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Ecological assessment of the Drini i Bardhë River basin based on biological quality elements (BQEs)

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Abstract

The ecological assessment of freshwater ecosystems represents an essential component of sustainable river basin management and environmental protection. This study evaluates the ecological condition of selected river sections within the Drini i Bardhë River basin, Kosovo, through the application of Biological Quality Elements (BQEs), including benthic macroinvertebrates, macrophytes, and fish fauna, supported by physico-chemical and hydromorphological parameters. Sampling was conducted at multiple sites representing different river types and varying degrees of anthropogenic influence. A total of 32 macroinvertebrate families, 57 macrophyte taxa, and several fish species characteristic of both mountain and lowland river habitats were identified. Macroinvertebrate-based indices, particularly BMWP and ASPT, revealed considerable spatial variation in ecological quality. Sites such as Burim–Istog, Drelaj, and Jasiq–Erenik showed relatively high biological quality and supported pollution-sensitive taxa, whereas several downstream and urban-influenced sites exhibited reduced diversity and lower ecological index values. Physico-chemical analyses indicated elevated concentrations of ammonium, nitrate, and phosphate at several locations, suggesting localized nutrient enrichment and wastewater influence. The ecological status classification demonstrated that only a limited number of investigated sites achieved Good ecological status, while most sites were classified as Moderate or Poor, and Lumi i Plavës was classified as Bad ecological status. The findings confirm the strong relationship between anthropogenic pressures and ecological degradation within the basin and demonstrate the effectiveness of Biological Quality Elements for river assessment in accordance with the principles of the European Water Framework Directive. The study contributes to the development of ecological monitoring approaches and provides scientific support for future river basin management, conservation strategies, and implementation of water protection policies in Kosovo.

Keywords: Biological Quality Elements, ecological status, macroinvertebrates, macrophytes, fish fauna, Water Framework Directive, Drini i Bardhë River basin, Kosovo.

1. Introduction

Rivers are among the most dynamic and ecologically valuable freshwater ecosystems, providing essential functions for biodiversity conservation, water supply, nutrient cycling, and human well-being. Nevertheless, these ecosystems are increasingly threatened by untreated wastewater discharges, diffuse agricultural pollution, excessive water abstraction, hydromorphological alterations, solid waste disposal, and changes in land use. Such pressures can modify habitat structure, reduce biological diversity, and impair the ecological functioning of riverine systems (European Parliament and Council of the European Union, 2000; European Commission, 2003a). In response to these challenges, the European Union Water Framework Directive (WFD; Directive 2000/60/EC) established an integrated framework for the protection and assessment of surface waters, requiring the classification of ecological status based on biological, physico-chemical, and hydromorphological quality elements (European Parliament and Council of the European Union, 2000). Biological Quality Elements (BQEs) are central to ecological status assessment because they integrate the effects of environmental pressures over time and provide a more realistic representation of ecosystem condition than chemical measurements alone. Similar integrated ecological assessments using aquatic bioindicators have demonstrated that biological communities respond sensitively to changes in water quality and environmental disturbance, providing reliable evidence of river ecosystem condition (European Parliament and Council of the European Union, 2000; European Commission, 2003a; Yusuf *et al.*, 2025). Metrics based on macroinvertebrate community composition, such as the Biological Monitoring Working Party Score (BMWP), Average Score Per Taxon (ASPT), and richness of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT), have been broadly applied in freshwater assessment and are compatible with the ecological principles of the WFD (AQEM Consortium, 2002; European Commission, 2003a). In addition, macrophytes and fish communities provide complementary information on nutrient enrichment, habitat complexity, longitudinal connectivity, and broader ecological integrity of river systems (European Parliament and Council of the European Union, 2000; European Commission, 2003b). Fish assemblages have also been widely used to evaluate river ecosystem health and to identify conservation priorities in freshwater basins because changes in species richness and community composition reflect both habitat degradation and water-quality deterioration (Shafa *et al.*, 2023).

The Drini i Bardhë River basin is the largest in Kosovo and represents one of the country's most important freshwater systems. It includes mountain streams, spring-fed tributaries, lowland river sections, and transboundary waters that ultimately drain toward Albania and the Adriatic Sea. Despite its ecological and hydrological importance, the basin is exposed to several anthropogenic pressures, including untreated municipal and industrial wastewater, nutrient inputs, riverbed gravel extraction, solid waste accumulation, water abstraction for irrigation, and local hydromorphological degradation. These pressures have contributed to the deterioration of water resources and river ecosystem quality, particularly in downstream and urban-influenced areas, while some upper mountain sections still maintain relatively undisturbed conditions and may serve as potential reference sites for ecological classification (Korça and Demaku, 2022; Whalley and Faloutsos, 2020; World Bank, 2018; Zhushi Etemi *et al.*, 2020). Although ecological monitoring in Kosovo has progressed in recent years, the development of river basin-specific ecological classification schemes in accordance with the WFD remains a key scientific and management challenge. Reliable ecological assessment requires the identification of type-specific reference conditions, the selection of sensitive and ecologically meaningful metrics, and the establishment of class boundaries capable of distinguishing between minimally disturbed and impacted sites (European Commission, 2003a, 2005). Previous work in the Drini i Bardhë basin has proposed a preliminary framework for ecological status classification, primarily based on macroinvertebrate metrics such as BMWP, ASPT, and EPT richness, while also emphasizing the need to further incorporate macrophytes, ichthyofauna, hydromorphological parameters, and longer-term monitoring database.

Therefore, this study aims to evaluate the ecological status of the Drini i Bardhë River basin through an integrated assessment of Biological Quality Elements, with particular emphasis on macroinvertebrates, macrophytes, and ichthyofauna, supported by physico-chemical and hydromorphological parameters. The study seeks to identify spatial differences in ecological condition among selected river sites, distinguish relatively undisturbed reference areas from anthropogenically affected sections, and assess the applicability of these biological indicators for ecological status classification in accordance with the principles of the European Water Framework Directive. It is hypothesized that river sections exposed to stronger anthropogenic pressures, particularly in urbanized and downstream areas, exhibit a lower ecological status, reflected by reduced biological quality, altered community composition of aquatic organisms, and less favorable physico-chemical and hydromorphological conditions, compared with upper mountain and spring-fed sites that are expected to maintain more natural ecological characteristics.

2. Materials and Methods

Study Area

The study was conducted in the Drini i Bardhë River basin, the largest river basin in Kosovo, covering an area of approximately 4,289 km² (see Fig.1). The basin comprises a complex hydrographic network of mountain streams, spring-fed tributaries, and lowland river sections, which drain westward toward Albania and ultimately into the Adriatic Sea. The investigated water bodies belong mainly to calcareous river systems distributed across different altitudinal zones and catchment sizes. According to the typological framework applied in the basin assessment, the selected sites represented different river types and varying degrees of anthropogenic influence.

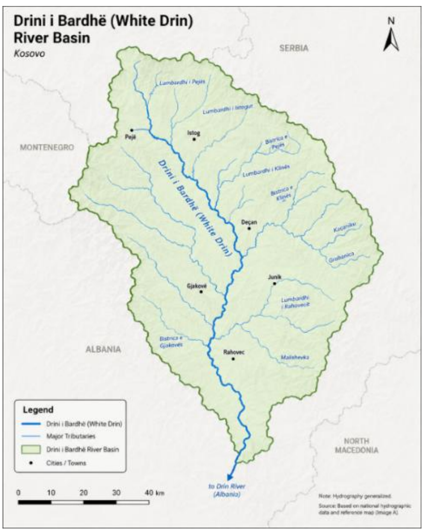

Figure 1. Map of the Drini i Bardhë River basin in Kosovo showing the investigated water bodies, sampling locations, and river typologies used for ecological status assessment. The selected sites represent spring-fed, mountain, tributary, and lowland river sections exposed to different degrees of anthropogenic pressure.

Sampling Design and Site Selection

Sampling locations were selected through a combination of desk-based review, analysis of available maps and previous studies, and field reconnaissance carried out in March 2022. The selection procedure followed the general principles of ecological status assessment recommended by the European Water Framework Directive, particularly the need to include reference or near-reference sites alongside locations exposed to anthropogenic pressures (European Commission, 2003a; European Parliament and Council of the European Union, 2000). A total of 20 sampling sites were18 investigated for macroinvertebrates during the second week of April 2018. The selected sites included upstream mountain sections, spring areas, tributaries, and lower river reaches exposed to different levels of human impact. Additional field campaigns for macrophytes and ichthyofauna were conducted in August 2018 at selected sites. Potential reference locations identified during the survey included Radavc, Burim-Istog, Drelaj, Lumi i Deçanit mbi Kishë, Jasiq-Erenik, Prevallë, and Burimi i Lumit Brod (see Table 1). At each site, sampling reaches were chosen to be representative of the surrounding river section in terms of substrate structure, flow velocity, depth, riparian vegetation, and microhabitat composition. Bridges, fords, and heavily altered access points were avoided whenever possible, and sampling was conducted upstream of such structures. In addition to biological sampling, field descriptions of the local environment and surrounding land use were recorded, including conditions within approximately 100-200 m of the riverbank and the broader 1-2 km approach to each location.

Table 1. Summary of sampling effort for Biological Quality Elements and supporting parameters, sampled area = 1 m^2.

Component	Sampling period	Number of sites/stations	Method	Main output
Benthic macroinvertebrates	Spring 2018	20 sampled sites; 19 used for classification	AQEM/STAR multi-habitat sampling	BMWP, ASPT, EPT richness
Macrophytes	Summer 2018	10 sites	Semi-quantitative survey	Taxa list, coverage, Macrophyte Index interpretation
Fish fauna	Summer 2018	10 stations	Electrofishing	Species composition, abundance, richness
Physico-chemical parameters	2016–2018	Selected monitoring sites	Field/laboratory measurements	Nutrients, DO, pH, conductivity
Hydromorphology	2018	Selected sites	Qualitative field observations	Supporting habitat interpretation

Macroinvertebrate Sampling

Benthic macroinvertebrates were sampled using a modified multi-habitat approach based on the AQEM/STAR methodology, which is widely applied in the ecological assessment of European rivers under the Water Framework Directive (AQEM Consortium, 2002; European Committee for Standardization, 2012). At each site, 16 subsamples were collected within a representative riffle section, with sampling effort distributed proportionally among the dominant substrate and microhabitat types. A standard hand net with a mouth size of 25 × 25 cm and a mesh size of 0.5 mm was used. In upper river sections, both kick-sampling and wash-sampling techniques were applied, generally in an approximately 50:50 ratio. In downstream alluvial sections, kick-sampling was used exclusively. The total sampled area per location was standardized to 1 m^2. Collected material was preserved in 80% ethanol, stored in cooling boxes during transport, and later processed in the laboratory for sorting and taxonomic identification AQEM Consortium, 2002). Macroinvertebrate data were subsequently used to calculate selected ecological metrics relevant for river quality assessment, including the Biological Monitoring Working Party Score (BMWP), Average Score Per Taxon (ASPT), and the richness of Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT). These metrics are commonly used to reflect sensitivity to organic pollution, habitat degradation, and overall ecological condition in lotic ecosystems (Alba-Tercedor & Sánchez-Ortega, 1988; AQEM Consortium, 2002).

Taxonomic identification and macroinvertebrate metrics

Benthic macroinvertebrate samples were processed in the laboratory after preservation in 80% ethanol. The organisms were sorted from the remaining organic and inorganic material and identified primarily at the family level, because the Biological Monitoring Working Party (BMWP) and Average Score Per Taxon (ASPT) indices applied in this study are based mainly on family-level tolerance scores. Where possible, selected taxa were identified to genus or species level in order to support ecological interpretation, particularly within pollution-sensitive groups such as Ephemeroptera, Plecoptera, and Trichoptera. Taxonomic identification followed the AQEM/STAR methodological framework and standard European freshwater macroinvertebrate identification keys. The use of family-level resolution was considered appropriate for the preliminary ecological assessment of the Drini i Bardhë River basin, especially because the objective of the study was to evaluate broad ecological quality gradients among sampling sites rather than to conduct a detailed taxonomic inventory. The BMWP score was calculated for each sampling site by summing the sensitivity scores assigned to all recorded macroinvertebrate families. Families that are more sensitive to organic pollution and habitat degradation contribute higher scores, whereas more tolerant families contribute lower scores. The ASPT value was calculated by dividing the total BMWP score by the number of scoring taxa recorded at the site:

ASPT = BMWP score/number of scoring taxa

EPT richness was calculated as the total number of taxa belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera recorded at each sampling site. These taxa were used as indicators of good ecological quality because they generally include organisms sensitive to organic enrichment, reduced oxygen availability, and habitat degradation. Together, BMWP, ASPT, and EPT richness were used to evaluate spatial variation in macroinvertebrate-based ecological quality across the investigated river sections.

Macrophyte Survey

Macrophyte surveys were conducted during the late summer field campaign, when aquatic vegetation is generally more developed and easier to identify. A total of 10 sampling sites were investigated for macrophytes. To improve observation accuracy, the survey was carried out by at least two observers examining the same river reach. All aquatic and riparian plant taxa recorded within the selected section were documented. Species presence and abundance were assessed semi-quantitatively using coverage categories ranging from simple presence to dominance. The scale included present species, rare species, occasional species, frequent species, abundant species, and dominant species. These data were then used to support the calculation of the Macrophyte Index (IM), which considers taxon identity, abundance, and spatial coverage within the river channel. The macrophyte survey data were used to support the interpretation of ecological conditions through the Macrophyte Index framework described by Suárez et al. (2005). Macrophyte taxa were recorded using semi-quantitative abundance and coverage categories, ranging from presence and rare occurrence to frequent, abundant, and dominant taxa. The Macrophyte Index considers both the ecological indicator value of recorded taxa and their relative abundance or coverage within the sampled river reach. In the present dataset, only two recorded taxa, *Potamogeton perfoliatus* and *Potamogeton crispus*, were included among the indicator species used directly for index interpretation. Therefore, the macrophyte assessment was used as supporting ecological evidence rather than as the primary basis for final ecological status classification. This limitation was considered when interpreting the overall ecological condition of the investigated sites. (Suárez et al., 2005).

Macrophyte-based assessment and limitations

Macrophyte data were used to provide supporting ecological information on river habitat condition, nutrient enrichment, and local environmental disturbance. A total of 57 aquatic and riparian plant taxa were recorded across the investigated sites, and these records were used to describe macrophyte richness, distribution patterns, and the presence of taxa associated with different ecological conditions. Species abundance and coverage were assessed using semi-quantitative categories, ranging from simple presence and rare occurrence to frequent, abundant, and dominant taxa.

The Macrophyte Index was interpreted following the framework described by Suárez et al. (2005), which considers the ecological indicator value of macrophyte taxa together with their relative abundance or coverage within the sampled river reach. However, in the present dataset, only two recorded taxa, *Potamogeton perfoliatus* and *Potamogeton crispus*, were included among the indicator taxa used directly for index interpretation. As a result, the macrophyte component was not used as an independent primary basis for final ecological status classification. Instead, macrophyte data were used as supporting evidence to complement macroinvertebrate-based assessment and physico-chemical interpretation.

Ichthyofauna Sampling

Fish assemblages were investigated using electrofishing, a standard method for sampling fish communities in wadeable rivers and streams. Depending on channel width, one or more anodes were used. