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ASSESSMENT OF THE ECOLOGICAL STATE OF THE ARGICHI RIVER (ARMENIA) BASED ON THE MACROPHYTE COMMUNITY

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Abstract
The Argichi River is the most abundant tributary of Lake Sevan and has a rich diversity of macrophyte species. In 2024, a comprehensive study of the Argichi River's macrophyte community was conducted in conjunction with physicochemical and microbiological investigations. The species composition, projective cover, and biomass of macrophytes were assessed under varying levels of anthropogenic impact. The study revealed the characteristics of macrophyte development concerning different environmental conditions. During the study, 36 species of macrophytes and riparian plants were identified, comprising 36.1% hydrophytes, 16.6% helophytes, 27.7% hygrohelophytes, and 19.4% hygrophytes. At the reference sites with minimal anthropogenic pressure and nutrient load, the dominant hydrophyte species was *Ranunculus trichophyllus* Chaix. Along the Argichi River, downstream of the settlements where the river is impacted by both agricultural runoff and sewage discharge, the dominant species were *Potamogeton pusillus* L. and *P. pectinatus* L. The relationships between macrophyte biomass and cover area, and bacteriological and physicochemical variables, were quantified using Pearson correlation analysis. Several macrophyte-based indices were applied to evaluate the river's trophic status, including the Indice Biologique Macrophytique en Rivière (IBMR), Mean Trophic Rank (MTR), and Macrophyte Index for Rivers (MIR). Our research revealed that the IBMR and MTR indices are comparable to the hydrological, physicochemical, and bacteriological parameters, and therefore, are considered the most appropriate tools for evaluating the river's trophic status. Conversely, the MIR index is not acceptable for assessing its ecological state.

Keywords: Cover area; macrophyte biodiversity; mesophilic saprophytic bacteria; physicochemical parameters

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ارزیابی وضعیت بوم‌شناختی رودخانه آرگیچی (ارمنستان) بر اساس جوامع ماکروفیت

هرپینه یپرمیان: مرکز علمی جانورشناسی وهیدرواکولوژی آکادمی ملی علوم جمهوری ارمنستان، ایروان، ارمنستان

لیلیت استپانیان: مرکز علمی جانورشناسی وهیدرواکولوژی آکادمی ملی علوم جمهوری ارمنستان، ایروان، ارمنستان

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ژانان میکرتچیان: مرکز علمی جانورشناسی وهیدرواکولوژی آکادمی ملی علوم جمهوری ارمنستان، ایروان، ارمنستان

اولینا گوکانیان: موسسه هیدرواکولوژی و ماهی شناسی مرکز علوم جانورشناسی و هیدرواکولوژی اکادمی ملی علوم جمهوری ارمنستان، ایروان، ارمنستان

چکیده: رودخانه آرگیچی پرآب‌ترین شاخه فرعی دریاچه سوان است و تنوع غنی‌ای از گونه‌های ماکروفیت دارد. در سال ۲۰۲۴، یک مطالعه جامع درباره جامعه ماکروفیت‌های رودخانه آرگچی همراه با تحقیقات فیزیکوشیمیایی و میکروبیولوژیکی انجام شد. ترکیب گونه‌ای، درصد پوشش تاجی و بیوماس ماکروفیت‌ها تحت سطوح متفاوتی از تأثیرات انسان‌زاد مورد ارزیابی قرار گرفت. نتایج این پژوهش ویژگی‌های رشد و توسعه ماکروفیت‌ها را در ارتباط با شرایط مختلف محیطی آشکار کرد. در طی این مطالعه، ۳۶ گونه از ماکروفیت‌ها و گیاهان ساحلی شناسایی شد که شامل ۳۶/۱ ٪ هیدروفیت،۱۶/۶ ٪ هلوفیت، ۱۷/۷ ٪ هیگروهلوفیت و ۱۹/۴ ٪ هیگروفیت بود. در ایستگاه‌های مرجع با کمترین فشار انسان‌زاد و بار مواد مغذی، گونه هیدروفیت غالب *Ranunculus trichophyllus* Chaix بود. در طول رودخانه آرگیچی، در بخش‌های پایین‌دست سکونتگاه‌ها که رودخانه تحت تأثیر رواناب کشاورزی و تخلیه فاضلاب قرار دارد، گونه‌های غالب *Potamogeton pusillus* L. و *P. pectinatus* L. مشاهده شدند. روابط میان بیوماس و سطح پوشش ماکروفیت‌ها با متغیرهای باکتریولوژیکی و فیزیکوشیمیایی با استفاده از تحلیل همبستگی پیرسون کمی‌سازی شد. چندین شاخص مبتنی بر ماکروفیت برای ارزیابی وضعیت تغذیه‌ای رودخانه به‌کار گرفته شد، از جمله شاخص زیستی ماکروفیت در رودخانه‌ها (IBMR)، رتبه میانگین تغذیه‌ای (MTR) و شاخص ماکروفیت برای رودخانه‌ها (MIR). پژوهش ما نشان داد که شاخص‌های IBMR و MTR با پارامترهای هیدرولوژیکی، فیزیکوشیمیایی و باکتریولوژیکی همخوانی دارند و بنابراین مناسب‌ترین ابزار برای ارزیابی وضعیت تغذیه‌ای رودخانه محسوب می‌شوند. برعکس، شاخص MIR برای ارزیابی وضعیت بوم‌شناختی این رودخانه قابل قبول نیست.

INTRODUCTION

The Armenian territory is covered by a dense network of rivers, most of which are classified as small mountain rivers. 9479 rivers and streams have been registered within the republic, characterized by steep falls and slopes, spring floods, and recharge from rain, meltwater, and groundwater (Chilingaryan & al. 2002). Although these ecosystems have significant self-purification potential (Hovhannisyan 1994), economic development in river basins has led to alterations in the quantitative and qualitative parameters of the natural river flow. As a result, river ecosystems are disturbed, water quality declines, living conditions for aquatic organisms deteriorate, biodiversity is reduced, and the restoration of biological resources becomes more difficult. The lack of plant treatment throughout the republic has contributed to an unfavorable ecological situation in nearly all of Armenia's rivers. This issue is especially critical when river water quality directly affects the water and biological resources of strategically important aquatic ecosystems.

The largest freshwater reserve in the South Caucasus is Lake Sevan, which holds strategic importance for the Republic of Armenia. It stores more than 80 percent of the country's water resources. Twenty-eight rivers and streams flow into the lake, many heavily impacted by human activities (Matishov & al. 2022). Among these, the Argichi River is the most abundant tributary of Lake Sevan. It is characterized by a rich and diverse macrophyte community (Yepremyan & Kobelyan 2015). Macrophytes play a primary role in shaping the structure and functioning of freshwater ecosystems, exerting significant control over their ecological stability. As sensitive bioindicators, riverine plants reflect the environmental conditions of their habitats (Franklin & al. 2008).

