İSTANBUL UNIVERSITY PRESS

Aquatic Sciences and Engineering

Aquatic Sciences and Engineering,
ASE 2025 , 40 (3): 192–204

https://doi.org/10.26650/ASE2025.1668358
Submitted: 30.03.2025
Revision Requested: 25.04.2025
Last Revision Received: 09.07.2025
Accepted: 11.07.2025

Research Article

Open Access

Seasonal Algal Diversity and Environmental Parameters of Streams of Samur-Yalama National Park, Azerbaijan

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Abstract This study provides the first comprehensive assessment of freshwater algal diversity and ecological status in the streams of Samur-Yalama National Park, Azerbaijan—a region of high biodiversity but limited baseline data. Seasonal surveys in 2023 recorded 46 algal taxa, including 37 first regional records, across ten rivers spanning contrasting hydrochemical environments. Heterokontophyta dominated (69.6% of taxa), with epilithic and benthic habitats supporting the highest diversity. Simpson's Dominance Index (0.120–0.131) and saprobic index (0.69–0.89) indicated high diversity and predominantly oligosaprobic to β-mesosaprobic conditions, reflecting mostly unpolluted, well-oxygenated waters. Principal Component Analysis identified mineralization (sulfate, calcium, TDS) and nutrient gradients as key drivers of algal community structure. Sensitive diatoms such as *Fragilaria capucina* and *Achnanthidium minutissimum* dominated pristine sites, while tolerant taxa like *Gomphonema parvulum* and *Nitzschia palea* increased under moderate enrichment. These findings establish a regional reference for algal-based biomonitoring, highlight the vulnerability of semi-arid stream ecosystems to environmental change, and provide essential baseline data for conservation planning, future monitoring, and ecosystem management in the South Caucasus and comparable dryland regions.

Keywords Biodiversity · Water quality · Freshwater ecosystems · Benthic algae · Macro algae · Phytoplankton

Citation: Abiyev, Y., Mukhtarova, S., Muradova, A., Markova, L. & Hasanova, G. (2025). Seasonal Algal Diversity and Environmental Parameters of Streams of Samur-Yalama National Park, Azerbaijan. *Aquat Sci Eng*, *40*(3), 192-204. https://doi.org/10.26650/ASE2025.1668358

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INTRODUCTION

Freshwater algae—including planktonic microalgae (phytoplankton), benthic microalgae, and macroalgae—play a fundamental role in aquatic food webs and serve as sensitive bioindicators of water quality (Dubey et al., 2022; Stancheva & Sheath, 2016). Phytoplankton alone contribute up to 50% of global primary production, while benthic forms help regulate nutrient dynamics, especially in littoral zones (Catalanotti et al., 2013).

Seasonal variations in light availability, temperature, and nutrient concentrations often drive shifts in algal community structure, favoring opportunistic and bloom-forming taxa—particularly cyanobacteria—under warm, eutrophic conditions (Paerl & Huisman, 2009; Paerl et al., 2011). In addition, water's physicochemical parameters, such as pH, turbidity, conductivity, and dissolved inorganic carbon, exert direct physiological constraints on algal growth and composition. For example, high turbidity reduces light penetration and limits diatom productivity, while silicate enrichment promotes diatom dominance (Smith, 1983; Beardall & Raven, 2016).

Many freshwater algal taxa have evolved stress-resilient life history traits, such as the ability to form dormant cysts or spores under unfavorable conditions like nutrient depletion or thermal extremes, enabling their persistence in fluctuating environments and making them robust ecological indicators (Flores-Moya et al., 2002; Graham et al., 2009).

The Samur–Davachi Lowland of northeastern Azerbaijan, which includes the Samur–Yalama National Park, is projected to experience a 1.5–3.5 °C rise in average temperature and a 10–20% decrease in precipitation by the end of this century (Abbasov et al., 2022). These climatic shifts, coupled with increased water extraction and agricultural runoff, are likely to impact streamflow regimes and nutrient loading—posing new challenges to aquatic biodiversity.

Despite the region's ecological significance, data on freshwater algal communities within these stream systems remain scarce. Previous studies have focused predominantly on vascular flora, leaving a major gap in our understanding of aquatic primary producers and their response to environmental change.

This study aims to fill that gap by integrating algal surveys with environmental measurements to:

- Document the taxonomic diversity and abundance of freshwater algae in selected streams of the Samur–Yalama National Park;
- Quantify key physicochemical parameters—such as nutrient concentrations (N, P, Si), pH, turbidity, and conductivity—and analyze their seasonal variation;
- Use principal component analysis (PCA) to explore relationships between environmental conditions and algal assemblages;

By combining species-level taxonomic identification with multivariate analysis of water quality, this study provides foundational knowledge to support biomonitoring and conservation efforts in Azerbaijan's freshwater ecosystems.

MATERIALS AND METHODS

Study Area

The Samur-Yalama National Park (SYNP; 41°37′33″–41°50′33″N, 48°33′31″–48°47′18″E) spans ca. 200 km² in the Khachmaz District of northeastern Azerbaijan, ~200 km NE of Baku (Abiyev et al., 2025) (Figure 1). The region experiences a semi-arid, temperate-warm climate, with mean annual temperature of 13 °C (range 1–17.5 °C) and annual precipitation of 300–400 mm, resulting in dry summers and mild winters. Major tributaries drain from the Caucasus Mountains into coastal plains, creating diverse lotic habitats.

Sampling Design

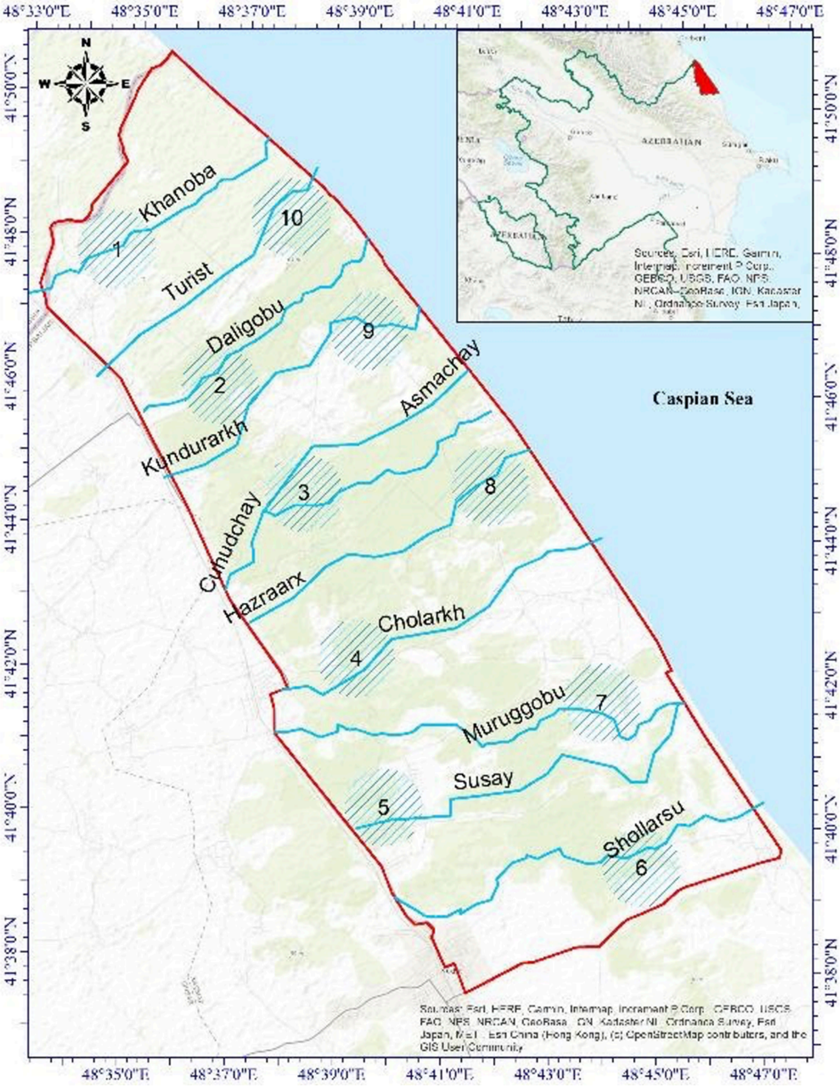
Seasonal sampling (January, April, July, October 2023) was conducted at 10 stream sites: Daligobu, Cuhudchay-Asmachay, Hazraarkh, Muruggobu, Shollarsu, Kundurarkh, Khanoba, Susay, Turist, and Cholarkh. At each site, three replicates of water and algal samples were collected along a 100 m reach to account for spatial heterogeneity.

In situ Measurements

Water temperature (°C) was measured in situ using a mercury thermometer. pH (model pH-200) and dissolved oxygen (DO, mg L^{-1}; MW 600) were determined with portable analyzers. Electrical conductivity (EC, µS cm^{-1}) and total dissolved solids (TDS, mg L^{-1}) were measured using a YK-22CT conductivity meter. Turbidity (NTU) was assessed using a TU2106 turbidimeter. Concentrations of biogenic elements (N, P, Si) were quantified by standard photometric methods as described in APHA (2017). Total suspended solids (TSS, mg L^{-1}) were determined according to Standard Method 2540D (APHA, 2005). Geographic coordinates and stream depth were recorded with a Garmin GPSMAP 64. All measurements and sampling procedures followed established quality control protocols.

Figure 1.

Study area



Water Chemistry Analysis

The samples for nutrient analyses were filtered through 0.45 µm membrane filters and stored at 4 °C until analysis. Concentrations of nitrate (NO_3–N), nitrite (NO_2–N), and ammonium (NH_4–N) were determined colorimetrically using Spectroquant® test kits (Merck) with detection ranges of 0.4–110.7 mg L^{-1} for NO_3–N, 0.02–3.0 mg L^{-1} for NO_2–N, and 0.01–3.0 mg L^{-1} for NH_4–N. Soluble reactive phosphate (SRP) was analyzed according to EPA Method 365.2. Silicate (SiO_2) was measured using the Spectroquant® Silicate Test (detection range: 0.005–5.0 mg L^{-1}). Sulfate (SO_4^{2-}) was determined in accordance with Standard Method 4500-SO_4^{2-} E, while calcium (Ca^{2+}) concentrations were measured by inductively coupled plasma–atomic emission spectrometry (ICP-AES) following EPA Method 6010D.

Algal Sampling and Identification

Phytoplankton samples were collected by vertical net hauls (10–64 µm mesh; flowmeter-calibrated) and preserved with Lugol's solution. Benthic algae were sampled by scraping defined 5 cm² areas of stones and macrophytes; epilithic diatoms via core tube (8 mm × 1 m). Biofilms were suspended and filtered through 20 µm mesh. Macroalgae (e.g., *Chara* spp.) were hand-harvested, rinsed, and weighed. Samples were stored on ice and processed within 24 h.

In the laboratory, algal taxa were identified under an optical microscope (Nikon E100) and SEM (JSM-35) following standard protocols (Van der Werff, 1999; Williams, 1985). Quantitative counts employed the Utermöhl method. Taxonomic references included Afanasyev et al. (2016, 2020) and Nuriyeva (2019).

Diversity and Saprobic Indices

Species dominance was quantified using Simpson's Dominance Index (D), calculated as:

$$D = \sum(\frac{n_i}{N})^2 \qquad (1)$$

where *ni* is the number of individuals of taxon *i*, and *N* is the total number of individuals in the sample (Magurran, 1988; Odum & Barrett, 2005). Values of *D* range from 0 (infinite diversity) to 1 (no diversity).

Organic pollution was assessed via the Saprobic Index (SI), defined as:

$$SI = \frac{\sum s.h}{\sum h} \qquad (2)$$

where *si* is the saprobic value assigned to species *i* (scale 1–4: oligio-, β-meso-, α-meso-, polysaprobic), and *hi* is the frequency of species *i* in samples (Persoone & De Pauw, 1979). Higher *SI* reflects increased organic load.

Classification of saprobic categories follows Zahradkova & Soldan (2008).

Statistical Analysis

Seasonal field data on physical parameters and hydrochemical composition of water collected in 2023 were analyzed using Principal Component Analysis (PCA) in PAST software (v4.13). For accurate results, only variables with normal or log-normal distribution were included in the analysis (Nong et al., 2024).

RESULTS AND DISCUSSION

Taxonomic Composition and Seasonal Distribution

A total of 46 algal species were identified, representing 5 phyla, 8 classes, 20 orders, 26 families, and 30 genera. The taxonomic structure of the studied flora is characterized by the overwhelming dominance of diatoms (Heterokontophyta: *Bacillariophyceae*), accompanied by relevant contributions from green algae (Charophyta, Chlorophyta) and cyanobacteria.

At the phylum level, Heterokontophyta accounted for 69.6% (32 species) of all taxa, forming the dominant group within the community. Charophyta (13.0%) and Cyanobacteria (10.9%) represented the next most abundant phyla, while Chlorophyta (4.3%) and Dinoflagellata (2.2%) were present in low proportions.

Within the class spectrum, *Bacillariophyceae* was strongly predominant (67.4%), reflecting the general pattern observed in freshwater habitats worldwide. *Cyanophyceae* and *Zygnematophyceae* were the leading secondary classes (each comprising 10.9% of the species pool), whereas other classes, including *Xanthophyceae, Charophyceae, Trebouxiophyceae*, and *Dinophyceae*, each accounted for only a single species (2.2%).

At the order and family levels, the highest species richness was recorded for Naviculales (21.7%) and *Naviculaceae* (17.4%), with Bacillariales, Zygnematales, and Oscillatoriales (each 8.7–10.9%) acting as additional key contributors. The most diverse families after *Naviculaceae* included *Stauroneidaceae, Oscillatoriaceae, Cymbellaceae*, and *Spirogyraceae* (each 6.5%).

Regarding the genus spectrum, *Navicula* was the most species-rich genus, comprising 15.2% of all recorded taxa, followed by *Spirogyra* and *Nitzschia* (each 6.5%). Although the total genus richness was relatively high (30 genera), the majority of species belonged to a small number of dominant and subdominant genera.

This taxonomic spectrum demonstrates a markedly polarized community structure, with diatoms clearly dominating both in species richness and ecological role, while green algae and cyanobacteria provide substantial secondary contributions.

A total of 37 algal species marked with an asterisk (*) were newly recorded for the Samur–Yalama region during this study. The majority belonged to Heterokontophyta (73%), followed by Cyanobacteria (14%) and Chlorophyta (11%), while Dinoflagellata was represented by a single species (2%). The dominance of diatoms among the new records reflects the overall taxonomic structure of the studied algal flora. These species were associated with a broad range of habitats, including benthic (*Navicula lanceolata*, *Spirogyra crassa*), epilithic (*Cocconeis placentula* var. *placentula*, *Staurosirella pinnata*), and epiphytic (*Achnanthidium affine*, *Tribonema affine*) environments. Some taxa, such as *Nitzschia palea* and *Chlorella vulgaris*, showed ecological plasticity by occurring in both planktonic and attached communities. This diversity of habitats reflects the substantial microenvironmental heterogeneity in the region's streams. Many of these species are important bioindicators, contributing to water quality assessment and ecological monitoring (Table 1, Figure 2).

Among the identified taxa, epilithic forms were most frequently encountered, followed by benthic and epiphytic taxa; planktonic, epipelic, and periphytic species were less common. Heterokontophyta exhibited the broadest habitat range and dominated both epilithic and benthic communities, reflecting their ecological plasticity. Charophytes were mostly confined to benthic habitats, while cyanobacteria were abundant in epilithic and planktonic niches (Table 1).

Seasonally, Heterokontophyta were present throughout the year, whereas other groups displayed distinct seasonal patterns: Chlorophyta were absent in winter, while Dinoflagellata occurred only in cold seasons. This pattern illustrates that environmental factors, particularly temperature and light, drive algal community succession in the region.

Seven taxa documented by Muxtarova and Muradova (2021) (*Frustulia vulgaris, Navicula cryptotenella, N. oblonga, Pinnularia viridis, Oscillatoria margaritifera, Phormidium ambiguum, Microspora palustris*) were confirmed in this study, indicating community persistence. Earlier charophyte records included *Chara vulgaris* f. *vulgaris* and *C. vulgaris* f. *longibracteata* (Romanov et al., 2025), but only *C. vulgaris* was observed here, suggesting local environmental shifts.

Diversity and Pollution Indices

Simpson's Dominance Index (D) values ranged from 0.120 to 0.131, confirming a high level of algal diversity with no single taxon dominating the assemblages throughout the studied streams. Saprobic Index (SI) values (0.69–0.89) classified the sites as oligosaprobic to β-mesosaprobic, indicating clean to only slightly polluted waters, typically associated with low organic enrichment from minor local inputs (Table 2).

