

РИБОГОСПОДАРСЬКА ГІДРОБІОЛОГІЯ ТА ІХТІОЛОГІЯ

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ДОСЛІДЖЕННЯ ПРОСТОРОВИХ І СЕЗОННИХ КОЛИВАНЬ ЯКОСТІ ВОДИ ТА РІЗНОМАНІТТЯ ВИДІВ РИБ У ПОТОЦІ МЕН, ГІМАЛАЇ, ШИВАЛІК, ІНДІЯ ЗА ДОПОМОГОЮ СИСТЕМИ КАРТОГРАФУВАННЯ ARCGIS¹

У дослідженні оцінювали якість води потоку Мен, важливої притоки річки Біс у Гімалаях (Шивалік, Хімачал Прадеш, Індія) шляхом аналізу змінних навколишнього середовища, індексу якості води і розподілу видів риб за допомогою Географічної інформаційної системи (GIS). Проби води відбирали на двох станціях (вище та нижче за течією) протягом року та аналізували її різні фізико-хімічні параметри. У дослідженні використовували індекс якості води Канадської ради міністрів навколишнього середовища (CCME-WQI), що відображає статус якості води від «задовільного» до «граничного». Для оцінки кореляції між фізико-хімічними параметрами води використовували коефіцієнт кореляції Пірсона. Загалом було знайдено 23 види риб, які належать до 6 рядів і 9 родин, з домінуванням представників ряду *Synbranchistius*. В угрупованнях риб спостерігали сезонні зміни. Індекс домінування був найвищим під час мусону, а індекси Сімпсона та Шеннона — найнижчими під час мусону та майже однаковими до і після мусону з незначними коливаннями. Проведена комплексна оцінка важлива для регулювання рибальства і загалом для сталого розвитку в регіоні.

Ключові слова: іхтіофауна, різноманіття, якість води, індекс якості води Канадської ради міністрів навколишнього середовища (CCME-WQI), Географічна інформаційна система (GIS), Шивалік, Гімалаї.

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Introduction

Water is among the most integral and crucial substances present on the Earth as each and every organism depend on water for their existence [69]. Freshwater aquatic resources are available in the form of rivers, streams, lakes, glaciers, ponds, etc. and cover about 0.5 % of Earth's surface [68]. Additionally, rivers constitute 0.01 % of the total water on the Earth but have enormous ecological significance [78]. These water resources are vital for fisheries, hydropower generation, industrial activities, agriculture, etc. Various natural factors, including atmospheric, hydrological, topographic, lithographic and climatic ones, influence water quality [49, 71]. Global water quality is deteriorated by various anthropogenic activities [77], industrialization [60] and agricultural activities [21]. Water pollution is common problem in developing countries, so management of water resources is of utmost importance [42].

Aquatic ecosystems harbor almost half of total vertebrates [27] and fish forms maximum diversity among them [25]. Fish plays an important role in maintaining equilibrium in aquatic ecosystems [58]. As fish communities are sensitive to wide range of environmental stressors so are indicative of status of aquatic ecosystems [40]. Their distribution is influenced by various environmental variables such as water temperature, pH, dissolved oxygen, alkalinity, availability of nutrients, etc. [59, 81]. An assessment of water quality is an important method of fishery management and sustainable development [1, 18]. The increasing pressure on aquatic ecosystems due to anthropogenic activities, land-use changes, habitat losses, alien species, climate change, etc. results in altered fish species richness, which needs to be checked [53]. Furthermore, contaminated water in addition to destroying aquatic life also deteriorates human health [41].

The ArcGIS mapping system for analysis proves to be an effective geospatial technology for managing water resources [14]. The GIS is a robust tool for gathering, retrieving, storing, and analyzing geographical data [20]. Different scientists use the ArcGIS mapping system for ecological evaluation in India [4, 10, 14, 19, 28, 34, 54, 57, 62, 67, 75].

The goal of the present study was to determine and classify the water quality of the Man stream based on variation of environmental variables, water quality index and fish species distribution using the Geographical Information System (GIS).

Material and Methods

Study area. The Shivalik Himalayas stretches over 2400 km and extends up to 50 km in Himachal Pradesh, having altitude of 600—1500 meters above mean sea level [43]. The Bilaspur, Hamirpur, Una and parts of Kangra, Cham-ba, Solan and Sirmaur districts come under the Shivalik range of the Northwestern Himalayas in Himachal Pradesh.

The Hamirpur district is situated in the Shivalik Himalayas between 76°18' and 76°44' E longitude and 31°25' and 31°52' N latitude having elevation from 400 to 1100 m. The district shares borders with the Mandi in the east, Bilaspur

in the south, Kangra in the north and Una in the west. The Beas River separates the Hamirpur from the Kangra and is a parent river to two tributaries, namely the Man and Kunah streams in the Hamirpur district [2].

The Man stream (Figure 1) is a major left bank tributary of the Beas River in the Hamirpur district, H.P. It originates in the Shivalik Hills of the lower Himalayas, about 40 km long, with the total catchment area of approximately 180 km², and joins the Beas River near the town of Nadaun. The stream passes through mountainous terrain, dense forests and agricultural fields before draining into the Beas River. Two sites viz., upstream and downstream were selected for sampling (Table 1).

Water sampling and analysis. Water samples from the said stream were collected for one year from January 2023 to December 2023, in 1000 ml sterilized plastic bottles from two sampling sites for physiochemical analysis. The physiochemical parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO) were analyzed in the field using digital probes. In this case, the total alkalinity, total hardness, calcium hardness, magnesium hardness, concentration of chlorides, nitrates and phosphates were analyzed in the lab titrimetrically and spectrophotometrically, following APHA [7] and APHA, AWWA, & WEF [8].

Fish sampling and identification. Fish samples were collected every month from January 2023 to December 2023 by local licensed fisherman using cast net and gill net. The collected samples were then put into 5—10 % formalin / 95 % ethyl alcohol and brought to the laboratory for further identification. The taxonomical identification of collected specimens was done using [22, 33, 70].

Statistical analysis of data. In the present research paper, data were analyzed on seasonal bases with March — June, July — September and October — February representing pre-monsoon, monsoon and post-monsoon seasons, respectively. The statistical analyses of data were done by the PAST (version 4.03). The spatial maps were made by the ArcGIS software (version 10.8.1) using the Inverse Distance Weighted (IDW) interpolation method.

Calculation of Water Quality Index. The CCME-WQI (Canadian Council of Ministers of Environment — Water Quality Index) was used to evaluate the water quality of the stream, which is based on three elements i.e., scope (F₁), frequency (F₂) and amplitude (F₃).

