERSITY

Degradation of the freshwater ecosystem is one of the most pressing issues of environmental concern of the present time. Freshwater diversity is seriously threatened today. The significant natural factors that are accountable for the reduction of river diversity are flash floods, landslides, and soil erosion. Construction activities, extraction of substratum, irregular agricultural practices, heavy sedimentation and dumping of sewage waste are the major anthropogenic factors accountable for the loss of river biodiversity (Kumar et al. 2020b).

CONSERVATION AND MANAGEMENT OF AQUATIC DIVERSITY

Rivers are among the most alluring and complicated ecosystems on the planet Earth. Both predictable (annual temperature pattern) and unpredictable (major flood event) variations are important in maintaining a structural and functional river ecosystem. The river biodiversity is

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**Table 9** | Average (avg ± SD values) seasonal spatial qualitative and quantitative distribution of macroinvertebrates at site S3 (Rudraprayag)

| Macroinvertebrates | **S3** | **Monsoon (Jul-Sep)** | **Autumn (Oct–Nov)** | **Winter (Dec–Mar)** | **Summer (Apr–Jun)** |
|--------------------|--------|-----------------------|----------------------|---------------------|---------------------|
|                    |        | Min | Max | X ± SD | Min | Max | X ± SD | Min | Max | X ± SD | Min | Max | X ± SD |
| **EPHIMEROPTERA**  |        | 23  | 31  | 26.3 ± 4.2 | 37  | 43  | 40 ± 4.2 | 45  | 57  | 50 ± 5.3 | 31  | 41  | 35.7 ± 5.0 |
| Baetis              |        | 13  | 19  | 15.7 ± 3.1 | 23  | 27  | 25 ± 2.8 | 29  | 33  | 30.8 ± 1.7 | 21  | 27  | 23.7 ± 3.1 |
| Ephemera           |        | 11  | 15  | 13.2 ± 2.0 | 17  | 23  | 20 ± 4.2 | 25  | 29  | 26.5 ± 1.9 | 17  | 21  | 19 ± 2.0 |
| Heptagenia         |        | 2   | 6   | 4.3 ± 2.1 | 7   | 9   | 8 ± 1.4 | 10  | 14  | 11.3 ± 1.7 | 3   | 7   | 5 ± 2.0 |
| Total              |        | 51  | 71  | 59.3 ± 10.4 | 84  | 102 | 93 ± 12.7 | 110 | 131 | 118.8 ± 8.8 | 72  | 96  | 83.3 ± 12.1 |
| **COLEOPTERA**     |        | 16  | 23  | 19.3 ± 5.5 | 27  | 29  | 28 ± 1.4 | 31  | 36  | 32.5 ± 2.4 | 23  | 28  | 25.7 ± 2.5 |
| Psephenus          |        | 13  | 22  | 16.7 ± 4.7 | 27  | 31  | 29 ± 2.8 | 31  | 37  | 33.8 ± 2.8 | 21  | 29  | 25 ± 4.0 |
| **TRICHOPTERA**    |        | 15  | 21  | 18.3 ± 5.1 | 31  | 37  | 34 ± 4.2 | 37  | 43  | 40 ± 2.6 | 24  | 33  | 28.7 ± 4.5 |
| Glossosoma         |        | 1   | 4   | 2.7 ± 1.5 | 7   | 9   | 8 ± 1.4 | 9   | 12  | 10.5 ± 1.3 | 1   | 6   | 3.3 ± 2.5 |
| Hydropsyche        |        | 29  | 47  | 37.7 ± 9.0 | 65  | 77  | 71 ± 8.5 | 78  | 90  | 84.3 ± 4.9 | 46  | 68  | 57 ± 11.0 |
| Philopotamus       |        | 33  | 39  | 35.7 ± 3.1 | 25  | 29  | 27 ± 2.8 | 15  | 19  | 17.5 ± 1.9 | 23  | 31  | 26.7 ± 4.0 |
| Total              |        | 67  | 76  | 70.3 ± 4.9 | 52  | 58  | 55 ± 4.2 | 30  | 40  | 34 ± 4.3 | 40  | 58  | 49 ± 9.0 |
| **DIPTERA**        |        | 32  | 37  | 34.7 ± 2.5 | 27  | 29  | 28 ± 1.4 | 13  | 21  | 16.5 ± 3.4 | 17  | 27  | 22.3 ± 5.0 |
| Protandrous        |        | 18.7 | 21  | 21 ± 2.5 | 11  | 13  | 12 ± 1.4 | 9   | 16  | 12.5 ± 2.9 | 7   | 13  | 9.7 ± 3.1 |
| Tabanus            |        | 20.7 | 23  | 23 ± 2.5 | 15  | 17  | 16 ± 1.4 | 16  | 21  | 18.8 ± 2.1 | 11  | 17  | 13.7 ± 3.1 |
| Total              |        | 39.3 | 44  | 44 ± 5.0 | 28  | 28  | 28 ± 0.0 | 25  | 37  | 31.3 ± 4.9 | 20  | 30  | 23.3 ± 5.8 |
| **PLECOPTERA**     |        | 12.7 | 15  | 15 ± 2.5 | 11  | 13  | 12 ± 1.4 | 9   | 16  | 12.5 ± 2.9 | 7   | 13  | 9.7 ± 3.1 |
| Isoperla           |        | 20.7 | 23  | 23 ± 2.5 | 15  | 17  | 16 ± 1.4 | 16  | 21  | 18.8 ± 2.1 | 11  | 17  | 13.7 ± 3.1 |
| Diploperla         |        | 39.3 | 44  | 44 ± 5.0 | 28  | 28  | 28 ± 0.0 | 25  | 37  | 31.3 ± 4.9 | 20  | 30  | 23.3 ± 5.8 |
| Total              |        | 226 | 242 | 242 ± 14 | 262 | 288 | 275 ± 18.4 | 278 | 326 | 300.8 ± 19.9 | 229 | 252 | 238 ± 12.1 |

