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Assessing the Impact of Water Quality on Algal Diversity in the Swat River Using Multivariate Statistical Approaches

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Abstract

Understanding the relationship between water quality and algal diversity is crucial for ecological health assessments. The current study aimed to assess the effects of environmental variables on algal communities using multivariate statistical approaches. The study spanned six administrative units and ten sampling stations, conducted over the summer and winter of 2019–2020. Algal specimens were collected and preserved using standard methodologies, with detailed analyses conducted under microscopes. The study identified a total of 54 species in summer and 61 species in winter. The number of Bacillariophyta species increased by 25.92% during summer and winter, followed by Charophyta at 11.11%. Chlorophyta and Euglenozoa showed no change, while Cyanophyta experienced a decrease of 16.6%. Temperature variations positively affected Bacillariophyta but negatively impacted Cyanophyta. The highest abundance score was found at the Ballogram sampling station, and the lowest was found at the Panjigram sampling station. According to the canonical correspondence analysis (CCA), the total inertia in summer and winter was 0.005. The findings indicate that temperature, pH, TDS, EC, resistivity, and salinity are the strongest variables in summer, while temperature, pH, resistivity, and salinity significantly affect the species number and distribution of various algal communities in winter. The different statistical analyses revealed the variation in the algal communities in the different seasons. It was concluded that the change in season leads to a quantitative change in the species. The study underscores the need for regular monitoring and management of water quality to preserve the ecological balance and biodiversity of the Swat River.

Keywords: Algal diversity, Variation, Correlation, Fresh water, Northern Pakistan.

Introduction

Freshwater, the scarcest and most quantifiable resource, accounts for only a small portion (2.5%) of surface water and is continually polluted from a variety of sources, including plastic waste disposal, domestic wastewater, intensive agricultural practices, and industrial operations, which are significant threats to both humans and other living organisms **(Jehan S. *et al.*, 2020)**. Swat district has a rich hydrogeography. The great basin of the Swat Valley empties into the Swat River, collecting water from numerous permanent and intermittent streams before flowing into the Kabul River in Charsadda District (Fig. 1). The Swat River, located in the Malakand division of Pakistan, is an incredibly important freshwater resource that serves as a lifeline for aquatic life and provides essential resources for local communities **(Ahmad H. *et al.*, 2015)**. Unfortunately, in the past few years, there has been growing concern about the declining quality of water in the Swat River. This decline is largely attributed to human activities such as pollution and other pressures on the environment **(Khan A. *et al.*, 2022)**. One noticeable effect of water quality degradation is the predominant algal species change with spatial-temporal fluctuations, which is a signal of the river's declining health and worsening water quality **(Park Y. *et al.*, 2014 and Giri S. 2021)** .

Climatic factors such as temperature and precipitation strongly influence algal species diversity. Temperature affects algal growth rates, with different species thriving in specific temperature ranges **(Grimaud G. M. *et al.*, 2017)**. Warmer temperatures generally enhance growth, while extreme temperatures can limit diversity **(Barinova S. *et al.*, 2015)**. Additionally, temperature influences the distribution of algae across various habitats, with cold-adapted species dominating in polar regions and warm-adapted species prevalent in tropical areas **(Singh S. and Singh P., 2015)**. Similarly, adequate precipitation provides the water necessary for algal growth and reproduction, promoting diversity **(Pires A. P. F. *et al.*, 2017)**. However, excessive rainfall can lead to nutrient runoff, altering water chemistry and favouring certain algal species over others. Conversely, drought conditions can reduce water availability, leading to decreased algal diversity, as only drought-tolerant species persist **(Kókai Z. *et al.*, 2023)**. Therefore, understanding the intricate relationships among temperature, precipitation, and algal species diversity is essential for effective environmental management and conservation efforts.

Various physicochemical properties play crucial roles in shaping algal communities. These properties include pH, which measures the acidity or alkalinity of the water, influencing the solubility of nutrients and metals critical for algal growth **(Asadian M. *et al.*, 2018)**. Redox potential, a measure of the tendency of a chemical species to acquire electrons, affects the availability of oxygen and other compounds essential for algal metabolism **(Fuhrmann J. J., 2021)** . Turbidity, which indicates the clarity of water due to suspended particles, impacts light penetration and, consequently, photosynthesis rates in algal populations **(Boyd C. E., 2020)**. Dissolved and suspended solids provide substrates for algal attachment and growth, while salinity levels regulate the types of algae that can thrive in a particular aquatic environment **(Coelho S.**

M., 2000). Alkalinity acts as a buffer against pH changes, influencing algal species composition and diversity **(Singh N. *et al.*, 2024)**. Dissolved oxygen availability is vital for aerobic respiration in algae, while carbon dioxide serves as a carbon source for photosynthesis **(Morales M. *et al.*, 2018)**. Nutrients such as nitrogen and phosphorus are primary drivers of algal biomass production, and their availability often determines the occurrence of algal blooms and community structure in aquatic ecosystems **(Wurtsbaugh W. A. *et al.*, 2019)**. Understanding the interplay of these physicochemical parameters is essential for managing and predicting algal dynamics in various aquatic habitats, from freshwater lakes to marine ecosystems **(Marrone B. L. *et al.*, 2024)**.