Comprehensive studies of the macrophyte community in Armenia have been conducted in recent decades (Yepremyan, 2014; Gabrielyan & al., 2019; Dallakyan & al., 2022; Yepremyan & al., 2022, 2025). The studies have revealed that the Armenian macrophyte community comprises several ecological groups: hydrophytes, helophytes, hygrohelophytes, and hygrophytes. Among these, hydrophyte species that grow in or on water play a crucial role in maintaining primary productivity of hydroecosystems, respond to fluctuations in nutrient levels in the water, and serve as indicators of water quality (Melzer 1999). Helophytes are characterized by their adaptation to marsh and waterlogged soil. They often grow along the edges of water bodies and are vegetation of the transition zone, ensuring the continuity of metabolism and energy flow between aquatic and terrestrial ecosystems (Pankova 2014). Hygrohelophytes belong to an intermediate group; they inhabit damp, waterlogged, slightly inundated, and periodically water-covered areas. These plants expand the range of biodiversity and contribute to the ecological stability of coastal and riverbank zones (Pankova 2014; Savinykh & al. 2017). Hygrophytes (wet plants) are plants that grow in particularly wet areas. They contribute to the accumulation of the soil’s humus layer, act as biological filters that regulate nutrient cycling, and often play an important role in carbon accumulation and storage processes (Pankova 2014).

Despite similarities in species composition of macrophytes among the countries of the region, certain species are either not found in Armenia's aquatic ecosystems or have a limited distribution. Thus, the macrophyte communities in the humid Black Sea climatic conditions of western Georgia are characterized by greater diversity, with helophyte and hygrohelophyte species particularly prevalent. This is largely due to the dense network of rivers and lakes, as well as the abundance of riparian zones (Vishnyakov & Efremov 2024). Iranian macrophyte flora consists of 68 species, from which 80% are hydrophytes (59% are submerged plants, 12% are floating-leaved, and 9% are free floating) and 20% are helophytes (Mehrabian & Nasab 2021). These features are due to the density of the hydrographic network, the diversity of water body types, as well as climatic and landscape variations, which together create unique conditions for the distribution of macrophytes (Vishnyakov & Efremov 2024).

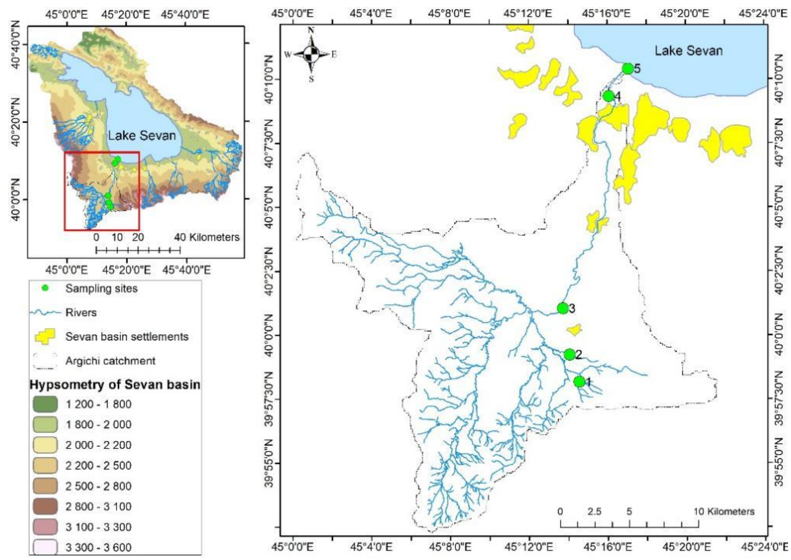
The taxonomic composition, species diversity, cover area, and biomass of macrophytes are widely recognized as key indicators of environmental health. According to the Water Framework Directive (WFD; European Union 2014), the member states of the European Union are obliged to assess and report on the ecological status of all rivers, which shall be determined by the biological quality elements, phytoplankton, macrophytes, and phytobenthos, benthic invertebrate fauna, and fish fauna (Schaumburg & al. 2004). Thus, macrophytes are extensively used to assess the ecological status of aquatic ecosystems.

In this study, we investigated changes in the structure of the macrophyte community in the Argichi River in relation to several hydrological and physicochemical factors. Based on the obtained results and the application of macrophyte-based indices, an assessment of the ecological status of the river was performed.

MATERIALS AND METHODS

Sampling sites

The Argichi River is a small mountain river, yet it has the largest discharge volume among all rivers in the Lake Sevan basin. The river originates on the northern slope of the Gndasar Mountain range in the Geghama volcanic plateau at an elevation of 2600 meters. Its length is 51 km, and the catchment area is 384 km² (Simonyan 2020). Its main sources are meltwater (55%) and groundwater (36%), with peak flow occurring between April and June. In winter, it freezes partly. The annual average discharge is 5.18 m³/s, and the flow is 163 million m³. In its upper reaches, the river flows northward through a swampy area within the depression of the same name, forming river terraces. Near the eastern foothills of Mount Armaghan, it passes through a shallow gorge before eventually flowing into Lake Sevan (Map 1) (Chilingaryan & al. 2002).



Map . 1. The coordinates of the sampling sites of the Argichi River.

The complex seasonal hydroecological investigations were done in spring, summer, and autumn 2024. Seasonal field campaigns were carried out at five sampling sites. Among them, sites A1 and A2 were designated as reference sites, selected as the best available sites, since no ideal reference sites exist on the Argichi River. Sites A3, A4, and A5 are located along the river course. The sampling sites were chosen based on the distribution of pollution sources. (Table 1).

Table 1. The coordinates of the sampling sites of the Argichi River.

Sampling site	Coordinates	
1. Reference site-A1	39°58'20.3"N	45°14'26.8"E
2. Reference site -A2	39°58'31.8"N	45°14'15.9"E
3. Meander-A3	40°00'55.8"N	45°13'34.7"E
4. Village Nerqin Getashen-A4	40°09'23.3"N	45°16'02.0"E
5. River mouth-A5	40°10'10.7"N	45°16'42.1"E

Sampling site A1 is the reference site located relatively close to the source of the Argichi River (Map 1). The anthropogenic effect is minimal, and there are no settlements or livestock farms in this area. The substrate composition consists of approximately 60% river gravel, 20% boulders, 10% sand, 5% cobblestones, and 5% silt. Sampling site A2 is also considered a reference site due to its low level of anthropogenic impact. (Map 1). At this site, 60% of the soil consists of large boulders, and 40% is composed of river gravel. The riverbed was covered with macrophyte vegetation.