Quality. If the diversity index is more prominent than (>4), it implies the water is clear and safe; if the diversity index is somewhere in the range of 3 and 4, it implies the water is somewhat contaminated; diversity indices from 2 to 3 imply the water is moderately polluted. If the value is less than 2, it implies the water is extremely contaminated or polluted (Shanthala et al. 2008).
Figure 2  (a) *Baetis* sp.; (b) *Diploperla* sp.; (c) *Ephemerella* sp.; (d) *Glossosoma* sp.; (e) *Heptagenia* sp.; (f) *Hydropsyche* sp.; (g) *Isoperla* sp.; (h) *Leptophlebia* sp.; (i) *Philopotamus* sp.

Figure 3  Canonical Correspondence Analysis (CCA) plot representing the effect of physicochemical parameters on the abundance of benthic macroinvertebrates in the Himalayan River Mandakini (S1 to S3) (pH: pH; DO: Dissolved Oxygen; Turb: Turbidity; Har: Hardness; Trans: Transparency; WV: Water Velocity; Sul: Sulphates; Ni: Nitrates; EC: Electrical Conductivity; TDS: Total Dissolved Solids; Alk: Alkalinity; Phos: Phosphates; Chl: Chlorides; WT: Water Temperature; AT: Air Temperature; FCO: Free CO2; Phil: Philopotamus sp.; Lap: Laptophlebia sp.; Iso: Isoperla sp.; Dip: Diploperla sp.; Tab: Tabanus sp.; Hyd: Hydropsyche sp.; Bat: Baetis sp.; Glo: Glossosoma sp.; Hep: Heptagenia sp.; Eph: Ephemerella sp.; Pse: Psephenus sp.; Pro: Protandrous sp.)
crucial to managing the balance of the river ecosystem. The important measures that can be used for the conservation and management of river biodiversity include the construction of solid embankments, dams, and reservoirs, afforestation in the affected areas, regular monitoring of water quality and biodiversity, and the participation of the general public in awareness programs. Academic institutions have to focus on research activities related to aquatic biodiversity. These important mitigating measures surely help the responsible authorities in the conservation and management of river biodiversity and water quality (Kumar et al. 2020b).