Algae are fundamental components of aquatic ecosystems and play essential roles in nutrient cycling, primary production, and food webs **(Das M. *et al.*, 2022)**. The productivity of aquatic systems is influenced by the variety and quantity of algal communities, which are regulated by nutrients, light availability, and flow patterns **(Stevenson J., 2014)**. Algae are used as indicator species in aquatic environments due to their occurrence and diversity patterns **(Kadam A. D. *et al.*, 2020)**. Algae are suitable for evaluating water quality due to their nutrient needs, fast reproduction, short life cycle, ability to absorb heavy metals, and quick response to changes in water chemistry, including pollution from industrial sources **(Gökçe D., 2016 and Ebrahimzadeh G. *et al.*, 2021)**. Compared with traditional animal indicators, algal indicators offer distinct insights into ecosystem conditions because they occupy the base of aquatic food webs **(Wu N. *et al.*, 2017)**.

Research on algal diversity in the rivers of the southern Hindu Kush region is still in its early phases. Our understanding of local algal diversity in Pakistan is incomplete, although some rivers and parks have been better studied, albeit sporadically **(Barkatullah FMS. 2013, Wu N. *et al.*, 2021 and Ullah N. *et al.*, 2023)**. The Swat River, which is situated in a remote mountainous region, has received inadequate research attention **(Barkatullah FMS. 2013)**. Therefore, understanding algal diversity helps scientists comprehend ecosystem functioning and resilience to environmental changes **(Mineur F. *et al.*, 2015)**. In addition, determining the relationships between water quality parameters and algal diversity is essential for effective river management and conservation efforts **(Singh H. *et al.*, 2017)**. Therefore, this study employed multivariate analysis techniques to investigate the complex interactions between various water quality parameters and algal diversity in the Swat River. By elucidating these relationships, this study aims to provide valuable insights into the ecological health of the river and contribute to informed decision-making for its sustainable management and conservation.

Materials and methods

Swat is one of the greenest valleys in northern Pakistan. The main towns in the valley are Mingora and Saidu Sharif. **(Rahman, A. *et al.*, 2023)**. The Swat Valley was divided into six different administrative units: Tehsil Babozai, Tehsil Behran, Tehsil Barikot, Tehsil Charbagh, Tehsil Kabal and Tehsil Matta (Fig. 1).

The geospatial location (latitude and longitude) of each sampling station was recorded using the Garmin eTrex 10 global handheld GPS navigator (Table 1).

The sampling stations used for algae collection were Utror, Ushu, Asrait, Madyan, Khwazakhela, Mingora, Ballogram, Panjigram, Barikot and Landakay. The data were collected during the summer and winter seasons of 2019–2020. Specimens were collected by picking up, scratching and squeezing objects. **(Edler and Elbrächter, 2010)**. The collected samples were immediately preserved in standard 100 ml and 500 ml jars with 5% formaldehyde, acetic acid and alcohol (FAA) to avoid spoilage **(Edler L.** and **Elbrächter M. 2010, Urbaniak J.** and **Gabka M., 2014)**.

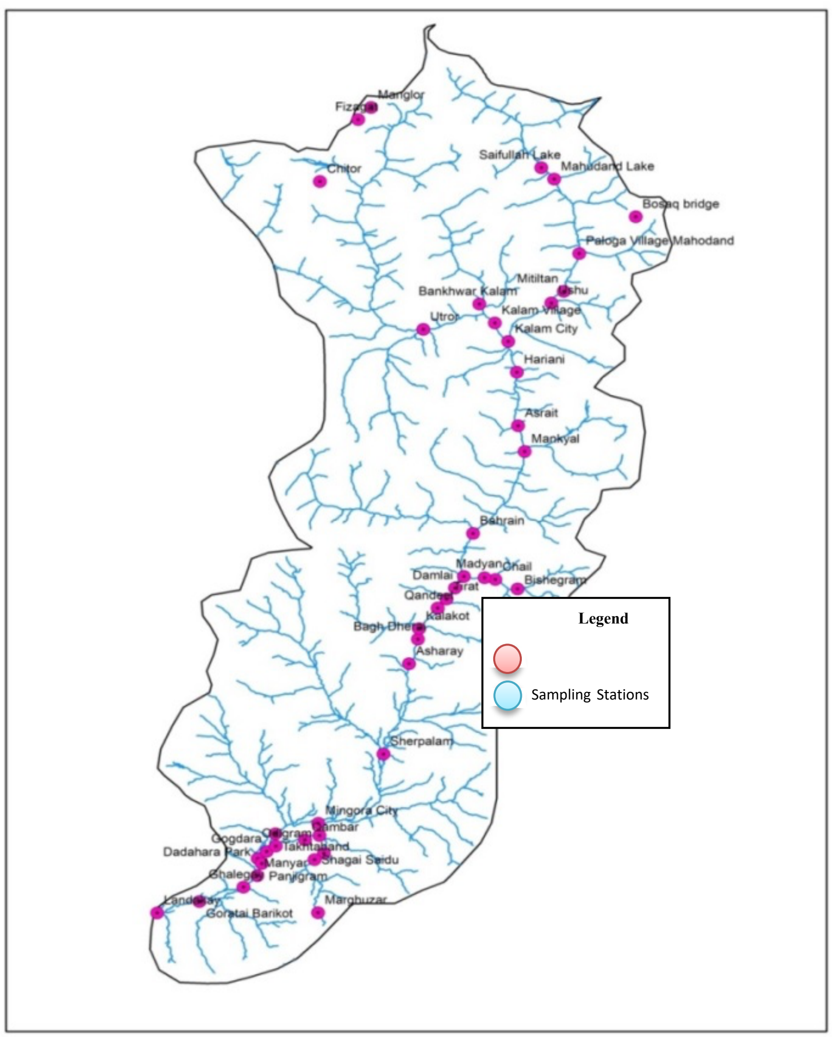

Figure 1. Study area map showing sampling stations and freshwater water channels (Barkatullah, 2013).

Table 1. Research Sites and Geospatial Positions

Site Names	Sampling tags	Latitude	Longitude
Asrait	S 01	35.35889	72.60639
Ballogram	S02	34.76639	72.31333
Barikot	S 03	34.68333	72.21278
Khwazakhela	S 04	34.93667	72.44944
Landakay	S 05	34.66417	72.13472
Madyan	S 06	35.14389	72.53556
Mingora	S 07	34.79222	72.34528
Panjigram	S 08	34.73472	72.27139
Ushu	S 09	35.53389	72.65
Utror	S 10	35.49639	72.4825

The samples from each location were labelled with the sampling site, collection season, collection time, and ecosystem type. The micromorphology of the algae was studied by the wet paste method of **Edler L. and Elbrächter M. (2010)**. Slides were prepared from preserved algal samples and then observed under the 10×, 20×, 40× and 100× objectives of a YJD microscope. Microphotographs of the taxa were taken using a microscope camera. Classification and identification were carried out according to the standard methods of **Prescott (1965)**. Algal species abundance scores were recorded according to the 6-point scoring scale of **Barinova *et al.*(2006)** and **Barinova S. (2017)** (Table 2). Multivariate analysis was used to measure species richness (R) by the species richness index, heterogeneity by the information index and the dominance index, and regularity (E) by the regularity index.

The main physicochemical variables of water quality (temperature, pH, electrical conductivity, total dissolved solids, resistivity and salinity) were determined by using a HANNAH HI-98194 multiparameter water quality meter and CANOCO V. 4.5 software for canonical correspondence analysis.

Results

Taxonomic diversity of algal species in summer and winter

In the present study, a total of 54 species in summer and 61 species in winter were recorded from different freshwater sampling sites in the River Swat. During summer, 27 species of Bacillariophyta were distributed in 11 families and 15 genera, while in winter, this phylum increased to 34 species. There were 9 Chlorophyta species recorded in summer, spanning 3 families and 4 genera, with a slight increase to 11 species in winter. Charophyta, in summer, had

9 species within 03 families and 4 genera, with a comparable increase to that of 10 species in winter. Similarly, Cyanophyta maintained consistency with the other six species in the summer, being distributed among 4 families and 4 genera, and with the remaining five species in the winter. Notably, there was no seasonal variation observed in Euglenozoa, which maintained 1 species in both summer and winter. The species contributions in the summer season were 51.92% for Bacillariophyta, 17.31% for Charophyta, 21.15% for Chlorophyta, 7.69% for Cyanophyta and 1.92% for Euglenozoa (Table 2).

Table 2. Algal diversity in the summer and winter seasons

	Summer			**Winter**		
Phylum	Family	Genus	Species	Family	Genus	Species
Cyanophyta	4	4	6	4	4	5
Bacillariophyta	11	15	27	15	19	34
Charophyta	3	4	9	3	4	10
Chlorophyta	6	9	11	6	9	11
Euglenozoa	1	1	1	1	1	1
Total	25	33	54	29	37	61

In summer, Bacillariophyta 5 species of *Surirella* and *Naviculazanonii*, 3 species each of *Cocconeis placentula, Didymosphenia geminate, Encyonemaminutum, Fragilaria capucina, Gomphonema sp*. And *Iconella linearis,* Charophyta was dominated by 4 species *of Mougeotia* sp., *Spirogyra, Cosmarium cataractarum* and *Cosmarium subcostatum* had 3 species each, 2 species each of *Closterium moniliferum* were also observed, Chlorophyta contained 5 species of *Tetradesmus obliquus*, *Stigeoclonium tenue* and *Pediastrum integrum* contained 3 species each, *Merismopedia tenuissima* of Cyanophyta dominated the class with 3 species, and *Merismopedia glauca*, with *Oscillatoria tenuis* having 2 species, and *Euglena hemichromata* of Euglenozoa contained 3 species (Table 3).

Similarly, in winter, Bacillariophyta (55.74%), Charophytes and Chlorophyta (16.39%), Cyanophyta (18.03%), and Euglena (1.64%) were distributed (Table 4).

