A COMPREHENSIVE STUDY OF ASSESSING WATER QUALITY AND PHYTOPLANKTON COMMUNITIES IN THE RIVER RAVI (INDIA)

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ABSTRACT

Due to anthropogenic activities, the water quality of freshwater bodies is rapidly decreasing. The aim of this study was to assess the water quality and phytoplankton diversity in the upper Ravi River basin between September 2022 and August 2023. Overall, the water quality was within the allowable limits, but in sampling zone 3, there was a deteriorating trend in certain physicochemical parameters, including turbidity, dissolved oxygen, and biological oxygen demand during monsoon months. Bacillariophyceae (11 genera) was the most dominant group followed by Chlorophyceae (8 genera). A total of 23 different genera of phytoplankton were observed. It can be concluded that human activities, such as mining in riverbeds, and the construction of dams and barrages, have a direct impact on water quality and phytoplankton diversity. These activities need to be monitored on a regular basis.

RÉSUMÉ: Étude approfondie de l’évaluation de la qualité de l’eau et des communautés de phytoplancton dans la rivière Ravi (Inde).

En raison des activités anthropiques, la qualité de l’eau des masses d’eau douce diminue rapidement. L’objectif des recherches actuelles était d’évaluer la qualité de l’eau et la diversité du phytoplancton dans le bassin supérieur du fleuve Ravi, entre septembre 2022 et août 2023. Dans l’ensemble, la qualité de l’eau était dans la limite autorisée, mais dans la zone d’échantillonnage 3, il y avait une tendance à la détérioration. Certaines mesures physico-chimiques, notamment la turbidité, l’oxygène dissous et la demande biologique en oxygène pendant les mois de mousson. Les Bacillariophyceae (11 genres) constituaient le groupe le plus dominant, suivi des Chlorophyceae (8 genres). Au total, 23 genres différents de phytoplancton ont été observés. On peut conclure que les activités humaines, telles que l’exploitation minière des lits des rivières, la construction de digues et de barrages, ont un impact direct sur la qualité de l’eau et la diversité du phytoplancton. Ces activités doivent être surveillées régulièrement.

REZUMAT: Un studiu comprehensiv de evaluare a calității apei și a comunităților de fitoplancton din râul Ravi (India).

Datorită activităților antropice, calitatea apei din corpurile de apă dulce scade rapid. Scopul cercetării actuale a fost acela de a evalua calitatea apei și diversitatea fitoplanctonului în bazinul superior al râului Ravi, în perioada septembrie 2022 – august 2023. În general, calitatea apei a fost în limitele admise, dar în zona de prelevare 3 a existat o tendință de deteriorare a anumitor parametri fizico-chimici, inclusiv turbiditatea, oxigenul dizolvat și cererea biologică de oxigen în lunile cu muson. Bacillariophyceae (11 genuri) a fost grupul dominant, urmat de Chlorophyceae (8 genuri). Au fost observate un total de 23 de genuri diferite de fitoplancton. Se poate concluziona că activitățile umane, cum ar fi mineritul în albiile râurilor și construcția de baraje, au un impact direct asupra calității apei și diversității fitoplanctonului. Aceste activități trebuie monitorizate în mod regulat.

INTRODUCTION

Freshwater ecosystems offer essential services to humans, including the generation of nutritional resources, the purification of water, recreational opportunities, and on a more global scale, the management of climate (Oberdorff, 2022). Rivers are the most dynamic natural water resource and an integral component of the freshwater environment, and rivers support a wide range of development-related activities (Antonelli et al., 2024; Vári et al. 2022; Boretti and Rosa, 2019), this is the situation in India too (Rumana et al., 2015; Jeeva et al., 2011)

Phytoplankton is considered a bioindicator because of its brief life cycle and rapid reaction to alterations in water quality, particularly in river ecosystems (Zhang et al., 2021).

Moreover, the presence of manufacturing, farming, and anthropic operations near the river inevitably leads to alterations in the quality of water (Cahyonugroho et al., 2022). In addition to removing nitrogen and ammonia from the water for growth, phytoplankton also plays a significant role in reducing the amounts of potentially harmful metabolites (Dembowska, 2021). Microorganisms, unicellular organisms, and phytoplankton generate their food photoautotrophically in aquatic environments. The overall nutrient cycles of any freshwater ecosystem depend on phytoplankton (Mitra and Leles, 2023; Kumar et al., 2023).

Plankton are sensitive to changes and disturbances that occur in their surrounding environment and quickly react to any disruption created (Chandel et al. 2023; Mishra et al. 2021; Bilous et al., 2013). They support the food net by acting as the primary food source in the freshwater. According to Zhang et al. (2021), water quality characteristics play a crucial role in controlling the distribution of phytoplankton in freshwater ecosystems. Yang et al. (2021) assert that rivers are of the highest importance among all the natural resources present on planet Earth. Water quality changes may have an effect on the distribution and life cycle of aquatic organisms (Sharma et al., 2023; Slathia et al., 2023). Freshwater ecosystems are now among the most globally sensitive habitats due to the cumulative escalation in anthropogenic activities (Chandel et al., 2024; Choudhary et al., 2023; Albert et al., 2021; Sharma et al., 2018). When a number of water quality indicators are studied, it can be problematic to understand the results, especially when different anthropogenic stressors have an impact on the exact parameters and can mimic water quality across different categories (Brar et al., 2023; Hassan, 2020). The distribution and abundance of phytoplankton is severely impacted by the changes and instability in freshwater ecosystems. The distribution, quantity, richness, and makeup of the freshwater community are all directly influenced by cyclical variations in water quality (Sharma et al., 2024; Kumari et al., 2023; Majhi et al., 2023).

The water quality characteristics and phytoplankton of bodies of freshwater are linked and impacted by the variation in land use (Sharma et al., 2019; Singh et al., 2013). According to Malik et al. (2020a, b), nutrient dynamics also significantly influence the diversity of phytoplankton species. Damaging techniques for sand mining, dam building, and barrage construction have been shown to potentially affect aquatic ecosystems and pose a serious threat (Sharma et al., 2024; Sharma et al., 2018).

This study's goal was to assess the status of the water quality and phytoplankton diversity of the Ravi River using diverse environmental techniques to evaluate how anthropogenic activities, the building of dams and barrages, and other developments affected the quality of water and its ability to nurture freshwater organisms. Monitoring the water quality and gathering information about phytoplankton biology indices that may be used as bioindicators of the condition and contamination of the Ravi River had not been conducted until now. This study will give the baseline information regarding water quality in relation to phytoplankton diversity of the upper Ravi River basin.

MATERIAL AND METHODS

Background

The Ravi River flows through two states (Himachal Pradesh and Punjab) and one union territory of India (Jammu and Kashmir). The Ravi River originates in Himachal Pradesh, in the Bara Bhangal District of Kangra. There are four major tributaries of the Ravi River in Himachal Pradesh, namely Budhil, Baira, Siul, and Sewa rivers (Sharma, 2019). It flows for about 180 kilometers in Himachal Pradesh before entering Punjab, where it runs another 720 kilometers before draining a catchment of 14,441 km^2 in India. It forms a triangle with the Pir Panjal and Dhauladhar hills on either side as it flows westward. Four sampling zones were selected based on different geomorphology along the catchment area of the upper Ravi River in Himachal Pradesh (Tab. 1; Fig. 1).

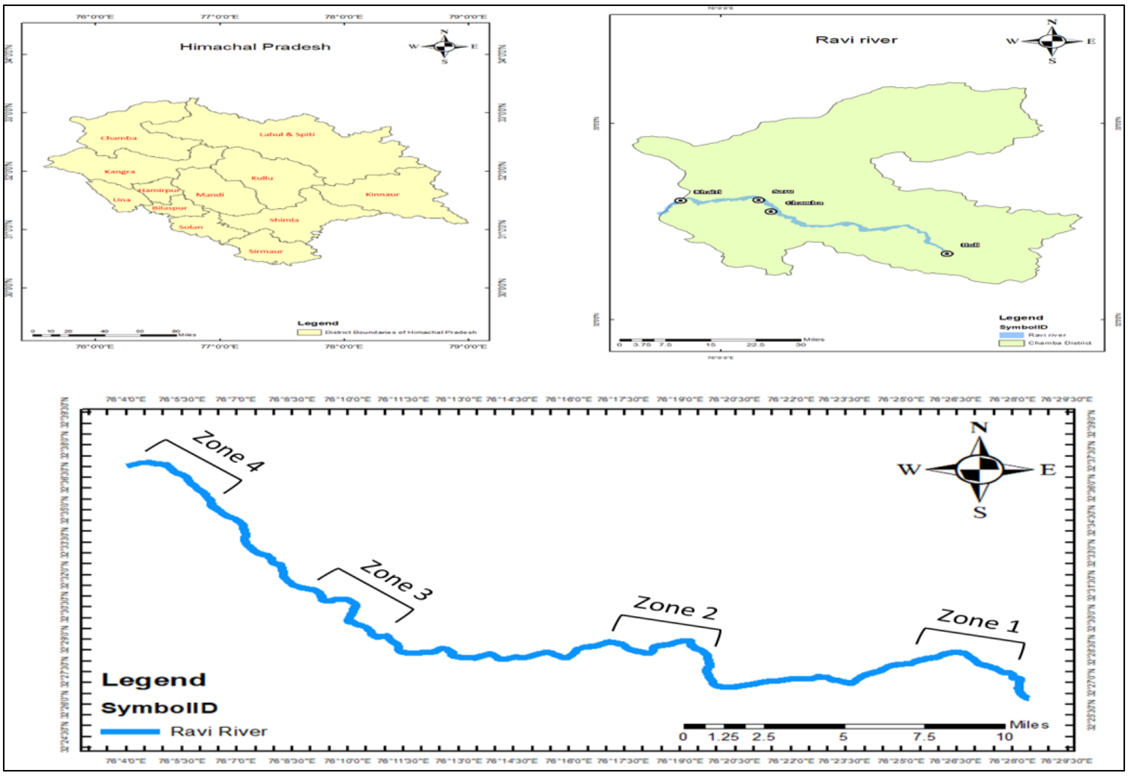

Figure 1: ArcGIS map showing selected study zones.

