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## ARTICLE

### Comparative study of water quality and phytoplankton composition across distinct sites of Srinagar Garhwal, Uttarakhand, India

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#### ABSTRACT

Freshwater ecosystems are dynamic and susceptible to human effects; therefore, conducting a quality analysis in these ecosystems is essential. The article highlights the evaluation of the quality of the water as well as phytoplankton diversity of four different areas in Srinagar Garhwal: Madhi Chauras, Sri Yantra Tapu, Chauras Bridge, and Billkedar from February to July 2025. The physical parameters used in the determination of the variation include temperature, turbidity, pH, alkalinity, hardness, nitrates, calcium, magnesium, chlorides, and total dissolved solids. On the same note, phytoplankton collection was performed. A total of 47 phytoplankton species belonging to the classes of Bacillariophyceae, Chlorophyceae and Cyanophyceae were found. Ecological metrics such as Shannon-Wiener index, Simpson Diversity index and Pielou evenness calculated by using PAST software revealed heterogeneity in the spatial distribution of algal abundance dominated by diatoms. Canonical Correspondence Analysis (CCA) also showed strong relationships of nutrient enrichment, turbidity and phytoplankton composition. Use of the Algal Genus Pollution Index (AGPI) showed high organic pollution in Sri Yantra Tapu and Chauras Bridge, but Madhi Chauras and Billkedar indicated non-polluted or less-polluted conditions. Thus, the study emphasises the potential of phytoplankton as biological indicators of water quality status and marks a first attempt to record a set of basic data on the algal composition of a particular Alaknanda River segment in Srinagar, Garhwal.

## 1. Introduction

Water is an integral natural resource on which life relies, and it plays an important role in maintaining ecological balance, facilitating socio-economic activity, and ensuring the health and well-being of human life (Kumar & Puri, 2012; Ramaraj et al., 2014a). Water can, therefore, be termed the basis for many activities performed by mankind, like industrial activity and agriculture (Angalika et al., 2022; Hangsapreurke & Pratoomchat, 2023). Thus, the freshwater system has high complexity in relation to size, composition, and diversity, making water the life-

supporting element (Aye et al., 2019; Wetzel, 2000). Increased human activities like industrial development, unplanned urbanisation, agricultural runoff, and indiscriminate disposal of sewage have greatly affected the quality of the country's freshwater bodies (Trivedy & Pattanshetty, 2002). In particular, the Garhwal Himalayas, known for their unique biodiversity, face serious environmental stress due to the above factors (Dhakar & Pandey, 2020; Ramaraj et al., 2015a; Tongsir et al., 2023).

Srinagar Garhwal lies on the bank of the river Alaknanda in the state of Uttarakhand, and it is an important urban settlement in the Central Himalayas region. The region, being part of the larger Ganga River Basin, not only provides ecological support but also

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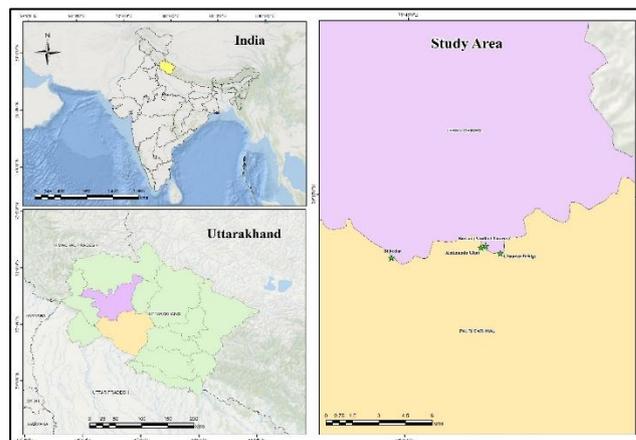
has important cultural and economic functions (Ramaraj et al., 2014b; Rawat et al., 2020). The river Alaknanda and its associated rivers act as important sources for potable water, irrigation, and aquatic life (Chahal et al., 2016). Nevertheless, the area is also observing an increasing level of environmental impacts caused by unregulated urbanisation, sand mining, and domestic Waste Disposal, affecting, in general, the level of water quality in the area (Rawat et al., 2020; Pandey et al., 2025). The level and composition of aquatic biodiversity are directly affected by interactions between abiotic factors, such as nutrients, temperature, and physicochemical composition (Bellard et al., 2012; Heinrichs et al., 2021; Palanisamy et al., 2023). Water pollution affects aquatic life in a harmful manner, dropping aquatic biodiversity, impacting food web sustainability, and affecting the overall potability of aquatic systems (Bhuyar et al., 2019, 2021). Within aquatic flora, phytoplankton are important organisms for maintaining an aquatic ecological balance (Matharu et al., 2021; Kumaran et al., 2023). Some species of phytoplankton act as bioindicators, which help in assessing the level of aquatic pollution effectively. Thus, regular checks on their level and diversity in the environment help in effectively controlling the physicochemical composition and quality of water (Tsai et al., 2015). Microalgae, including diatoms, green algae, and cyanobacteria, are the most dominant phytoplankton in freshwater bodies (Tsai et al., 2017; Whangchai et al., 2018; Bhuyar et al., 2021). These phytoplankton are sensitive to changes in environmental factors such as nutrient levels, temperatures, pH levels, and dissolved oxygen levels (Reynolds, 2006; Ramaraj et al., 2025b). Microalgae are an important indicator of water quality (Nithin et al., 2020). They show the trophic status of the water source along with the level of pollution in that particular water body (Tsai et al., 2012, 2023; Yadav, 2024). Phytoplankton bio-indicators like Algal Genus Pollution Index (AGPI) have been acknowledged as a cheaper analysis method to measure water quality (Kadam et al., 2020). The AGPI relies on the occurrence of particular species, with some being highly tolerant to pollution and including genera like *Oscillatoria* sp. and *Euglena*, as well as others like *Fragilaria* and *Synedra*, which are generally found in less polluted water (Palmer, 1969).

Accordingly, this research aims to evaluate water quality based on AGPI and algal genus diversity at four locations. The Algal Genus Pollution Index (AGPI) is used in assessing organic pollution, particularly focusing on microalgae and diatoms that can thrive in pollution-infused waters. PAST (Paleontological Statistics) software is employed in calculating values of ecological diversity, such as Shannon-Wiener and Simpson's Index, which are currently recognised and accepted in assessing and studying biodiversity and ecologies (Hammer et al., 2001; Kadam et al., 2020). Furthermore, a relationship of water quality factors and algal genus composition is likewise analysed through a Principal Component Analysis technique in a PAST setting (Kadam et al., 2020). This paper proposes three main objectives: (i) to analyse algal diversity at specific sites to determine algal biodiversity at Madhi Chauras, Sriyantra Tapu, Chauras Bridge, and Bill Kedar, (ii) Algal diversity measures, including diversity, dominance, evenness, the Shannon-Wiener Index, and the Simpson Index, would be calculated using PAST software and, (iii) Water quality at specific sites would be compared using the Algal Genus Pollution Index (AGPI). In this context, this holistic or integral analysis examines and provides a greater understanding of phytoplankton genus composition under various environmental and anthropogenic conditions.

## 2. Materials and Methods

### 2.1 Physiology of the Study Area

Four Study areas (Sites) were selected, which are Madhi Chauras, Sri Yantra Tapu, Chauras Bridge, and Billkedar. Site 1 Madhi Chauras Water Source is characterised by freshwater with GPS coordinates 30°48'30.996" N and 78°12'21.456" E. Site 2 Sri Yantra Tapu is characterised by freshwater, but it is impacted by urban runoff, making its quality variable. The site is located at GPS coordinates 30°13'17.0364" N and 78°46'48.1620" E. Site 3 Chauras Bridge, situated near the H.N.B. Garhwal University, is characterised by stagnant water conditions with GPS coordinates 30°13'10.9704"N and 78°48'23.5584"E. Site 4 Billkedar (Bud Gaon) near Kirtinagar is characterised by freshwater with GPS coordinates 30°12'55" N and 78°44'55" E (Figure 1).