Bioindication based on algal communities further supports these findings: upper reaches of the streams harbored predominantly oligosaprobic diatom species such as *Fragilaria capucina* and *Achnanthidium minutissimum*, well-known for their intolerance to organic pollution and their prevalence in oligotrophic, well-oxygenated environments. In contrast, downstream sites exhibited a subtle increase in organic matter, as reflected by the presence and greater relative abundance of more tolerant taxa such as *Gomphonema parvulum* and *Nitzschia palea*—both classic β-mesosaprobic indicators that flourish under mild organic enrichment and elevated nutrient levels.

The co-occurrence of both sensitive (*Fragilaria*, *Achnanthidium*, *Encyonema*) and tolerant (*Gomphonema*, *Nitzschia*) taxa in some samples highlights the mixed influence of pristine and mildly enriched conditions—a pattern consistent with ecological gradients described in similar Caucasus mountain streams (Neplyukhina et al., 2022). This is further corroborated by the occasional presence of *Chara vulgaris* (Charophyta), a macrophyte known to thrive in clear, calcareous, low-nutrient environments and to disappear under significant eutrophication. Although *Chara* is not typically included in saprobic indices, its persistence provides additional evidence that these streams have not crossed into heavily polluted or eutrophic states (Bellino and Baldantoni, 2023).

Comparative data from regional studies (Barinova and Kukhaleishvili, 2017) show similar upstream–downstream transitions: headwaters classified as oligosaprobic, with lower reaches becoming oligo- to β-mesosaprobic due to slight anthropogenic inputs, but without substantial loss of sensitive taxa or a shift toward full eutrophication. The dominance of Heterokontophyta (over 50% of identified taxa), rapid response of these groups to changes in water quality, and the consistent performance of algal-based indices (including saprobic and trophic Heterokontophyta indices) together provide a robust, evidence-based assessment of ecological condition.

In summary, the integration of structural (Simpson index), functional (Saprobic index), and taxonomic bioindication confirms that the streams of Samur-Yalama National Park are predominantly characterized by low nutrient loads, high oxygenation, and mineral-rich waters. Only minor spatial and seasonal signs of organic enrichment are observed, and the overall ecosystem remains far from critical pollution thresholds.

Hydrochemical Parameters and Seasonal Variation

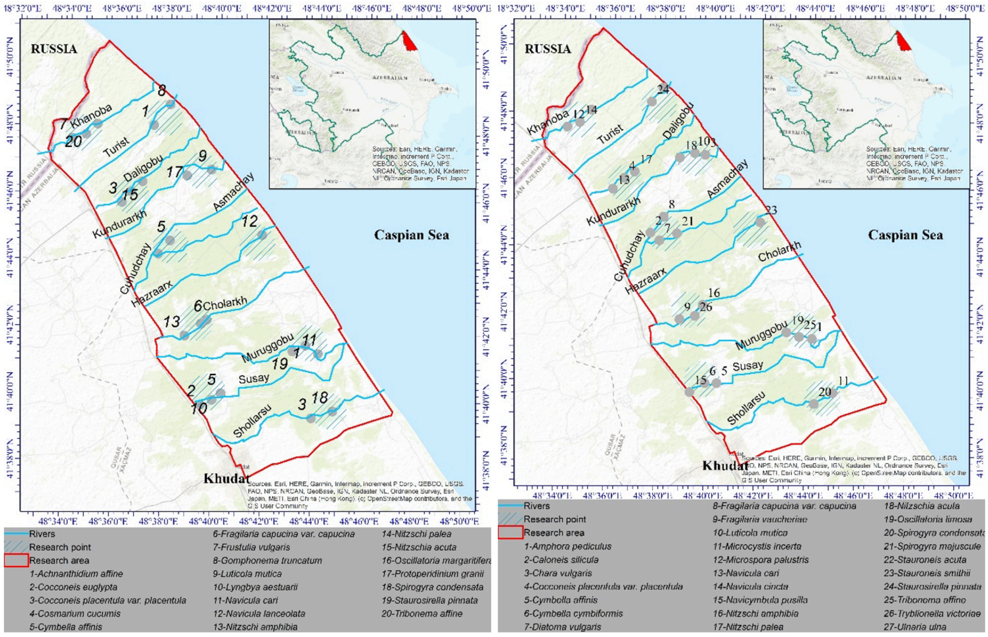
The ecological status of streams in Samur-Yalama National Park was assessed through the analysis of fourteen hydrochemical parameters and their relationships with algal community structure. Water temperature exhibited pronounced seasonal and spatial variation, ranging from 1.4 °C to 21.6 °C (mean: 11.6 °C), with the majority of samples falling within the 7.2–16.8 °C interval. Seasonal averages were 2.6 °C in winter, 13.1 °C in spring, 18.4 °C in summer, and 10.8 °C in autumn.

The first principal component (PC1) accounted for approximately 50% of variance during spring, summer, and autumn, increasing to about 70% in winter. PC1 was strongly and positively correlated with sulfate (SO_4^{2-}), calcium (Ca^{2+}), and total dissolved solids (TDS), and negatively correlated with dissolved oxygen (DO) and turbidity. This axis reflected a mineralization gradient governed primarily by lithological and hydrological characteristics of the catchments (Figure 8).

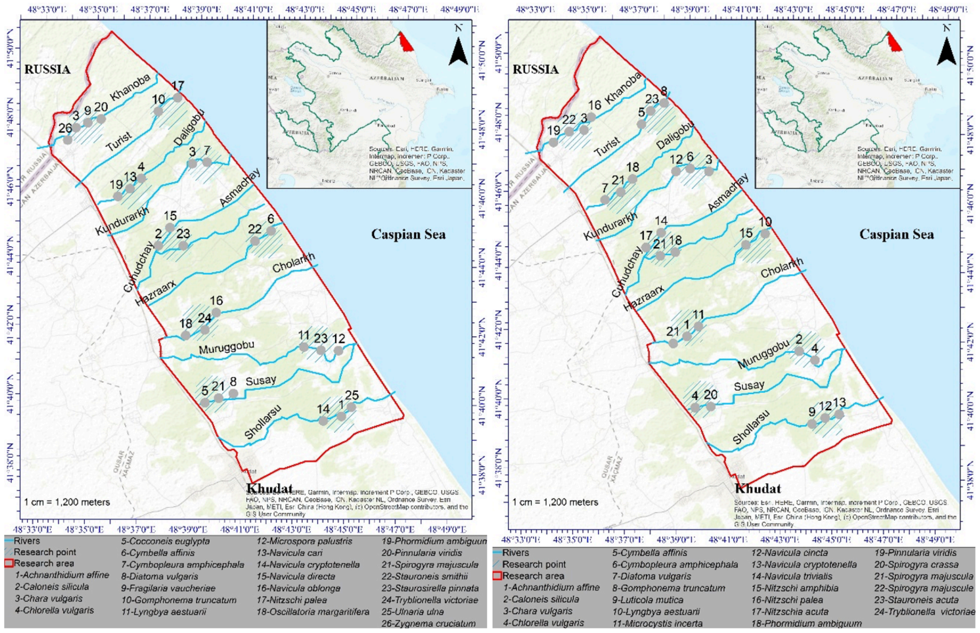
The second principal component (PC2) exhibited season-dependent variation: in winter and summer, PC2 was strongly associated with biogenic nutrients—phosphate (PO_4^{3-}), nitrate (NO_3^-), nitrite (NO_2^-), and silicate (Si)—capturing a nutrient enrichment gradient. Conversely, in spring and autumn, PC2 shifted towards physical parameters such as pH, temperature, and DO, which gained prominence during transitional periods.

Figure 2.

(a-d). Distribution maps of algae due to seasons



a) winter *b) spring*



c) summer *d) autumn*

Thus, the nutrient (biogenic) component became the third most important variance factor in these seasons (Figure 8).

Ordination plots derived from PCA revealed three main river groups based on hydrochemical similarity:

- **Group 1:** Rivers Susay, Muruggobu, and Colarkh exhibited relatively stable water chemistry year-round, characterized by moderate mineralization (350–520 mg L^{-1} TDS), slightly acidic pH, and consistently low nutrient concentrations. These conditions supported diverse and sensitive algal communities typical of oligotrophic to mesotrophic systems (Wetzel, 2001).