Sampling site A3 is located in the middle stream of the river, where the number of livestock barns has increased (Map 1). At this site, the river flows through a flat area, forming meanders that reduce flow velocity and raise water temperature. The soil composition consists of 60% river gravel, 5% cobble, 3% rock fragments, 12% silt, and 20% sand. Approximately 90% of the riverbed is covered with macrophytes. Sampling site A4 is situated in the densely populated Nerkin Getashen village, where anthropogenic influences are significant (Map 1). The soil here is primarily composed of gravel (60%), with additional amounts of sand, silt, and cobble. The river periodically floods this area, and the left bank remains predominantly wet. Sampling site A5 is located downstream and relatively close to the river mouth (Map 1). The river flows through a forested area. The soil consists mainly of boulders, gravel, and sand, with 15% silt. Relevant hydrochemical, hydrobiological, microbiological, and other methods have been used to assess the state of river ecosystems.

Macrophyte community investigations

The macrophyte community was studied using standard methods (CEN 14184:2003; WDF-UKTAG 2014; Di Franco 2019). Sampling was conducted in spring, summer, and autumn. Samples were collected from an area of 100 m² at each river station with 5 repetitions (Di Franco 2019). The study included all ecological groups of macrophytes (hydrophytes, helophytes, hygrohelophytes, and hygrophytes, as well as mosses and macroalgae).

In the field, the percentage range of projective cover for each macrophyte species was determined using a nine-point scale (Table 2) (Holmes & al. 1999). Macrophyte abundance was assessed using the “Kohler method” (Table 2) (Engloner 2012).

Table 2. Projective cover and abundance scale of the macrophytes.

Scale	Projective Cover (%)
1	< 0.1
2	0.1 – 1
3	1 – 2.5
4	2.5 – 5
5	5 – 10
6	10 – 25
7	25 – 50
8	50 – 75
9	> 75

Score	Abundance Description
1	Rare
2	Occasional
3	Frequent
4	Abundant
5	Very abundant

The collections of the study materials are stored in the herbaria of the Institute of Hydroecology and Ichthyology of the Scientific Center of Zoology and Hydroecology, NAS RA. The macrophytes were classified in the laboratory conditions using keys and guides as well as nomenclature of scientific plant names based on The Plant List (Euro + Med Plant Base 2006; European Nature Information System 2016; Global Biodiversity Information Facility 2001).
Based on the collected data, the trophic level of the river was assessed using the Macrophyte Index for Rivers - MIR (Szoszkiewicz & al. 2019), French Indice Biologique Macrophytique en Rivière - IBMR (Haury & al. 2006), and Mean Trophic Rank Index - MTR (Holmes & al. 1999) (Table 3).

Table 3. Color scale table of the trophic status of the river with macrophytes. Abbreviations: MIR= Macrophyte Index for Rivers; IBMR= Indice Biologique Macrophytique en Rivière; MTR= Mean Trophic Rank Index.

MIR	IBMR (Trophic status)	Ecological status
MIR >44.5	IBMR ≥ 14 (very low)	High
35-44.5	14 ≥ IBMR >12 (low)	Good
25.4-35	12≥IBMR>10(medium)	Moderate
18.8-25.4	10 ≥ IBMR >8 (high)	Poor
MIR<15.8	**IBMR ≤ 8 (very high)**	**Bad**

MTR	Trophic status
MTR>65	Low level of eutrophication
25-65	There is a risk of eutrophication
MTR<25	**Eutrophic state**

Hydrochemical investigations

In parallel with macrophyte sampling, water samples were collected for chemical and microbiological analyses. Water velocity and temperature were measured at the sampling site. Dissolved oxygen (DO) and pH were measured on-site using a Milwaukee pH 56PRO Waterproof pH meter (USA) and a Milwaukee MW 600 Dissolved Oxygen meter (USA). Nutrient concentrations were measured in the laboratory using a UV 68 TOUCH spectrophotometer (USA), following standard ISO methods: ISO 6777:1984 for nitrite nitrogen, ISO 7890-3:1988 for nitrate nitrogen, and ISO 6878:2004 for phosphate phosphorus. Ammonium nitrogen was analyzed by Nessler's reagent colorimetry method (Wang & al. 2019). The ecological status of surface waters in the rivers was assessed according to the Government Decision of RA No. 75-N on January 27, 2011 (Table 4).

Table 4. Color scale table of ecological status and classes according to the Government Decision No.75-N, 2011.

Ecological status	Class
High	I
Good	II
Moderate	III
Poor	IV
Bad	**V**

Microbiological investigations

The microbiological investigations were conducted following the methods accepted in hydrobiology (GOST 51592-2000; Pruntova & Sakhno 2005; Namsaraev & al. 2006; Larionova & al. 2010; Leonova 2012). Sampling was performed using sterile containers. Planting and growth of mesophilic saprophytic bacteria were carried out on solid media at temperatures of +35 - +37°C. Following the spread plate method, the number of mesophilic saprophytic bacteria in river water was determined using a nutrient medium prepared from dry nutrient agar. Two replicates of each sample, each 0.1 mL, were plated. The morphological and growth characteristics of the saprophytic bacteria were then studied according to standard microbiological methods (Zvyagintsev & al.

1980). To assess the sanitary quality of water, both mesophilic bacteria (incubation temperature: +37°C) and fecal coliforms (E. coli) were studied (Pravosudova & Melnikov 2014). Based on the quantitative values of bacteria grown on nutrient media, water quality was evaluated according to Romanenko's Ecological and Sanitary Assessment of Surface Waters (Romanenko & al. 1990) (Table 5).

Table 5. Color scale table of ecological status based on bacteriological parameters as reported by Romanenko's Ecological and Sanitary Assessment of Surface Waters.

Ecological status	E. coli cell/ L	Mesophilic bacteria cell/ L
High	1-30	1-100
Good	30-2000	100-1000
Moderate	2100-10000	1100-5000
Poor	11000-100000	5100-10000
Bad	**>100000**	**>10000**

Data analysis

The correlations between the bacteriological and physicochemical parameters with macrophyte biomass and projective cover were calculated using the Pearson correlation method (Cohen & al. 2013).

All tables presenting quantitative data are enhanced with color-coding in the form of heatmaps to visually represent water quality based on the variation of the measured parameters.

RESULTS & DISCUSSION

Macrophytes of the river

Macrophytes are one of the basic elements used in assessing and classifying the ecological status of the hydroecosystems. They are considered reliable indicators of water quality because of their sensitivity to changes in the aquatic environment (Kolada 2010).

Based on the results of our study, a total of 36 species of macrophytes and riparian plants were identified, representing 23 families and 28 genera. Of these, 36.1% were hydrophytes, 16.6% helophytes, 27.7% hygrohelophytes, and 19.4% hygrophytes. The highest species richness was recorded within the families Cyperaceae, Poaceae, and Potamogetonaceae. Spatial variation in dominant species, biomass, and vegetative cover was observed along the river, influenced by differences in flow velocity, substrate characteristics, and nutrient availability

In the reference site A1, where the anthropogenic pressure and nutrient load are minimal, we observed an insignificant amount of biomass of the hydrophyte macrophytes. The main hydrophyte species was *Ranunculus trichophyllus* Chaix ex Vill (Fig.1), which had a cover area of 10% and a biomass of 500g/m^2 in the summer. Riparian vegetation, which prefers humidity, has also been observed in this section of the river. In total, we identified 15 species of aquatic plants: 8 hygrohelophytes, 4 hygrophytes, and 2 hydrophyte species. In the riparian zone, during the maximum growth period of macrophytes in summer, the dominant species in terms of cover area was a hygrohelophyte species, *Catabrosa aquatica* (L.) P. Beauv., while in terms of biomass, the dominant was a hygrophyte species, *Berula erecta* (Huds.) Coville (Table 6). At this sampling site, we also recorded the presence of hygrohelophyte species *Mentha aquatica* L., which, according to earlier studies, had not been previously reported in this region (Yepremyan & Kobelyan, 2015; Gabrielyan & al. 2019).

At sampling site A2, where the level of anthropogenic impact is low, 19 species of aquatic plants were recorded. Among these, five were hydrophyte species: *Cladophora glomerata* (L.) Kütz., *Lemna minor* L., *Persicaria amphibia* (L.) Gray, *Enteromorpha intestinalis* (L.) Link, and *Ranunculus trichophyllus* Chaix. *Ranunculus trichophyllus* remained the dominant species, with both its cover area and biomass increasing. In summer, its macrophyte cover reached 25% and biomass reached 1500 g/m². In addition to hydrophytes, we recorded 9 hygrohelophyte species and 5 hygrophyte species. The dominant species was *Veronica anagallis-aquatica* L., which is a hygrohelophyte species. At this site, the *Mentha aquatica* L. species was observed, but represented by a small population (Table 6).

Along the Argichi River, the highest species richness was recorded at sampling site A3. Out of the 36 species, 11 hydrophyte species were present in this sampling site: *Ceratophyllum demersum* L., *Cladophora glomerata* (L.) Kütz., *Fontinalis antipyretica* Hedw., *Lemna minor* L., *L. trisulca* L., *Myriophyllum spicatum* L., *Potamogeton pectinatus* L., *P. pusillius* L. (Figs. 1 & 2; Table 6). In this section of the river, meanders reduced the flow velocity and promoted the accumulation of biogenic elements, thereby creating favorable conditions for the development of macrophytes. The total macrophyte cover area at this sampling site reached 100% with a biomass of 5502 g/m² during the summer (Table 6). *Ranunculus trichophyllus* was the dominant hydrophyte species both in summer (cover area is 25%, biomass is 800 g/m^2) and autumn (cover area is 20%, biomass is 1000 g/m^2). Additionally, *Potamogeton pusillus* L. was dominant in summer, with a cover area of 80% and biomass of 1100 g/m^2. In this section, on the left bank of the river, we also recorded the rare hydrophyte species *Groenlandia densa* Fourr. (Fig. 2; Table 6). In Armenia, this species has only been found in the Sevan catchment basin and is listed in the Red Book of plants of Armenia (2010). Furthermore, 1 helophyte and 3 hygrohelophyte species in very low abundance were recorded at this sampling site. Sampling sites A4 and A5 are located downstream of the settlements (Verin Getashen and Nerqin Getashen villages), where the river is impacted by both agricultural runoff and sewage discharge. These factors have influenced the composition and development of the river's plant communities. At sampling site A4, three hydrophyte species were recorded: *Fontinalis antipyretica* Hedw., *Ranunculus trichophyllus* Chaix, and *Potamogeton pusillus* L. The dominant species was *Potamogeton pusillus* (projective cover is 20%, biomass is 1000 g/m^2) (Fig.2). Furthermore, 4 helophytes, 5 hygrohelophytes, and 1 hygrophyte species were also recorded at this sampling site. Among them *Eleocharis palustris* (L.) Roem hygrohelophyte species was dominant (Table 6). At sampling site A5, we recorded 25 species of macrophytes, including 8 hydrophytes, 4 helophytes, 6 hygrohelophytes, and 6 hygrophyte species. Among the hydrophytes *Potamogeton pectinatus* L. (projective cover is 15%, biomass is 1000 g/m^2) and *Potamogeton pusillus* L. (projective cover is 10%, biomass is 800 g/m^2) were dominant species. Both species are classified as α-mesosaprobic species (Table 6).

Fig. 1. A, *Ranunculus trichophyllus*; B, close-up image of (1), *R. trichophyllus* & (2), *Potamogeton pectinatus*; C, *R. trichophyllus* (herbarium specimens); D, *P. pectinatus*.