Table 1: Sampling zones along with their respective Geocoordinates

Sampling Zone	Name	Geo-Coordinates		Altitude	Reason for site selection
		Longitude	Latitude		
Zone 1	Holi	76.5503°E	32.3307°N	1,810 m	Having negligible anthropogenic impact
Zone 2	Chamba	76.1258°E	32.5534°N	1,006 m	Having considerable anthropogenic impact
Zone 3	Saru	76.0813°E	32.6038°N	489 m	River bed mining area
Zone 4	Khairi	75.9100°E	32.6066°N	475 m	Final zone after which river enters J&K UT.

Samples collection

Monthly sampling was conducted in selected zones of the study area from September 2022 to August 2023. Every month, the sampling procedure occurred over two days, with sampling from two different locations conducted simultaneously on one of these days. Sampling took place from six to nine o'clock in the morning. Materials used included bottles for sampling, pipettes, reagents, glassware, thermometers, pH meters, plankton nets, buckets, forceps, formaldehyde, and containers (Tab. 2). Some of the physicochemical characteristics that influence water quality were analyzed by using standard practical methodologies (Sharma et al., 2022; APHA, 2012; Goel and Trivedi, 1984)

Phytoplankton collection, identification and statistical analysis

One hundred liters of sampled water were filtered through a plankton net, and five percent formalin was applied to these samples that were obtained. After allowing the samples to settle for a twenty-four hours period, one millimeter of concentrated solution was moved across the glass slide both horizontally and vertically for counting. Additional concentration was added to the Sedgwick Rafter counting cell after the sample was introduced.

Slides were prepared using the concentrated sample. These slides were examined using a digital microscope, and identification was carried out. Phytoplankton was identified according to Needham and Needham (1962).

Canonical Correspondence Analysis (CCA) was performed using Paleontological Statistics (PAST, Version 4.03) software to determine the relationship between dominant phytoplankton species and water quality parameters.

Diversity indices

A quantitative metric that shows the number of distinct types (such as species) present in a dataset (a community) is referred to as a diversity index (Supriatna, 2018). The calculation of diversity indices is crucial in determining the health of aquatic ecosystems. These indices assist in the evaluation of water quality through the precise depiction of variations in phytoplankton structure and nutrient concentrations (Cai et al., 2022).

Shannon Index

$$\text{Shannon Index (H)} = -\sum_{i=1}^{s} p_i \, 1n \, p_i$$

In this formula, p represents the comparison between the number of individuals of a certain species found (n) and the overall number of individuals found (N). The natural log, denoted as ln, represents the sum of the calculations, and the number of species, denoted as s, represents the total number of individuals found.

Table 2: Instruments used, methodology, and studied parameters.

Station number	Parameter	Instrument	Method
1.	Water temperature (°C)	Digital thermometer (Digital TP101).	The physicochemical characteristics that influence water quality were analyzed by using standard methodologies (APHA, 2012) and (Goel and Trivedi, 1984)
2.	pH	pH meter (eco Testr)	
3.	Total dissolved solids (mg/L)	TDS meter (eco Testr)	
4.	Conductivity (μS/cm^2)	Conductivity meter (Cyber Scan PCD 650)	
5.	Dissolved oxygen (mg/L)	DO kit (Cyber Scan PCD 650)	
6.	Biological oxygen demand (mg/L)	Winkler's method	
7.	Turbidity (NTU)	Tube method	
8.	Nitrate (mg/L)	Spectrophotometry	
9.	Phosphorous	Spectrophotometry	
10.	Sulphate	Turbidimetric method	
11.	Calcium, and magnesium	Titration method/Flame photometry	
12.	Phytoplankton analysis	Plankton net, Sedgwick rafter scale and digital microscope (Magnus CH20iLED) with camera (Magnus Magcam DC Plus 10)	Phytoplankton were identified according to Needham and Needham (1962)
13.	Statistical analysis	Using computer software correlation between water quality parameters and phytoplankton was calculated	Canonical Correspondence Analysis (CCA) was performed using Paleontological Statistics (PAST, Version 4.03) Software

Simpson Index

$$\text{Simpson Index (D)} = \frac{1}{\sum_{i=1}^{s} p_i^2}$$

The Simpson index, denoted as D, represents the proportion of individuals belonging to a specific species that were discovered (n/N) divided by the overall number of individuals discovered (N). Additionally, Σ represents the sum of the calculations, and s represents the total number of species present.

Evenness Index

$$\text{Species Eveness Index} = \frac{\text{SDI}}{\max(\text{SDI})} = -\sum_{i}^{m}(p_i \, * 1n(p_i\,))/1n(m)$$

In order to offer information on the composition and richness of an area, the Species Evenness Index (SEI) should be used. The number of distinct land cover types (m) recorded along the straight line, as well as the relative abundances of those land cover types (Pi), are considered in this calculation. To determine it, the Shannon diversity index is divided by its maximum value, denoted by the symbol h (m). This means that it can range anywhere from 0 to 1, and it is not overly complicated to understand.

RESULTS AND DISCUSSION

Physiochemical parameters

The evaluation of the water quality, as well as the restoration of habitat ecology, is significantly aided by the regular monitoring of physicochemical water quality parameters (Sharma et al., 2022; Rahman et al., 2021). The outcomes of the physical and chemical indicators that were measured at the chosen sampling sites in Ravi River are as follows.

The mean variation in water temperature ranged from 14.6°C in zone 1 to 16.5°C in zone 3 (Fig. 2). A similar trend of water temperature was observed in the Beas River in Himachal Pradesh (Kumar et al., 2015).

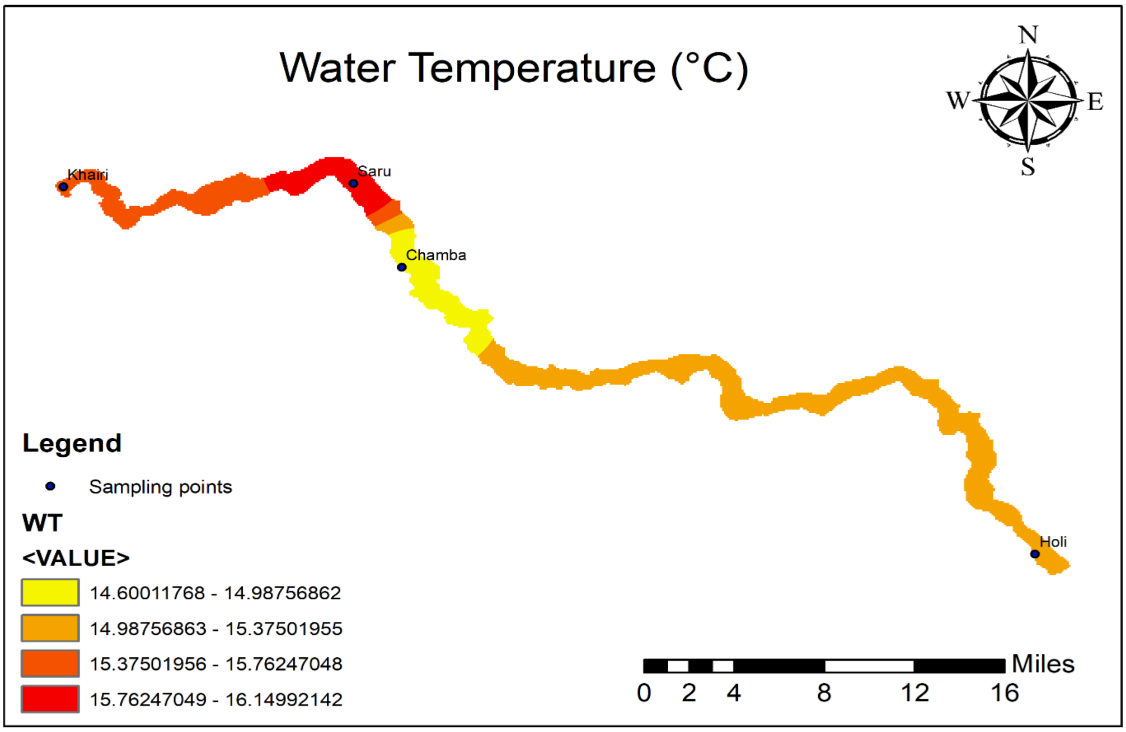

Figure 2: Mean variation of water temperature in selected sampling zones of river Ravi.

In this research, the mean value in total dissolved solids (TDS) ranged between 129.57 mg/L in zone 1 to 133.68 mg/L in zone 3 (Fig. 3). These values are within the permissible limit in all four studied zones. TDS values were within a similar range in the Ganga River (Malik et al., 2021). Lower TDS in Ravi River might be attributed to lower BOD, less silt, and reduced nutrient concentration. Only magnesium was present in higher amounts.

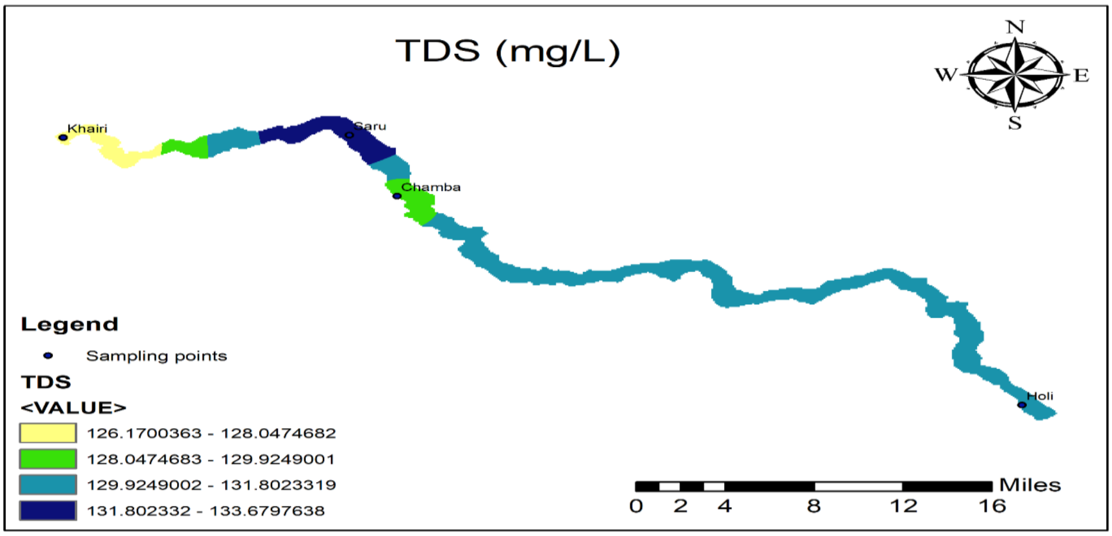

Figure 3: Mean variation of TDS
in selected sampling zones of river Ravi.

Together with the rise in TDS up to a certain level, there is an increase in biomass, growth rate, phytoplankton count, and chlorophyll-a (Chapman and McPherson, 2016).

The mean values of electrical conductivity (EC) ranged from 207.31 µmhos/cm^2 to 213.88 µS/cm^2. Electrical conductivity was found to be 217.83 ± 137.56 µS/cm^2 in the Beas River (Sharma et al., 2018; Sharma and Kumar, 2016). TDS = k EC (in 25°C) is a basic equation that typically shows the relation between these two variables. The pH readings in the upper Ravi River were within the permissible range, which is between 6.5 and 8.5, and varied from 7.33 to 7.63. In the third sampling zone, the pH was measured and found to have the lowest mean, a value of 7.33 (Fig. 4). The alkaline quality of the water in the lower reaches of the Ravi River has also been documented by Mahmood et al. (2000) in Pakistan and by Kumar and Dua (2010) in Madhopur (Punjab, India).

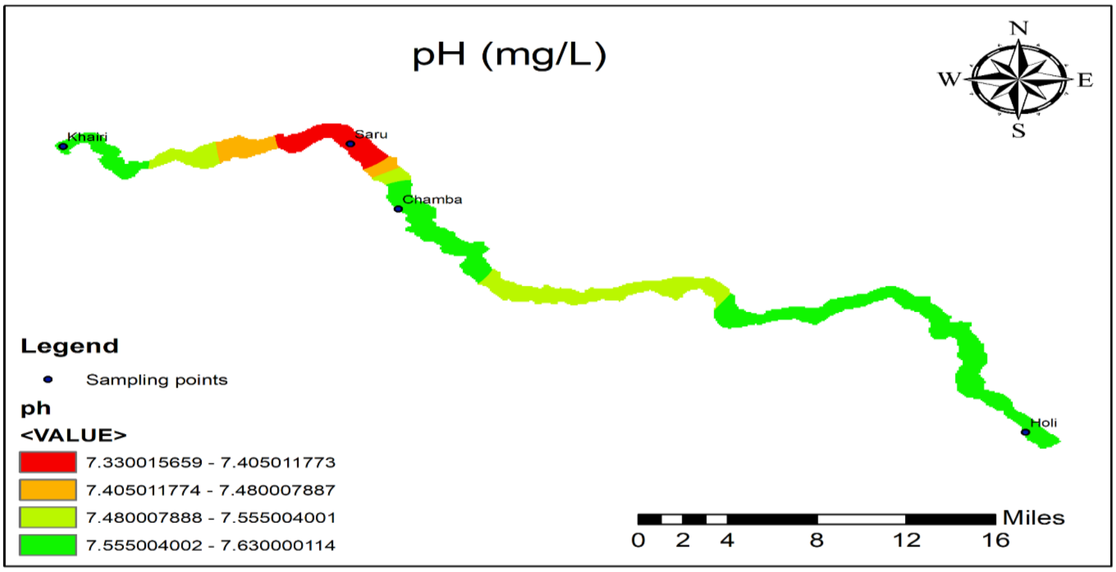

Figure 4: Mean variation of pH
in selected sampling zones of river Ravi.

Turbidity ranged between 60.5 NTU and 200.0 NTU over the course of the current investigation, with the highest turbidity reported in zone 3 (Fig. 5). All of the sampling zones experienced turbidity levels exceeding the standard limit of 5 NTU, as per FMEnv (2011). The highest turbidity values were observed during the monsoon season. Similarly, Kamboj et al. (2020) reported a similar trend in the Ganga. Tyler et al. (2022) found that excessive turbidity directly impacts organisms living in aquatic environments. However, levels of turbidity in rivers do not significantly affect plankton populations, particularly when the turbidity results from natural sources, such as particle resuspension from riverbeds or changes in water flow (Neun et al., 2022).

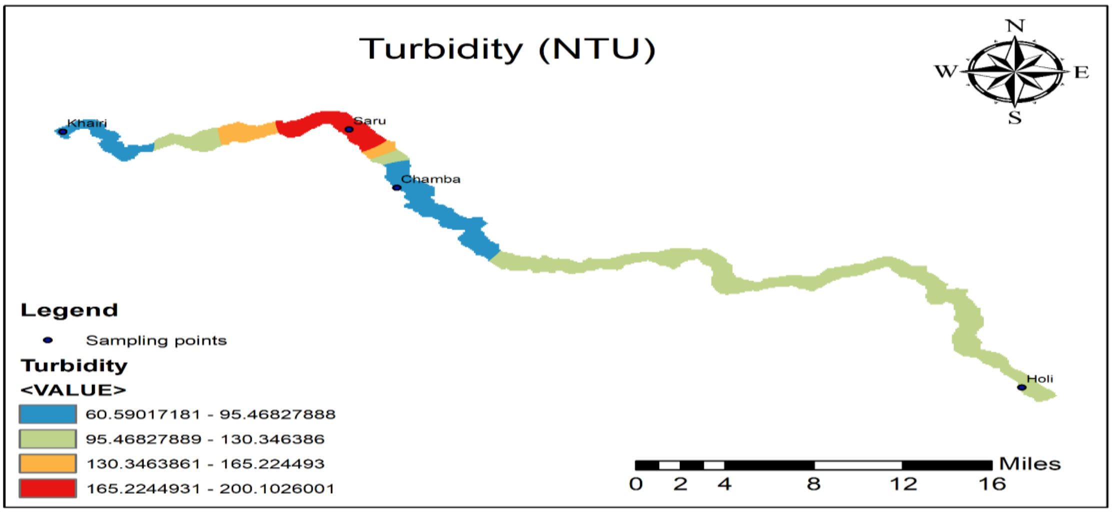

Figure 5: Mean variation of turbidity
in selected sampling zones of river Ravi.

Sharma et al. (2019) revealed that a dissolved oxygen (DO) content of more than 5 mg/L is essential for maintaining the freshwater ecosystem, supporting a diverse aquatic community, and enhancing fish production. According to Hanjaniamin et al. (2023), DO stratification can occur when turbidity levels are higher. In the selected sampling zones of river Ravi, the DO ranged from 7.27 to 8.13 mg/L (Fig. 6).

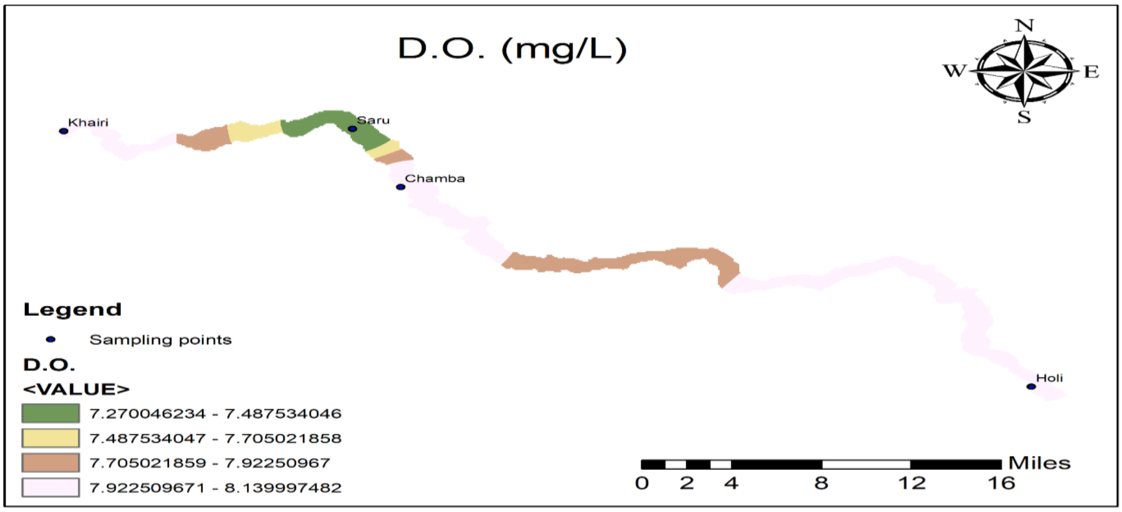

Figure 6: Mean variation of DO
in selected sampling zones of river Ravi.

All mean DO values were within the permissible limit set by FMEnv. (2011), which is greater than 5 mg/L. The concentration of dissolved oxygen in river water is influenced not only by natural areation but also by photosynthetic activity from phytoplankton and water temperature (Ni'am et al., 2022). On the other hand, the biological oxygen demand (BOD) ranged from 1.50 to 2.01 mg/L, below the acceptable limit of 3 mg/L. Sampling zone 3 had higher BOD levels compared to zones 1, 2, and 4 (Fig. 7). BOD is an indicator of organic pollutants in the river (Giri et al., 2022). Lower BOD levels suggest fewer organic pollutants and better water quality, indicating less contamination from sources such as domestic, agricultural, and commercial waste (Chapra et al., 2021). Meanwhile, the mean value of free carbon dioxide (FCO_2) was 2.36 mg/L in zone 1 and 2.58 mg/L in zones 3 and 4. A similar trend was observed in the Ganga River by Kamboj et al. (2020).

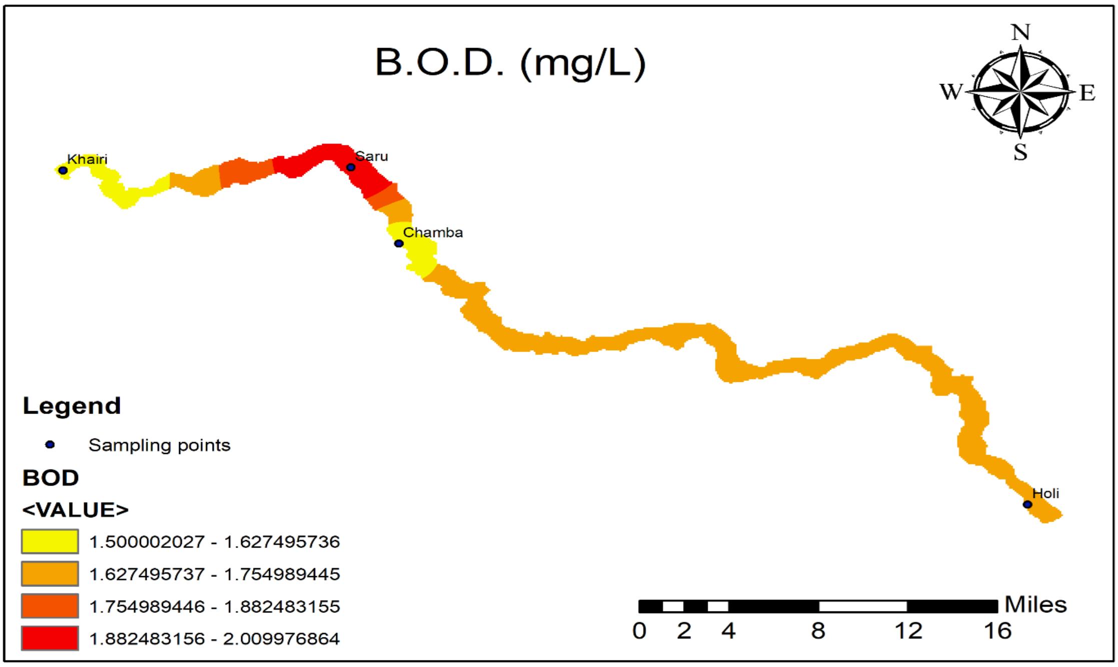

Figure 7: Mean variation of BOD
in selected sampling zones of river Ravi.

Calcium levels were within permissible limits in all sampling zones, ranging from 12.19 mg/L to 20.18 mg/L with sampling zone 3 having substantially higher levels than the others (Fig. 8). Magnesium levels at all sampling stations were also adequate, with mean magnesium levels ranging from 52.5 mg/L in zone 1 to 71 mg/L in zone 3 (Fig. 9). In the Jehlum River, calcium and magnesium values ranging from 23-45 mg/L and 4-22 mg/L were reported by Mir et al. (2016). Possible sources of calcium and magnesium in river water include geological formations, soil types, vegetation, local environmental conditions, and anthropogenic factors such as agricultural and municipal effluent (Katutis and Rudzianskaitė, 2015).

The existence, growth, and survival of phytoplankton depend on calcium and magnesium. Magnesium is necessary for chlorophyll synthesis, which enables effective photosynthesis and the creation of organic material that support marine environments, and calcium helps to maintain the rigidity of their cell walls (Ahmed et al., 2023; Kumar et al., 2019).

Phosphorous concentrations varied from 0.12 mg/L in sampling zone 1 to 0.44 mg/L in sampling zone 3 (Fig. 10), with the maximum value still within the permissible limit. Various amounts of phosphorous serve as an indicator of nutrient concentrations and eutrophication in the freshwater ecosystem (Akinnawo, 2023; Kamboj and Kamboj, 2020; Kumar et al., 2018). Phosphorus is essential for phytoplankton as it is a key component in nucleic acids, phospholipids, and adenosine triphosphate (ATP), which are vital for cellular functions such as growth and reproduction. Excessive phosphorus can lead to eutrophication, a phenomenon where excessive growth of algae reduces oxygen levels in water, resulting in detrimental effects on aquatic ecosystems (Lovio-Fragoso et al., 2021; Kumar et al., 2018). Mean sulphate concentrations were well within the permissible limits in the River Ravi, ranging from 0.2 mg/L in zones 1 to 0.49 mg/L in zone 3 (Fig. 11).

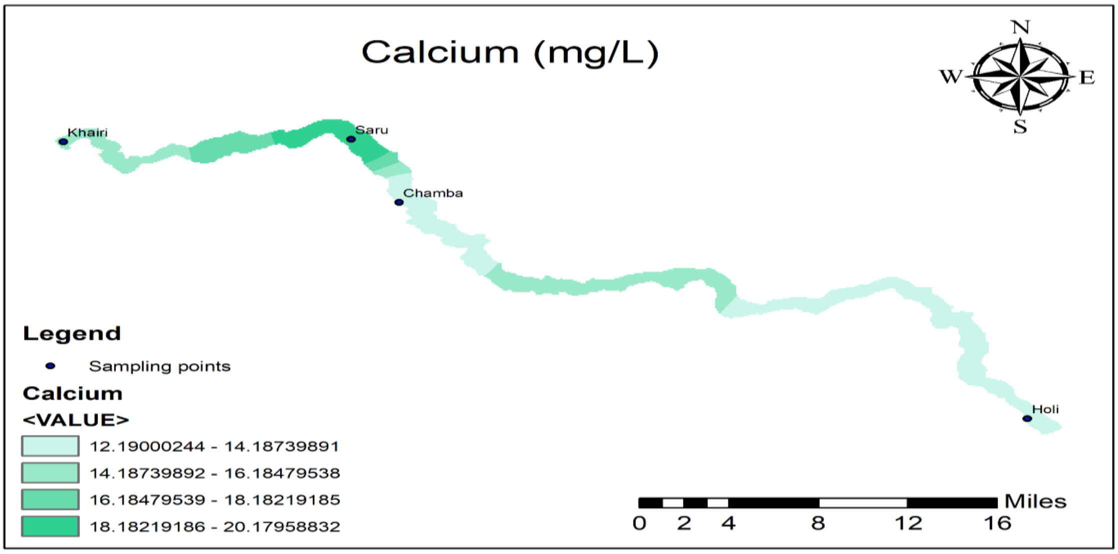

Figure 8: Mean variation of calcium
in selected sampling zones of river Ravi.

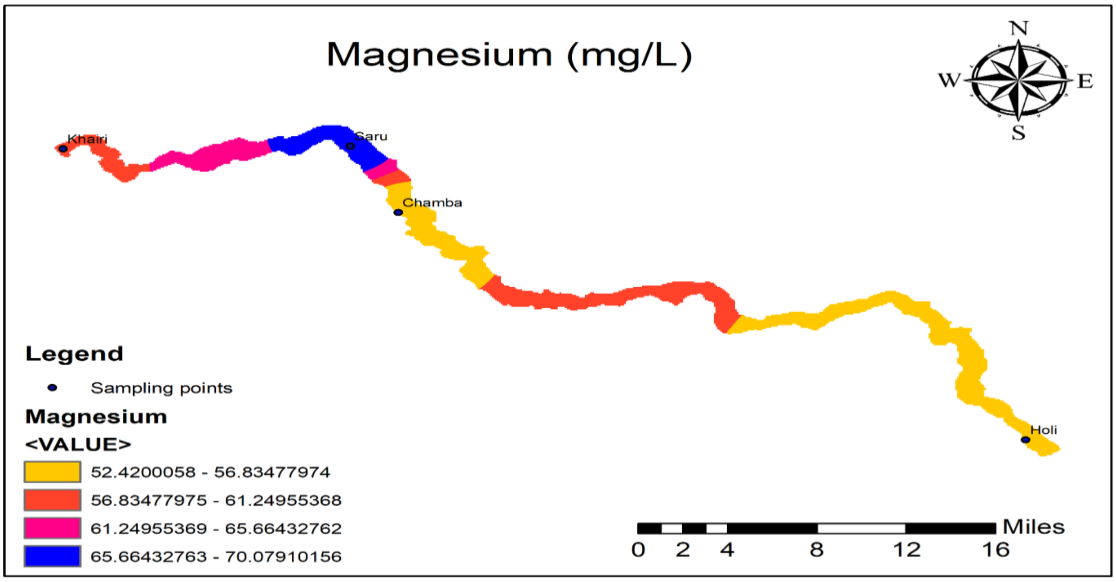

Figure 9: Mean variation of magnesium
in selected sampling zones of river Ravi.

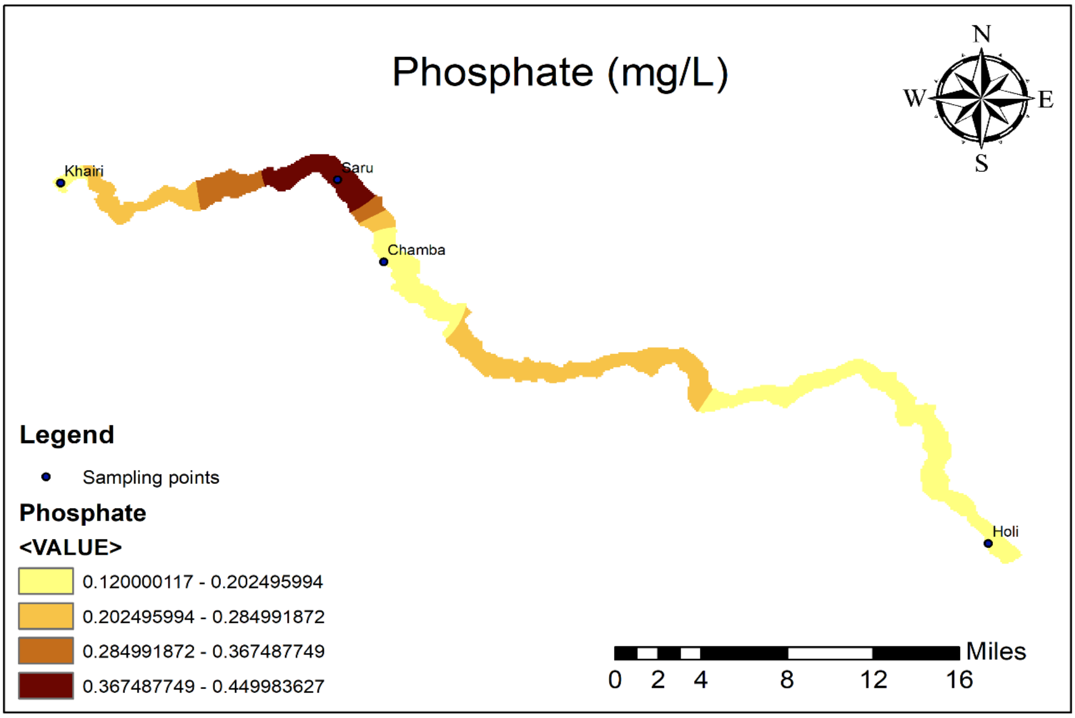

Figure 10: Mean variation of phosphorus
in selected sampling zones of river Ravi.