**Figure 1.** Distinct study sites of Srinagar Garhwal, Uttarakhand.

### 2.2 Physicochemical Parameters Analysis

Physicochemical parameters were measured in water samples collected from the four study sites from February to July. Air temperature was recorded using a digital thermometer, and water temperature was determined in situ using a mercury bulb thermometer. pH (EUTECH PC700), turbidity (turbidity meter MI415), and total dissolved solids or conductivity (Conductivity Meter 950). Nitrate was analysed via (cadmium reduction using a HACH DR-500 UV-spectrophotometer), total alkalinity, total hardness, chloride ions, magnesium ions, calcium, and colour of the water samples were analysed with the support of the Jal Sansthan (Water supply plant), Srinagar, Garhwal.

### 2.3 Microalgal Sample Collection and Their Identification

Sampling was conducted at four study sites between February and July 2025. Microalgal mats were randomly collected from the riverbanks. Stone-attached microalgal samples were scraped off with razor blades and collected using forceps and a spatula into sterile polybags. Water samples were taken every month from February to July in sterile bottles and transported to the laboratory for further analysis of physicochemical parameters. The physical and chemical characteristics of the samples are tested and analysed in the Water Supply Plant of Srinagar, Garhwal. In the laboratory, the collected algal samples were preserved in a 4% formaldehyde solution (Goswami & Singh, 2018). The morphological features of various algal taxa in the collected samples were then examined using a compound light microscope (Olympus MLX-B SN-17C0080). Additionally, the identification of microalgae to the genus and species levels was performed using standard literature Desikachary (1959); Gupta (2005); Kale and Karthick (2015) & Zhou et al. (2023), and the online database Algae Base (<http://www.algaebase.org>) and Diatom database

(<https://diatoms.org/>). Palmer's (1969) algal pollution index was used to determine the level of organic pollution at four study sites.

#### 2.4 Statistical Analysis of the Dataset

Sampling was conducted to enable subsequent statistical analysis of the data. Computational evaluation of species diversity was executed using the formula established by Shannon and Weaver (1949).

$$H' = - \sum_{i=1}^S \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

Where 'H' represents the species diversity, 'n' signifies the number of individuals of a species, 'N' denotes the total number of individuals, and 'S' represents the total number of species in the sample. Furthermore, the species richness index developed by Margalef (1951) was subsequently determined:

$$D = \frac{S - 1}{\log_{10} N}$$

Herein, the variable 'S' denotes the number of species, while 'N' represents the total count of individuals. The alternative equation for species diversity was introduced by Simpson et al. (1949).

$$H' = \sum_{i=1}^S P_i^2$$

Here in Variables is  $P_i$  Fraction of the entire community made up of species  $i$ .

By utilising Pielou's (1966) formula for Evenness or Equitability, one can ascertain the even distribution and fairness among species.

$$\Sigma' = \frac{H'}{\log_2 S}$$

The above-mentioned methodologies play a role in the increase of species diversity, and their evenness and richness; we thus can expect some outcomes based on the experimental results.

#### 2.5 Analysis Tool for the Statistical Data

Statistical evaluations, such as the calculation of different diversity indices, were carried out with the help of Paleontological Statistics Software (PAST). Cluster analysis in PAST was used to find out the degree of similarity between the two sampling stations. In addition, Canonical Correspondence Analysis (CCA) was used as part of the software Past to explore patterns and relationships between the distribution of algal species and the measured physicochemical parameters.

### 3. Results and Discussion

#### 3.1 Physicochemical Parameters

Water temperature showed a clear seasonal fluctuation and varied from 12 °C to 30 °C in the selected sites. At Site S1, the lowest score of 12.2 °C was noted in February, and the highest of 28.1 °C was noted in July. At S2, the temperature varied from 13.5 °C in February to 30.3 °C in July, while S3 had a minimum of 13.8 °C in February and a maximum of 30.4 °C in July. Similarly, S4 showed some fluctuations, varying between 12.9 °C in February to 29.7 °C in July (Table 1). These fluctuations are strongly linked to seasonal climatic conditions as lower temperatures are found during the winter months and higher values are found during the summer. Water temperature is important in controlling the concentration of dissolved oxygen, the metabolic activity of aquatic organisms, and phytoplankton productivity, and is therefore one of the most significant factors determining the ecology of rivers.

Turbidity values showed strong seasonal variation at the various study locations, with the lowest levels in February and the highest levels in July. At S1, turbidity was between 1.7 NTU in February and 2.6 NTU in July. At S2, there was a sharp increase in values from 8.1NTU in February to 53.6NTU in July. Similarly, S3 had 9.7 NTU in Feb and the highest value of 60.8NTU in Jul. At S4, turbidity varied from 3.1 NTU in February to 28.4 NTU in July (Table 1). The results clearly show that turbidity levels were much higher during the pre-monsoon and monsoon transition months, probably as a result of increased surface runoff, sediment load, and organic matter input from catchment areas. Microscopic aquatic diversity, eroded soil, suspended sediment, and chemicals are most often responsible for turbidity (Davies-Colley & Smith, 2007). The WHO (World Health Organisation) and BIS (Bureau of Indian Standards) have both recommended 5.0 NTU to be the maximum permissible limit of turbidity in the water consumed by human beings. Comparable seasonal trends linked to turbidity have been reported in rivers in the Himalayas and elsewhere throughout freshwater, which is associated with runoff during the monsoon season, leading to elevated values (Rawat et al., 2020).

Water colour varied quite markedly between study locations and seasons and ranged from 1 to 11 Hazen units. At Site S1, the colour measure was very low - it was consistently at 1 Hazen unit in February and June, suggesting little variation. Conversely, S2 and S3 had larger seasonal cycles as 3 Hazen units in February increased to 11 Hazen units at S2 in June, and 8 Hazen units at S3 in July. S4 showed only a slight rise in seasonality from 1 Hazen unit in February to 3 Hazen units in July. These types of patterns indicate the influence of seasonality and in particular the pre-monsoon/monsoon changeover causes an increase in water colour which is likely influenced by high levels of suspended particulates and dissolved organic matter (Table 1). Further, at S1, pH was 7.1-7.8 with low winter values due to poor photosynthesis and a slight summer increase, associated with the activity of *Spirogyra* (Sharma & Sharma, 2021). At S2 the pH rose from 7.6 to 8.6 which could probably be attributed to improved productivity and higher bicarbonate inputs during the pre-monsoon period (Seth et al., 2016). S3 was found to exhibit the greatest variability (7.6-8.9) with elevated values being attributed to phytoplankton blooms, as well as nutrient-rich inflows. At S4, the pH ranged from 7.2 to 8.3, where *Rhizoclonium* and diatoms had a moderate impact on increasing alkalinity, but turbulent flow stopped alkalinity from rising excessively (Pimpimol et al., 2020; Saengsawang et al., 2020; Khammee et al., 2021).

The concentration of dissolved nitrate values in the study sites varied from 0.06 to 1.07 mg/L, the lowest value detected was at S1 in February, while the highest values were recorded at S2 and S3 during July (Table 1). Seasonal spikes during the monsoon season were especially observed at S2 and S3, which can be attributed to increased surface run-off and nutrient input from water source areas. Nitrate concentrations in all the locations were still well below the WHO guideline limit of 45 mg/L for drinking water - indicating that there is no direct health hazard. However, the higher concentrations at S2 and S3 during the monsoon months imply possible localised nutrient enrichment, which may have an impact on the phytoplankton productivity and species composition.

At Site S4, the concentration of nitrate was consistently low, with concentrations of 0.14 milligrams per liter in February and 0.12 milligrams per liter in July. This limited seasonal variability gives us some indication of a minimum amount of anthropogenic or ag input in the surrounding drainage basin, which would indicate a reasonably stable nutrient regime. Such low availability of nitrate could limit the overgrowth of phytoplankton, which would result in an imbalance in community structure, avoiding eutrophication

(Patang et al., 2018; Yang et al., 2021). These results indicate that, although the studied portion of the Alaknanda River is oligotrophic to mesotrophic, seasonal enrichment of nitrate during the monsoon period may be favourable to enhanced growth of diatoms and chlorophytes, which in turn influence phytoplankton species and community dynamics. Thus, nitrate enrichment during monsoon is acting as a critical driver of the seasonal diversity of phytoplankton assemblage, especially supporting growth of diatom and chlorophyte-dominated assemblages in Alaknanda River.

Similarly, dissolved Calcium and Magnesium, Chloride and total alkalinity are measured (Table 1). The total hardness of water between the study sites varied between 79 - 258 mg/L with significant seasonal variations. The lowest value of 79 mg/L was observed at S4 in February and the highest value of 258 mg/L was observed at S1 in July. Seasonal variation was evident in the different sites: at S1 from 222 mg/L (winter) to 258 mg/L (monsoon), S2 from 90 mg/L (winter) to 168 mg/L (monsoon), S3 from 93 mg/L (winter) to 180 mg/L (monsoon), and S4 from 79 mg/L (winter) to 155 mg/L (monsoon). The present values, though varying seasonally, mostly do not exceed the permissible limit of 200 mg/L recommended by WHO/BIS standards, which is an

indication of good water quality for domestic and ecological use. However, localised lithological influence and a decrease in dilution effects also demonstrate the occasional higher values, such as at S1 (258 mg/L). The total dissolved solids (TDS) of the water on the study sites were determined during the study period and they have a maximum value of 329 mg/L and a minimum value of 110 mg/L.

In terms of the seasonal variations, we also observed a difference in total alkalinity between February and July. In S1 the value for the total dissolved solids is 245 mg/L in the month of February and 329 mg/L in the month of July (Table 1). In S2 the value of the total dissolved solids is 150 mg/L in the month of February and 287 mg/L in the month of July. In S3 the value for total dissolved solids was 110 mg/L in February and 294 mg/L in July. In S4, however, the total dissolved solids value in February and July was 115 and 260 mg/L, respectively. The total dissolved solids in the period of study were lower than the standard value (500 mg/L) recommended by the WHO and BIS for water used for human consumption. Rainfall and livestock are present near the river, which are responsible for high quantities of TDS.

**Table 1.** Seasonal variations in physicochemical environmental variables of distinct areas during February to July.

Environmental variables	Sites	Months					
		February	March	April	May	June	July
<b>Air temp (°C)</b>	S1	21.2	26.3	29.6	32.4	35.6	35.1
	S2	23.2	27.3	31.6	35.4	38.7	38.3
	S3	23.8	27.5	31.9	35.5	38.9	38.5
	S4	22.1	26.6	30.5	33.9	37.7	37.5
<b>Water temp (°C)</b>	S1	12.2	16.2	20.5	25.4	28.2	28.1
	S2	13.5	18.5	22.3	27.9	30.6	30.3
	S3	13.8	18.6	22.7	28.1	30.8	30.4
	S4	12.9	17.9	21.7	27.5	29.9	29.7
<b>Turbidity (NTU)</b>	S1	1.7	1.7	1.7	2.4	2.5	2.6
	S2	8.1	20.6	20.9	22.3	25.2	53.6
	S3	9.7	20.9	21.6	236	25.9	60.8
	S4	3.1	3.3	4.6	5.7	17.7	28.4
<b>TDS (mg/L)</b>	S1	245	276	295	300	328	329
	S2	150	157	178	196	276	287
	S3	110	128	137	144	288	294
	S4	115	137	149	159	168	260
<b>Total Alkalinity (mg/L)</b>	S1	95	97	121	143	240	265
	S2	68	79	88	96	126	142
	S3	72	75	87	94	164	185
	S4	82	87	99	105	186	197
<b>pH</b>	S1	7.1	7.2	7.1	7.4	7.9	7.8
	S2	7.6	7.7	7.9	8.6	8.7	8.6
	S3	7.6	7.9	8.1	8.8	8.9	8.8
	S4	7.2	7.3	7.8	7.9	8.4	8.3
<b>Chlorides (mg/L)</b>	S1	0.8	0.7	0.9	1.1	1.2	1.3
	S2	4.7	4.9	5.4	5.5	4.4	4.2
	S3	4.7	4.9	5.8	5.6	5.5	5.9
	S4	3.1	2.9	3.5	3.4	2.8	2.7
<b>Total Hardness(mg/L)</b>	S1	222	220	223	234	246	258
	S2	90	95	110	128	148	168
	S3	93	102	118	152	185	180

	S4	79	82	86	92	96	155
<b>Magnesium ion (mg/L)</b>	S1	21.4	22.3	23.5	25.7	25.6	25.8
	S2	13.1	13.5	10.3	11.7	11.6	12.5
	S3	14.7	14.2	14.3	15.4	16.3	16.2
	S4	6.6	6.1	6.4	6.6	5.3	5.5
<b>Calcium (mg/L)</b>	S1	45.5	45.8	49.5	50.1	56.4	55.7
	S2	31.9	32.9	38.5	38.6	40.5	38.8
	S3	32.1	33.4	38.7	38.9	42.2	40.6
	S4	22.8	21.9	27.6	27.7	29.3	28.6
<b>Nitrates (mg/L)</b>	S1	0.06	0.08	0.08	0.09	0.11	0.12
	S2	0.24	0.52	0.69	1.05	1.07	1.07
	S3	0.23	0.62	0.78	1.02	1.06	1.07
	S4	0.14	0.15	0.18	0.17	0.16	0.12
<b>Colour (Hazen)</b>	S1	1	1	1	1	1	1
	S2	3	3	4	4	8	11
	S3	3	4	4	5	6	8
	S4	1	1	1	2	2	3

### 3.2 Phytoplankton Distribution

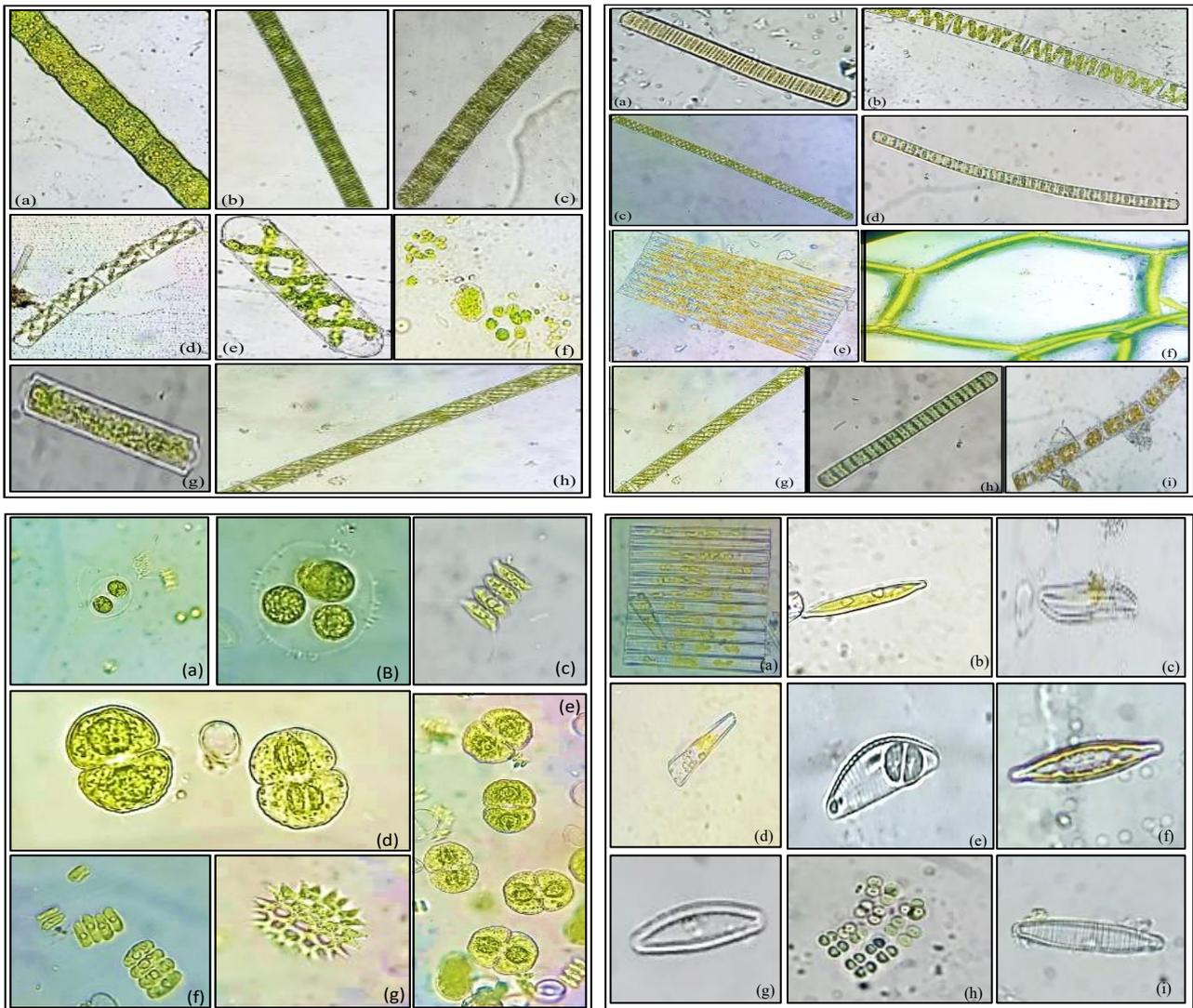
Phytoplankton is likely to play a crucial role in resolving a few environmental issues, in studying photosynthesis, in understanding aquatic ecosystems, and in the production of useful substances. In the current study, a monthly analysis of phytoplankton communities was carried out, along with an assessment of the

diversity and density of different species, to evaluate the phytoplankton structure at four study sites. Forty-seven species from three groups, Bacillariophyceae, Chlorophyceae, and Cyanophyceae, of phytoplankton were observed and recorded over a six-month period (Figure 2). The seasonal disparity in phytoplankton density was observed at sites S1, S2, S3, and S4 during the monsoon season. The highest abundance of species was

**Table 2.** Microalgal diversity and species abundance found at different sampling sites of Srinagar Garhwal, Uttarakhand.

Sr. No.	Microalgae	Sampling Site			
		S1	S2	S3	S4
15.	<i>Mastogloia elliptica</i>	+	+++	+++	-
16.	<i>Melosira varians</i>	-	+++++	+++++	+
17.	<i>Navicula radiosa</i>	+	+++	+++	+++
18.	<i>Navicula salinarum</i>	+	+++	+++	+++
19.	<i>Nitzschia dissipata</i>	+++++	+++++	+++++	+
20.	<i>Nitzschia filiformis</i>	+++++	+++++	+++++	+
21.	<i>Nitzschia frustulum</i>	+++	+++	+++	+++
22.	<i>Nitzschia sp.</i>	+++++	+++	+++	+++
23.	<i>Pleurosira laevis</i>	+	+	+	-
<b>Chlorophyceae (Green algae)</b>					
24.	<i>Chlorella sp.</i>	+	+	+	+
25.	<i>Cosmarium moniliforme</i>	-	+	+	+
26.	<i>Cosmarium pachydermum</i>	-	+	+	+
27.	<i>Cosmarium vexatum</i>	-	+	+	+
28.	<i>Cosmarium sp.</i>	-	+	+	+
<b>Bacillariophyceae (Diatoms)</b>					
1.	<i>Amphora sp.</i>	-	+	+	+
2.	<i>Coscinodiscus sp.</i>	-	+	+	-
3.	<i>Craticula riparia</i>	-	+++	+	+
4.	<i>Cymbella compacta</i>	+++	+++++	+++++	+++
5.	<i>Cymbella subturgidus</i>	+++++	+++	+++	+++
6.	<i>Cymbella sp.</i>	+++++	+++++	+++	+
7.	<i>Cymbella tumida</i>	+++	+++	+++++	+
8.	<i>Cymatopleura solea</i>	+	+++	+++	+
9.	<i>Diatoma sp.</i>	+	+++	+++	+
10.	<i>Fragilaria capucina</i>	+++	+++	+	+++
11.	<i>Geissleria decussis</i>	-	+	+	+
12.	<i>Gomphonema sp.</i>	+++	+++	+++	+
13.	<i>Gomphonema truncatum</i>	+	+++	+++	+
14.	<i>Gyrosigma attenuate</i>	+++	+++++	+++++	+++

29.	<i>Coelastrum sphaericum</i>	+	+	+	+	40.	<i>Spirogyra bichromatophora</i>	+++++	+++++	+++++	+++
30.	<i>Desmodesmus serratus</i>	+	+	+	+	41.	<i>Spirogyra communis</i>	+++++	+++++	+++++	+++
31.	<i>Golenkinia radiata</i>	+	+	+++	-	42.	<i>Spirogyra maravillosa</i>	+++++	+++++	+++++	+++
32.	<i>Hydrodictyon sp.</i>	-	+++	+	+++	43.	<i>Spirogyra sp.</i>	+++++	+++++	+++++	+++
33.	<i>Merismopedia glauca</i>	-	+	+	-	44.	<i>Ulothrix zonata</i>	+	+	+	+
34.	<i>Oocystis sp.</i>	+	+	+	-	45.	<i>Urospora sp.</i>	+	+	+	+
35.	<i>Pediastrum spp.</i>	+	+	+	-	<b>Cyanophyceae (Blue-green algae / Cyanobacteria)</b>					
36.	<i>Rhizoclonium lubricum</i>	+	+	+	+++++	46.	<i>Oscillatoria amphibia</i>	-	+++++	+	-
37.	<i>Rhizoclonium subtile</i>	+	-	-	+++++	47.	<i>Oscillatoria subbrevis</i>	-	+++++	+	-
38.	<i>Rhizoclonium sp.</i>	+	+	+	+++	<b>Note:</b> +++++ Abundant; +++ Moderate; + Low; - Absent.					
39.	<i>Scenedesmus tropicus</i>	+	+	+	-						



**Figure 2.** Different microalgae (40X binocular compound light microscope Olympus MLX-B SN-17C0080) were found in various collected water samples from different sites of Srinagar Garhwal, Uttarakhand, India.