During winter, *Navicularadiosa* of Bacillariophyta was the dominant genus, with 6 species according to the abundance score, followed *by Navicula cryptotenella* with 5 species and 4 species each *of Cymbellaturgidula, Fragilaria crotonensis* and *Navicula cryptocephala.* Among the Chlorophyta, *Scenedesmus quadricauda* contributed 4 species, *Hydrodictyon reticulatum* contributed 3 species, and *Desmodesmus denticulatus* contributed 2 species. Charophytes were predominantly represented by 4 species of Cosmarium - 6 -eave, followed by 3 species of Cosmarium amoenum and 2 species each of *Cosmarium bioculatum, Cosmarium subspeciosum,* and Spirogyra sp.

Table 3. Species distribution with their abundance scores in the summer season

Algal Species	Number	Class
Surirella sp	5	Bacillariophyta
Naviculazanonii	5	Bacillariophyta
Cocconeis placentula	3	Bacillariophyta
Didymosphenia geminata	3	Bacillariophyta
Encyonemaminutum	3	Bacillariophyta
Fragilaria capucina	3	Bacillariophyta
Gomphonema sp	3	Bacillariophyta
Iconella linearis	3	Bacillariophyta
Mougeotia sp	4	Charophyta
Spirogyra sp	3	Charophyta
Cosmarium cataractarum	3	Charophyta
Cosmarium subcostatum	3	Charophyta
Closterium moniliferum	2	Charophyta
Tetradesmus obliquus	5	Chlorophyta
Stigeoclonium tenue	3	Chlorophyta
Pediastrum integrum	3	Chlorophyta
Merismopedia tenuissima	3	Cynobacteria
Merismopedia glauca	2	Cynobacteria
Oscillatoria tenuis	2	Cynobacteria
Euglena hemichromata	3	Euglenozoa

In the Cyanophyta phylum, *Oscillatoria* sp. Contained 3 species, followed by *Merismopedia tenuissima* and *Oscillatoria tenuis* and *Merismopedia glauca. Euglena hemichromata* of Euglenozoa contained 1 species according to the abundance score data (Table 4). In the summer season, temperature positively influences Bacillariophyta species while negatively influencing Cyanophyta species.

Table 4. Species distribution with their abundance scores in the winter season

Algal Species	Number	Class
Navicularadiosa	6	Bacillariophyta
Navicula cryptotenella	5	Bacillariophyta
Cymbellaturgidula	4	Bacillariophyta
Fragilaria crotonensis	4	Bacillariophyta
Navicula cryptocephala	4	Bacillariophyta
Scenedesmus quadricauda	4	Chlorophyta
Hydrodictyon reticulatum	3	Chlorophyta
Desmodesmus denticulatus	2	Chlorophyta
Cosmarium leave	4	Charophytes
Cosmarium amoenum	3	Charophytes
Cosmarium bioculatum,	2	Charophytes
Cosmarium subspeciosum	2	Charophytes
Spirogyra sp	2	Charophytes
Oscillatoria sp	3	Cyanophyta
Merismopedia tenuissima	1	Cyanophyta
Oscillatoria tenuis	1	Cyanophyta
Merismopedia glauca.	1	Cyanophyta
Euglena hemichromata	1	Euglenozoa

pH positively influences Cyanophyta and Euglenozoa species while negatively influencing Bacillariophyta species. Resistivity positively influences Chlorophyta species while negatively influencing Charophyta species. EC, TDS, and salinity positively influence Charophyta species while negatively influence Chlorophyta species (Fig. 2).

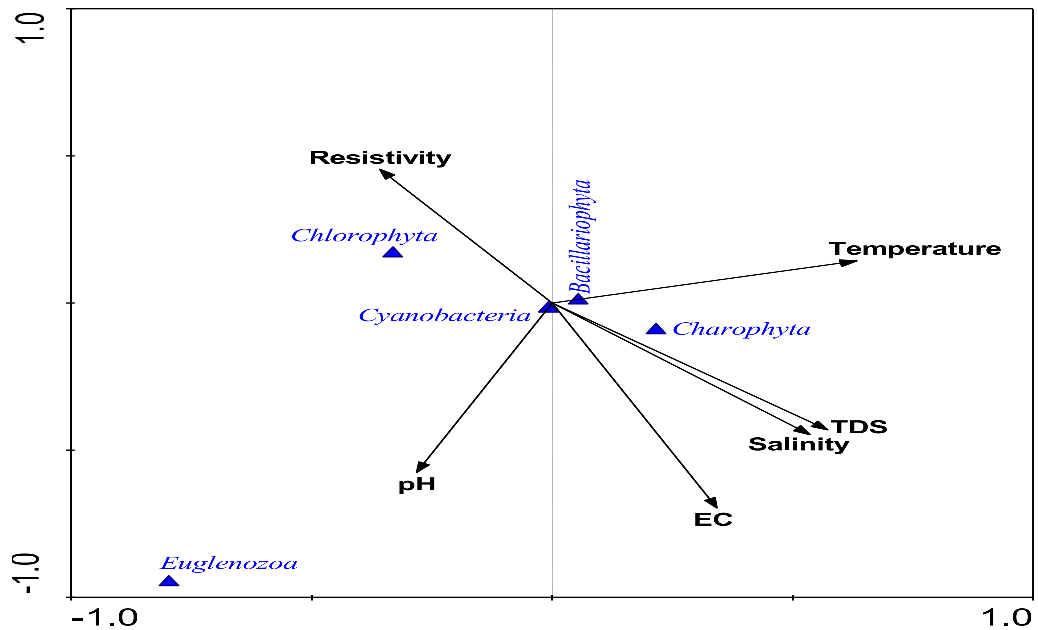

Figure 2. Correlation of the water physicochemical properties with the different families of algae in summer.

Euglenozoa, Charophyta and Cyanophyta species were positively influenced by TDS and negatively influenced by pH and resistivity. Salinity positively influences Chlorophyta species. Bacillariophyta species were positively influenced by EC, pH and resistivity (Fig. 3).

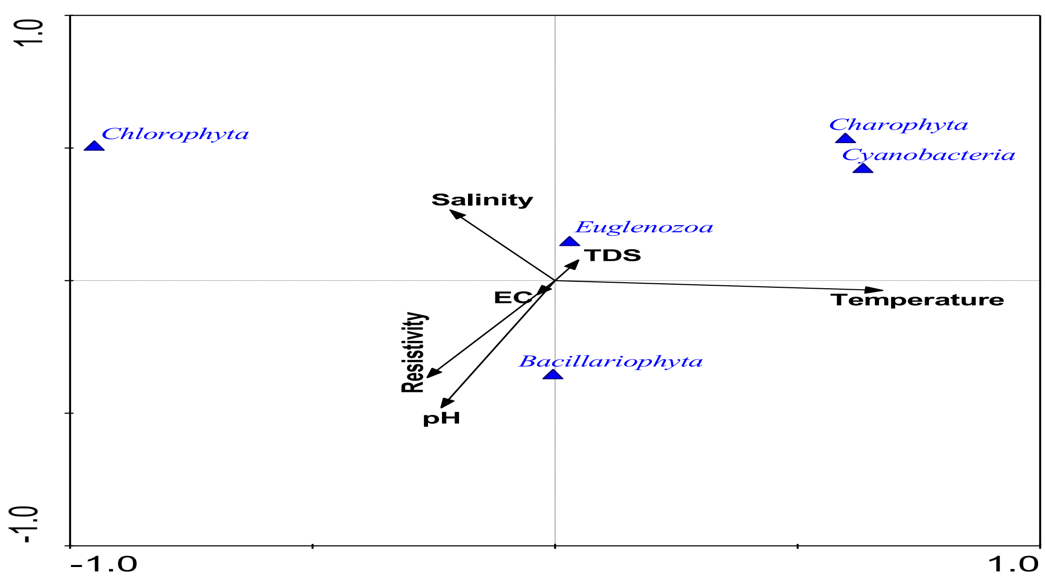

Figure 3. Correlations of the water physicochemical properties with the different families of algae in winter.

Discussion

A comparison between the summer and winter distributions

A comparison between the summer and winter distributions revealed a consistent dominance of Bacillariophyta in both seasons, with a slight increase from 51% in summer to 55.74% in winter. Charophytes in both seasons showed a slight change in the speed at which water affected the colonies of the group, with 17.31% of the species affected in summer and 16.39% in winter and Chlorophyta showed a large change in the species count, with 21.15% in summer and 16.39% in winter, indicating that low temperature affected the quantitative structure of this algal class. A total of 7.69% of Cyanophyta in summer and 18.03% in winter experienced low water speeds, low temperatures and low anthropogenic activity because of low pollution at the picnic spots where fresh water helps this algal phylum grow and increase, and 1.92% of Euglena in summer and 1.64% of Euglena in winter show that seasonal variation has a very low rank effect on this class show minor variations in their contributions between the two seasons.

In terms of species diversity in terms of species count, *Surirella* sp. and *Naviculazanonii* had 5 species each in summer. However, in winter, *Navicularadiosa* had more than one member and had 6 abundance scores for the phylum Bacillariophyta. In summer, the *Mougeotia* sp. domminiating Charophyta had 4 members, while in winter, the same phylum was dominated by *Cosmarium amoenum*, with 3 species. *Tetradesmus obliquus* of chlorophyta had 5 members in summer, while in winter; the *Scenedesmus quadricauda* had 4 species in winter. *Merismopedia tenuissima* had 3 species of Cynophyta in summer, while in winter, *Oscillatoria sp*. domminiated the class, with 3 species. The summer was the most suitable for the euglenozoa, with 3 species of *Euglena hemichromata,* while in winter, the same species reduced to one only.

All showed remarkable variation in number and seasonal variation in the number of algal colonies. The percentage of spores of the Bacillariophyta tiding over the water was mostly high in both seasons, as it has the ability to resist environmental stresses. The numbers of all the different phyla showed a remarkable variation with the change in the water quality during the different seasons. The different marked changes in the quantitative study showed that high temperatures in the summer accelerated the water flow because of the melting of ice on the different peaks of the swat valley, accelerating the water, which disturbed the attachments of the algal species to the substratum, leading to the destruction of the algal habitats; thus, the number of algal members decreased beginning in the winter season. The analysis of the algal community of the Aragvi River in Georgia revealed that the pattern of diversity distribution depends on local climatic conditions and altitude, and pollution affects water physicochemical properties at moderate levels, thus leading to changes in the number of algal species. This study revealed a correlation between the current study of the River Swat Kp Pakistan and the Aragvi River in Georgia by **Barinova *et al.* (2014)**.

Effects of seasonal variations on the algal distribution in the summer and winter seasons

The impacts of seasonal variations on the algal distribution in summer and winter were analyzed. In summer, significant variations were observed in the quantitative analysis of the algal communities. The highest abundance score of 137 was noted in S4, which contrasted with the lowest score of 123 in S8. The Margalef Index peaked at 13.36 in S2 and reached its lowest value at 12.45 in S7. Similarly, the Menhinick index reached its highest value of 5.66 in S2 and its lowest at 5.36 in S7. The Shannon and Wiener indices were highest (4.37) in S2 and lowest (4.25) in S7 and S4. The Brillouin index ranged from 3.54 in S2 to 3.42 in S8. The Simpson index remained consistent at 0.99 across all stations, whereas the Berger and Parker indices ranged from 0.04 at multiple stations to 0.03 at S2, S8, and Barikot. Pielou'sevenness index reached its peak at 1.04 at S2 and S8, with a low value of 1.03 at the other stations. The Brillouin evenness index varied from 1.17 in S2 to 1.12 in Utror.

Similarly, in winter, the statistical analysis of the algal communities at the sampling stations revealed notable differences. The highest abundance score recorded was 146 in S2, while the lowest was 117 in S8. The Margalef index was greatest at 13.44 in S2 and lowest at 12.77 in S7. Similarly, the Menhinick index reached its peak at 5.63 in S2 and it’s lowest at 5.35 in S5. The Shannon and Wiener index reached its highest value of 4.37 in S2, which contrasted with its lowest value of 4.21 in S7. The Brillouin index ranged from 3.56 in S2 to 3.37 in S8. The Simpson index remained constant at 0.99 across all stations, while the Berger and Parker indices varied from 0.04 in S1, S4, S6, S7, S9, and S10 to 0.03 in S2, S3, S8, and S5.

The analysis of seasonal variations in the algal distribution revealed significant differences between summer and winter. In summer, diverse abundance scores were observed across all the sampling stations (S1,S2,S3,S4,S5,S6,S7,S8,S9 and S10), with the highest score recorded in S4 and the lowest in S8, which clearly shows that erosion from hills during the Moon in the summer and other anthropogenic activities (picnic spots, hotels, city sewage systems, etc.) affecting the physicochemical properties and purity of water leads to changes in the quantitative parameters of algal studies. The Evenness indices of Margalef, Menhinick, Shannon and Wiener, Brillouin, and Pielou varied among the stations, indicating fluctuations in the algal community structure. Similarly, in winter, differences in abundance scores were noted, with S2 having the greatest difference (Table 5).

The entrance of a stream of fresh water originating from the elumpasses, which increases the species richness of all the parameters of the quantitative algal structure, and the variation from S8 was the lowest due to local anthropogenic factors (e.g., the Marble industry) of physicochemical disturbance in the algal habitat. The Evenness indices Margalef, Menhinick, Shannon and Wiener, Brillouin, and Pielou displayed variations across the stations, reflecting changes in the algal community composition. Despite these variations, Simpson’s index remained constant across all stations in both seasons, indicating consistent species dominance. Overall, the analysis highlights the dynamic nature of algal communities in response to seasonal changes, with certain indices showing distinct patterns across sampling stations.

Correlations between physicochemical properties and the algal population

There was a significant correlation between the physicochemical properties and the algal population, indicating the impact of water quality on algal diversity and habitat. In the summer season, variations in water parameters were observed across the sampling stations. Higher temperatures were noted in S5 at 26°C, and lower temperatures were noted in S10 at 16°C.

Table 5. Significant variations in the quantitative analysis of the algal communities

	Asrait s 01	Ballo gram s02	Barikot 03	Khwaza Khela 04	Landakay 05	Madyan 06	Mingora 07	Panjigram 08	Ushu 09	Utror 10
Abundance Score (S)	130	140	131	137	135	134	134	123	132	133
Abundance Score (W)	137	146	137	135	143	131	139	117	132	142
Species Richness Indices										
Margalef Index (S)	12.9	13	12.9	13	12.6	12.86	12.5	12.47	12.7	12.88
Margalef Index (W)	13	13	12.8	13	12.7	12.92	12.8	11.97	12.7	12.91
Menhinick Index (S)	5.61	5.7	5.59	5.4	5.42	5.53	5.36	5.5	5.48	5.55
Menhinick Index (W)	5.55	5.6	5.47	5.7	5.35	5.59	5.43	5.36	5.48	5.46
Information Indices										
Shannon and Wiener Index (S)	4.29	4.4	4.3	4.3	4.26	4.29	4.25	4.26	4.29	4.28
Shannon and Wiener Index (W)	4.3	4.4	4.3	4.3	4.26	4.29	4.27	4.21	4.28	4.28
Brillouin Index (S)	3.45	3.5	3.46	3.5	3.46	3.47	3.44	3.42	3.46	3.45
Brillouin Index (W)	3.48	3.6	3.49	3.5	3.48	3.46	3.47	3.37	3.46	3.48
Dominance Indices										
Simpson’s Index (S)	0.99	1	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99
Simpson’s Index (W)	0.99	1	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99
Berger and Parker Index (S)	0.04	0	0.03	0	0.04	0.04	0.04	0.03	0.04	0.04
Berger and Parker Index (W)	0.04	0	0.03	0	0.03	0.04	0.04	0.03	0.04	0.04
Species Evenness Indices										
Pielou's Evenness Index (S)	1.03	1	1.03	1	1.03	1.03	1.03	1.04	1.03	1.03
Pielou's Evenness Index (W)	1.03	1	1.03	1	1.03	1.03	1.03	1.04	1.03	1.03
Brillouin Evenness Index (S)	1.14	1.2	1.15	1.1	1.13	1.14	1.13	1.16	1.15	1.12
Brillouin Evenness Index (W)	1.14	1.2	1.15	1.1	1.11	1.14	1.12	1.16	1.14	1.11

***(S)=summer, (W)=winter**

Elevated pH levels were found in S6 at 8.05, indicating higher basicity, while S5 had a pH of 7.02. The electrical conductivity (EC) was highest in S7 at 196°C and lowest in S10 at 70°C. Total dissolved solids (TDS) peaked at S7 at 98°C, whereas the lowest TDS was recorded at S10 at 35°C. The resistivity was highest in S10 at 14490 and lowest in S6 at 5102. The salinity rates varied, being highest in S3, S6 and S7 and lowest in S10 at 0.

Positive correlations were observed between temperature and EC (0.4440), TDS (0.6769), and salinity (0.6652), while negative correlations were found with pH (-0.5523) and resistivity (-0.6024). pH showed a positive correlation with resistivity (0.2257) but a negative correlation with EC (-0.0199), TDS (-0.2420), and salinity (-0.1448). EC was positively correlated with TDS (0.9338) and salinity (0.9035) but negatively correlated with resistivity (-0.9510). The TDS was positively correlated with salinity (0.9512) and negatively correlated with resistivity (-0.9670). Resistivity showed a negative correlation with salinity (-0.9432) (Tables 7 & 8).

Table 6. Comparative Analysis of the Physicochemical Properties in the summer and winter Seasons

Sampling stations	Sampling tags	Temp [°C]	pH	EC [µS/cm]	TDS [ppm]	Resistivity [Ω-cm]	Salinity [PSU]
Asrait (s)	S1	19	8	88	44	11630	0.04
Asrait (w)	S1	8	7	192	96	8281	0.09
Ballogram (s)	S2	22	7	153	82	5701	0.06
Ballogram (w)	S2	15	7	137	78	5812	0.09
Barikot (s)	S3	24	7	176	89	5523	0.09
Barikot (w)	S3	22	7	203	104	4782	0.06
Khwazakhela (s)	S4	21	7	160	80	6329	0.07
Khwazakhela (w)	S4	16	8	68	34	14710	0.03
Landakay (s)	S5	26	7	112	81	8260	0.07
Landakay (w)	S5	20	7	221	111	4525	0.1
Madyan (s)	S6	22	8	186	98	5102	0.09
Madyan (w)	S6	16	8	125	63	8000	0.06
Mingora (s)	S7	22	8	196	98	5128	0.09
Mingora(w)	S7	19	7	293	111	5612	0.12
Panjigram (s)	S8	23	8	178	89	5618	0.08
Panjigram (w)	S8	23	7	208	104	4785	0.1
Ushu (s)	S9	18	8	165	83	6061	0.08
Ushu (w)	S9	9	7	315	157	3157	0.15
Utror (s)	S10	16	8	70	35	14490	0
Utror (w)	S10	5	7	313	159	3135	0.15

***(S)=summer, (W)=winter**

Table 7. Correlations among different variables of the water physicochemical properties in summer and winter

Seasons	Variables	Temperature	pH	EC	TDS	Resistivity	Salinity
Summer	Temperature	1					
	pH	-0.552	1				
	EC	0.444	-0.020	1			
	TDS	0.677	-0.242	0.934	1		
	Resistivity	-0.602	0.226	-0.951	-0.967	1	
	Salinity	0.665	-0.145	0.904	0.951	-0.943	1
	Salinity	0.297	-0.405	0.997	0.994	-0.872	1
Winter	Temperature	1					
	pH	0.095	1				
	EC	-0.306	-0.709	1			
	TDS	-0.398	-0.738	0.956	1		
	Resistivity	0.062	0.853	-0.807	-0.864	1	
	Salinity	-0.474	0.741	0.920	0.924	-0.789	1

Table 8. Positive and Negative Correlations along with Different Axis in Summer and Winter

	Temperature	pH	EC	TDS	Resistivity	Salinity
Axis-I (S)	0.1035	0.2229	-0	-0.1	-0	-0
Axis-II (S)	0.1108	-0.1237	0.3	0.3	-0	0.3
Axis-I (W)	0.6746	-0.2346	-0	0	-0	-0
Axis-II (W)	-0.0373	-0.4794	-0	0.1	-0	0.3

In winter, similar trends were observed in the physicochemical properties of the water across the sampling stations. The highest temperature of 23°C was recorded at S8 (Panjigram), and the lowest temperature of 23°C was recorded at S10 (Utror). The pH varied, being highest at S4 (Khwazakhela) and lowest at S9 (Ushu), at 6.88. The EC peaked at 315 in S9 (Ushu) and was lowest at 68 in S4 (Khwazakhela). The TDS was highest at S10 (Utror), at 159%, and lowest at S4 (Khwazakhela), at 34%. The resistivity was highest at S4 (Khwazakhela), at 14710, and lowest at S7 (Mingora), at 5612. The salinity was highest at S5 (Landakay) and S8 (Panjigram), at 0.1, and lowest at S4 (Khwazakhela), at 0.03.

Positive correlations were noted between temperature and pH (0.0948) and between temperature and resistivity (0.0615), while negative correlations were found with EC (-0.3062), TDS (-0.3979), and salinity (-0.4735). pH showed a positive correlation with resistivity (0.8534) but a negative correlation with EC (-0.7085), TDS (-0.7379), and salinity (-0.7410). EC was positively correlated with TDS (0.9559) and salinity (0.9201) but negatively correlated with resistivity (-0.8071). TDS correlated positively with salinity (0.9241) and negatively with resistivity (-0.8643). Resistivity showed a negative correlation with salinity (-0.7894) (Fig. 3).

The analysis of the physicochemical properties and algal populations in both the summer and winter revealed significant correlations, indicating the influence of water quality on algal diversity. In summer, variations in temperature, pH, EC, TDS, resistivity, and salinity were observed across sampling stations, with positive correlations between temperature and several parameters, such as EC, TDS, and salinity, while negative correlations were found with pH and resistivity. Similar trends were observed in winter, with variations in temperature, pH, EC, TDS, resistivity, and salinity across stations. Positive correlations between temperature and pH were noted, along with negative correlations with EC, TDS, and salinity. These findings underscore the importance of understanding the relationships between physicochemical parameters and algal populations for the effective management of aquatic ecosystems. The relationship between the composition of algal communities and climatic changes is not clearly understood The positive correlation of the communities to any physicochemical factor revealed their tolerance or importance. The negative correlation indicates that this factor is not favorable for the community, as shown by **Palmer (1980)**, who reported that *Scenedesmus*is positively related to eutrophic water. It has been found that algal communities respond to changes in temperature conditions, which was revealed using the bio indication method **(Barinova S. *et al*., 2014)**. The distributions of the total number of phytoplankton species and the number of diatom species in the Yakutiya and Chukotka Rivers in terms of the gradient of the GEO index are given in terms of correlation indices by **Barinova S. *et al*., (2014)**.

The use of statistical methods makes it possible to establish a relationship between climate change and algae diversity. However, under conditions in the Far North, the development of phytoplankton was negatively correlated and thus inhibited, as shown by our correlation index studies. Climatic changes essentially influence the distributions of Bacillariophyta, Chlorophyta, and Chrysophyta.

For example, for algae occurring in the basin of the Vakhsh River (Tajikistan), the contribution of diatoms decreased with altitude. In this case, the contribution of algae from other divisions remained almost unchanged **(Barinova S. *et al*., 2015)** because the different sampling stations of the river swat had the same output. Current studies of freshwater river swat ecosystems focusing on algal communities show a strong index of similarity with different discoveries worldwide.

Conclusions

The study emphasized how swat river in Pakistan algal variety significantly impacted by water quality factor such as PH, nitrate, phosphate and dissolved oxygen. While balanced circumstances supported variety of communities, high nitrogen levels boosted algal biomass, but decreased algal diversity, indicating eutrophication. Spatial patterns and important water quality-algae interaction successfully detecting using multivariate techniques (CA, PCA and RDA). In order to preserve ecological equilibrium, the result highlight the necessity of routine water quality monitoring. To get deeper understanding of these dynamics, future studies should concentrate on long term evaluations as well as other biological and chemical components. In the order to protect river biodiversity, sustainable management techniques are crucial.

Authors Contribution: Wisal Muhammad Khan conceptualize and supervise the study, Murad Khan conducted sampling, analyze the data, carried software analysis, written original manuscript, Izaz Ahmad identified the algal species and validate the results, Asghar Khan written, edited and review the manuscript, Sajid Jamir Khan conducted water sampling and physico chemical analysis. Nisha Sharma edited and review the manuscript, Vijay Kumar Chattu edited and review the manuscript, Yogesh K Ahlawat edited and review the manuscript.

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