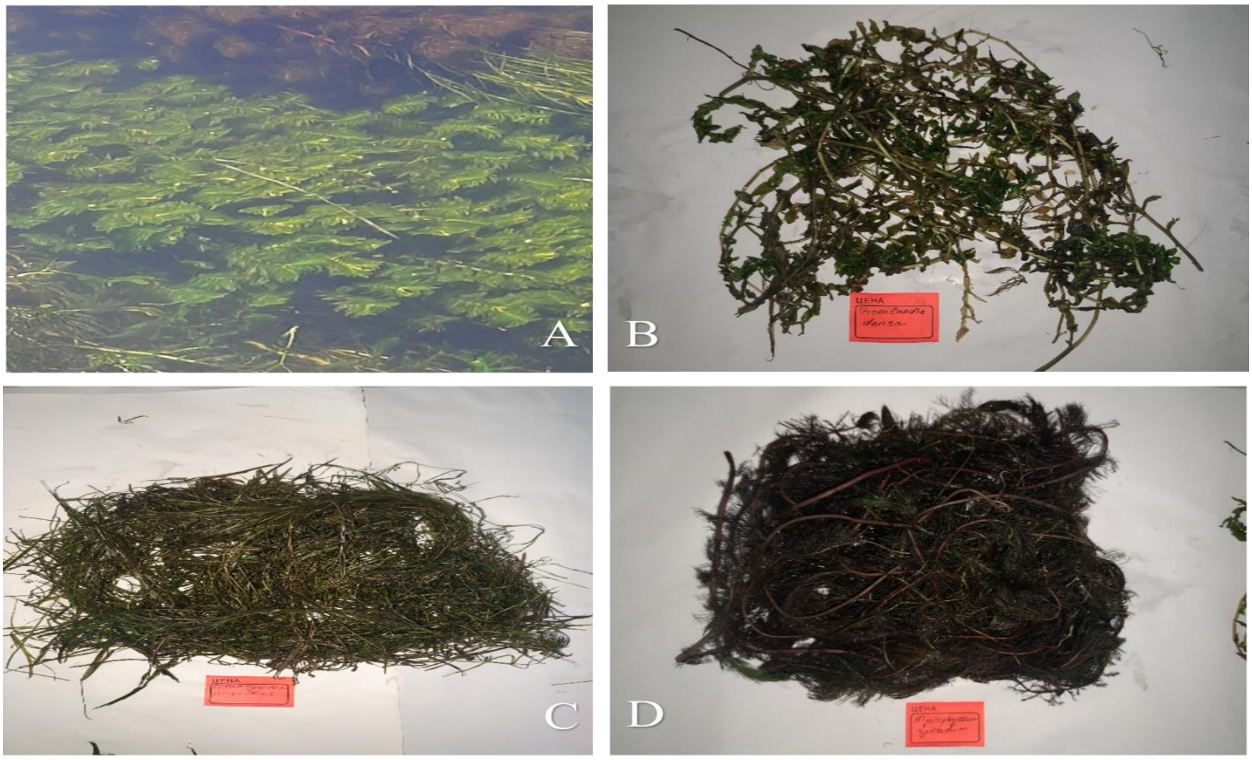


Fig. 2. A & B, *Groenlandia densa*.; C, *Potamogeton pusillus*; D, *Myriophyllum spicatum*.

Our results show that in the reference sections, the macrophyte community is primarily dominated by *Ranunculus trichophyllus*, a β-mesosaprobic species adapted to well-oxygenated, flowing waters with low nutrient demands (Chambers & al. 2008). This species is notably absent in nutrient-rich rivers like the Hrazdan River (Yepremyan & al. 2025). Furthermore, *Ranunculus trichophyllus* has a wide spread distribution and has been reported not only in Armenia but also in the floras of neighboring countries, including Iran and Turkey (POWO 2025). The dominant hydrophyte species in the middle section of the river were *Ceratophyllum demersum*, *Cladophora glomerata*, and *Potamogeton pectinatus.* These species have a wide distribution range, indicating their broad ecological adaptability (GBIF, 2001). *Ceratophyllum demersum* has also been recorded in the northern regions of Iran, where it has been studied using both morphological and molecular markers (ISSR and SRAP), confirming the stability of its distribution in the region (Bahadori & al. 2022). The rare species *Groenlandia densa* was found exclusively in a microhabitat along the left bank of this section, highlighting localized ecological differences between the riverbanks. The flow on the left bank is relatively fast, which prevents nutrient accumulation, and the species composition of macrophytes is poorer here.

However, *Groenlandia densa* is characterized as a submerged species that prefers flowing conditions. In contrast, the right bank, characterized by slower flow and greater nutrient accumulation, supported a higher diversity of hydrophytes. This pattern reflects the combined influence of hydrological conditions and nutrient availability. Although *Groenlandia densa* is listed in the Red Book of Plants of Armenia (2010), it has a relatively wide distribution in Western Asia and has been reported in neighboring countries such as Iran and Turkey (Dinarvand & al. 2022). Downstream sections of the river are subject to increased anthropogenic pressures, resulting in a shift in community composition toward α-mesosaprobic species such as *Potamogeton pectinatus* and *P. pusillus*. These species are typically eurybionts, exhibiting broad ecological tolerance and a preference for substrates enriched with biogenic elements and slower-flowing water bodies. Having a cosmopolitan distribution and occurring across nearly all climatic regions (Pilon & al. 2002), they have been the subject of numerous studies in temperate areas (Hootsmans 1999), the southern Mediterranean region (Ebrahem & al. 2013), South Africa (Asaeda & al. 2001), and Western Asia (Dinarvand & al. 2022).

Table 6. List of macrophyte species, their ecological groups, and the values of projective cover (%) and biomass. Symbols: I, hydrophytes; II, helophytes; III, hygrohelophytes; IV, hygrophytes; *The species is in small numbers; - indicates the species has not been identified.

Sampling site			**Spring**		**Summer**		**Autumn**	
Family	**Species**	**Ecological Group**	**Projective cover (%)**	**Biomass (g/m²)**	**Projective cover (%)**	**Biomass (g/m²)**	**Projective cover (%)**	**Biomass (g/m²)**
	A1							
Ranunculaceae	*Ranunculus trichophyllus* Chaix	I	-	-	10	500	2	120
Apiaceae	*Berula erecta* (Huds.) Coville	IV	0.5	15	2	180	4	340
Ranunculaceae	*Caltha palustris* L.	III	0.1	6	3	58	-	-
Cyperaceae	*Carex riparia* Curtis	III	1	15	3	45	1	15
Cyperaceae	*Carex vesicaria* L.	III	1	10	3	38	2	20
Poaceae	*Catabrosa aquatica* (L.) P.Beauv.	III	1	18	5	45	2	25
Equisetaceae	*Equisetum palustre* L.	III	0.2	8	2	35	2	20
Poaceae	*Glyceria fluitans* (L.) R.Br.	III	0.5	8	5	40	2	25
Lamiaceae	*Mentha aquatica* L.	III	0.5	12	2	38	-	-
Lamiaceae	*Mentha longifolia var. asiatica* (Boriss.) Rech.f.	IV	1	10	2	42	2	80
Boraginaceae	*Myosotis palustris* (L.) Lam.	IV	0.1	5	1	15	-	-
Polygonaceae	*Persicaria amphibia* (L.) Gray	I	0.2	6	2	22	-	-
Polygonaceae	*Persicaria hydropiper* (L.) Spach	IV	1	13	4	26	2	15
Plantaginaceae	*Veronica beccabunga* L.		0.5	14	2	15	-	-
Plantaginaceae	*Veronica anagallis-aquatica* L.	III	1	18	10	98	5	50
	A2							
Cyperaceae	*Carex acuta* L.	III	-	-	2	50	-	-
Cyperaceae	*Carex riparia* Curtis	III	0.5	10	2	32	2	25
Cyperaceae	*Carex vesicaria* L.	III	-	-	2	35	2	20
Poaceae	*Catabrosa aquatica* (L.) P.Beauv.	III	1	12	2	15	2	18
Cladophoraceae	*Cladophora glomerata* (L.) Kütz.	I	-	-	2	25	8	340
Equisetaceae	*Equisetum palustre* L.	III	-	-	2	17	-	-
Cyperaceae	*Eleocharis palustris* (L.) Roem. & Schult.	III	-	-	3	32	2	15
Ulvaceae	*Enteromorpha intestinalis* (L.) Link	I	-	-	-	-	1	6
Poaceae	*Glyceria fluitans* (L.) R.Br.	III	0,5	8	1	18	2	35
Araceae	*Lemna minor* L.	I	-	-	1	5	1	3
Juncaceae	*Juncus inflexus* L.	IV	-	-	2	13	-	-
Lamiaceae	*Mentha aquatica* L.	III	0,5	10	5	25	-	-
Lamiaceae	*Mentha longifolia* var. *asiatica* (Boriss.) Rech.f.	IV	1	12	3	45	3	60
Boraginaceae	*Myosotis palustris* (L.) Lam.	IV	0,2	5	1	5	-	-
Polygonaceae	*Persicaria amphibia* (L.) Gray	I	0,2	5	-	-	-	-
Polygonaceae	*Persicaria hydropiper* (L.) Spach	IV	1	13	2	15	3	20
Ranunculaceae	*Ranunculus trichophyllus* Chaix	I	-	-	25	1500	3	250
Brassicaceae	*Rorippa amphibia* (L.) Besser	IV	-	-	0,5	8	1	15
Plantaginaceae	*Veronica anagallis-aquatica* L.	III	1	20	5	80	10	850
	A3							
Butomaceae	*Butomus umbellatus* L.	II	-	-	-	5	8	20
Cyperaceae	*Carex riparia* Curtis	III	1	13	2	15	-	-
Poaceae	*Catabrosa aquatica* (L.) P.Beauv.	III	-	-	2	10	1	30
Ceratophyllaceae	*Ceratophyllum demersum* L.	I	-	-	10	400	3	100
Cladophoraceae	*Cladophora glomerata* (L.) Kütz.	I	5	250	2	80	2	200
Fontinalaceae	*Fontinalis antipyretica* Hedw.	I	7	520	5	450	-	-
Potamogetonaceae	*Groenlandia densa* (L.) Fourr.	I	-	-	20	670	-	-
Araceae	*Lemna minor* L.	I	15	20	30	30	2	3
Araceae	*Lemna trisulca* L.	I	15	18	50	65	2	15

Table 6- continued:

Sampling site			**Spring**		**Summer**		**Autumn**	
Family	**Species**	**Ecological Group**	**Projective cover (%)**	**Biomass (g/m2)**	**Projective cover (%)**	**Biomass (g/m2)**	**Projective cover (%)**	**Biomass (g/m2)**
Haloragaceae	*Myriophyllum spicatum* L.	I	0,2	35	15	402	5	400
Polygonaceae	*Persicaria amphibia* (L.) Gray	I	1	5	5	25	1	35
Potamogetonaceae	*Potamogeton pectinatus* L.	I	-	-	10	700	2	300
Potamogetonaceae	*Potamogeton pusillus* L.	I	-	-	80	1100	1	10
Plantaginaceae	*Veronica anagallis-aquatica* L.	III	2	25	2	30	-	-
Ranunculaceae	*Ranunculus trichophyllus* Chaix	I	25	800	80	1400	20	1000
	A4							
Alismataceae	*Alisma plantago-aquatica* L.	II	1	15	2		2	80
Cyperaceae	*Carex vesicaria* L.	III	2	10	4	45	2	30
Cyperaceae	*Carex riparia* Curtis	III	2	10	-	-	-	-
Poaceae	*Catabrosa aquatica* (L.) P.Beauv.	III	1	10	-	-	2	20
Fontinalaceae	*Fontinalis antipyretica* Hedw.	I	-	-	5	120	-	-
Poaceae	*Glyceria maxima* (Hartm.) Holmb.	IV	-	-	2	52	2	23
Amblystegiaceae	*Leptodictyum riparium* (Hedw.) Warnst.	II	-	-	5	68	3	35
Potamogetonaceae	*Potamogeton pusillus* L.	I	-	-	20	800	-	-
Brassicaceae	*Rorippa amphibia* (L.) Besser	II	-	-	2	40	1	25
Ranunculaceae	*Ranunculus trichophyllus* Chaix	I	-	-	1	20	2	30
Equisetaceae	*Equisetum palustre* L.	III	0,5	8	5	80	-	-
Cyperaceae	*Eleocharis palustris* (L.) Roem. & Schult.	III	-	-	3	45	1	8
Typhaceae	*Sparganium erectum* L.	II	-	-	-	-	2	500
	A5							
Alismataceae	*Alisma plantago-aquatica* L.	II	0,1	3	1	15	5	30
Cyperaceae	*Carex riparia* Curtis	III	1	5	-	-	-	-
Poaceae	*Catabrosa aquatica* (L.) P.Beauv.	III	1	5	2	12	5	25
Cladophoraceae	*Cladophora glomerata* (L.) Kütz.	I	0,1	6	2	50	2	30
Cyperaceae	*Eleocharis palustris* (L.) Roem. & Schult.	III	-	-	2	13	-	-
Equisetaceae	*Equisetum palustre* L.	III	0,2	3	2	10	-	-
Poaceae	*Glyceria fluitans* (L.) R.Br.	III	0,2	5		15	30	45
Poaceae	*Glyceria maxima* (Hartm.) Holmb.	IV	-	-	2	25	2	40
Araceae	*Lemna minor* L.	I	-	-	15	18	10	30
Araceae	*Lemna trisulca* L.	I	-	-	3	7	-	-
Amblystegiaceae	*Leptodictyum riparium* (Hedw.) Warnst.	II	-	-	2	*	2	*
Boraginaceae	*Myosotis palustris* (L.) Lam.	IV	0,2	2	-	-	-	-
Haloragaceae	*Myriophyllum spicatum* L.	I	-	-	5	450	-	-
Lamiaceae	*Mentha longifolia* var. *asiatica* (Boriss.) Rech.f.	IV	-	-	2	56	5	80
Lamiaceae	*Mentha aquatica* L.	IV	-	-	-	-	5	32
Polygonaceae	*Persicaria amphibia* (L.) Gray	I	-	-	1	15	-	-
Polygonaceae	*Persicaria hydropiper* (L.) Spach	IV	1	4	3	22	40	25
Poaceae	*Phragmites australis* (Cav.) Trin. ex Steud.	II	3	125	3	800	4	950
Potamogetonaceae	*Potamogeton pectinatus* L.	I	-	-	15	1000	50	1200
Potamogetonaceae	*Potamogeton pusillus* L.	I	-	-	10	800	-	-
Plantaginaceae	*Veronica anagallis-aquatica* L.	III	0,5	9	4	95	5	85
Ranunculaceae	*Ranunculus trichophyllus* Chaix	I	5	85	10	600	5	360
Brassicaceae	*Rorippa amphibia* (L.) Besser	IV	-	-	-	-	1	12
Typhaceae	*Sparganium erectum* L.	II	-	-	2	960	10	840
Zygnemataceae	*Spirogyra* sp.	II	-	-	1	*	1	*

Furthermore, at sampling sites A4 and A5, a decline in the number of hydrophyte species was recorded, accompanied by a relative increase in hygrohelophytes and helophytes. These findings indicate that anthropogenic impacts are driving structural changes in the macrophyte communities of the river by reducing the presence of typical species while promoting the spread of pollution-tolerant species.

Hydrological and physicochemical parameters of the water

Water temperature (WT), flow (velocity/discharge), pH, the availability of nutrients, and competition with other submerged macrophyte species are the most important factors for the distribution and seasonal development of river macrophytes (Franklin & al. 2008; Madsen & al. 2001; Preiner & al. 2020). During the study period, the highest WT recorded was 23.4 °C in summer in sampling site A2, and the lowest was 10 °C in spring in sampling site A1 (Table 7). Water velocity is a primary controller of the distribution, composition, and metabolism of photosynthetic organisms in rivers. (Franklin & al 2008; Chambers & al. 1991). In the Argichi River, the flow rate ranged from 0.1 to 0.9 m/s. Macrophyte cover was closely related to flow velocity: at sampling sites A1 and A2, where the highest flow rates were recorded, macrophyte cover was below 50%. In contrast, at sampling site A3 during summer, where the lowest flow rate was observed, the macrophyte cover reached 100%. Statistical analysis revealed a strong inverse correlation between macrophyte cover and water velocity in spring ($r = -0.9684$; $p < 0.01$) (Fig. 3).

Table 7. Seasonal parameters of the temperature and velocity of the river in 2024.

Sampling sites	**T°C**			**V m/s**		
	1	**2**	**3**	**1**	**2**	**3**
A1	10	22.7	11	0.8	0.3	0.8
A2	11	23.4	15	0.9	0.4	0.7
A3	14	19.5	11.5	0.6	0.1	0.2
A4	13	19	18	0.5	0.5	0.7
A5	13	18	16.1	0.7	0.6	0.5

The optimum pH for sustainable aquatic life is between 6.5 and 8.5 (Nikanorov 2001). Some studies have shown that a weak alkaline environment promotes plant growth (Song & al. 2018). The pH value ranged from 6.7 to 7.8, indicating that the pH was within the optimal range during the study period (Table 8). A positive correlation ($r = 0.9235$; $p = 0.02$) was recorded between pH and projective cover in spring (Fig.3). Macrophytes are the most important components of hydroecosystems, capable of absorbing and accumulating nutrients in their biomass (Preiner & al., 2020). Ammonium (NH_4-N) is the preferred nitrogen source for the growth of plants, but at high concentrations, it can be harmful to plants (Yu & al. 2022). The ammonium (NH_4-N) concentration in the Argichi River ranged from 0.098 to 0.882 mg N/L. According to Government Decision No. 75-N, the river's water is considered excellent (class I) in spring. However, the ammonium nitrogen concentration increased during the summer and autumn in the middle and downstream sections of the river, where the water quality is classified as moderate (class III). In summer, the biomass of the macrophytes was the highest (5502 g/m^2), and the correlation between ammonium (NH_4-N) and macrophyte biomass ($r = 0.874$; $p = 0.05$) is positive, which means that a high amount of ammonia promoted macrophyte growth. In autumn, we received a positive correlation between ammonium (NH_4-N) and projective cover ($r = 0.867$; $p = 0.05$) (Fig. 3).

The NO_2-N concentration in the Argichi River was low during all study seasons, and the water quality ranged from excellent to good. In river ecosystems, nitrates (NO_3-N) are the most characteristic forms of inorganic nitrogen, as the water is well-aerated, making nitrite and ammonium forms unstable. The concentration of nitrates can vary greatly in the same sampling site. The minimum nitrate content observed in aquatic plants' vegetation period increases in autumn, reaching a maximum in winter (Nikanorov 2001). In the Argichi River, where the biomass and biodiversity of macrophytes were high during all study seasons, the nitrate concentration was low, ranging from 0.02 to 0.34 mg N/L (Table 8). According to Government Decision No. 75-N, the water is classified as high quality, class I. In our study, we observed a strong positive correlation between nitrate (NO_3-N) and macrophyte cover in autumn ($r=0.87$, $p=0.05$) (Fig. 3).

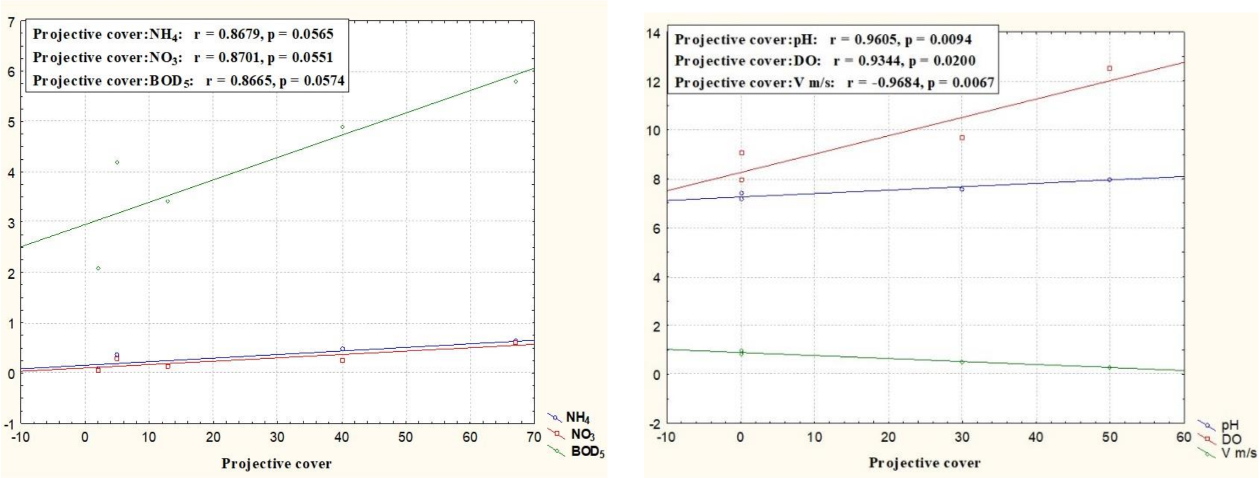


Fig. 3. Pearson correlation between projective cover and hydrological and physicochemical parameters

The regime of phosphates in the river is similar to that of nitrates, and their concentration is also minimal during the vegetative season. The variation of orthophosphates in Argichi River ranged from 0.022 mgP/L (high quality, class I) to 0.194 mgP/L (moderate quality, class III) (Table 8). The value of dissolved oxygen (DO) in the river ranged from 8 to 12.5 mg O_2/L, and according to Government Decision No.75-N, the water in the river belongs to the excellent quality of class I. The BOD_5 value in the river ranged from 1.7 to 7.1 mgO_2/L, which indicates that the water quality ranged from excellent to moderate. Our results showed a positive correlation between BOD_5 and projective cover ($r=0.86$; $p=0.05$) (Fig. 3).

A Pearson correlation analysis revealed that dissolved oxygen (DO), biochemical oxygen demand (BOD_5), water velocity, ammonium, and nitrate concentrations emerged as the main factors influencing macrophyte growth and distribution (Fig. 3)

Bacteriological load of the river.