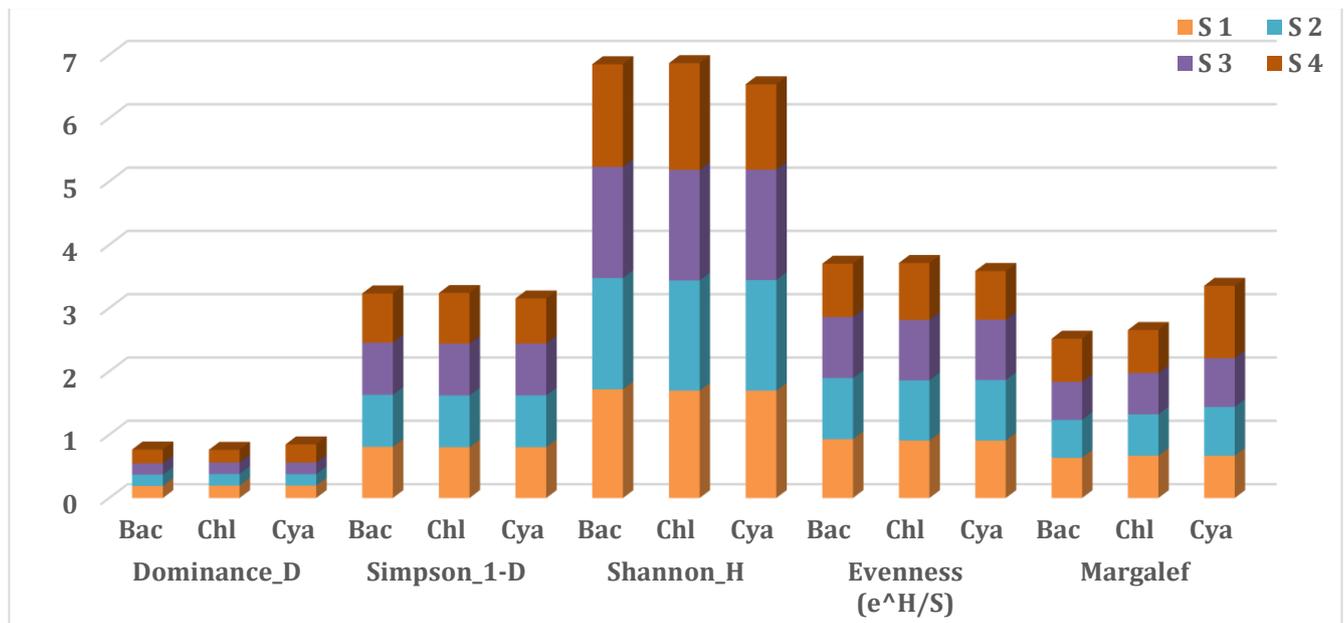
recorded in S2 and S3, while the lowest frequency of abundance was recorded in S1 and S2. During the autumn season, the highest abundance of frequency was recorded in S2 and S3 as well as S4, while the lowest abundance of frequency was recorded in S1 (Table 2). During the winter season, the highest frequency of abundance was recorded in S1, S2, S3, and S4 (Table 2). During the summer season, the phytoplankton frequency decreased. The diversity of Bacillariophyceae biomass dominated the S2, S3 and S4. Nautiyal et al. (1997) reported similar observations in the Mandakini River, where phytoplankton dominated. However, the family Bacillariophyceae was found to have higher diversity. It is well established that a combination of physical, chemical, and biological factors determines the distribution of Bacillariophyceae in rivers (Fabricius, 2004).

### 3.3 Diversity Indices

The ‘Dominance\_D’ of phytoplankton across the study sites revealed distinct taxonomic patterns, indicating that different algal groups responded variably to site-specific and seasonal conditions. During the study period, the mean dominance value of Bacillariophyceae was 0.1918, Chlorophyceae recorded 0.1903, and Cyanophyceae exhibited the highest value at 0.2120 across S1, S2, S3, and S4 (Figure 3). The relatively high dominance of Cyanophyceae suggests that this group exerted greater control over the phytoplankton community, likely reflecting episodes of nutrient enrichment and ecological stress. Cyanobacteria are known to tolerate extreme conditions, fix atmospheric nitrogen, and outcompete other groups under high-nutrient and high-temperature regimes, often leading to reduced evenness and the formation of blooms (Paerl & Huisman, 2009). ‘Simpson’s 1-D’ diversity index of phytoplankton classes in the study sites exhibited site- and season-specific variation, reflecting differences in community structure and ecological balance. The mean values recorded were 0.8082 for Bacillariophyceae, 0.8096 for Chlorophyceae, and 0.2817 for Cyanophyceae across all sites. The comparatively higher Simpson’s diversity values for Chlorophyceae and Bacillariophyceae suggest that these groups were more evenly distributed. Bacillariophyceae, in particular, are

often associated with good water quality, silica availability, and higher transparency in winter months, while Chlorophyceae typically flourish under moderate nutrient input during summer and pre-monsoon (Round et al., 1990; Reynolds, 2006; Padisák et al., 2009).

Similarly, ‘Shannon H’ diversity index values of phytoplankton in the Alaknanda River showed variation across major classes, reflecting differences in richness and evenness at the study sites. The mean Shannon H’ values were 1.7172 for Bacillariophyceae, 1.713 for Chlorophyceae, and 1.6337 for Cyanophyceae during the study period. The relatively high Shannon values of Bacillariophyceae (1.7172) and Chlorophyceae (1.713) indicate greater richness and more even distribution of individuals within these groups. The ‘Evenness (e<sup>H/S</sup>)’ index of phytoplankton communities in the study sites showed noticeable variation across groups and sites, indicating differences in the relative distribution of species. The mean values recorded were 0.9254 for Bacillariophyceae, 0.9283 for Chlorophyceae, and 0.8967 for Cyanophyceae during the study period. The relatively higher evenness values of Chlorophyceae (0.9283) and Bacillariophyceae (0.9254) suggest a more equitable distribution of individuals among species within these groups. This indicates that environmental conditions, such as moderate nutrient enrichment, favourable light penetration, and stable hydrological regimes, supported coexistence without a few species becoming overly dominant. ‘Margalef’s richness’ index of phytoplankton communities in the study sites showed site and season-based variation, reflecting differences in species richness under varying environmental conditions. The mean richness values recorded were 0.6634 for Chlorophyceae, 0.6291 for Bacillariophyceae, and 0.5687 for Cyanophyceae during the study period. Thus, the present findings suggest that Chlorophyceae and Bacillariophyceae contribute more to richness and ecological stability, whereas Cyanophyceae reflect reduced richness and possible stress conditions. This highlights the influence of nutrient status, hydrological conditions, and site-specific anthropogenic impacts on phytoplankton community structure in the study sites.



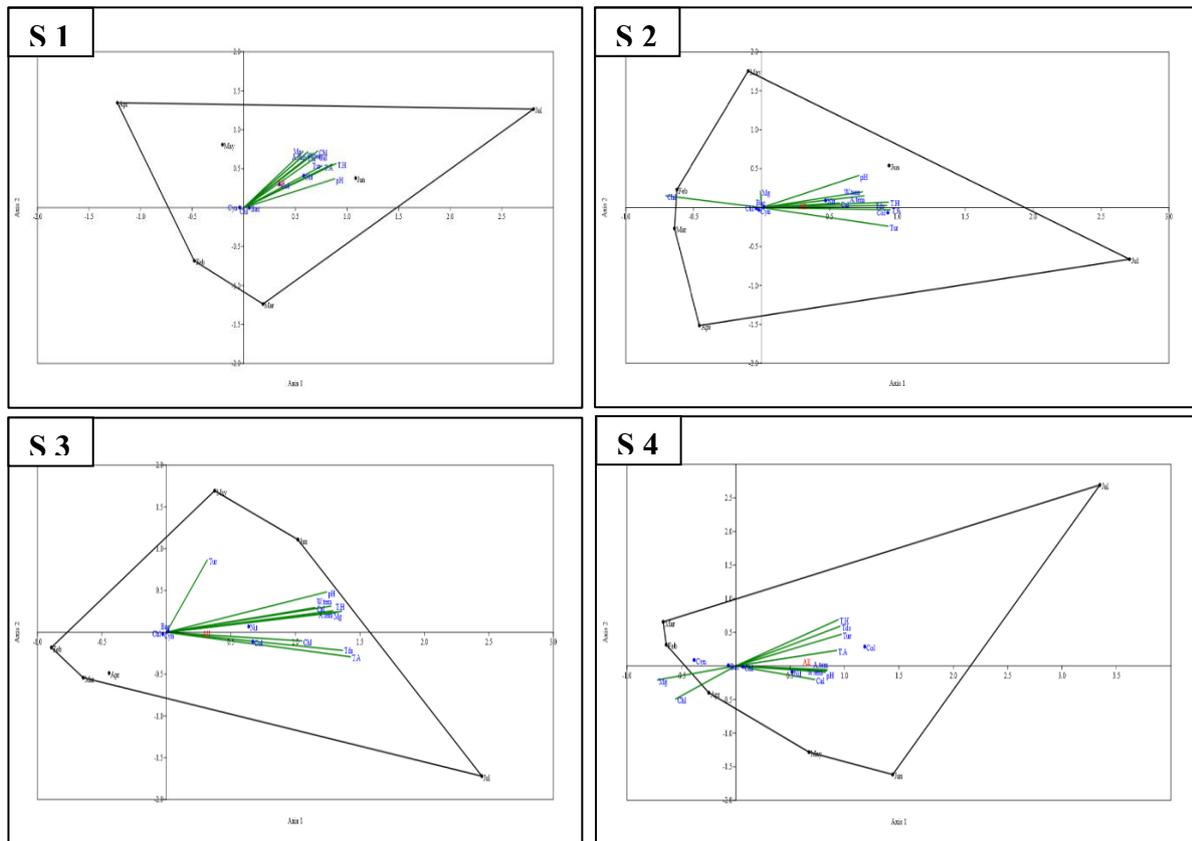
**Figure 3.** Diversity indices of four different sites, where Bac = Bacillariophyceae; Chl = Chlorophyceae; Cya = Cyanophyceae.

### 3.4 CCA For the Physiological Parameters and Microalgal Diversity

Multivariate analyses were performed with consideration for the physicochemical characteristics to determine the factors that significantly affect the composition of algal communities, indicating their association with the Physicochemical parameters of the study site. The link between physicochemical factors and the microalgal and cyanobacterial communities at the study sites (S1, S2, S3, and S4) was examined using Canonical Correspondence Analysis (CCA). In S1 CCA, the environmental variables are represented as vectors in the plot, with their direction and length indicating the strength and direction of their influence on species distribution. Among the environmental variables, chlorine (chl), magnesium (Mg), total alkalinity (T.A), total hardness (T.H), and pH appear to have the strongest influence on species distribution, as indicated by the longer arrows for these factors. Turbidity (Tur) also contributes, but to a lesser extent, as reflected by the shorter vector. All the physicochemical parameters are positioned along the positive side of Axis 1, indicating a potential association with higher values of chlorine (chl), magnesium (Mg), total alkalinity (T.A), total hardness (T.H), and pH. This suggests that the three classes: Bacillariophyceae, Chlorophyceae, and Cyanophyceae are adapted to or thrive in environments with elevated values of these factors. Axis 2 is not associated with physicochemical factors, and the microalgae distribution is positioned near the centre of the plot suggests a more general tolerance to environmental

gradients across the study period.

At S2, CCA physicochemical parameters are positioned on the positive side of Axis 1, indicating that these classes are adapted to or thrive in environments with these factors. In S3, the environmental variables such as pH, total hardness (T. H), and magnesium (Mg) appear to have the strongest influence on species distribution, as indicated by the longer arrows for these factors. Turbidity (Tur) also contributes, but to a lesser extent, as reflected by the shorter vector. Chlorine (Chl), total dissolved solids (Tds), and total alkalinity (T.A). In S4, total hardness (T.H), total dissolved solids (Tds), and turbidity (Tur) are positioned along the positive side of Axis 1, indicating a potential association with higher values of these factors. This suggests that Bacillariophyceae and Chlorophyceae class species are adapted to or thrive in environments with elevated values of these parameters in March to April. Conversely, pH and calcium are positioned along the negative side of Axis 1, indicating less influence on the classes. Axis 2 is associated with factors like magnesium and chlorine, and class Cynophyceae are distributed towards the upper side of Axis 2, indicating that species might be more sensitive to or influenced by magnesium (Mg) and chlorine (Chl) levels. One of the key controlling elements in changing the aquatic environment and impacting the distribution and development patterns of flora and fauna is water temperature. According to Kadam et al. (2020), similar results were obtained for influencing the class of Bacillariophyceae by adjusting the water temperature. Ikram et al. (2021) found that pH influences *Craticula* sp. pH is a crucial factor affecting the Bacillariophyceae class.



**Figure 4.** Canonical Correspondence Analysis (CCA) ordination diagram illustrating the relationship between physicochemical parameters and the microalgal and cyanobacterial community of S1, S2, S3 and S4.

### 3.5 Sampling Sites Algal Genus Pollution Index (AGPI)

A water quality index was calculated for each of the four sampling sites based on algal community composition (Palmer, 1969). The Algal Genus Pollution Index (AGPI) was used to assess the water quality of stagnant water in S1, S2, and S3, as well as flowing water bodies in S4. AGPI scores range from 0-10 (low pollution), 10-15 (moderate pollution), 15-20 (likely high pollution), and 20 or more (high organic pollution). S2, S3, and S4 exhibited an AGPI score of 10, 21, and 21, respectively, suggesting probable high organic pollution, whereas S1 recorded a score of 2, indicating low organic contamination (Table 3). This alarming situation necessitates immediate attention from governing authorities. As Stevenson (2014) emphasised, algal community composition is a crucial indicator for assessing and managing water quality, including nuisance and harmful algal blooms. The identified highly polluted water bodies require urgent and comprehensive investigations to prevent further degradation and restore the health of the aquatic ecosystem. Consistent with Sharma and Sharma (2021), the present study documented the presence of pollution-tolerant algal species, including green algae: *Chlorella* sp., *Spirogyra* sp., *Stigeoclonium* sp. and diatoms: *Navicula* sp., *Nitzschia* sp.

**Table 3.** Pollution index of algal genera according to Palmer (1969) at four sampling sites of Srinagar, Garhwal, Uttarakhand, India

Sr. No.	Microalgae	Sampling sites			
		S 1	S 2	S 3	S 4
1.	<i>Gomphonema</i> sp.	+1	+1	+1	+1
2.	<i>Melosira</i> sp.	-	+1	+1	+1
3.	<i>Navicula</i> sp.	-	+3	+3	-
4.	<i>Nitzschia</i> sp.	-	+3	+3	+3
5.	<i>Chlorella</i> sp.	-	+3	+3	-
6.	<i>Coelastrum</i> sp.	+1	+1	+1	+1
7.	<i>Scenedesmus</i> sp.	-	+4	+4	+4
8.	<i>Oscillatoria</i> sp.	-	+5	+5	-
<b>Total</b>		<b>2</b>	<b>21</b>	<b>21</b>	<b>10</b>

### 4. Conclusions

The present research work was carried out to identify the distribution of microalgae across the freshwater of Madhi Chauras (S1), Bud-Gaon Billkedar (S4), and the stagnant water bodies of Chauras Bridge (S3) and Sri Yantra Tapu (S2) in the Garhwal region, Uttarakhand, India. The desirability of each water body was determined by analysing physical parameters such as pH, turbidity, total dissolved solids, nitrate, magnesium, and calcium. A total of 47 microalgal species were identified across three classes: Bacillariophyceae, Cyanophyceae, and Chlorophyceae. In particular, Bacillariophyceae became the leading class. Further, site-specific dominance of species was observed, revealing clear ecological differences between flowing and stagnant habitats. At Site 1 (Madhi Chauras), species of *Spirogyra* sp. were most abundant throughout the study period, indicating favourable growth conditions in relatively flowing waters. Site 2, being part of the main river channel, supported a broader diversity, with dominance of *Oscillatoria* sp., *Hydrodictyon* sp., *Spirogyra* sp., and various diatom species, reflecting the influence of continuous water movement and nutrient inflow. In contrast, Site 3, a stagnant water body, was characterised by massive growth of *Spirogyra* sp. and *Oscillatoria* sp. along with dense diatom populations,

suggesting that reduced flow and higher nutrient retention favoured bloom-like conditions. At Site 4, *Rhizoctonium* sp. was found dominant, highlighting site-specific ecological niches. Hydrological, physicochemical, and nutrient factors affect the distribution of phytoplankton in the flowing and stagnant habitats. Diversity indices were analyzed using PAST software and CCA was done. Environmental conditions caused a difference in species composition across habitats. AGPI was used to measure the level of pollution in S1-S4 where pollution-tolerant microalgae were used to reflect on the ecological status. The present study offers algal diversity data that can be used in the future.

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### CRedit authorship contribution statement

**Neha Kumari:** Writing - original draft, Conceptualization, Statistical Analysis with PAST software. **Ritika Pandey:** Writing - original draft, Conceptualization, Statistical Analysis with PAST software. **Rahul Goswami:** Writing - review & editing. **Margdarshi Bhatt:** Writing - review & editing. **Gautami Bhatt:** Writing - review & editing. **Pushpendra Singh Rawat:** Writing - original draft, Data curation, Conceptualization, and Formal Analysis. **Prakash Bhuyar:** Writing - review & editing. **Natanamurugaraj Govindan:** Supervision, Validation, Writing - review & editing.

### Conflict of interest

The authors declare that they have no conflicts of interest.

### References

- Angalika, M. W., Suzuki, S., Le-Huynh, T. L., Itayama, T., & Tanaka, W. (2022). Assessing nutrient budget of ungauged catchment using intermittent water quality markers. *Maejo International Journal of Energy and Environmental Communication*, 4(3), 1-10. <https://doi.org/10.54279/mijeec.v4i3.247534>
- Aye, K. L., Itayama, T., Shwe, K. P., Tasaki, K., Hayata, Y., & Tada, A. (2019). Study on dynamic behaviors of water quality and mechanisms of eutrophication in Kandawgyi Lake, Yangon City, Myanmar. *Maejo International Journal of Energy and Environmental Communication*, 1(3), 39-46. <https://doi.org/10.54279/mijeec.v1i3.244929>
- Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters*, 15(4), 365-377. <https://doi.org/10.1111/j.1461-0248.2011.01736.x>
- Bhuyar, P., Farez, F., Ab Rahim, M. H., Pragas Maniam, G., & Govindan, N. (2021). Removal of nitrogen and phosphorus from agro-industrial wastewater by using microalgae collected from coastal region of peninsular Malaysia. *African Journal of Biological Sciences*, 3(1), 58-66.
- Bhuyar, P., Hong, D. D., Mandia, E., Rahim, M. H. A., Maniam, G. P., & Govindan, N. (2019). Desalination of polymer and chemical industrial wastewater by using green photosynthetic microalgae, *Chlorella* sp. *Maejo International Journal of Energy and Environmental Communication*, 1(3), 9-19.

- Bhuyar, P., Trejo, M., Dussadee, N., Unpaprom, Y., Ramaraj, R., & Whangchai, K. (2021). Microalgae cultivation in wastewater effluent from tilapia culture pond for enhanced bioethanol production. *Water Science and Technology*, 84(10-11), 2686-2694.
- Chahal, P., Rana, N., Ray, P. K. C., Bisht, P., Bagri, D. S., Wasson, R. J., & Sundriyal, Y. (2016). Identification of landslide-prone zones in the geomorphically and climatically sensitive Mandakini valley, (central Himalaya), for disaster governance using the Weights of Evidence method. *Geomorphology*, 284, 41–52. <https://doi.org/10.1016/j.geomorph.2016.11.008>
- Davies-Colley, R. J., & Smith, D. G. (2001). Turbidity suspended sediment, and water clarity: A review. *Jawra Journal of the American Water Resources Association*, 37(5), 1085–1101. <https://doi.org/10.1111/j.1752-1688.2001.tb03624.x>
- Desikachary, T.V. (1959). Cyanophyta. ICAR Monograph on Algae, New Delhi, 1-686.
- Dhakar, K., & Pandey, A. (2020). Microbial Ecology from the Himalayan Cryosphere Perspective. *Microorganisms*, 8(2), 257. <https://doi.org/10.3390/microorganisms8020257>
- Fabricius, K. E. (2004). Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin*, 50(2), 125–146. <https://doi.org/10.1016/j.marpolbul.2004.11.028>
- Goswami, G., & Singh, D. (2018). Water quality and function of Mandakini River ecosystem of Central Himalaya. *International Journal of Biosciences*, 12(6), 102-116.
- Gupta, P. K. (2005). *Methods in Environmental Analysis: Water, Soil and Air* (pp. 1-127). Jodhpur: Agrobios.
- Hammer, Øyvind, Harper, David A.T., and Paul D. Ryan, (2001). Past: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica*, vol. 4, issue 1, art. 4: 9pp., 178kb.
- Hangsapreurke, K., & Pratoomchat, B. (2023). Impact of water temperature on the shipping of berried female broodstock (*Macrobrachium rosenbergii*): A study on survival, egg retention, hatching duration, and hatching success rate. *Maejo International Journal of Energy and Environmental Communication*, 5(2), 14-20. <https://doi.org/10.54279/mijeec.v5i2.250742>
- Heinrichs, H., Mourao, Z., Venghaus, S., Konadu, D., Gillissen, B., Vögele, S., Linssen, J., Allwood, J., Kuckshinrichs, W., Robinius, M., & Stolten, D. (2021). Analysing the water and land system impacts of Germany's future energy system. *Renewable and Sustainable Energy Reviews*, 150, 111469. <https://doi.org/10.1016/j.rser.2021.111469>
- Ikram, S. F., Kumar, D., Singh, V., Tripathi, B. N., & Kim, B. H. (2021). Microalgal and cyanobacterial diversity of two selected hot springs of Garhwal Himalaya, Uttarakhand, India. *Fundamental and Applied Limnology*, 195(2), 111-127 <https://doi.org/10.1127/fal/2021/1366>
- Kadam, A. D., Kishore, G., Mishra, D. K., & Arunachalam, K. (2020). Microalgal diversity as an indicator of the state of the environment of water bodies of Doon valley in Western Himalaya, India. *Ecological Indicators*, 112, 106077. <https://doi.org/10.1016/j.ecolind.2020.106077>
- Kale, A., & Karthick, B. (2015). The diatoms. *Resonance*, 20(10), 919–930. <https://doi.org/10.1007/s12045-015-0256-6>
- Kumaran, M., Palanisamy, K. M., Bhuyar, P., Maniam, G. P., Rahim, M. H. A., & Govindan, N. (2023). Agriculture of microalgae *Chlorella vulgaris* for polyunsaturated fatty acids (PUFAs) production employing palm oil mill effluents (POME) for future food, wastewater, and energy nexus. *Energy Nexus*, 9, 100169.
- Margalef, R. (1951) Diversidad de 3 especies en les comunicades Naturales, Publ. Inst. Biol. Apl. Barcelona, 95-27.
- Matharu, M., Jain, R., & Kamboj, S. (2020). Understanding the impact of lifestyle on sustainable consumption behavior: a sharing economy perspective. *Management of Environmental Quality an International Journal*, 32(1), 20–40. <https://doi.org/10.1108/meq-02-2020-0036>
- Nautiyal, P., Badoni, K., Nautiyal, R., Bhatt, J., Kishore, B. (1997). Variations in the epilithic diatom community structure due to river valley projects on the Ganga between Rishikesh and Hardwar. BOOK.
- Nithin, B. R., Bhuyar, P., Trejo, M., Rahim, M. H. A., Maniam, G. P., & Govindan, N. (2020). Culturing of green photosynthetic microalgae (*Chlorella* sp.) using palm oil mill effluent (POME) for future biodiesel production. *Maejo International Journal of Energy and Environmental Communication*, 2(1), 1-8.
- Padisák, J., Crossetti, L. O., & Naselli-Flores, L. (2009). Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. *Hydrobiologia*, 621(1), 1–19. <https://doi.org/10.1007/s10750-008-9645-0>
- Paerl, H. W., & Huisman, J. (2009). Climate change: a catalyst for global expansion of harmful cyanobacterial blooms. *Environmental Microbiology Reports*, 1(1), 27–37. <https://doi.org/10.1111/j.1758-2229.2008.00004.x>
- Palanisamy, K. M., Bhuyar, P., Ab. Rahim, M. H., Govindan, N., & Maniam, G. P. (2023). Cultivation of microalgae *Spirulina platensis* biomass using palm oil mill effluent for phycocyanin productivity and future biomass refinery attributes. *International Journal of Energy Research*, 2023(1), 2257271.
- Palmer, C.M. (1969). Composite rating of algae tolerating organic pollution. *J. Phycol.* 5,78-82. phytoplankton. *Hydrobiologia* 289:43-55
- Pandey, R., Kumari, N., Rawat, P. S., Bhatt, M., Ramisetty, N. B. C., Bhuyar, P., & Govindan, N. (2025). Sustainable treatment of dairy wastewater using a selective microalgal consortium of *Chlorella vulgaris*, *Scenedesmus obliquus*, and *Chlorococcus minutus*. [ph02.tci-thaijo.org. https://doi.org/10.54279/mijeec.v7i1.263554](https://doi.org/10.54279/mijeec.v7i1.263554)
- Patang, F., Soegianto, A., & Hariyanto, S. (2018). Benthic macroinvertebrates diversity as bioindicator of water quality of some rivers in East Kalimantan, Indonesia. *International Journal of Ecology*, 2018, 1–11. <https://doi.org/10.1155/2018/5129421>
- Pielou, E. (1966). Species-diversity and pattern-diversity in the study of ecological succession. *Journal of Theoretical Biology*, 10(2), 370–383. [https://doi.org/10.1016/0022-5193\(66\)90133-0](https://doi.org/10.1016/0022-5193(66)90133-0)
- Pimpimol, T., Tongmee, B., Lomlai, P., Prasongpol, P., Whangchai, N., Unpaprom, Y., & Ramaraj, R. (2020). Spirogyra cultured in fishpond wastewater for biomass generation. *Maejo International Journal of Energy and Environmental Communication*, 2(3), 58-65. <https://doi.org/10.54279/mijeec.v2i3.245041>
- Puri, A., & Kumar, M. (2012). A review of permissible limits of drinking water. *Indian Journal of Occupational and Environmental Medicine*, 16(1), 40. <https://doi.org/10.4103/0019-5278.99696>
- Ramaraj, R., Tsai, D. D. W., & Chen, P. H. (2014a). An exploration of the relationships between microalgae biomass growth and related environmental variables. *Journal of Photochemistry and Photobiology B: Biology*, 135, 44-47. <https://doi.org/10.1016/j.jphotobiol.2014.04.001>
- Ramaraj, R., Tsai, D. D. W., & Chen, P. H. (2014b). Freshwater microalgae niche of air carbon dioxide mitigation. *Ecological*

- engineering, 68, 47-52. <https://doi.org/10.1016/j.ecoleng.2014.03.058>
- Ramaraj, R., Tsai, D. D. W., & Chen, P. H. (2015a). Biomass of algae growth on natural water medium. *Journal of Photochemistry and Photobiology B: Biology*, 142, 124-128. <https://doi.org/10.1016/j.jphotobiol.2014.12.007>
- Ramaraj, R., Tsai, D. D. W., & Chen, P. H. (2015b). Carbon dioxide fixation of freshwater microalgae growth on natural water medium. *Ecological Engineering*, 75, 86-92. <https://doi.org/10.1016/j.ecoleng.2014.11.033>
- Rawat, M., Arunachalam, K., Arunachalam, A., Alatalo, J. M., Kumar, U., Simon, B., Hufnagel, L., Micheli, E., & Pandey, R. (2020). Relative contribution of plant traits and soil properties to the functioning of a temperate forest ecosystem in the Indian Himalayas. *CATENA*, 194, 104671. <https://doi.org/10.1016/j.catena.2020.104671>
- Reynolds, C. S. (2006). The ecology of phytoplankton. In Cambridge University Press eBooks. <https://doi.org/10.1017/cbo9780511542145>
- Round, F.E., Crawford, R.M. and Mann, D.G. (1990) *The Diatoms. Biology and Morphology of the Genera*. Cambridge University Press, Cambridge, 747 pp.
- Seth, R., Mohan, M., Singh, P., Singh, R., Dobhal, R., Singh, K. P., & Gupta, S. (2016). Water quality evaluation of Himalayan Rivers of Kumaun region, Uttarakhand, India. *Applied Water Science*, 6(2), 137–147. <https://doi.org/10.1007/s13201-014-0213-7>
- Shannon, C. E., & Weaver, W. (1949). *The Mathematical Theory of Communication*. Urbana, IL: The University of Illinois Press, 1-117.
- Sharma, B. K., & Sharma, S. (2021). Phytoplankton diversity of a de-mineralized subtropical reservoir of Meghalaya state, northeast India. *Aquatic Research*, 4(3), 233-249. <https://doi.org/10.3153/ar21018>
- Simpson, E. H. (1949). Measurement of diversity. *Nature*, 163(4148), 688. <https://doi.org/10.1038/163688a0>
- Stevenson, K. T., Peterson, M. N., Bondell, H. D., Moore, S. E., & Carrier, S. J. (2014). Overcoming skepticism with education: interacting influences of worldview and climate change knowledge on perceived climate change risk among adolescents. *Climatic Change*, 126(3–4), 293–304. <https://doi.org/10.1007/s10584-014-1228-7>
- Tongsiri, S., Bhat, O. A., Ramaraj, R., & Pimpimol, T. (2023). Harnessing aquaculture wastewater with *Chlorella protothecoides* for biodiesel and bioethanol production. *Maejo International Journal of Energy and Environmental Communication*, 5(2), 21-28. <https://doi.org/10.54279/mijeec.v5i2.250790>
- Tsai, D. D. W., Chen, P. H., & Ramaraj, R. (2017). The potential of carbon dioxide capture and sequestration with algae. <https://doi.org/10.1016/j.ecoleng.2016.10.049>
- Tsai, D. D. W., Chen, P. H., Chou, C. M. J., Hsu, C. F., & Ramaraj, R. (2015). Carbon sequestration by alga ecosystems. *Ecological Engineering*, 84, 386-389. <https://doi.org/10.1016/j.ecoleng.2015.09.024>
- Tsai, D. D. W., Ramaraj, R., & Chen, P. H. (2012). Growth condition study of algae function in ecosystem for CO<sub>2</sub> bio-fixation. *Journal of Photochemistry and Photobiology B: Biology*, 107, 27-34. <https://doi.org/10.1016/j.jphotobiol.2011.11.005>
- Tsai, D. D., Ramaraj, R., Unpaprom, Y., Bhuyar, P., Ramaraj, R., & Chen, P. H. (2023). Autotrophic production of bio-functional proteins from freshwater microalgae using natural water medium for an economical and ecofriendly approach. *Maejo International Journal of Energy and Environmental Communication*, 5(2), 29-34.
- Wetzel, R. G., & Likens, G. E. (2000). *Limnological analyses*. <https://doi.org/10.1007/978-1-4757-3250-4>
- Whangchai, N., Chitmanat, C., Ramaraj, R., & Itayama, T. (2018). Effects of water flow rate and water quality on tilapia culture in the Mae Ping River, Thailand. *Chiang Mai Journal of Science*, 45(3), 1318-1322.
- Yadav, S. C. (2024). Water pollution: the problems and solutions. *Science Insights*, 44(2), 1245–1251. <https://doi.org/10.15354/si.24.re905>
- Yang, Z., Su, Q., Chen, H., & Yang, G. (2021). Anthropogenic impacts recorded by a 200-year peat profile from the Zoige Peatland, northeastern Qinghai-Tibetan Plateau. *CATENA*, 206, 105463. <https://doi.org/10.1016/j.catena.2021.105463>
- Zhou, S., Li, W., & He, S. (2023). Microalgal diversity enhances water purification efficiency in experimental microcosms. *Frontiers in Ecology and Evolution*, 11. <https://doi.org/10.3389/fevo.2023.1125743>