These fluctuations directly influenced algal succession: Heterokontophyta such as *Fragilaria capucina* and *Achnanthidium minutissimum* dominated during colder periods, reflecting the well-documented preference of psychrophilic diatoms for low temperatures (Butterwick et al., 2005; Lürling et al., 2018). Under warmer conditions (above 18 °C) led to increased occurrence of filamentous green algae (e.g., *Ulothrix*, *Spirogyra*) and cyanobacteria (*Oscillatoria margaritifera*, *Microcystis incerta*), although diatoms continued to prevail. This pattern is consistent with observations from Caucasus mountain streams and

Table 1.

*Algae species distributed in Samur-Yalama National Park (*it was found for the first time in this research for the region.)*

Family	Species	Habitat	Saprobe
***Heterokontophyta* Moestrup, R.A. Andersen&Guiry**			
Catenulaceae Mereschkowsky	*Amphora pediculus* (Kützing) Grunow*	Benthic	-
Achnanthidiaceae D.G. Mann	*Achnanthidium affine* (Grunov) Czarn*	Epiphytic	o-β
Cocconeidaceae Kützing	*Cocconeis euglypta* Ehrenberg*	Epilithic	-
	Cocconeis placentula var. *placentula* Ehrenberg*	Epilithic	o-β
Cymbellaceae Kützing	*Cymbopleura amphicephala* (Nägeli ex Kützing) Krammer*	Periphytic	o-β
	Cymbella cymbiformis C. Agardh*	Benthic	-
	Cymbella affinis Kütz*	Epilithic	β- o
Diadesmidaceae D.G. Mann	*Luticola mutica* (Kütz.) D.G. Mann in Round, Crawford et Mann	Epipelic	o
Fragilariaceae Kützing	*Fragilaria capucina* Desmazières *	Epilithic, benthic	o
	Fragilaria vaucheriae (Kütz.) J.B.Petersen*	Epiphytic	-
Gomphonemataceae Kützing	*Gomphonema truncatum* Ehrenberg*	Epilithic, benthic	o-x
	Gomphonema parvulum Kütz*		x
Tabellariaceae Kützing	*Diatoma vulgaris* Bory*	Epiphytic	x
Naviculaceae Kützing	*Caloneis silicule* (Ehrenberg) Cleve*	Benthic	x
	Navicula cryptotenella Lange- Bert. In Krammeret Lange-Bert	Epilithic	o-β
	Navicula oblonga (Kütz.) Kütz	Epilithic	β
	Navicula lanceolata (C. Agardh) Ehrenb*	Benthic	x- β
	Navicula cari Ehrenb*	Epilithic, benthic	-
	Navicula directa (W. Smith) Brébisson*	Benthic	o-β
	Navicula trivialis Lange-Bertalot *	Benthic	-
	Navicula cincta (Ehrenb.) Rafls*	Epiphytic, epilithic	-
Bacillariaceae Ehrenberg	*Nitzschia acuta* Hantzsch*	Epiphytic	-
	Nitzschia amphibian Grunov*	Epiphytic	-
	Nitzschia palea (Kütz) W.Sm. *	Planktonic, epiphytic, epilithic	-
	Tryblionella victoriae Grunov*	Epiphytic, epilithic	o-x
Amphipleuraceae Grunow	*Frustulia vulgaris* (Thwaites) De Toni	Epilithic	x- β
Pinnulariaceae D.G. Mann	*Pinnularia viridis* (Nitz.) Ehrenb	Benthic	o-x
Stauroneidaceae D.G.Mann	*Stauroneis acuta* W. Smith*	Benthic	o-x
	Staurosirella pinnata (Ehrenb.) D.M.Williams & Round*	Epilithic	β
	Stauroneis smithii Grunow	Epilithic	-
Ulnariaceae E.J.Cox	*Ulnaria ulna* (Nitzsch) P. Compere*	Planktonic, epilithic	o-α
Tribonemataceae G.S.West	*Tribonema affine* (Kütz.) G. S. West*	Epiphytic	-
***Cyanobacteria* Stanier ex Cavalier-Smith**			
Microcoleaceae O.Strunecky, J.R.Johansen & J.Komárek	*Lyngbya aestuarii* Liebman ex Gomont*	Planktonic, benthic	o
Oscillatoriaceae Engler	*Oscillatoria limosa* Agardh ex Gomont*	Planktonic, epilithic	β
	Oscillatoria margaritifera Kützing ex Gomont*	Benthic	-
	Phormidium ambiguum Gomont ex Gomont*	Epilithic, benthic	β
Microcystaceae Elenkin	*Microcystis incerta* Lemmerm*	Epilithic	β
***Chlorophyta* Reichenbach**			
Microsporaceae Bohlin	*Microspora palustris* Wichmann	Benthic	-
Chlorellaceae Brunnthaler	*Chlorella vulgaris* Beij*	Planktonic	α
***Charophyta* Migula**			
Characeae S.F.Gray	*Chara vulgaris* Linnaeus	Benthic	-
Desmidiaceae Ralfs	*Cosmarium cucumis* Corda ex Ralfs	Benthic	-

Family	Species	Habitat	Saprobe
Spirogyraceae Bessey	*Spirogyra condensate* (Vaucher) Dumort*	Benthic	-
	Spirogyra crassa (Kützing) Kützing*	Benthic	β
	Spirogyra majuscula Kützing*	Planktonic	o-α
Zygnemataceae Kützing	*Zygnema cruciatum* (Vaucher) C.Agardh*	Benthic	x- β
	***Dinoflagellata* Fensome et al.**		
Protoperidiniaceae Bujak&E.H.Davies	*Protoperidinium granii* (Ostenf.) Balech*	Epiphytic, epipelic	-

Table 2.

Seasonal values for main indices

Season	Winter	Spring	Summer	Autumn
D	0.129	0.131	0.129	0.120
SI	0.69	0.85	0.89	0.81

Figure 3.

Seasonal variation in physical parameters of stream. (a) Temperature; (b) Turbidity; (c) Dissolved Oxygen

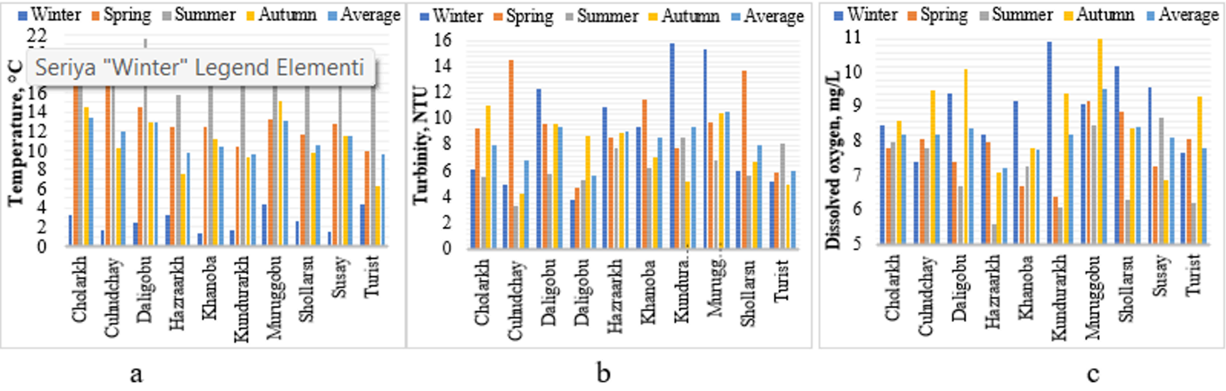
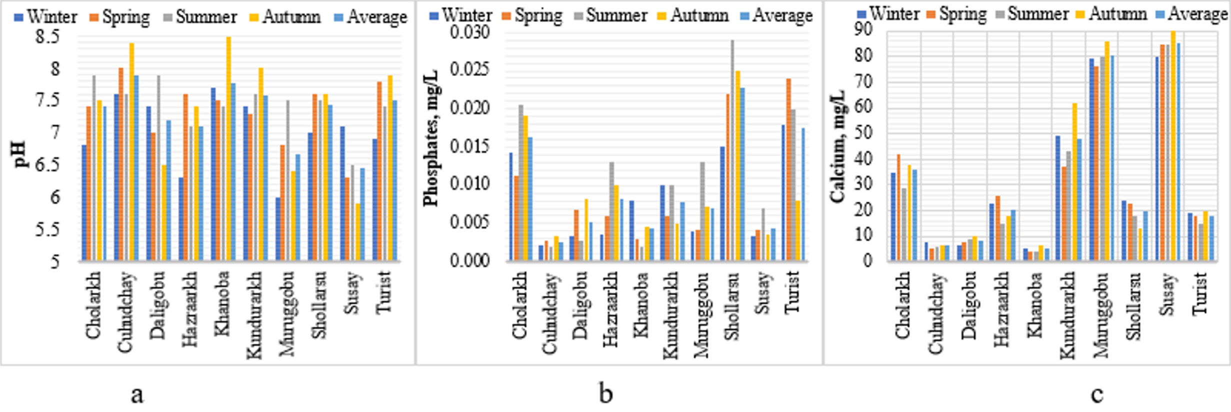


Figure 4.

Seasonal changes in general chemical properties. (a) pH; (b) Electrical Conductivity; (c) TDS



corresponds to global thermal optima for these algal groups (Reinl et al., 2023; Cottingham et al., 2021) (Figure 3).

Dissolved oxygen concentrations ranged from 5.6 to 11.3 mg L^{-1} (mean: 8.2 mg L^{-1}), with the majority of measurements falling within the 7.5–8.6 mg L^{-1} interval. These values reflect consistently well-aerated conditions across all sites and seasons. No significant decline in DO was observed, even during periods of elevated water temperature or increased algal biomass, indicating the absence of strong organic pollution and effective stream aeration (Wetzel, 2001). High dissolved oxygen levels supported diverse communities of diatoms and green algae, including *Staurosirella pinnata*, *Navicula cari*, and *Diatoma vulgaris*, all of which were most abundant at DO concentrations above 7.8 mg L^{-1}. Hypoxia-tolerant taxa were largely absent, further confirming favorable oxygen regimes throughout the study area. The pH of stream waters ranged from 5.9 to 8.5 (mean: 7.26), falling within the 6.9–7.6 interval. Acidic waters favored acidophilic taxa such as *Mougeotia* and *Pinnularia*, while neutral to alkaline conditions promoted greater diversity of diatoms and cyanobacteria. Peak diatom richness was observed at near-neutral pH, with taxa such as *Achnanthidium affine* and *Tryblionella victoriae* frequently occurring within the pH range of 6.0–7.5 (Tasnim et al., 2023; Zepernick et al., 2021) (Figure 3).

Electrical conductivity exhibited substantial spatial variation, ranging from 110 to 1970 µS cm⁻¹ (mean: 575 µS cm⁻¹, median: 315 µS cm⁻¹), and was closely mirrored by TDS (54–520 mg L⁻¹, mean: 219 mg L⁻¹, median: 157 mg L⁻¹) (Figure 4). These two parameters were strongly correlated ($r = 0.87$), reflecting parallel variation in dissolved mineral content across sites. Streams with moderate mineralization supported oligotrophic and sensitive diatom taxa such as *Gomphonema truncatum, Stauroneis smithii*, and *Navicula cryptotenella*. In contrast, sites with higher conductivity and TDS showed increased abundance of euryhaline, halotolerant species, particularly *Navicula oblonga, Fragilaria capucina*, and *Luticola mutica*, alongside filamentous green algae such as *Spirogyra majuscula*.

Lower mineralization correlated with the abundance of sensitive diatoms, while higher values supported β-mesosaprobic indicators (*Nitzschia palea, Gomphonema parvulum*). Turbidity ranged from 3.4 to 22.3 NTU (mean: 8.2 NTU) and total suspended solids (TSS) from 1 to 98 mg L⁻¹ (mean: 29 mg L⁻¹). Moderate to high turbidity favored sediment-tolerant filamentous cyanobacteria and green algae, whereas low turbidity supported a diverse assemblage of benthic diatoms (Sánchez et al., 2013; U.S. EPA, 2019).

Nutrient concentrations were consistently low to moderate, reinforcing the streams' oligotrophic to mesotrophic status. Soluble phosphate ranged from 0.002 to 0.029 mg L⁻¹ (mean: 0.009 mg L⁻¹), with the majority of samples falling within the 0.003–0.013 mg L⁻¹ interval, well below the threshold for phosphorus-limited bloom formation (Vuorio et al., 2020; Ballah et al., 2019). Nitrate varied from 0.08 to 0.48 mg L⁻¹ (mean: 0.26 mg L⁻¹), with most samples between 0.15 and 0.35 mg L⁻¹, and did not approach levels associated with cyanobacterial blooms (Hecky et al., 1993). Ammonium and nitrite concentrations remained consistently low across all sites, with minimal variation detected, further corroborating the absence of recent or ongoing organic pollution events (Elser et al., 1995). Nitrogen limitation likely favored diatom over cyanobacterial dominance, especially in spring and autumn.

The prevailing low-nutrient regime was reflected in the predominance of oligotrophic and sensitive diatom taxa such as *Gomphonema truncatum, Navicula cryptotenella, Stauroneis smithii, Achnanthidium minutissimum*, and *Fragilaria capucina*, as well as green algae like *Spirogyra majuscula* and *Zygnema* spp. Filamentous cyanobacteria, including *Oscillatoria margaritifera*, were only sporadically encountered, mainly at sites with slightly elevated nutrient concentrations (Figure 5).

Major ions including calcium (5.1–91 mg L⁻¹, mean 33 mg L⁻¹), sulphate (14–302 mg L⁻¹, mean 124 mg L⁻¹), and silicate (4–9.8 mg L⁻¹, mean 6.5 mg L⁻¹) varied spatially across the study area (Figure 6). Higher calcium concentrations consistently supported the occurrence of charophytes, particularly *Chara vulgaris* and *Chara contraria*, both indicators of clear, calcareous, low-nutrient waters (Herbst and Schubert, 2018). Sufficient silicate concentrations (typically >5 mg L⁻¹) enabled a robust and diverse diatom flora, including *Achnanthidium minutissimum, Fragilaria capucina*, and *Navicula oblonga*, with no evidence of silicate limitation. Sulphate-rich streams did not show a reduction in overall algal diversity but sometimes favored halotolerant taxa such as *Nitzschia palea* and *Gomphonema parvulum*, as well as green algae like *Ulothrix zonata* and *Spirogyra majuscula* (Kirkwood et al., 2006).

Only variables with normal or log-normal distribution were included to ensure robustness of the multivariate analysis. The first three principal components explained between 78% and 91% of total variance, depending on season (Figure 7).

- **Group 2:** Rivers Turist, Shollarsu, Khanoba, Cuhudchay, and Hazraarkh had low mineralization (TDS 54–194 mg L⁻¹), placing them among the least mineralized streams in the study area. pH conditions ranged from near-neutral to slightly alkaline, with no clear division into distinctly alkaline or acidic groups. Nutrient concentrations were generally low; however, Turist and Shollarsu exhibited relatively elevated phosphate (up to 0.018 mg L⁻¹) and nitrate (up to 0.33 mg L⁻¹) levels compared to other sites.
- **Group 3:** Kundurarkh River displayed intermediate ion concentrations (171–319 mg L⁻¹ TDS) and low nutrient content, while Daligobu River demonstrated pronounced intra-annual hydrochemical variability, shifting from low-mineralization in spring and summer to moderately mineralized, acidic waters in autumn (Wetzel, 2001).

The PCA gradients closely matched the main ecological drivers of algal community structure in the region.

Figure 5.

Seasonal variation of major ions and nutrients I. (a) Nitrate; (b) Phosphate; (c) Calcium

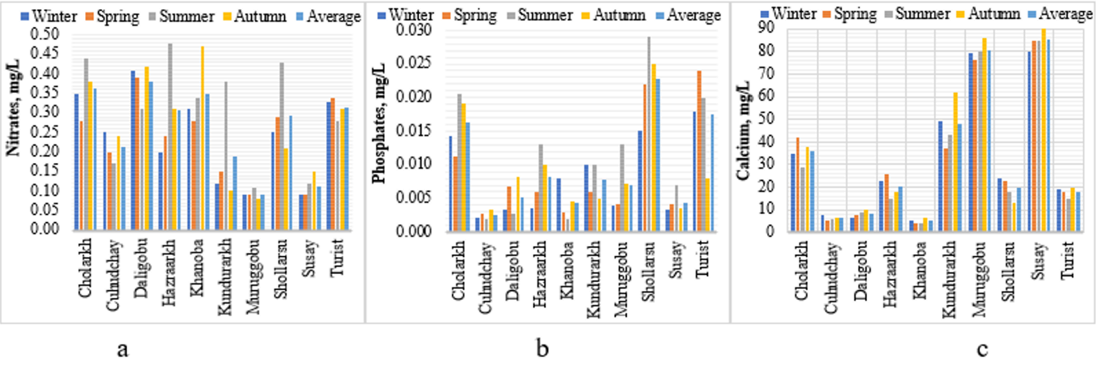


Figure 6.

Seasonal variation of major ions and solids II. a) Slicate; b) Sulphate; c) Total Suspended Solids (TSS)

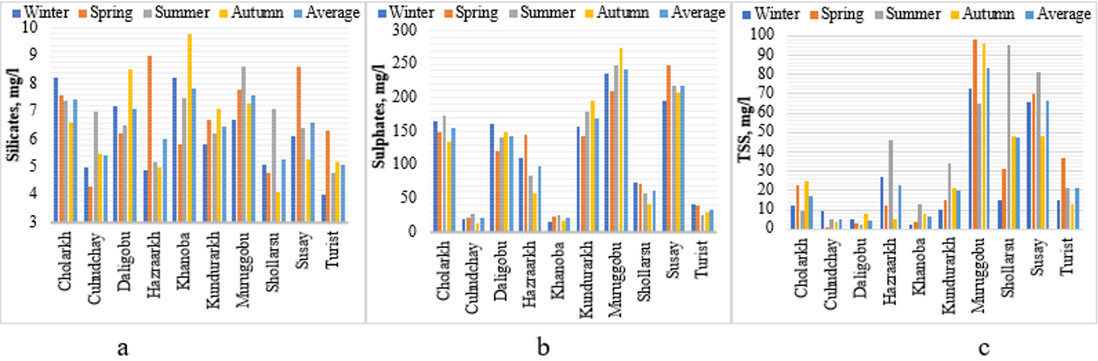
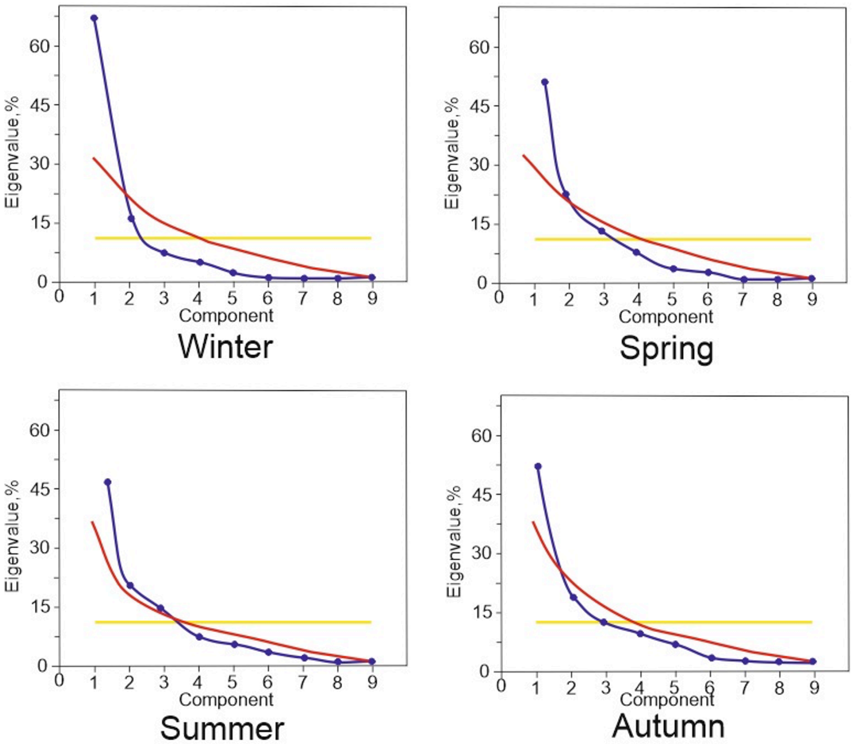


Figure 7.

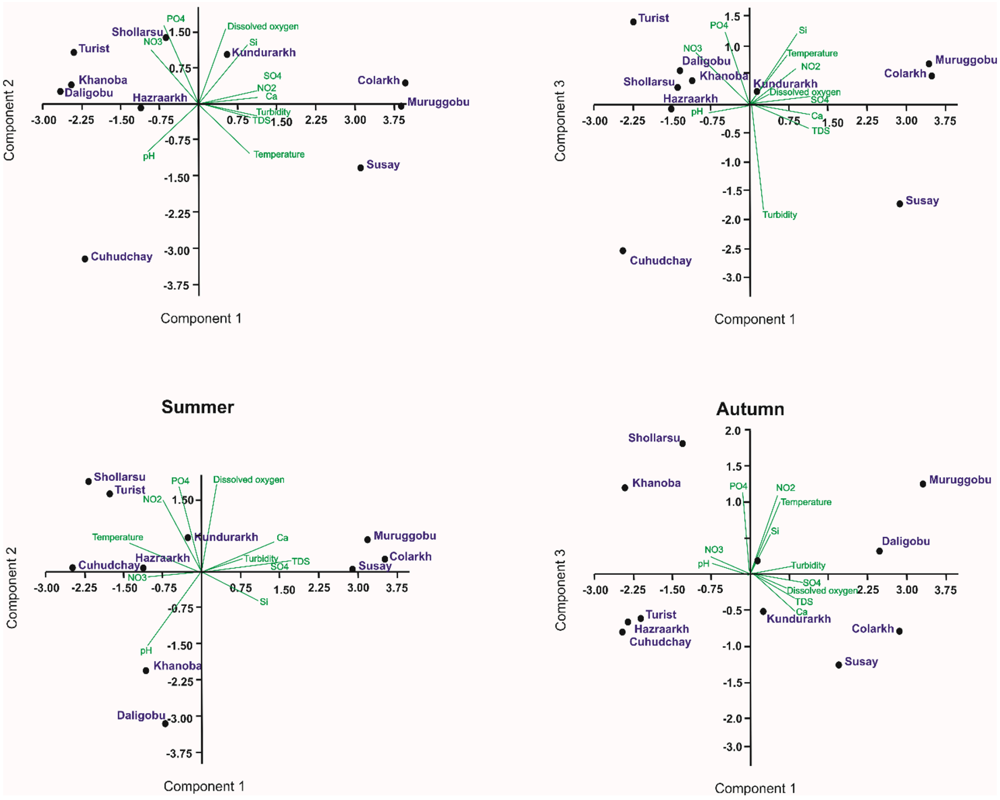
Scree plot of the first three principal components explaining 78–91% of total variance.



PC1's mineralization axis was strongly associated with the distribution of halotolerant and calciphilic taxa, such as *Nitzschia palea* and *Gomphonema parvulum*—both recognized β-mesosaprobic bioindicators tolerant of elevated

Figure 8.

Physical and hydrochemical characteristics of rivers on PCA ordination diagrams.



salinity and organic matter (Stenger-Kovács et al., 2023). Conversely, oligotrophic indicator taxa such as *Fragilaria* spp. and *Achnanthidium* spp. clustered in sites with low mineralization and conductivity (Stenger-Kovács et al., 2023).

PC2, representing nutrient enrichment, influenced taxonomic composition by modulating phosphate and nitrate availability—key factors in algal productivity. Elevated phosphate concentrations, although below bloom-triggering thresholds (<0.03 mg L^{-1}), coincided with increased abundances of pollution-tolerant cyanobacteria (*Oscillatoria* spp.) and green algae (*Chlorella vulgaris*), especially during summer low-flow periods (Barinova et al., 2017). In contrast, streams with lower nutrient loads favored sensitive Heterokontophyta and charophytes, signaling higher ecological quality (Oemke and Burton, 1986; Glibert, 2020)

Integration of these hydrochemical and biological gradients confirms that water chemistry, particularly mineral content and nutrient availability, is the primary determinant of algal assemblages in the Samur-Yalama rivers. While some spatial and seasonal variation occurs, most streams retain a diverse algal flora, with communities reflecting the generally good water quality and only minor evidence of anthropogenic enrichment or ecological stress (Kristiansen, 1996).

CONCLUSION

In conclusion, multivariate analyses revealed two primary hydrochemical gradients—mineralization (SO_4^{2-}, Ca^{2+}, TDS vs. DO, turbidity) and nutrient enrichment (PO_4^{3-}, NO_3^-, Si)—which together explained over 90 % the variance in water chemistry and delineated to three distinct stream groups. Seasonal surveys across ten rivers documented 46 algal taxa, including 37 newly recorded for the region. Sensitive diatoms (e.g., *Fragilaria capucina, Achnanthidium minutissimum*) dominated pristine headwaters, whereas tolerant taxa such as *Gomphonema parvulum* and *Nitzschia palea* prevailed in moderately enriched reaches. These results demonstrate a clear species–environment linkage and confirm the largely oligosaprobic status of Samur-Yalama streams. The study thus establishes a statistically robust baseline for algal-based biomonitoring and provides critical guidance for future conservation and water-management efforts in semi-arid South Caucasus catchments.

Peer Review	Externally peer-reviewed.
Author Contributions	YA: collection of samples, writing, analysis, mapping, SM: supervisor, manuscript review; AM: species identification; LM, PCA. The main rights of the article belong to the responsible author.
Conflict of Interest	The authors have no conflict of interest to declare.

Grant Support The authors declared that this study has received no financial support.

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References

Abbasov, R., Karimov, R., & Jafarova, N. (2022). Ecosystem services in Azerbaijan: Value and losses. Springer. https://doi.org/10.1007/978-3-031-08770-7

Abiyev, Y., Eker, R., Açıl, A., & Coskuner, K. A. (2025). Assessing fire susceptibility of threatened plant species in temperate forest ecosystem of Azerbaijan using Maxent method. *Croatian Journal of Forest Engineering, 46*(1), 141–154. https://doi.org/10.5552/crojfe.2025.2456

Afanasyev, D. F., Kamnev, A. N., Sushkova, E. G., & Steinhagen, S. (2016). The field guide to *Ulva* species found in the Black, Azov, Caspian Seas and eastern Baltic. Pero Publishing House. ISBN: 978-5-906883-16-2

Afanasyev, D. F., Sushkova, E. G., & Kamnev, A. N. (2020). Marine and brackish species of *Cladophoraceae* and *Aegagropila* found in the Ponto-Caspian basin: The field guide. Pero Publishing House. https://repository.marine-research.ru/handle/299011/13575

American Public Health Association (APHA). (2005). Standard methods for the examination of water and wastewater. American Public Health Association.

Ballah, M., Bhoyroo, V., & Neetoo, H. (2019). Assessment of the physico-chemical quality and extent of algal proliferation in water from an impounding reservoir prone to eutrophication. *Journal of Ecology and Environment, 43*, Article 5. https://doi.org/10.1186/s41610-018-0094-z

Barber, J., & Andersson, B. (1992). Too much of a good thing: Light can be bad for photosynthesis. *Trends in Biochemical Sciences, 17*(2), 61–66. https://doi.org/10.1016/0968-0004(92)90104-O

Barinova, S., & Kukhaleishvili, L. (2017). Diversity and ecology of algae and cyanobacteria in the Enguri River, Georgia. *Elixir Bio Science*. 104. 45934-45947).

Beardall, J., & Raven, J. A. (2016). Carbon acquisition by microalgae. In M. A. Borowitzka, J. Beardall, & J. A. Raven (Eds.), The physiology of microalgae (Developments in Applied Phycology, Vol. 6, pp. 89–100). Springer. https://doi.org/10.1007/978-3-319-24945-2_4

Bellino, A., & Baldantoni, D. (2023). Biodiversity, Ecology and Distribution of Mediterranean Charophytes in Southern Italy. *Plants (Basel, Switzerland), 12*(19), 3434. https://doi.org/10.3390/plants12193434

Blankenship, R. E. (2014). Molecular mechanisms of photosynthesis (2nd ed.). Wiley-Blackwell. ISBN 978-1-4051-8975-0

Butterwick, C., Heaney, S. I., & Talling, J. F. (2005). Diversity in the influence of temperature on the growth rates of freshwater algae, and its ecological relevance. *Freshwater Biology, 50*(2), 291–300. https://doi.org/10.1111/j.1365-2427.2004.01317.x

Catalanotti, C., Yang, W., Posewitz, M. C., & Grossman, A. R. (2013). Fermentation metabolism and its evolution in algae. *Frontiers in Plant Science, 4*, 150. https://doi.org/10.3389/fpls.2013.00150

Chen, J., Wang, S., Yan, Z., Zhao, X., Feng, M., Wang, J., & Zhou, Q. (2023). eDNA of zooplankton reveals the ecological community thresholds for key environmental factors in the Baiyangdian Lake aquatic ecosystem. *Environmental Sciences Europe, 35*(1), 91. https://doi.org/10.1186/s12302-023-00761-0

Cottingham, K. L., Weathers, K. C., Ewing, H. A., Greer, M. L., & Carey, C. C. (2021). Predicting the effects of climate change on freshwater cyanobacterial blooms requires consideration of the complete cyanobacterial life cycle. *Journal of Plankton Research, 43*(1), 10–19. https://doi.org/10.1093/plankt/fbaa059

Dubey, D., Kumar, S., & Dutta, V. (2022). *Algae and macrophytes as bioindicators of freshwater ecosystem*. CRC Press. https://doi.org/10.1201/9781003220824-33

Elser, J. J., Bracken, M. E., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., & Smith, J. E. (2009). Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. *Ecology Letters, 10*(12), 1135–1142. https://doi.org/10.1111/j.1461-0248.2007.01113.x

Elser, J. J., Marzolf, E. R., & Goldman, C. R. (1990). Phosphorus and nitrogen limitation of phytoplankton growth in the freshwaters of North America: A review and critique of experimental enrichments. *Canadian Journal of Fisheries and Aquatic Sciences, 47*(7), 1468–1477. https://doi.org/10.1139/f90-165

Elser, J. J., Chrzanowski, T. H., Sterner, R. W., Schampel, J. H., & Foster, D. K. (1995). Elemental ratios and the uptake and release of nutrients by phytoplankton and bacteria in three lakes of the Canadian shield. *Microbial ecology, 29*(2), 145–162. https://doi.org/10.1007/BF00167161

Falkowski, P. G., & Raven, J. A. (2007). Aquatic photosynthesis (2nd ed.). Princeton University Press. https://doi.org/10.1515/9781400849727

Fanton, H., Affre, L., Franquet, E., et al. (2023). Heavy ionic pollution disrupts assemblages of algae, macroinvertebrates and riparian vegetation. *Environmental Pollution, 331*(Part 1), 121791. https://doi.org/10.1016/j.envpol.2023.121791

Flores-Moya, A., Posudin, Y. I., Fernández, J. A., Figueroa, F. L., & Kawai, H. (2002). Photomovement of the swarmers of the brown algae *Scytosiphon lomentaria* and *Petalonia fascia*: Effect of photon irradiance, spectral composition and UV dose. *Journal of Photochemistry and Photobiology B: Biology, 66*(2), 134–140. https://doi.org/10.1016/S1011-1344(02)00233-6

Fourtanier, E., & Kociolek, J. P. (2009). *Catalogue of Diatom Names*. California Academy of Sciences.

Glibert P. M. (2020). Harmful algae at the complex nexus of eutrophication and climate change. *Harmful algae, 91*, 101583. https://doi.org/10.1016/j.hal.2019.03.001

Gollerbach, M. M., & Polyansky, V. I. (1951). *Freshwater algae and their study: Identifier of freshwater algae of the USSR* (Vol. 2). California Academy of Sciences.

Graham, L. E., Graham, J. M., & Wilcox, L. W. (2009). *Algae* (2nd ed.). Benjamin Cummings.

Hao, B., Wu, H., You, J., Xing, W., & Cai, Y. (2021). Biomass and physiological responses of green algae and diatoms to nutrient availability differ between the presence and absence of macrophytes. *Ecological Indicators, 129*, 107987. https://doi.org/10.1016/j.ecolind.2021.107987

Hecky, R. E., Campbell, P., & Hendzel, L. L. (1993). The stoichiometry of carbon, nitrogen, and phosphorus in particulate matter of lakes and oceans. *Limnology and Oceanography, 38*(4), 709–724. https://doi.org/10.4319/lo.1993.38.4.0709

Jin, X., Zhang, Y., Li, Y., & Wang, Z. (2023). Suspended phosphorus pulses (TP ~0.05 mg L^{-1} vs. SRP < 0.01 mg L^{-1}) can sustain bloom events under low-flow conditions. *Science of The Total Environment, 876*, 162669. https://doi.org/10.1016/j.scitotenv.2023.162669

Khalil, S., Mahnashi, M. H., Hussain, M., Zafar, N., Waqar-Un-Nisa, Khan, F. S., Afzal, U., Shah, G. M., Niazi, U. M., Awais, M., & Irfan, M. (2021). Exploration and determination of algal role as bioindicator to evaluate water quality – probing fresh water algae. *Saudi Journal of Biological Sciences, 28*(10), 5728–5737. https://doi.org/10.1016/j.sjbs.2021.06.004

Kirkwood, A.E. and Henley, W.J. (2006). Algal communıty dynamıcs and halotolerance ın a terrestrıal, hypersalıne envıronment. *Journal of Phycology*, 42: 537-547. https://doi.org/10.1111/j.1529-8817.2006.00227.x.

Kristiansen, J. (1996). Dispersal of freshwater algae — a review. *Hydrobiologia* 336, 151–157 (1996). https://doi.org/10.1007/BF00010829

Lilisti, Z., Zamdial, Hartono, D., Brata, B., & Simarmata, M. (2021). The structure and composition of macrozoobenthos community in varying water qualities in Kalibaru waters, Bengkulu, Indonesia. *Biodiversitas, 22*(1), 106–112. https://doi.org/10.13057/biodiv/d220115

Lürling, M., Mello, M. M. E., van Oosterhout, F., de Senerpont Domis, L., & Marinho, M. M. (2018). Response of natural cyanobacteria and algae assemblages to a nutrient pulse and elevated temperature. *Frontiers in Microbiology, 9*, 1851. https://doi.org/10.3389/fmicb.2018.01851

Magurran, A. E. (1988). *Ecological diversity and its measurement*. Princeton University Press.

Muxtarova, Ş. C., & Muradova, A. B. (2021). Xaçmaz və Şabran rayonlarında yerləşən kontinental sututarlarında yayılan diatom yosunların elektron mikroskopik üsullarla öyrənilməsi [Electron microscopic study of diatom algae distributed in continental wetlands located in Khachmaz and Shabran regions]. *Azerbaijan Journal of Botany, 2*, 50–57.

Muniz, I. P. (1990). Freshwater acidification: Its effects on species and communities of freshwater microbes, plants and animals. *Proceedings of the Royal Society of Edinburgh Section B: Biological Sciences, 97*, 227–254. https://doi.org/10.1017/S0269727000005364

Naselli-Flores, L., & Padisák, J. (2023). Ecosystem services provided by marine and freshwater phytoplankton. *Hydrobiologia, 850*, 2691–2706. https://doi.org/10.1007/s10750-022-04795-y

Neplyukhina, A. A., Saifutdinov, R. A., Paskhina, A. A., & Korobushkin, D. I. (2022). Diatom diversity, distribution and ecology in Mediterranean ecosystems of Abrau Peninsula, north-western Caucasus. *Biodiversity data journal, 10*, e89405. https://doi.org/10.3897/BDJ.10.e89405

Nong, X., Guan, X., Chen, L., et al. (2024). Identifying environmental impacts on planktonic algal proliferation and associated risks: A five-year observation study in Danjiangkou Reservoir, China. *Scientific Reports, 14*, Article 21568. https://doi.org/10.1038/s41598-024-70408-4

Nunes, P., Roland, F., Amado, A. M., Resende, N. da S., & Cardoso, S. J. (2022). Responses of phytoplanktonic chlorophyll-a composition to inorganic turbidity caused by mine tailings. *Frontiers in Environmental Science, 9*, Article 605838. https://doi.org/10.3389/fenvs.2021.605838

Nuriyeva, M. A. (2019). Diversity and taxonomic structure of Cyanoprokaryota in the Azerbaijani sector of the Caspian Sea. *Plant & Fungal Research, 2*(2), 2–10.

Odum, E. P., & Barrett, G. W. (2005). Fundamentals of ecology (5th ed.). Thomson Brooks/Cole.

Oemke, M.P., Burton, T.M. (1986). Diatom colonization dynamics in a lotic system. *Hydrobiologia* 139, 153. https://doi.org/10.1007/BF00028099)

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

Paerl, H. W., & Otten, T. G. (2013). Harmful cyanobacterial blooms: Causes, consequences, and controls. *Microbial Ecology, 65*(4), 995–1010. https://doi.org/10.1007/s00248-012-0159-y

Paerl, H. W., Hall, N. S., & Calandrino, E. S. (2011). Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic- and climatic-induced change. *Science of the Total Environment, 409*(10), 1739–1745. https://doi.org/10.1016/j.scitotenv.2010.12.001

Persoone, G., & De Pauw, N. (1979). Systems of biological indicators for water quality assessment (pp. 39–75). ECSC, EEC, EAEC Luxembourg.

Reinl, K. L., Harris, T. D., North, R. L., Almela, P., Berger, S. A., Bizic, M., Burnet, S. H., Grossart, H.-P., Ibelings, B. W., Jakobsson, E., Knoll, L. B., Lafrancois, B. M., McElarney, Y., Morales-Williams, A. M., Obertegger, U., Ogashawara, I., Paule-Mercado, M. C., Peierls, B. L., Rusak, J. A., ... Yokota, K. (2023). Blooms also like it cold. *Limnology and Oceanography Letters, 8*(6), 546–564. https://doi.org/10.1002/lol2.10316

Romanov, R. E., Zhakova, L. V., Efremov, A. N., Konechnaya, G. Y., Boldina, O. N., Afanasyev, D. F., Akatova, T. V., & Melnikov, D. G. (2025). The Charophytes (Characeae, Charophyceae) of the Caucasus. *Plants, 14*(12), Article 1788. https://doi.org/10.3390/plants14121788

Sánchez, M., Pérez, G., Izaguirre, I., & Pizarro, H. (2013). Influence of underwater light climate on periphyton and phytoplankton communities in shallow lakes from the Pampa Plain (Argentina) with contrasting steady states. *Journal of Limnology, 72*(1), 62–78. https://doi.org/10.4081/jlimnol.2013.e6

Schmid, A. M. M. (1994). Aspects of morphogenesis and function of diatom cell walls with implications for taxonomy. *Protoplasma, 181*, 43–60.

Seckbach, J., & Kociolek, P. (2011). *The diatom world*. Springer.

Smith, V. H. (1983). Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. *Science, 221*(4611), 669–671. https://doi.org/10.1126/science.221.4611.669

Stancheva, R., & Sheath, R. G. (2016). Benthic soft-bodied algae as bioindicators of stream water quality. *Knowledge and Management of Aquatic Ecosystems, 417*, Article 15. https://doi.org/10.1051/kmae/2016002

Stenger-Kovács, C., Béres, V. B., Buczkó, K., Tapolczai, K., Padisák, J., Selmeczy, G. B., & Lengyel, E. (2023). Diatom community response to inland water salinization: a review. *Hydrobiologia,* 850(20), 4627–4663. https://doi.org/10.1007/s10750-023-05167-w

Tasnim, N., Karmakar, D., Hasan, R., et al. (2023). Effect of light intensity and pH on cell density assessed by spectrophotometry for the unicellular algae *Chlorella vulgaris*. *American Journal of Plant Sciences, 14*, 472–481. https://doi.org/10.4236/ajps.2023.144031

U.S. Environmental Protection Agency. (2019). National recommended water quality criteria—Aquatic life criteria table (EPA-822-R-19-001). https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

Van der Werff, A. (1999). A new method of concentrating and cleaning diatoms and other organisms. *Verhandlungen des Internationalen Vereins für Limnologie, 12*, 276–277.

Volkova, E. A., Zimens, E. G., & Vishnyakov, V. S. (2020). New taxonomic records of Zygnemataceae (Charophyta) from the Lake Baikal region. *Limnology and Freshwater Biology, 6*, 1090–1100.

Vuorio, K., Järvinen, M., & Kotamäki, N. (2020). Phosphorus thresholds for bloom-forming cyanobacterial taxa in boreal lakes. *Hydrobiologia, 847*, 4389–4400. https://doi.org/10.1007/s10750-019-04161-5

Wehr, J. D., Sheath, R. G., & Kociolek, J. P. (2015). *Freshwater algae of North America: Ecology and classification* (2nd ed.). Academic Press.

Williams, D. M. (1985). Morphology, taxonomy and inter-relationships of the ribbed araphid diatoms from the genera *Diatoma* and *Meridion* (Diatomaceae: Bacillariophyta). *Bibliotheca Diatomologica, 8*, 1–228.

Zahradkova, S., & Soldan, T. (2008). Saprobic system. In S. E. Jorgensen & B. D. Fath (Eds.), *Encyclopedia of Ecology* (pp. 3242–3343). Elsevier BV.

Zepernick, B. N., Gann, E. R., Martin, R. M., Pound, H. L., Krausfeldt, L. E., Chaffin, J. D., & Wilhelm, S. W. (2021). Elevated pH conditions associated with Microcystis spp. blooms decrease viability of the cultured diatom *Fragilaria crotonensis* and natural diatoms in Lake Erie. *Frontiers in Microbiology, 12*, Article 598736. https://doi.org/10.3389/fmicb.2021.598736