During the study period, the number of mesophilic bacteria in river samples ranged from 30 to 3200 cfu/mL. The lowest value was recorded in the spring, while the highest was observed in the autumn, probably due to the decrease in macrophyte cover and the decay of macrophytes. In summer, we observed strong positive correlations between mesophilic bacteria with both macrophyte cover and biomass (Fig. 4).

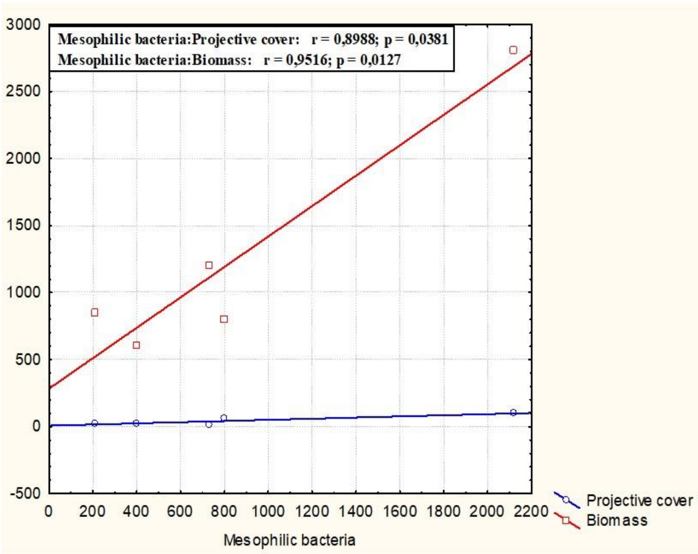


Fig. 4. Pearson correlation between mesophilic saprophytic bacteria with macrophyte biomass and cover.

Table 8. Seasonal hydrochemical parameters of the Argichi River in 2024.

Sampling sites	NO_2^- mgN/L			NO_3^- mgN/L			NH_4^+ mgN/L			PO_4^{3-} mgP/L			DO mgO_2/L			BOD_5 mgO_2/L			pH		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
A1	0.002	0.002	0.001	0.10	0.02	0.05	0.11	0.09	0.09	0.022	0.03	0.026	9.1	9.2	9.7	3.2	1.7	2.1	7.2	7.6	7.5
A2	0.008	0.003	0.004	0.08	0.09	0.14	0.12	0.15	0.25	0.028	0.08	0.092	8.1	9.7	9.5	1.7	3.1	3.4	7.4	7.7	7.6
A3	0.009	0.006	0.007	0.12	0.16	0.27	0.24	0.88	0.52	0.07	0.14	0.185	12.5	10.5	8.7	4.1	3.2	4.9	8	7.4	7.7
A4	0.008	0.006	0.009	0.25	0.21	0.29	0.33	0.57	0.41	0.14	0.16	0.194	8.2	9.5	9.3	2	4.2	5.2	7.2	6.7	7.2
A5	0.008	0.003	0.006	0.14	0.27	0.61	0.33	0.52	0.67	0.17	0.15	0.178	9.7	11.0	9.1	1.6	7.1	5.8	7.6	7.1	7.3

The counts of *Escherichia coli* in river water samples ranged from 100 to 1800 cfu/100 mL. The highest value was recorded in the summer at sampling site A2. Interestingly, at sampling site A3, where the projective cover was the highest (100%), the number of *E. coli* decreased. It is known that *Escherichia coli* can adsorb onto aquatic plants (Malnik, 2019). At the specified station, plant samples were analyzed, and it was found that after washing the plants, the bacterial count in the wash water was 5 to 6 times higher than in the river water samples.

According to Romanenko's Ecological and Sanitary Assessment of Surface Waters (1990), the waters of the Argichi River ranged from "excellent" to "poor" based on bacterial counts, which suggests that the river's water quality fluctuated significantly across sampling points over time (Table 9).

As a result, relationships between macrophytes and bacterial communities indicated that changes in macrophyte abundance influence the functional characteristics of mesophilic bacterial communities, thereby affecting water quality along the river.

Table 9. Water quality of the Argichi River based on microbiological parameters.

Sampling sites	According to *Escherichia coli*			According to mesophilic bacteria		
	Spring	Summer	Autumn	Spring	Summer	Autumn
A1	0	100	0	30	210	300
A2	200	1800	1700	50	400	700
A3	100	900	500	30	2120	4500
A4	300	500	1000	110	730	2000
A5	200	100	500	70	800	1100

Macrophyte indices

To assess the ecological status of the Argichi River, several macrophyte-based indices, including IBMR, MTR, and MIR, were applied. According to the IBMR (Indice Biologique Macrophytique en Rivière), water quality along the river ranged from "clean" near the source to "polluted" near the mouth. Nevertheless, as illustrated in Table 10, the river is predominantly characterized by moderate levels of pollution. The MTR (Mean Trophic Rank) index indicates a consistent risk of eutrophication across all surveyed seasons. Although the MIR (Macrophyte Index for Rivers) includes species more commonly encountered in the study area, it fails to accurately reflect the Argichi River's actual trophic state. According to the MIR, the river is classified as having "excellent" to "good" ecological status in all study sampling sites and seasons, which contradicts physicochemical and biological evidence.

Table 10. Macrophyte indices and ecological status of the water quality of the Argichi River.

Sampling sites	**IBMR**			**MTR**			**MIR**		
	Spring	**Summer**	**Autumn**	**Spring**	**Summer**	**Autumn**	**Spring**	**Summer**	**Autumn**
A1	12.1 Good	12 Moderate	11.7 Moderate	46 Moderate	50 Moderate	48.5 Moderate	48.7 Good	50 Good	50.3 Good
A2	12.1 Good	11.6 Moderate	10.8 Moderate	44 Moderate	53.4 Moderate	40.9 Moderate	44 High	51 Good	37.9 High
A3	10 Moderate	11.8 Moderate	9.7 Poor	41 Moderate	36.4 Moderate	31 Moderate	39 High	36.4 High	41 High
A4	11 Moderate	10.9 Moderate	11.4 Moderate	47 Moderate	44.2 Moderate	40 Moderate	48 Good	56 Good	41 High
A5	11 Moderate	9 Poor	8.3 Poor	50 Moderate	39.1 Moderate	37 Moderate	70 Good	36.8 High	36 High

Comparing the macrophyte-based indices, physicochemical, and bacteriological parameters indicates that the macrophyte distribution is primarily shaped by the site-specific environmental conditions. The IBMR and MTR indices are comparable with physicochemical and bacteriological parameters and, therefore, are considered the most appropriate tools for evaluating the trophic status of the river. Conversely, our research revealed that the MIR index is not acceptable for assessing its ecological status.

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