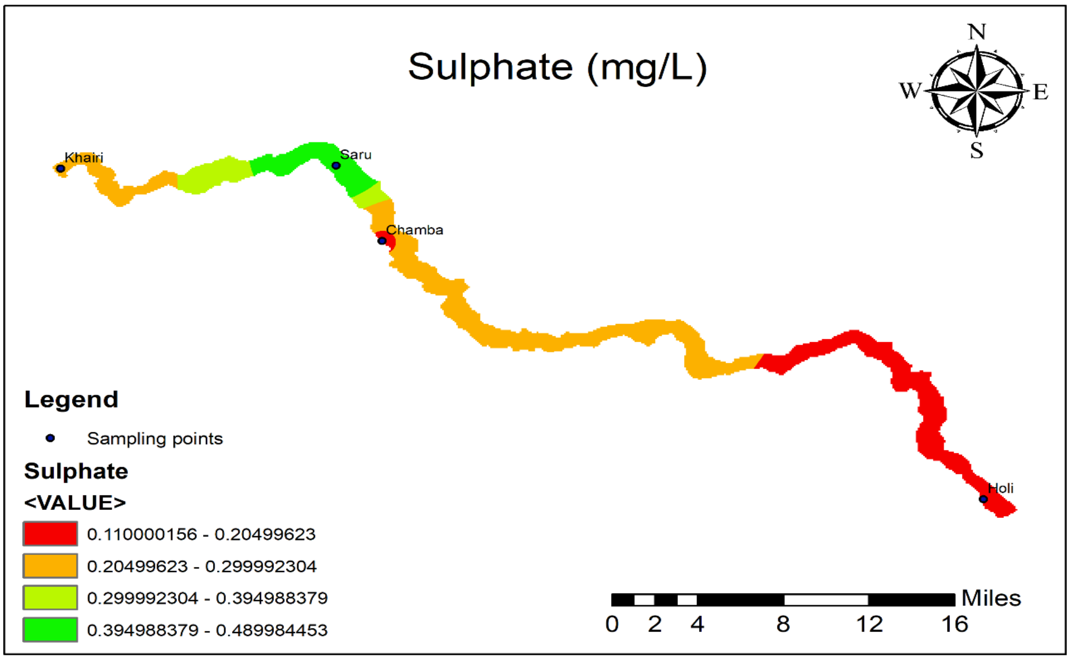

Figure 11: Mean variation of sulfur
in selected sampling zones of river Ravi.

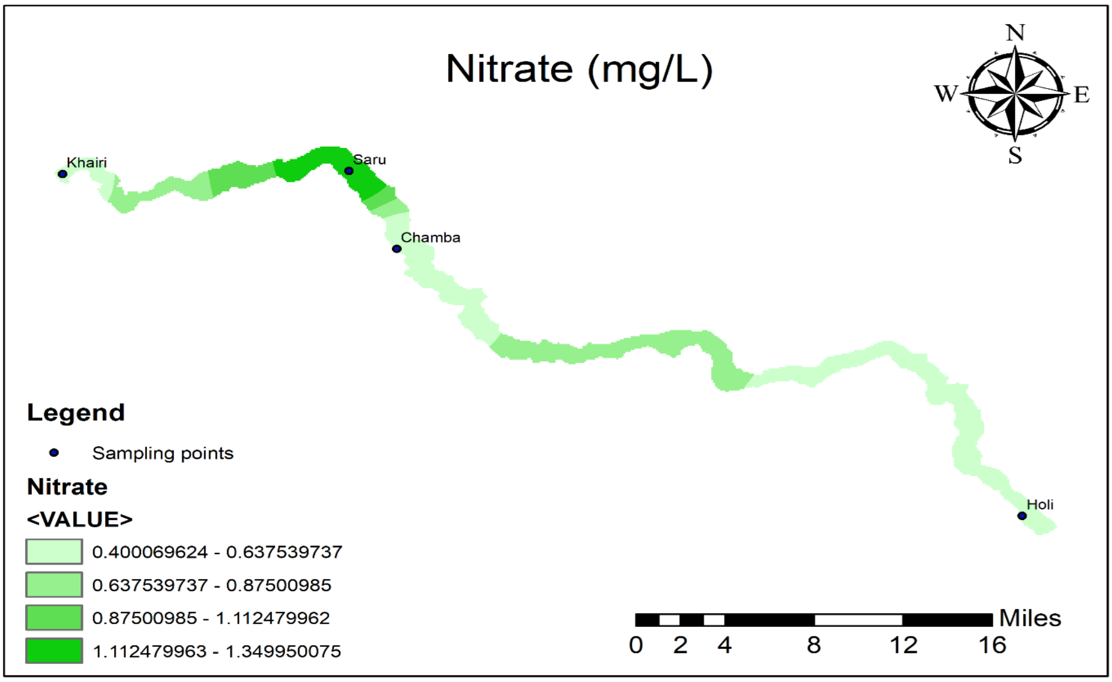

Figure 12: Mean variation of nitrate
in selected sampling zones of river Ravi.

Sampling zone 3, exhibited significantly higher levels compared to the other sampling stations. Although the investigation found low ionic concentrations, they remained within acceptable limits. The low ionic levels might be attributed to the region's geomorphology and rock composition, a trend similarly observed in the Bhagirathi River (Sharma et al., 2020). Nitrates have a vital role in promoting phytoplankton growth by serving as a primary source of nutrients. They significantly ifluence the metabolism and enzyme activity of phytoplankton, particularly nitrate reductase, which is essential for their survival and the production of blooms (Kumar et al., 2023; Rahav et al., 2020). Additionally, nutrients like nitrogen and phosphorus are vital for supporting plankton growth, especially during the winter season (Damseth et al., 2024; Malik et al. 2018; Thakur et al. 2013).

Biotic parameters

Phytoplankton generate sugars by utilising sunlight, carbon dioxide, and the nutrients from water, which fuel the food web in estuaries ecosystems. The abundance of growing phytoplankton is crucial as they serve as a source of nutrition for aquatic organisms such as zooplankton and fish (Parker and Lehman, 2021). Phytoplankton, due to their short life span and sensitivity to changing water quality, serve as an indicator of water quality (Dembowska, 2021), particularly in river ecosystems. In the Ravi River in Himachal Pradesh, the phytoplankton community is comprised of five main groups: Xanthophyceae, Euglenophyceae, Myxophyceae, Chlorophyceae, and Bacillariophyceae. A total of 23 phytoplankton genera were recorded across different zones during the research (Fig. 17). Bacillariophyceae (Fig. 13) was the most dominant in all sampling zones, followed by Chlorophyceae (Fig. 14), Myxophyceae (Fig. 15), Euglenophyceae (Fig. 16), and Xanthophyceae, which was the least dominant group.

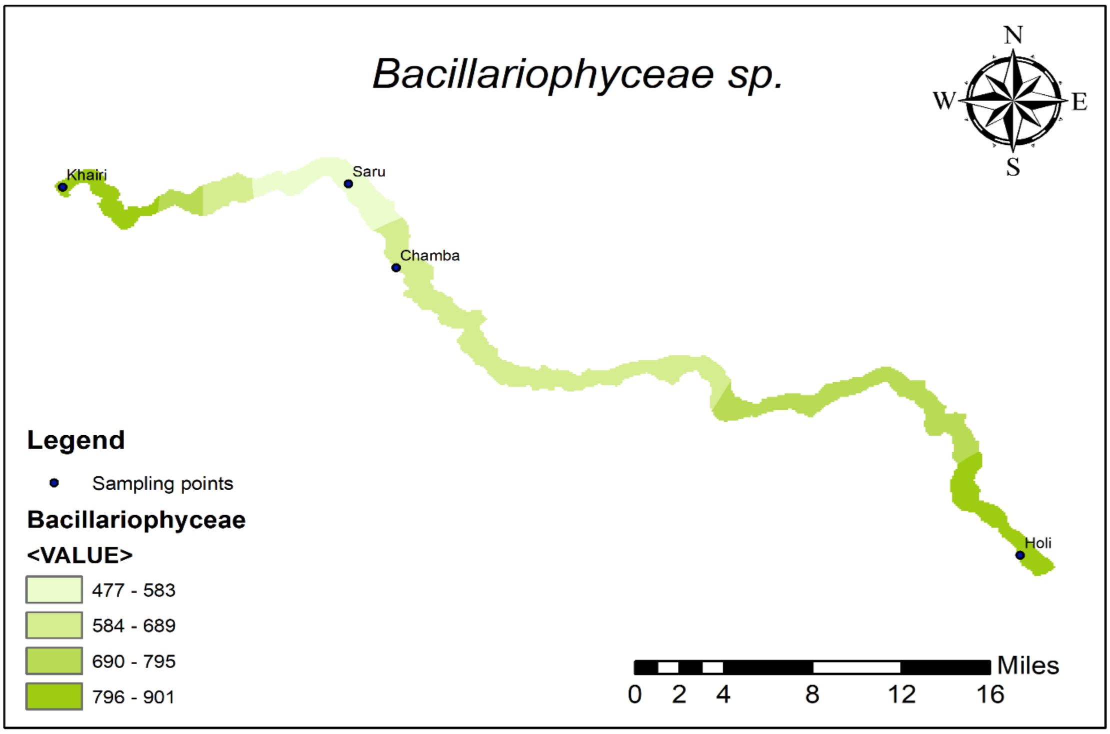

Figure 13: Mean variation of Bacillariophyceae
in selected sampling zones of river Ravi.

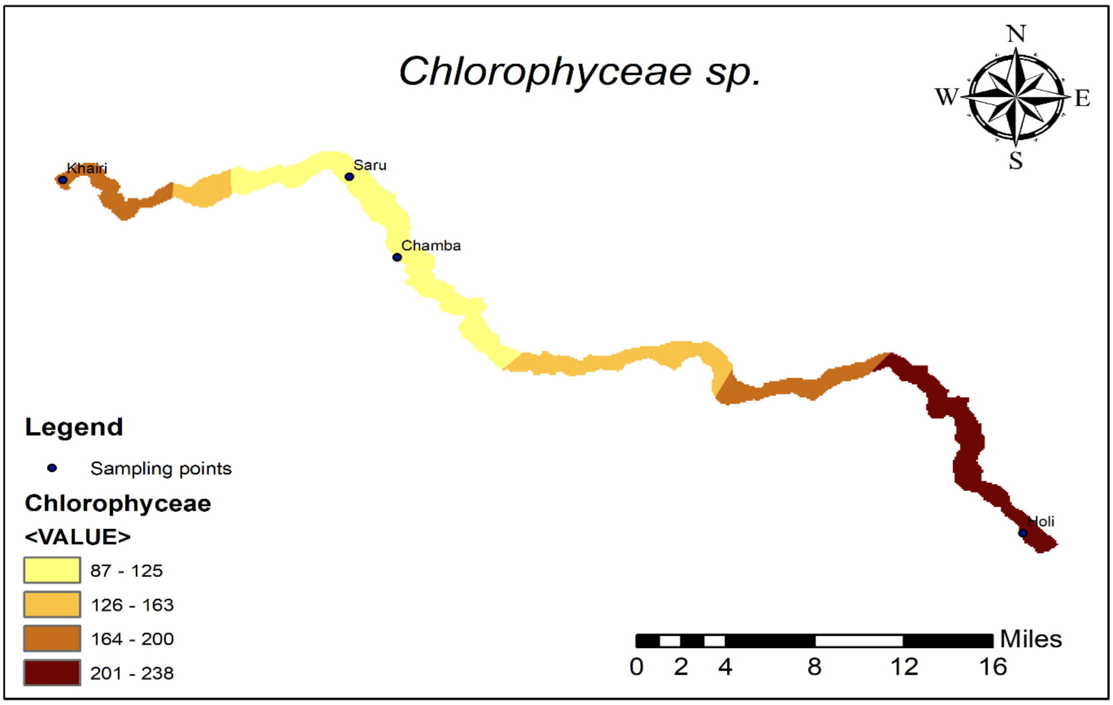

Figure 14: Mean variation of Chlorophyceae
in selected sampling zones of river Ravi.

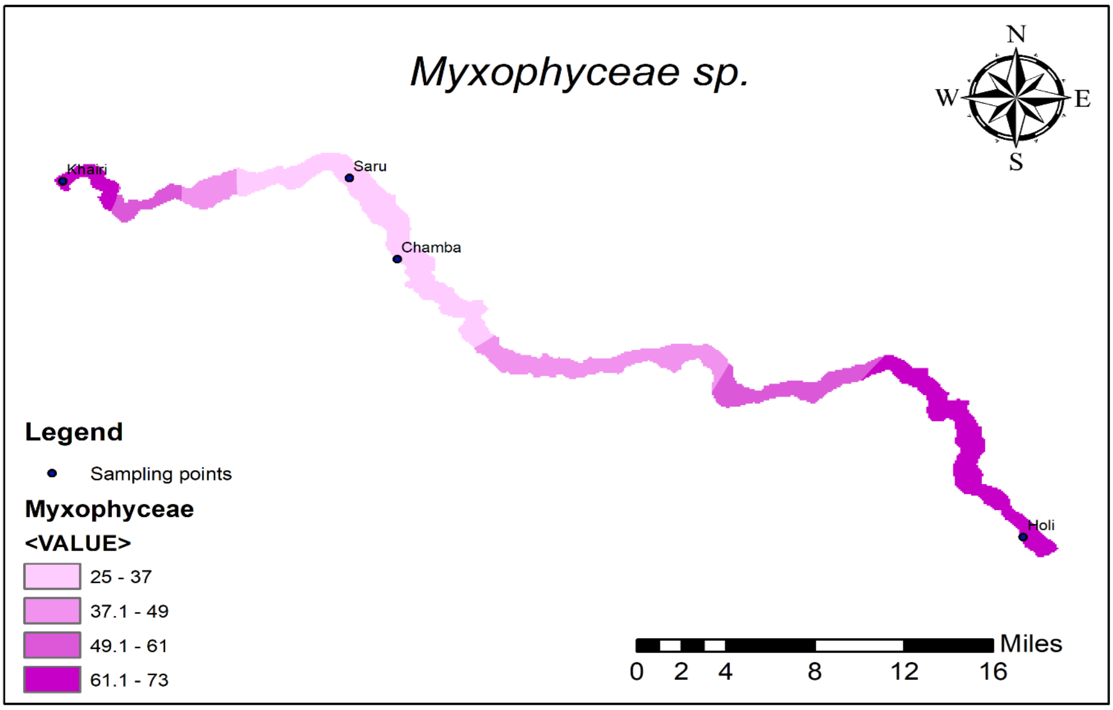

Figure 15: Mean variation of Myxophyceae
in selected sampling zones of river Ravi.

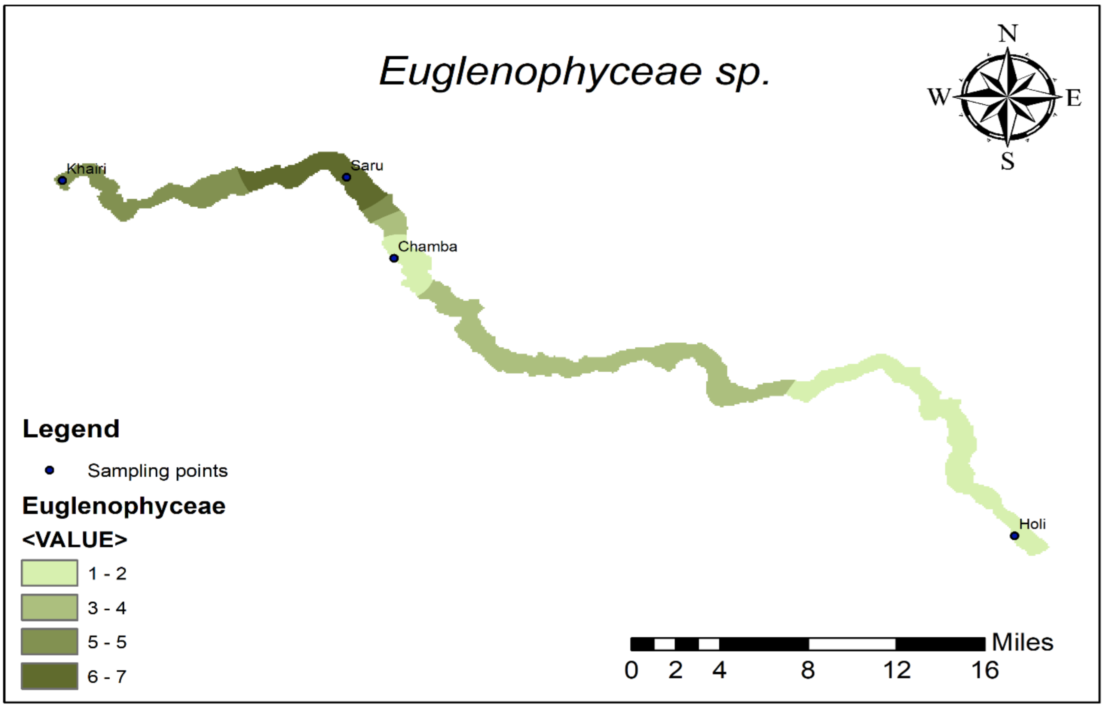

Figure 16: Mean variation of Euglenophyceae
in selected sampling zones of river Ravi.

Sampling zone 4 recorded the highest number of phytoplankton, while sampling zone 3 witnessed the least number of phytoplankton individuals.

This pattern of phytoplankton abundance may be attributed to the physicochemical characteristics of the water and various developmental activities taking place along the Ravi River basin. Factors such as the presence of a dam downstream of zone 1 and zone 3, along with temporary riverbed mining in zone 3, likely influence the distribution of phytoplankton. Sand mining in zone 3 has lead to the degradation of both the physical and chemical characteristics of the riverbed. This results in water quality and habitat ecology, and reduces the presence of appropriate surfaces for plankton to adhere to, affecting their growth. Additionally, increased turbidity, caused by these activities, reduced light penetration, limiting photosynthetic activity and primary productivity, despite the presence of nutrients (magnesium, nitrates, etc.) that are vital for phytoplankton.

A similar trend was observed by Kumar et al. (2018) in the Beas River and by Malik et al. (2021) in the Ganga River. Among all the phytoplankton genera in the upper stretch of Ravi River, *Achananthes* sp. was the most abundant.

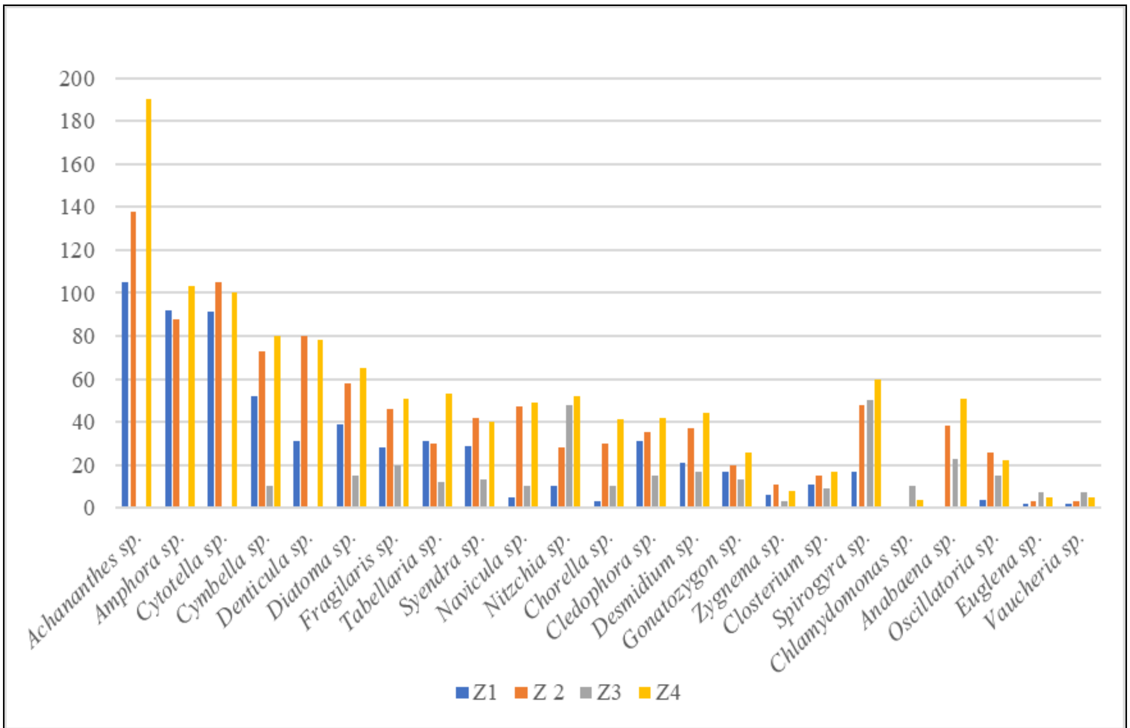

Figure 17: Phytoplankton assemblage in Ravi River
(Z1 = Zone 1, Z2 = Zone 2 Z3 = Zone 3 and Z4 = Zone 4).

However, species like *Chlamydomonas* sp., *Euglena* sp., and *Vaucheria* sp. were dominant in zone 3 (Fig. 17). A similar trend for *Achananthes* sp. was observed by Srivastava et al. (2020) in the Ganga River in the Gangotri region, where they concluded that the river water quality was affected by dam construction, altering the phytoplankton assemblage. Additionally, municipal dumping and anthropogenic activities in zone 2 also impacted water quality and plankton distribution. Kaur and Singh (2017) similarly reported that household water and dumping can influence plankton diversity and abundance in certain river areas.

The Shannon index was highest in zone 4, with a maximum of 2.795, indicating that this zone exhibits the greatest species diversity and a more even distribution of individuals compared to other zones. The other zones followed closely, with values of 2.776 in zone 2, 2.771 in zone 3, and 2.642 in zone 1. A higher Shannon index value indicates higher diversity. Conversely, the Simpson index was at 0.921 in zone 2 and lowest at 0.899 in zone 1. Values of the Simpson index ranges from 0 to 1, where lower diversity is indicated by values close to 0 and higher diversity is indicated by values close to 1. The maximum evenness value of 0.729 was reported in zone 2, while the minimum value 0.694 was recorded in zone 3. These results suggest that the species in zone 2 are more evenly distributed compared to the other zones (Tab. 4). An eveness value closer to 1 indicates the highest eveness. For the Shannon index, the highest value of 3.14 and lowest value of 3.07 was observed by Malik et al. (2021), with a similar trend reported by Dembowska (2021).

The phytoplankton assemblage structure and diversity indices reveal that zone 3 has a lower number and more uneven distribution compared to other zones. This discrepency may be attributed to riverbed mining and various anthropogenic activities in the area. Additionally, several sensitive genera are notably absent in zone 3. On the contrary, the lower diversity indices in zone 1 can be attributed to the absence or negligible numbers of certain pollution-resistant phytoplankton genera. The high altitude, steeper slope and high water velocity in zone 1 may also contribute to the reduced presence or abundance of certain species.

Table 4: Mean variation in diversity indices of phytopankton’s in selected study sites.

	Zone 1	Zone 2	Zone 3	Zone 4
Shannon_H	2.642	2.776	2.771	2.795
Simpson_1-D	0.8997	0.921	0.9173	0.9196
Evenness_e^H/S	0.7019	0.7296	0.6944	0.7111

The technique used to explore the connections between biological groups of species and their environmental contexts is Canonical Correspondence Analysis (CCA) (Zhou et al., 2023). The results of CCA analysis were plotted using two axis (Figs. 19-22). The length of a variable’s vector in CCA reflects the significance of that variable. In our analysis, the longest vector length was associated with dissolved oxygen, indicating a significant relationship across all zones. Conversely, the vector lengths of water temperature and BOD were oriented in opposite direction of dissolved oxygen in all the zones, indicating an inverse relationship between these water quality parameters. According to Kamboj et al. (2022), increased water temperature tends to decrease the level of dissolved oxygen in water. Moreover, a moderate increase in light intensity and water temperature enhances phytoplankton growth (primary productivity) resulting in higher BOD (Malik et al., 2020a).

In zone 1, species showed a significant positive relation with phosphorous, while in zone 2, species had a positive relationship with magnesium. In zone 3, a statistically significant positive relation was found between BOD and *Chlamydomonas* sp. (Figs. 19-21). Zone 3 also exhibited the longest vector lengths, most nutrient parameters, water temperature, turbidity, and BOD. All zones showed a significant positive relation in June and July for these parameters, indicating a disturbance in the water quality and plankton community in zone 3. According to Malik et al. (2020b), sediment load and water temperature of the riverine system increases during the rainy season due to landslides and surround run off, leading to higher turbidity.

The highest number of phytoplankton was observed in zone 4, followed by zone 2, zone 1 and zone 3 respectively. The eigenvalue of axis 1 accounted for 28.47%, 31.34%, 29.43%, and 29.29% of the relationship between environmental variables and phytoplankton diversity in zones 1, 2, 3, and 4, respectively. The corresponding eigenvalues were 0.01298, 0.013703, 0.013425, and 0.014039. Meanwhile, axis 2, with eigenvalues of 0.010467, 0.01069, 0.011228, and 0.010478 explained 22.95%, 24.45%, 24.61%, and 21.86% of the relationship between environmental factors and phytoplankton diversity in the respective zones (Tab. 5). These results clearly demonstrate the inverse relationship between turbidity and key physiochemical parameters essential for sustaining plankton communities.

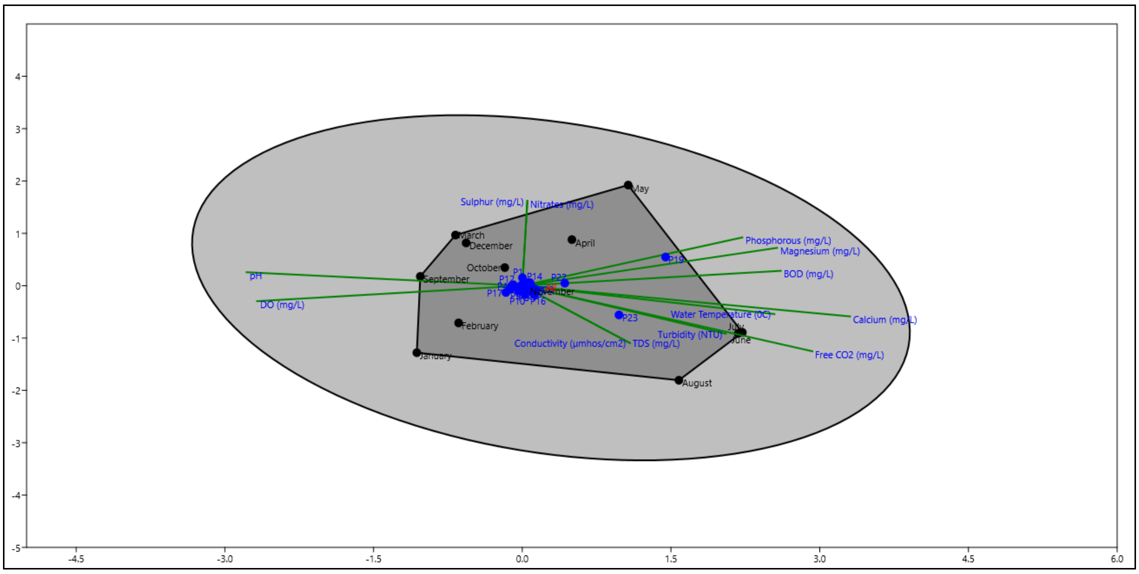

Figure 18: Ecological factors and phytoplankton taxa
in a CCA biplot of sampling zone 1.

Table 5: Biplot of Canonical Correspondence Analysis (CCA) displaying the relationship between environmental parameters and phytoplankton genera.

	Zone 1		Zone 2		Zone 3		Zone 4	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
P1	0.001	0.153	0.008	0.163	0.027	0.135	0.031	0.047
P2	–0.039	–0.098	–0.028	–0.082	–0.043	–0.130	–0.075	0.086
P3	–0.061	–0.029	–0.053	–0.013	–0.060	–0.031	–0.067	0.028
P4	–0.109	–0.006	–0.125	–0.008	–0.126	0.048	–0.101	–0.112
P5	0.043	–0.076	0.054	–0.063	0.034	–0.087	0.026	0.035
P6	–0.001	0.012	–0.023	–0.024	–0.026	0.057	0.014	–0.148
P7	0.085	0.017	0.094	0.044	0.101	–0.035	0.064	0.155
P8	–0.004	–0.065	–0.007	–0.026	0.001	–0.101	–0.058	0.147
P9	–0.121	–0.066	–0.120	–0.076	–0.143	–0.109	–0.158	0.041

Table 5 (continued): Biplot of Canonical Correspondence Analysis (CCA) displaying the relationship between environmental parameters and phytoplankton genera.

	Zone 1		Zone 2		Zone 3		Zone 4	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
P10	0.025	–0.166	0.019	–0.144	0.008	–0.186	–0.041	0.084
P11	0.036	–0.032	0.026	–0.062	0.018	0.010	0.053	–0.125
P12	–0.090	0.018	–0.107	–0.026	–0.111	0.069	–0.060	–0.174
P13	–0.008	0.012	–0.001	–0.028	0.003	0.061	0.052	–0.143
P14	0.061	0.060	0.048	0.027	0.064	0.105	0.099	–0.135
P15	0.065	0.015	0.046	–0.010	0.067	0.035	0.071	–0.064
P16	0.124	–0.171	0.112	–0.217	0.106	–0.071	0.150	–0.233
P17	–0.165	–0.128	–0.132	–0.088	–0.143	–0.138	–0.178	0.100
P18	0.036	–0.032	0.026	–0.062	0.018	0.010	0.053	–0.125
P19	1.445	0.548	1.422	0.678	1.429	0.255	1.337	0.630
P20	0.127	–0.065	0.111	–0.099	0.117	–0.050	0.116	–0.071
P21	0.078	0.059	0.041	0.013	0.043	0.070	0.072	–0.114
P22	0.429	0.048	0.443	–0.042	0.458	0.057	0.505	–0.150
P23	0.975	–0.558	1.088	–0.510	0.960	–0.547	0.991	0.137
September	–1.029	0.178	–0.992	0.408	–1.010	–0.161	–1.183	0.944
October	–0.177	0.347	–0.243	0.107	–0.165	0.444	–0.066	–0.619
November	0.078	0.018	–0.026	–0.517	–0.070	0.585	0.384	–2.049
December	–0.566	0.818	–0.707	0.440	–0.600	1.439	–0.174	–1.973
January	–1.064	–1.280	–1.008	–1.106	–1.136	–1.268	–1.305	0.403
February	–0.643	–0.711	–0.569	–0.610	–0.665	–0.674	–0.717	0.155
March	–0.674	0.968	–0.578	1.124	–0.463	0.652	–0.555	0.780
April	0.500	0.881	0.575	1.012	0.650	0.625	0.617	0.660
May	1.068	1.923	0.988	2.015	1.180	1.422	1.096	0.796
June	2.176	–0.914	2.065	–0.812	1.985	–1.050	1.771	0.585
July	2.220	–0.893	2.237	–0.813	2.178	–0.866	2.066	0.365
August	1.579	–1.806	1.611	–1.779	1.453	–1.852	1.228	0.519
Water (°C)	0.727	–0.155	0.802	–0.120	0.763	–0.372	0.736	0.430
pH	–0.795	0.074	–0.812	0.205	–0.512	0.189	–0.490	–0.153
TDS (mg/L)	0.310	–0.313	0.309	–0.303	0.285	–0.332	0.251	0.141
Conductivity (μmhos/cm^2)	0.310	–0.313	0.309	–0.303	0.285	–0.332	0.251	0.141
Turbidity (NTU)	0.586	–0.262	0.482	–0.168	0.030	–0.294	0.267	0.318
DO (mg/L)	–0.764	–0.085	–0.709	–0.069	–0.724	0.048	–0.717	–0.188

Table 5 (continued): Biplot of Canonical Correspondence Analysis (CCA) displaying the relationship between environmental parameters and phytoplankton genera.

	Zone 1		Zone 2		Zone 3		Zone 4	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
BOD (mg/L)	0.745	0.081	0.586	0.165	0.639	0.148	0.789	0.377
Free CO2 (mg/L)	0.836	–0.358	0.839	–0.322	0.763	–0.432	0.720	0.255
Calcium (mg/L)	0.945	–0.168	0.727	0.293	0.771	–0.033	0.790	0.486
Magnesium (mg/L)	0.734	0.207	0.717	0.339	0.773	–0.010	0.790	0.540
Phosphorous (mg/L)	0.634	0.264	0.356	0.034	0.282	0.071	0.802	0.491
Sulphate (mg/L)	0.015	0.463	0.040	0.351	0.287	0.426	0.781	0.231
Nitrates (mg/L)	0.015	0.463	0.356	0.034	0.282	0.071	0.802	0.491
Eigenvalue	0.013	0.010	0.014	0.011	0.013	0.011	0.014	0.010
%	28.47	22.95	31.34	24.45	29.43	24.61	29.29	21.86

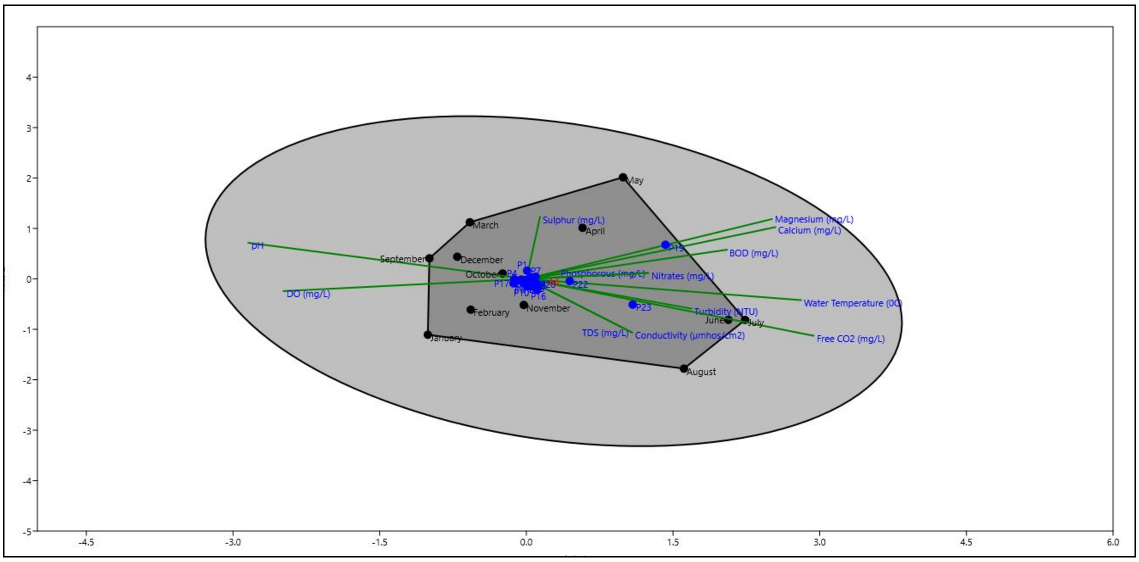

Figure 19: Ecological factors and phytoplankton taxa in a CCA biplot of sampling zone 2.

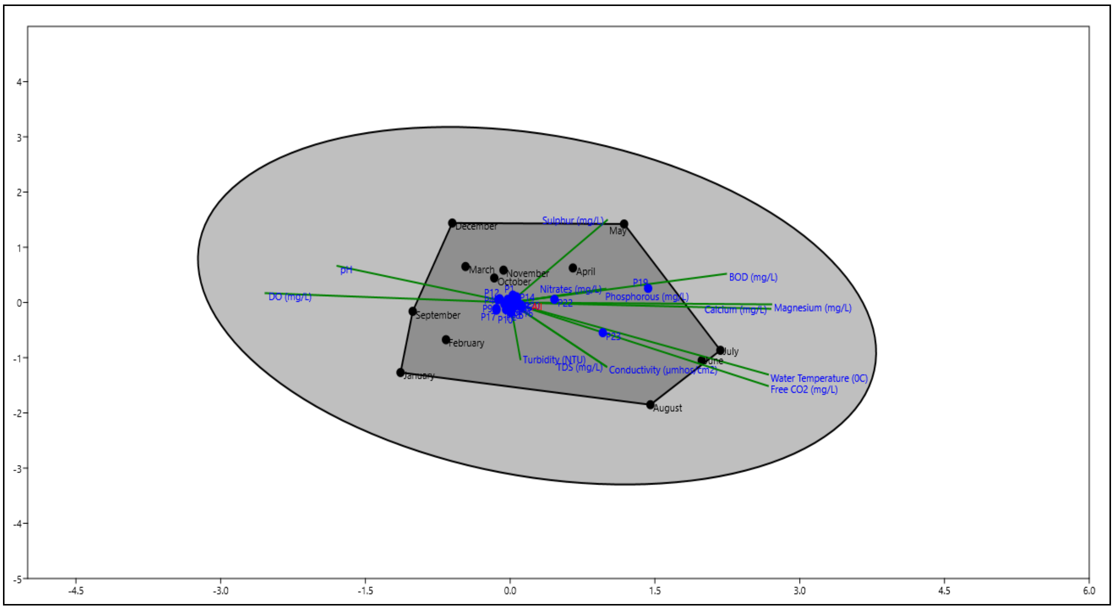

Figure 20: Ecological factors and phytoplankton taxa
in a CCA biplot of sampling zone 3.

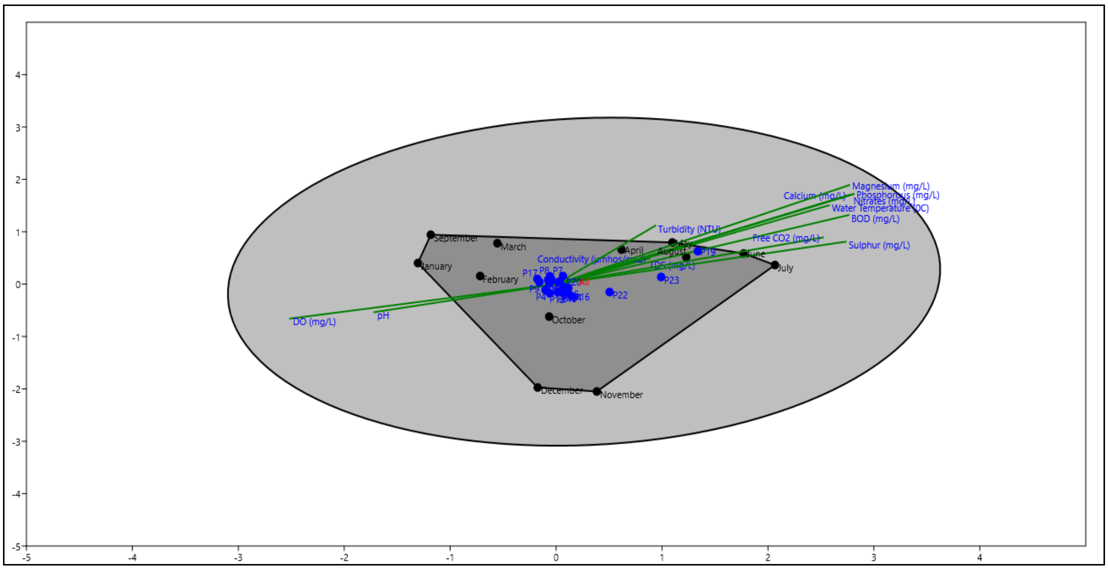

Figure 21: Ecological factors and phytoplankton taxa
in a CCA biplot of sampling zone 4.

CONCLUSIONS

The water quality of the upper Ravi River is capable of supporting a diverse range of freshwater biodiversity. Based on the current research, it can be concluded that while the water quality and phytoplankton assemblage in all selected zones were good, the water quality and plankton diversity in sampling zone 3 decline, trending toward the deprived water quality category.

Based on the present findings, the condition of Ravi River can be categorized as having good water quality. While some water-quality parameters indicated decreasing trends, they remained within the acceptable limits. Sampling station 3 recorded higher values for all measured parameters compared to the other sampling zones. The study also highlights that certain development activities, particularly the construction of dam, barrages, and riverbed mining have altered the water quality at station 3. Other factors, such as the hydrology of the river, have an immense impact on the water quality and plankton diversity in the river, suggesting that futher research could deepen our understanding in this area. These types of activities will need regular scientific monitoring and should be strictly regulated. In this context, "National Water Mission" outlines key strategies to ensure sustainable water management. This includes developing a detailed water database accessible to the public, studying climate change and its impact on natural water resources, and promoting awareness of integrated, basin-level water resource management and conservation efforts.

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