CONCLUSION

The seasonal effect on benthic macroinvertebrates was highest in the monsoon season, which adversely affects the frequency and variety of these organisms. The key factors that disturbed the river water quality were the velocity of the water and the expansion of poisonous and perilous synthetic compounds in the water body from the nearby agricultural fields. The calculated value of WQI ranged from 47.91 to 483.81. A total of 12 taxa of macroinvertebrates from five major groups (Ephemeroptera, Coleoptera, Trichoptera, Diptera, and Plecoptera) were recognized during the study period. It can also be concluded that the river water is polluted and unsafe for human consumption without proper treatment. Components that upset the variety and environment of the lake are credited to natural and anthropogenic factors, for example, soil disintegration, overgrazing, the travel industry burden, and solid waste. A technique for protection and management, for example, off-site and on-site conservation, regular monitoring of water quality and biodiversity, public awareness, waste management, and research programmes, could be helpful.

Table 10 | Monthly Shannon–Wiener diversity index of macroinvertebrates for sites S1–S3 of the Mandakini River

| Macroinvertebrates | July | Aug | Sept | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | June |
|--------------------|------|-----|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| S1                 |      |     |      |     |     |     |     |     |     |     |     |     |
| Ephemeropera       | 1.517| 1.047| 1.149| 1.183| 1.213| 1.268| 1.281| 0.268| 1.251| 1.205| 1.182| 1.097|
| Coleoptera         | 0.00 | 0.00| 0.00 | 0.00| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Trichoptera        | 0.884| 0.692| 0.841| 0.883| 0.923| 0.944| 0.966| 0.199| 0.871| 0.814| 0.834| 0.789|
| Diptera            | 0.89 | 0.692| 0.693| 0.692| 0.694| 0.69| 0.69 | 0.146| 0.688| 0.686| 0.692| 0.691|
| Plecoptera         | 0.888| 0.691| 0.683| 0.692| 0.674| 0.678| 0.683| 0.145| 0.674| 0.647| 0.688| 0.687|
| Grand Total        | 4.179| 3.122| 3.366| 3.451| 3.502| 3.584| 3.620| 0.758| 3.484| 3.352| 3.396| 3.264|
| S2                 |      |     |      |     |     |     |     |     |     |     |     |     |
| Ephemeropera       | 1.024| 1.275| 1.277| 1.285| 1.307| 1.287| 1.293| 1.247| 1.205| 1.187| 1.097| 1.011|
| Coleoptera         | 0.00 | 0.00| 0.00 | 0.00| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Trichoptera        | 0.756| 0.857| 0.958| 0.966| 1.004| 1.042| 1.052| 1.053| 1.052| 1.042| 0.997| 0.924|
| Diptera            | 0.693| 0.692| 0.693| 0.694| 0.693| 0.692| 0.69 | 0.691| 0.692| 0.693| 0.692| 0.692|
| Plecoptera         | 0.692| 0.692| 0.69 | 0.688| 0.687| 0.688| 0.683| 0.689| 0.681| 0.318| 0.69 | 0.692|
| Grand Total        | 3.165| 3.516| 3.618| 3.633| 3.691| 3.710| 3.720| 3.679| 3.629| 3.239| 3.477| 3.319|
| S3                 |      |     |      |     |     |     |     |     |     |     |     |     |
| Ephemeropera       | 1.274| 1.156| 1.252| 1.246| 1.266| 1.262| 1.276| 1.282| 1.275| 1.243| 1.23 | 1.195|
| Coleoptera         | 0.00 | 0.00| 0.00 | 0.00| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Trichoptera        | 0.912| 0.817| 0.925| 0.958| 0.969| 0.964| 0.992| 0.988| 0.969| 0.928| 1.224| 0.78 |
| Diptera            | 0.695| 0.692| 0.692| 0.694| 0.692| 0.692| 0.691| 0.684| 0.686| 0.682| 0.691| 0.691|
| Plecoptera         | 0.692| 0.693| 0.692| 0.69 | 0.67 | 0.676| 0.685| 0.667| 0.654| 0.647| 0.688| 0.684|
| Grand Total        | 3.571| 3.358| 3.561| 3.588| 3.597| 3.594| 3.644| 3.621| 3.584| 3.500| 3.833| 3.350|
ACKNOWLEDGEMENT

The authors (Rama Kumari, Chandi Prasad, Stanzin Namtak, Akash Deep) thankfully acknowledge the fellowship given by the University Grant Commission, New Delhi, through Hemwati Nandan Bahuguna Garhwal University (a Central University), Srinagar Garhwal, Uttarakhand, India, for undertaking the present work.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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First received 19 August 2020; accepted in revised form 9 January 2021. Available online 22 January 2021