F₁ (Scope) represents the percentage of selected parameters do not meet the standard limits during analysis. It is calculated as

$$F_1 = \frac{\text{No. of failed variables}}{\text{Total no. of variables}} \cdot 100$$

F₂ (Frequency) represents percentage of monitoring quality variables exceeding the standards. It is calculated as

$$F_2 = \frac{\text{No. of failed tests}}{\text{Total no. of tests}} \cdot 100.$$

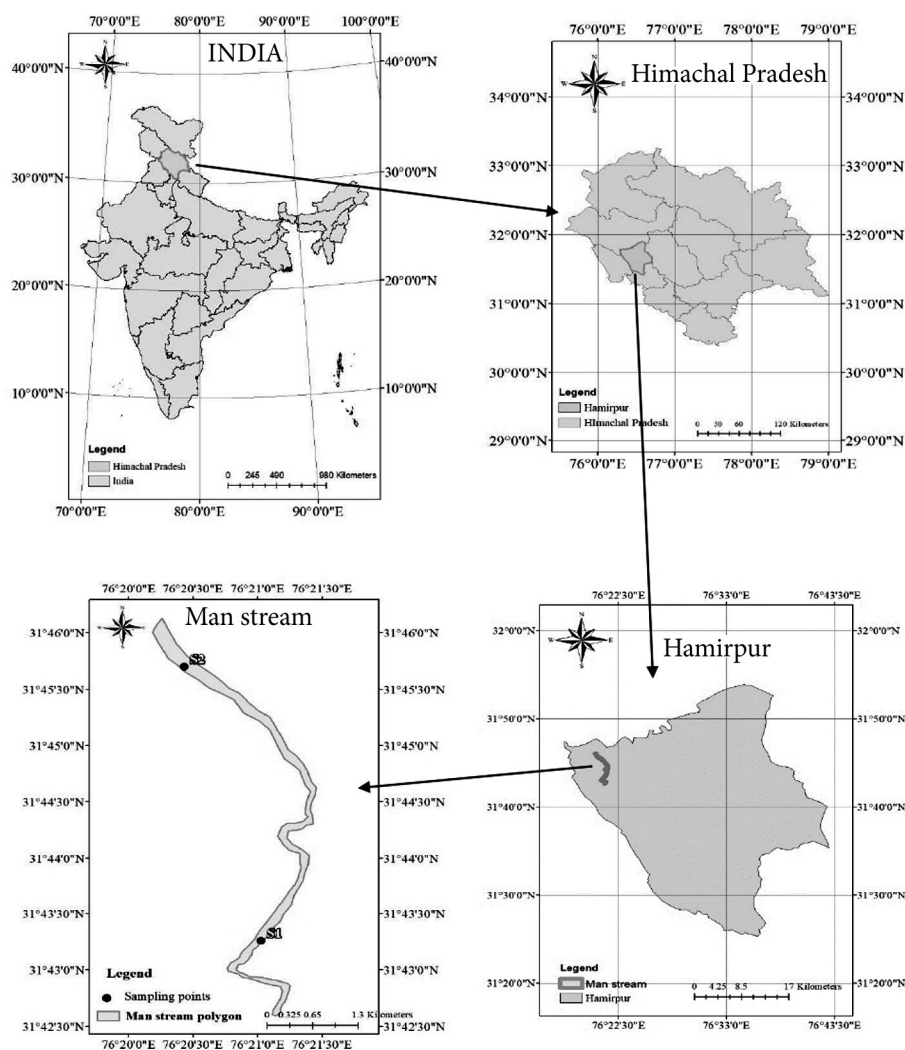


Fig. 1. Map showing the area of study

F_3 (Amplitude) measures the amount, by which failed tests do not meet their objectives. It is calculated in three steps:

Step 1 — Calculation of excursion. It is the number of times, by which an individual concentration is higher (or less than, when an objective is minimum) than the objective.

Table 1

GPS coordinates of different sampling sites within the Man stream

Sampling site	Latitude	Longitude	Altitude (fts)
S1 (Upstream)	31°43'15.61"N	76°21'1.60"E	1653
S2 (Downstream)	31°45'44.84"N	76°20'21.46"E	1581

When the test value does not exceed the objective, it is measured as

$$\text{excursion} = \frac{\text{Failed test value}}{\text{Objective}} - 1.$$

When the test value must be no less than objective, it is measured as

$$\text{excursion} = \frac{\text{Objective}}{\text{Failed test value}} - 1.$$

Step 2 — Calculation of normalized sum of excursions (nse). It is the total amount, by which individual tests are out of compliance. It is calculated as

$$\text{nse} = \frac{\sum_{i=1}^n \text{excursion}}{\text{Total no. of tests}}.$$

Step 3 — Calculation of F_3 (Amplitude). It is calculated by an asymptotic function that scales the normalized sum of excursions from the objectives to yield a range between 0 and 100.

$$F_3 = \frac{\text{nse}}{0.01\text{nse} + 0.01}.$$

Finally, CCME-WQI is calculated as

$$\text{CCME-WQI} = 100 \cdot \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right)$$

On the bases of the CCME-WQI value, water quality of the water body can be categorized into five categories (Table 2).

Results and Discussion

Variation of environmental variables. A total of 12 physiochemical parameters, including water temperature, pH, dissolved oxygen (DO), electrical

Table 2

CCME-WQI categorization as per [29]

CCME-WQI value	Water quality status
95—100	Excellent
80—94	Good
65—79	Fair
45—64	Marginal
0—44	Poor

conductivity (EC), total dissolved solids (TDS), total alkalinity, total hardness, calcium hardness, magnesium hardness, concentration of chlorides, nitrates and phosphates were taken to analyze the water quality of the stream for three seasons viz., pre-monsoon, monsoon and post-monsoon in two different sampling sites i.e., S1 (upstream) and S2 (downstream). The range and mean value of these physiochemical parameters are given in Tables 3, 4 and the mean variation of different physiochemical parameters are given in Figure 2. These parameters played a crucial role in creating prediction maps for the Man stream, Shivalik Himalayas and associated with fish fauna diversity.

Temperature, an important ecological parameter influencing aquatic communities [26], also regulates concentration of DO in the water [39]. During the present study, the temperature of stream water ranged from 15.5 to 34.5°C. Maximum water temperature was recorded during pre-monsoon and minimum — during post-monsoon in both the study sites, which may be due

Table 3

Range and mean value of different physiochemical parameters in the Man stream upstream (S1) during different seasons

Parameters	Seasons		
	Pre-monsoon	Monsoon	Post-monsoon
Water temperature, °C	<u>23–33.7</u> 28.4	<u>22.4–29.5</u> 25.5	<u>14.7–23</u> 18.7
pH	<u>7.6–9.1</u> 8.4	<u>6.9–7.9</u> 7.4	<u>8.1–8.9</u> 8.52
TDS, mg/L	<u>109–144</u> 125.75	<u>148–156</u> 151.66	<u>105–150</u> 133
EC, µS/cm	<u>260–380</u> 332.5	<u>343–400</u> 367.66	<u>275–360</u> 329
DO, mg/L	<u>5.8–7.4</u> 6.67	<u>5.2–6.4</u> 5.93	<u>6.8–7.8</u> 7.3
Total alkalinity, mg/L	<u>164–285</u> 214.5	<u>196–250</u> 194	<u>206–383</u> 255.8
Total hardness, mg/L	<u>128–184</u> 214.5	<u>173.6–200</u> 191.2	<u>170.4–188</u> 178.56
Calcium hardness, mg/L	<u>62.4–141.2</u> 90.35	<u>121.5–154.4</u> 141.96	<u>52–146.4</u> 107.04
Magnesium hardness, mg/L	<u>42.8–119.6</u> 73.45	<u>24.4–52.1</u> 40.7	<u>33.6–125.2</u> 71.52
Chlorides, mg/L	<u>33–62</u> 44.25	<u>20–32</u> 25	<u>30–50</u> 37.6
Nitrates, mg/L	<u>0.019–0.052</u> 0.031	<u>0.063–0.117</u> 0.088	<u>0.014–0.063</u> 0.044
Phosphates, mg/L	<u>0.02–0.048</u> 0.031	<u>0.064–0.119</u> 0.093	<u>0.02–0.095</u> 0.044

to day length and availability of sunlight, which was highest during pre-monsoon season. During all the three seasons, temperature of S2 was higher than S1, which may be due to altitudinal variation. Similar observations were also made in the Godavari River [38] and in the Beas River in the Mid-Himalayan zone [35]. In different water bodies in the Doon valley, water temperature ranged from 18.9 to 21.5°C [37], which was lesser than the present findings.

pH shows acidic and alkaline nature of the water. The water with low pH leads to decreased diversity of biotic communities, whereas, high pH shows greater buffering capacity and high productivity of aquatic ecosystems [17]. During the present study, the value of pH ranged from 6.5 to 9.1. The highest value of pH (9.1) was recorded during post-monsoon season and lowest (6.5) — during monsoon season. The value of pH lies between acceptable limit as per WHO [79] (6.5 — 9.2). During monsoon season, photosynthetic communities

Table 4

Range and mean value of different physiochemical parameters in the Man stream downstream (S2) during different seasons

Parameters	Seasons		
	Pre-monsoon	Monsoon	Post-monsoon
Water temperature, °C	27–34.5 30.02	23.1–30.7 27.93	15.5–24.5 19.66
pH	7.4–8.8 8.15	6.5–8 7.45	7.8–9.1 8.48
TDS, mg/L	112–145 128.75	136–158 150	117–146 129.8
EC, µS/cm	280–370 340	323–410 364.33	282–360 330.4
DO, mg/L	6–7.6 6.57	5.8–6.6 6.1	7–7.6 7.34
Total alkalinity, mg/L	175–300 216.75	195–355 265.33	195–363 250
Total hardness, mg/L	230–180 162.4	152–200 183.46	173.2–196 183.6
Calcium hardness, mg/L	38.4–142.4 96.4	106.2–161.6 126.6	52–140 105.92
Magnesium hardness, mg/L	37.6–138.8 66	18.6–86.4 50.26	40–133.2 105.92
Chlorides, mg/L	30–70 42.5	16–30 24.66	25–54 38.6
Nitrates, mg/L	0.019–0.061 0.032	0.074–0.108 0.093	0.042–0.082 0.062
Phosphates, mg/L	0.035–0.05 0.043	0.05–0.201 0.118	0.031–0.2 0.089

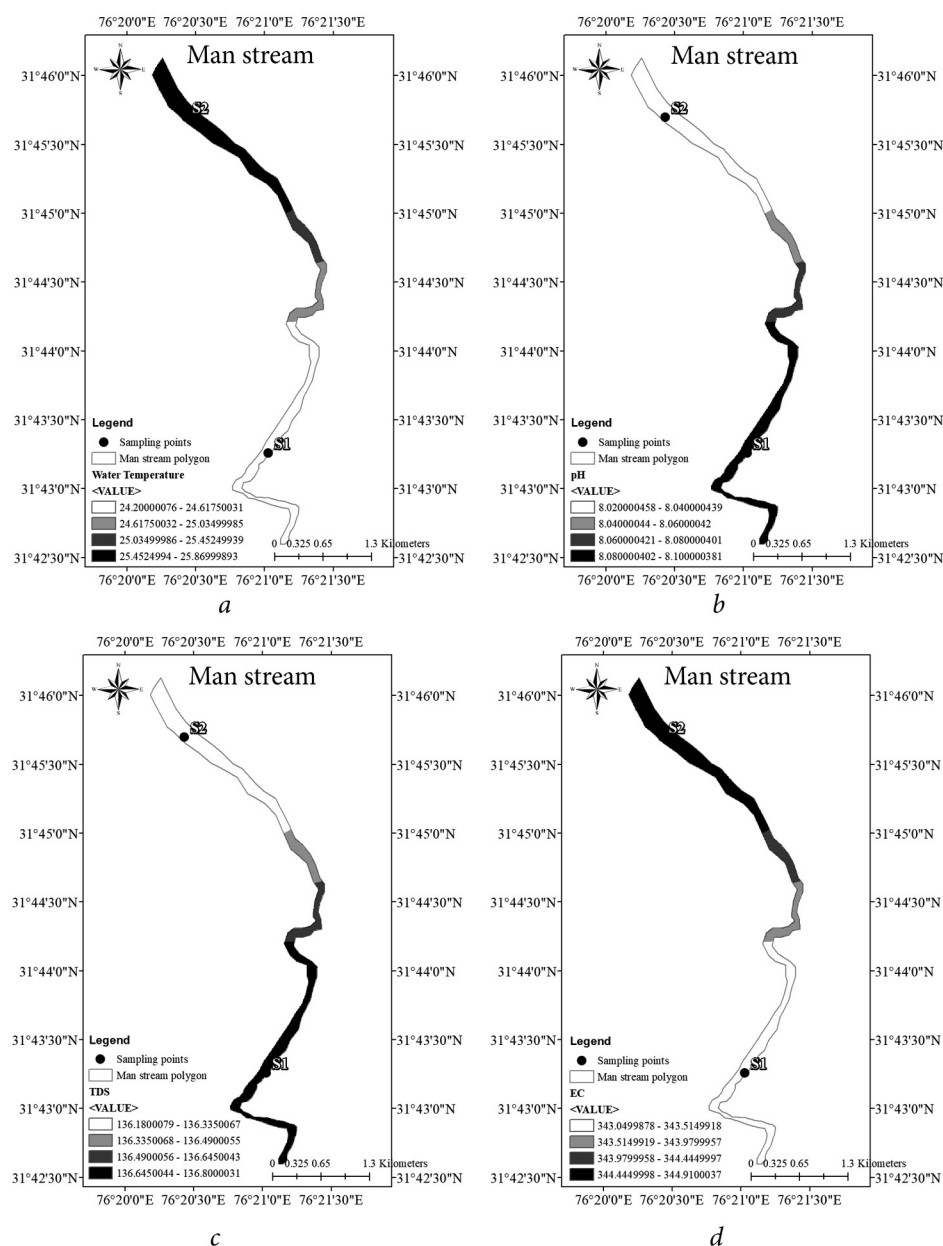


Fig. 2. Mean variation of different physiochemical parameters in the stream: *a* — water temperature; *b* — pH; *c* — total dissolved solids; *d* — electrical conductivity

were washed away by heavy run-off, which may lead to increased CO₂ level in the water, which in-turn leads to decreased pH of stream water. High pH values during winters in the rivers of the Garhwal Himalayas were recorded by [9, 55]. pH of the stream was found mostly alkaline, which promotes high algal productivity [45], which in turn promotes higher growth of fish fauna. pH range of

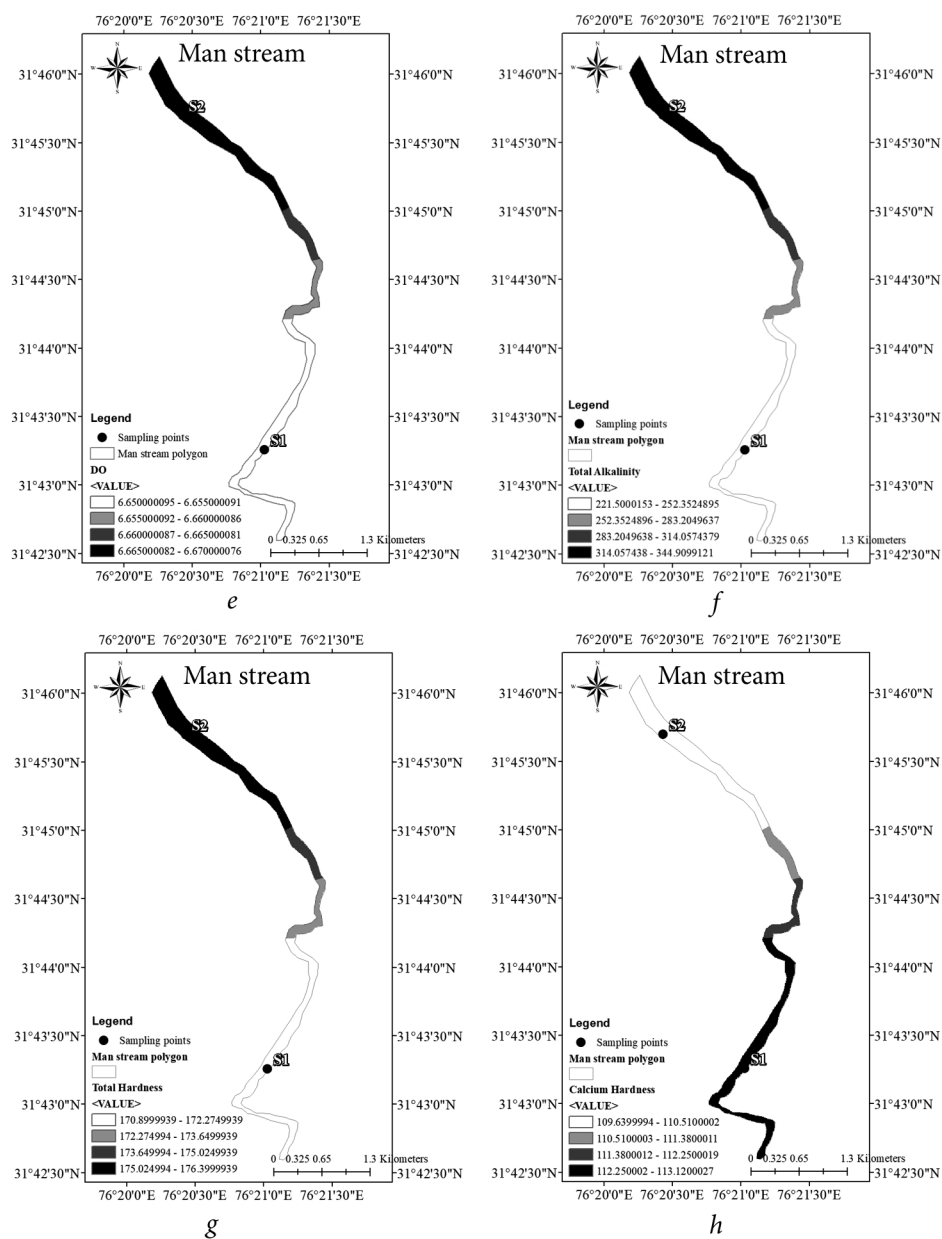


Fig. 2. Mean variation of different physiochemical parameters in the stream (continued): *e* — dissolved oxygen; *f* — total alkalinity; *g* — total hardness; *h* — calcium hardness

7.06 to 8.35 was reported in the Ganga River [36], and pH value of 7.63 ± 0.15 — in the Tons River [48]. pH range from 7.52 to 8.03 was reported in different water bodies of the Doon valley [37].

Total alkalinity and pH are two interdependent parameters and directly proportional to each other. During the present investigation, the value of alkalinity ranged from 164 to 383 mg/L. The highest value of alkalinity was recor-

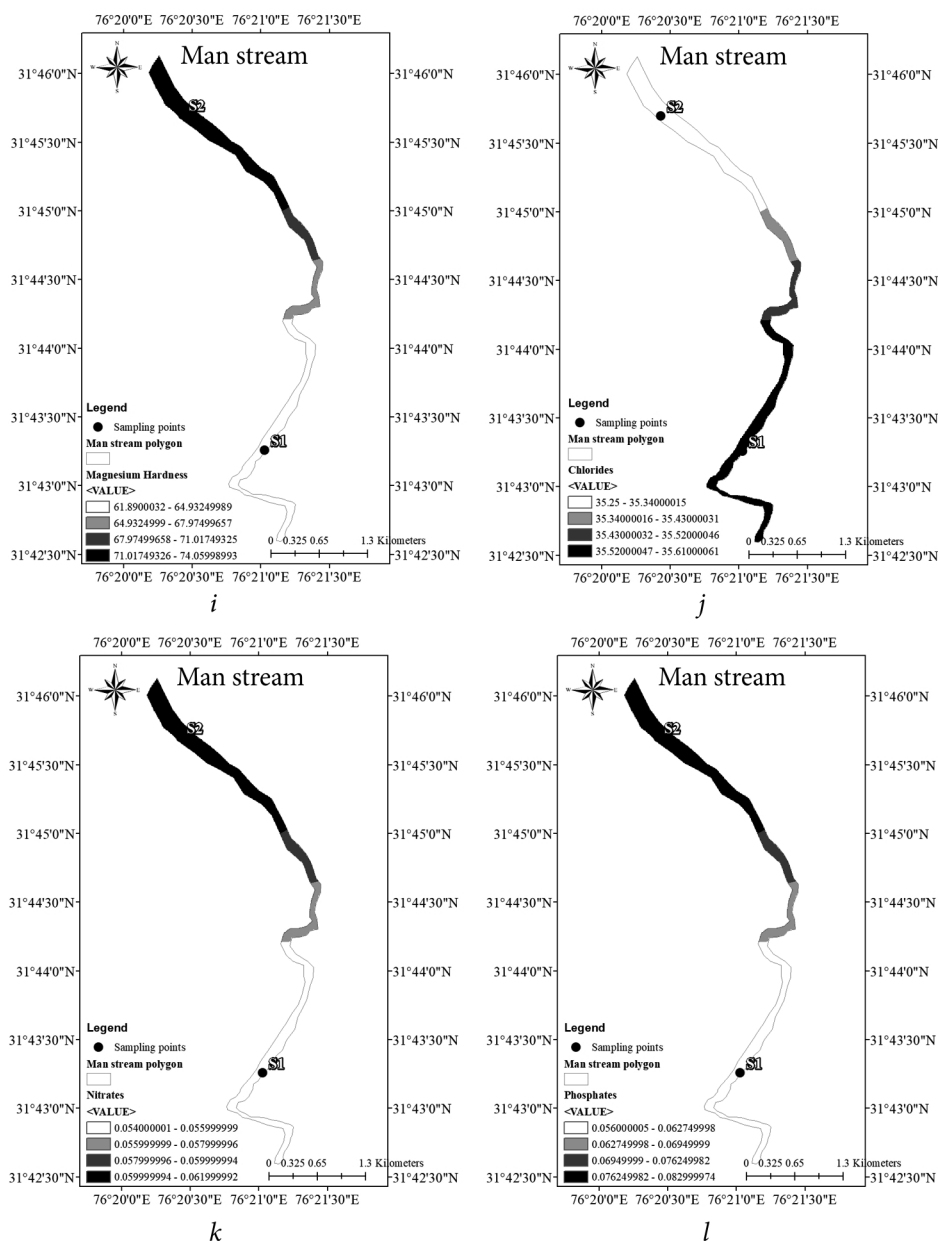


Fig. 2. Mean variation of different physiochemical parameters in the stream (continued): *i* —magnesium hardness; *j* — chlorides; *k* — nitrates; *l* — phosphates

ded during post-monsoon and lowest — during pre-monsoon at both the study sites. Alkalinity was found to be within the permissible limit set by the BIS [16]. In contrast to present findings, low values of the total alkalinity were recorded in the Beas River and its tributaries, including the Gaj and Baner streams [14, 66].

TDS and EC both measure the total dissolved ions and serve as an effective indicator of water quality. A specific concentration of the ions in the water is crucial, as they act as essential nutrients for aquatic life [23]. TDS was found highest during monsoon in both the study sites and was within the standard limits of the BIS [16], WHO [79] and USPHS [73]. High TDS during monsoon season in the Beas River were also recorded by [35], which may be due to turbulent water flow. TDS and EC are two interconnected parameters, so EC was also recorded to be highest during monsoon in both the sampling sites of the stream. EC was found to be slightly higher than permissible limits (300 $\mu\text{S}/\text{cm}$) of USPHS [73].

DO is another important physiochemical parameter affecting the growth and distribution of biotic communities in an aquatic ecosystem. DO shows inverse correlation with water temperature [32]. In the present stream, the maximum DO (7.8) was recorded during post-monsoon and minimum (5.2) — during monsoon season at S1. In the Beas River, the highest value of DO was recorded during winter season and its lowest value — during summer season [35]. Various factors, including organic matter outflow, nutrient concentration, and presence of different chemicals, influence the amount of dissolved oxygen in the water [64]. DO >5.0 mg/L is essential for proper growth and survival of biotic communities, including fish fauna, in a particular water body [11, 12].

The value of total hardness ranged from 130 to 200 mg/L and was recorded to be highest during monsoon and lowest during pre-monsoon at both study sites. The value of total hardness of stream water shows hard to very-hard nature of stream water as per WHO [79]. Lower values of total hardness in comparison to present study were recorded in the Beas River and in the Ganga River and its tributaries [35, 50]. Calcium hardness was highest during monsoon in both the sites, whereas, lowest — during post-monsoon at S1 and pre-monsoon at S2. Limestone containing rocks are prime source of calcium in the water [14]. Magnesium hardness was recorded to be lowest during monsoon period at both sites, whereas maximum was recorded during post-monsoon and pre-monsoon at S1 and S2, respectively.

Chlorides concentration was found to be highest during pre-monsoon season and lowest during post-monsoon season at both the study sites. Generally, chlorides possess lower health risks, but high intake leads to serious health issues [14]. High concentrations of chlorides correspond to open defecation and domestic waste disposal [35]. During the present study chlorides concentration was found to be within the permissible limits of WHO (500 mg/L) [79], BIS [16] and USPHS (250 mg/L) [73].

Both nitrates and phosphates concentration was found to be highest during monsoon at both the study sites. The inflow of agricultural runoff and allochthonous material into the stream during monsoon contributes to high concentration of nitrates and phosphates in stream water. Similar observations were recorded in the Tons River [63], in the Ghagra and Gandak Rivers [61] and in the headwater stream of Garhwal Himalayas [65].

Water Quality Index. Water Quality Index is a single value which integrates varied physiochemical parameters, helping researchers or environmental-

lists to assess water quality trends of particular water body [3]. Different types of WQI methods were developed for assessing water quality such as WAWQI [30], CCME-WQI [47], NSF-WQI [15], Al-Olthman method [6], the House index [72], etc. Out of these, CCME-WQI was widely used by different researchers [5, 13, 24, 31, 44, 52, 74, 76] to evaluate the water quality of different water bodies. The CCME-WQI offers various advantages such as its applicability for water quality assessment in specific areas, adherence to various legal regulations and varied types of water use, tolerance for missing data and flexibility in selection criteria [51, 78], so this method was used to evaluate water quality of the current stream, which shows that stream water has «fair» to «marginal» water quality (Table 5). Notably, the highest value of WQI was recorded during pre-monsoon at S1 and lowest — during post-monsoon at S2, depicting marginal water quality of stream water during post-monsoon. The ArcGIS mapping of the CCME-WQI of stream water is given in Figure 3.

Correlation coefficient. Pearson's correlation coefficient was used to evaluate the correlation between different physiochemical parameters during different seasons.

At S1, during pre-monsoon (Figure 4, *a*), there is strong positive correlation between DO and pH, DO and phosphates, nitrates and phosphates, nitrates and calcium hardness, total hardness and TDS, total hardness and total alkalinity, EC and magnesium hardness and phosphates and calcium hardness. There is perfect negative correlation between total hardness and chloride. Water temperature shows negative correlation with pH, DO and nitrates. Also, there is strong negative correlation between pH and EC, TDS and chlorides concentration and phosphates and magnesium hardness.

During monsoon (Figure 4, *b*), there is strong positive correlation between water temperature and calcium hardness, DO and pH, TDS and nitrates, nitrates and EC, total alkalinity and chlorides, total hardness and nitrates, total hardness and calcium hardness, nitrates and calcium hardness, phosphates and calcium hardness, chlorides and magnesium hardness and there is perfect positive correlation between TDS and EC. Whereas, there is strong negative correlation between total hardness and chlorides, water temperature and pH, water temperature and DO, total hardness and pH, pH and calcium hardness, phosphates and DO, total alkalinity and nitrates, TDS and total alkalinity, TDS and magnesium hardness, TDS and chloride, total alkalinity and calcium hardness, nitrates and magnesium hardness and calcium hardness and chloride concentration. There is perfect negative correlation between pH and phosphates, EC

Table 5

Depiction of CCME-WQI at different sampling sites in the stream during different seasons

Sites	Pre-Monsoon	Monsoon	Post-Monsoon
Site 1	73.2112	66.7427	65.5749
Site 2	68.27459	66.1638	60.6997

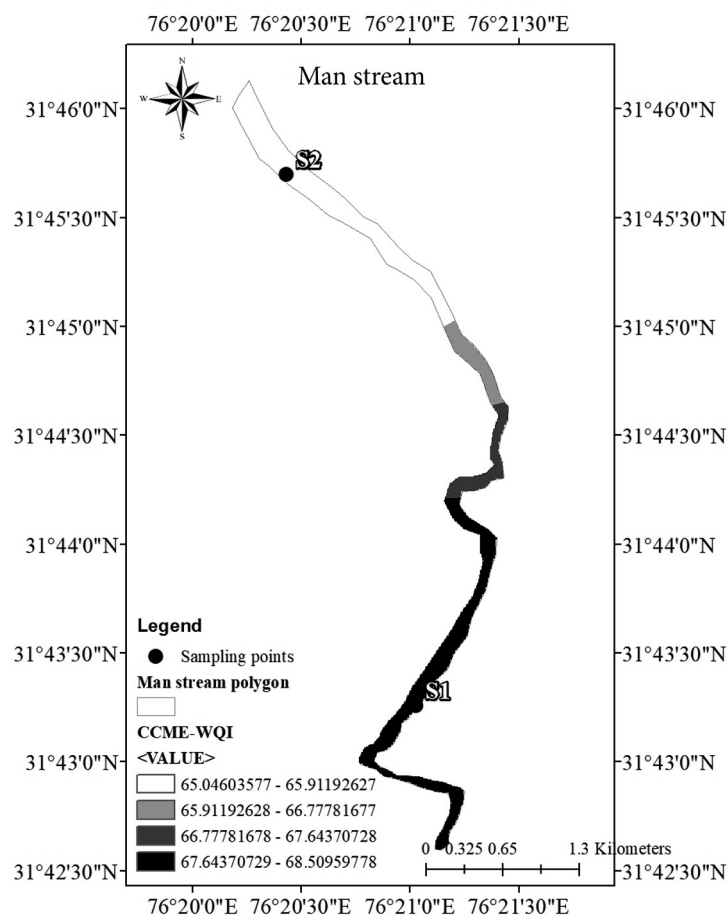


Fig. 3. GIS map showing spatial variation of the average CCME-WQI of the Man stream

and magnesium hardness, total alkalinity and total hardness and chlorides and nitrates concentration.

During post-monsoon (Figure 4, c), there is strong positive correlation between water temperature and calcium hardness, pH and total alkalinity, TDS and EC, DO and magnesium hardness, total hardness and phosphates concentration, whereas there is strong negative correlation between water temperature and DO, water temperature and magnesium hardness, DO and calcium hardness and magnesium and calcium hardness.

At S2, during pre-monsoon (Figure 5, a), there is strong positive correlation between pH and chlorides, TDS and EC, TDS and total hardness, EC and total hardness, DO and chlorides, nitrates and phosphates concentration, whereas there is strong negative correlation between DO and EC, TDS and phosphates, EC and chlorides, DO and total hardness, chlorides and total hardness and calcium and magnesium concentrations.

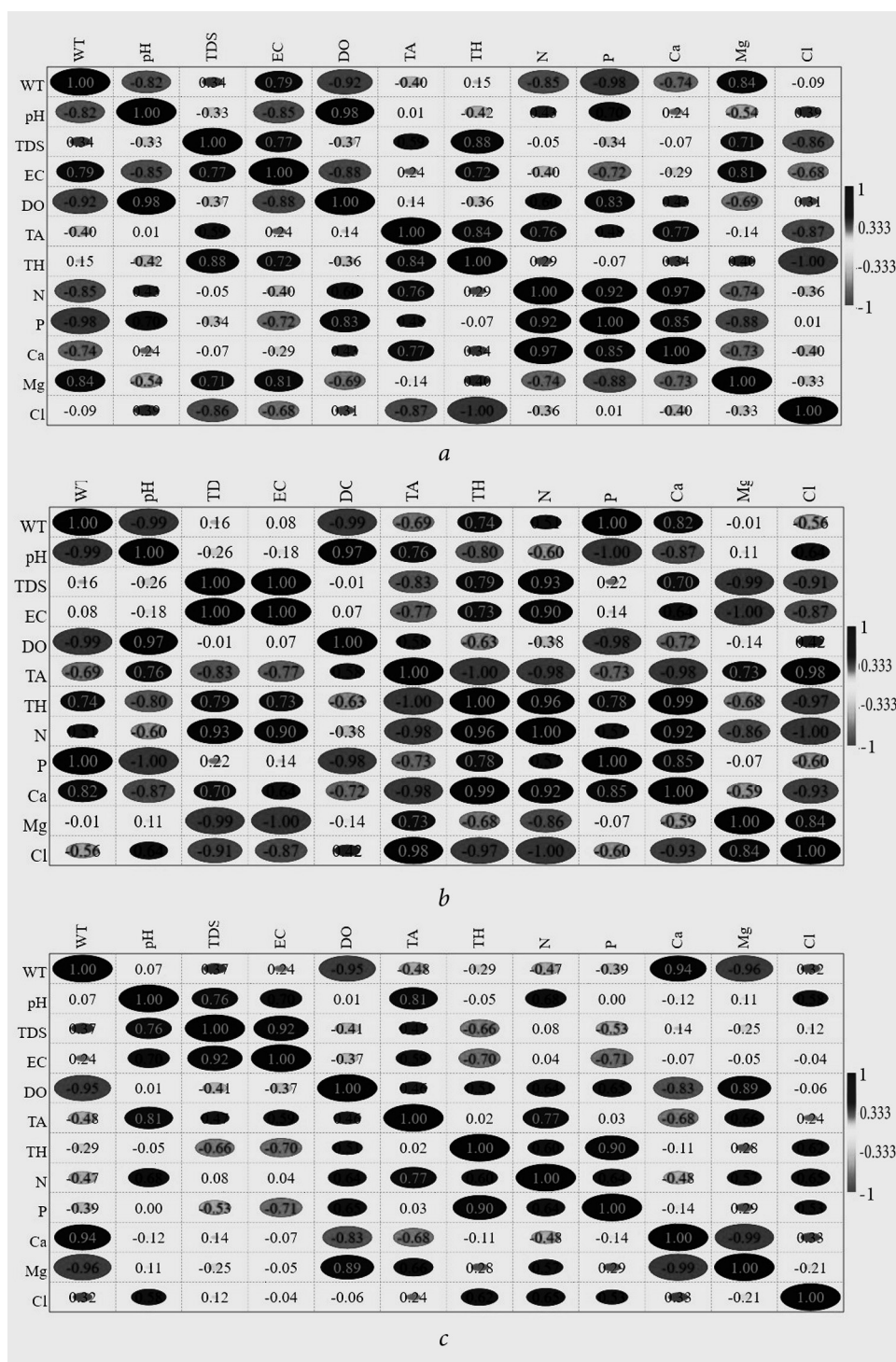


Fig. 4. Pearson's correlation coefficient between different physiochemical parameters in the Man stream (S1) during different seasons: *a* — pre-monsoon; *b* — monsoon; *c* — post-monsoon

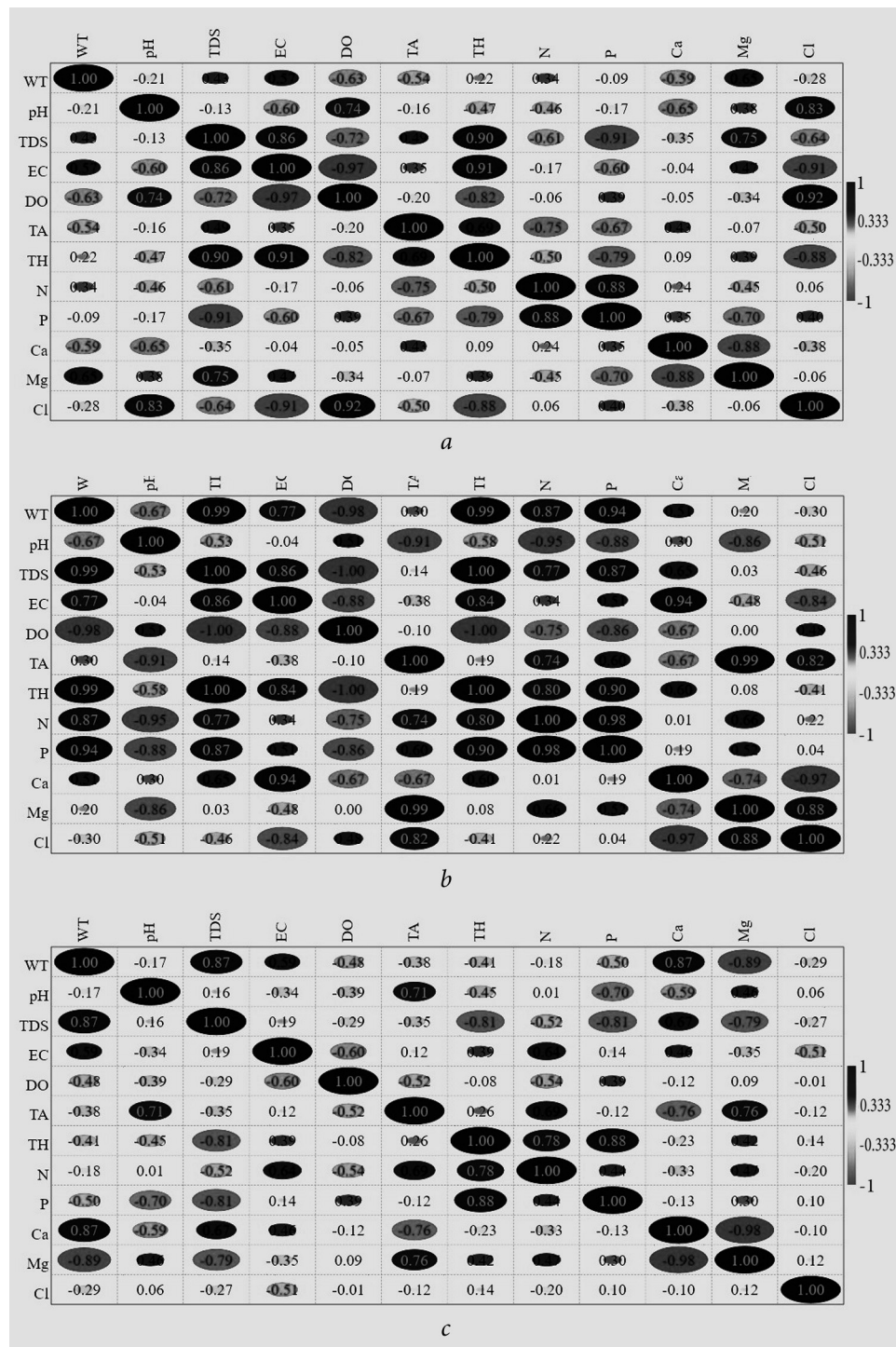


Fig. 5. Pearson's correlation coefficient between different physiochemical parameters in the Man stream (S2) during different seasons: *a* — pre-monsoon; *b* — monsoon; *c* — post-monsoon

During monsoon (Figure 5, *b*), water temperature shows strong positive correlation with TDS, total hardness, nitrates and phosphates, TDS shows strong positive correlation with EC and phosphates, total hardness shows strong positive correlation with EC, nitrates and phosphate, total alkalinity with magnesium hardness and chlorides, EC with calcium hardness, nitrates with phosphates, chlorides with magnesium hardness. There is perfect positive correlation between TDS and total hardness. In contrast, pH shows strong negative correlation with total alkalinity, nitrates, phosphates and magnesium concentration, DO shows strong negative correlation with water temperature, EC, phosphates, chlorides show strong negative correlation with EC and calcium hardness, whereas, DO shows perfect negative correlation with TDS and total hardness.

During post-monsoon (Figure 5, *c*), there is strong negative correlation between water temperature and TDS, water temperature and calcium hardness, total hardness and phosphates, whereas, there is strong negative correlation between water temperature and magnesium hardness, TDS and total hardness, TDS and phosphates and calcium and magnesium hardness.

Fish species diversity. A total of 23 fish species belonging to 6 orders and 9 families were reported from the stream (Table 6). The order Cypriniformes is the dominant order consisting of 3 families viz., Cyprinidae, Danionidae and Nemacheilidae having 8, 4 and 2 species, respectively. Siluriformes is the second dominant order having 2 families, Siluridae (2 species) and Bagridae (1 species), which is followed by Anabantiformes having the family Channidae (2 species) and Synbranchiformes having the family Mastacembelidae (2 species). Beloniformes and Ovalentaria/Misc. consists of family Belonidae (1 species) and Ambassidae (1 species), respectively. Previously Cypriniformes order with the family Cyprinidae was recorded to be dominant in Himalayan ecosystem [56].

Table 6

Fish faunal species recorded in the Man stream, Shivalik Himalayas

Fish species
Order: Cypriniformes
Family: Cyprinidae
<i>Cyprinus carpio</i> (Linneaus, 1758)
<i>Tor putitora</i> (Hamilton, 1822)
<i>Tariqilabeo diplocheilus</i> (Heckel, 1838)
<i>Garra gotyla</i> (Gray, 1830)
<i>Pethia ticto</i> (Hamilton, 1822)
<i>Pethia conchoni</i> (Hamilton, 1822)
<i>Osteobrama cotio</i> (Hamilton, 1822)
<i>Systomus sarana</i> (Hamilton, 1822)
Family: Danionidae

Продовження табл. 6

Fish species
<i>Opsarius bendelisis</i> (Hamilton, 1807)
<i>Barilius vagra</i> (Hamilton, 1822)
<i>Barilius barila</i> (Hamilton, 1822)
<i>Salmostoma bacaila</i> (Hamilton, 1822)
Family: Nemacheilidae
<i>Acanthocobitis botia</i> (Hamilton, 1822)
<i>Schistura horai</i> (Menon, 1952)
Order: Siluriformes
Family: Siluridae
<i>Glyptothorax pectinopterus</i> (McClelland, 1842)
<i>Glyptothorax indicus</i> (Talwar, 1991)
Family: Bagridae
<i>Mystus bleekeri</i> (Day, 1877)
Order: Anabantiformes
Family: Channidae
<i>Channa punctata</i> (Bloch, 1793)
<i>Channa gachua</i> (Hamilton, 1822)
Order: Ovalentaria/Misc.
Family: Ambassidae
<i>Chanda nama</i> (Hamilton, 1822)
Order: Beloniformes
Family: Belonidae
<i>Xenontodon cancila</i> (Hamilton, 1822)
Order: Synbranchiformes
Family: Mastacembelidae
<i>Mastacembelus armatus</i> (Lacepede, 1800)
<i>Macrognathus pancalus</i> (Hamilton, 1822)

Diversity indices. Fish-faunal diversity indices assist in understanding the diversity of the studied stream and the quality of water based on the observed fish species. Table 7 shows seasonal variation of fish faunal diversity at S1 and S2 sites of the Man stream. The dominance index is highest during monsoon season at both the study sites, which shows dominance of some species such as *Cyprinus carpio*, *Channa punctata*, *Mastacembelus armatus*, etc. during the se-

Table 7

Fish fauna diversity during different seasons in the Man stream

Indices	Pre-Monsoon		Monsoon		Post-Monsoon	
	S1	S2	S1	S2	S1	S2
Dominance D	0.05931	0.05363	0.08245	0.06655	0.05709	0.05441
Simpson 1-D	0.9407	0.9464	0.9176	0.9335	0.9429	0.9456
Shannon H	2.894	2.997	2.598	2.768	2.971	2.978
Evenness e^H/S	0.9035	0.9099	0.8954	0.9368	0.8872	0.9356

ason, as these can withstand turbulent water flow. Simpson's index considers both the number and abundance of species; a higher value of Simpson's index signifies higher ichthyofaunal diversity [17]. Simpson diversity index was nearly same during pre-monsoon and post-monsoon with insignificant fluctuations, whereas it was lowest at S1 during monsoon season. The Shannon index considers both the number of individuals and the number of taxa. Shannon diversity index was also found the lowest at S1 during monsoon season and found nearly same during pre-monsoon and post-monsoon season at both the study sites. Evenness index was found to be highest during monsoon season at S2 and lowest at S1 during post-monsoon season. The highest dominance and evenness index was recorded during monsoon in the Eastern Indian rivers [46]. The Arc-GIS mapping of the average of different diversity indices is given in Figure 6.

Conclusion

The study revealed seasonal variations in environmental variables and physiochemical parameters, with the stream's water quality ranging from «fair» to «marginal». The parameters like EC, calcium hardness, and magnesium hardness exceeded the permissible limits set by the BIS, WHO, and USPHS in all the three seasons. EC was particularly high during pre-monsoon and post-monsoon also, while total hardness was highest during pre-monsoon, surpassing permissible limits. Moreover, marginal water quality at S2 during post-monsoon may be due to various anthropogenic activities and accumulation of various domestic and agricultural waste waters brought about by surface run-off during monsoon season.

The research identified 23 fish species, emphasizing the stream's biodiversity and the need for effective management to preserve this aquatic ecosystem. Fish diversity was linked to the stream's water quality. During pre-monsoon, the Water Quality Index (WQI) was highest, as were Simpson's and Shannon diversity indices. Additionally, a high dominance index during the monsoon at both sites indicated the prevalence of certain species adapted to turbulent water flow.

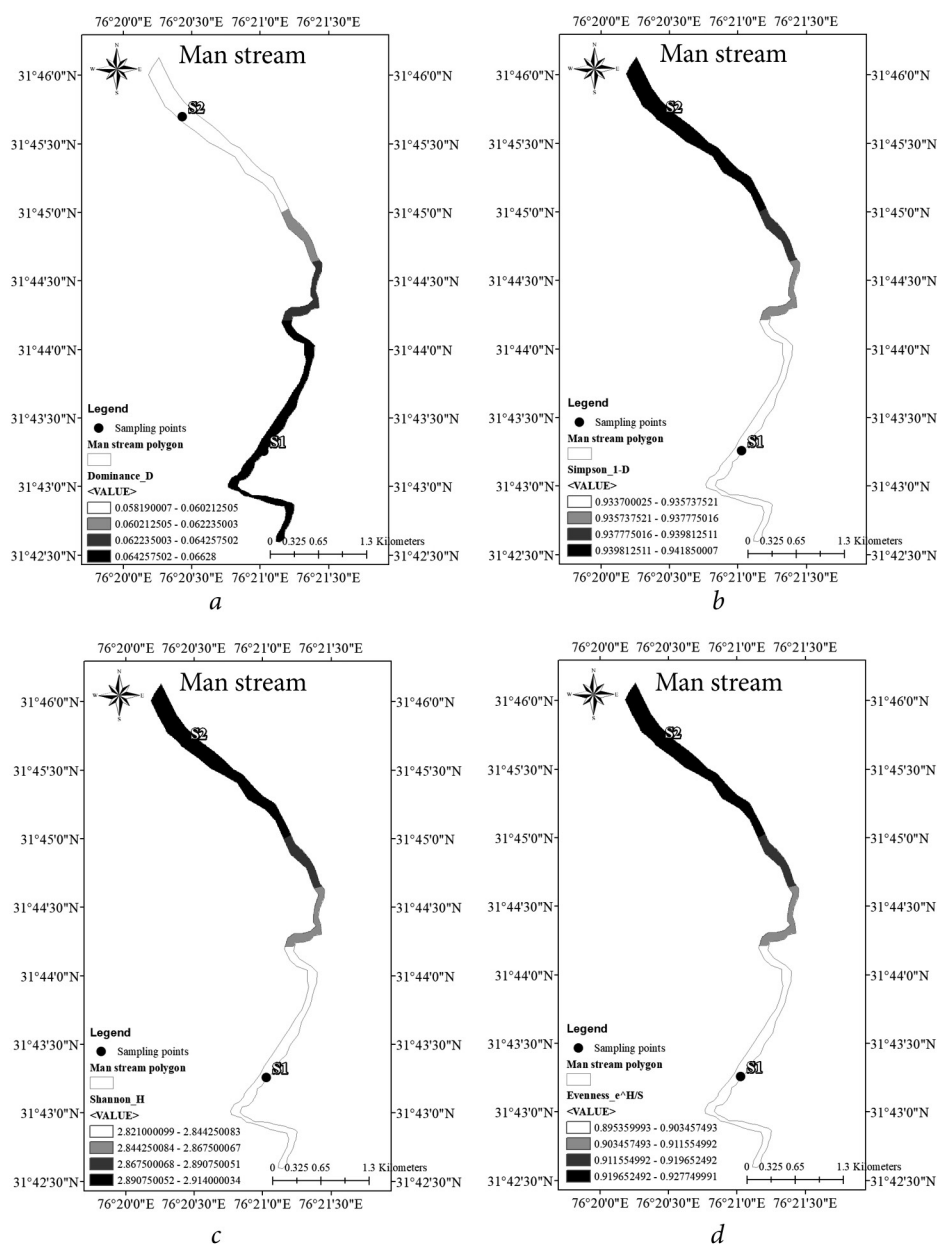


Fig 6. GIS map showing spatial variation of the average of different diversity indices in the Man stream: *a* — dominance; *b* — Simpson; *c* — Shannon; *d* — evenness

As the stream is a major tributary of the Beas River in Shivalik range of the Northwestern Himalayas, the study provides valuable insight of varied environmental variables on the biotic communities of both the stream and the Beas River. The present findings highlight the need for continuous monitoring and management of water resources to mitigate anthropogenic impacts and ensure the health and sustainability of aquatic ecosystems.

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STUDIES ON SPATIAL AND SEASONAL VARIATION OF WATER QUALITY AND
FISH SPECIES DIVERSITY IN THE MAN STREAM, SHIVALIK, HIMALAYAS,
INDIA USING THE ARCGIS MAPPING SYSTEM

The present study assesses water quality of the Man stream, a significant tributary of the Beas River in Shivalik, Himalayas, Himachal Pradesh, by analyzing environmental variables, Water Quality Index (WQI) and fish species distribution using the Geographical Information System (GIS). Water samples were collected from two sites (upstream and downstream), over a year and various physiochemical parameters were analyzed. The study utilized the Canadian Council of Ministers of Environment — Water Quality Index (CCME-WQI) to evaluate water quality, depicting «fair» to «marginal» water quality status. Pearson's correlation coefficient was used to assess the correlation between physiochemical parameters. A total of 23 fish species belonging to 6 orders and 9 families was reported, with Cypriniformes being the dominant order. Diversity indices revealed seasonal variations in fish communities, with the highest dominance index during monsoon and the Simpson and Shannon indices lowest during monsoon and nearly the same during pre-monsoon and post-monsoon with insignificant fluctuations. This comprehensive assessment provides valuable insights for fishery management and sustainable development in the region.

Keywords: fish fauna, diversity, water quality, the Canadian Council of Ministers of Environment — Water Quality Index (CCME-WQI), the Geographical Information System (ArcGIS), Shivalik, Himalayas.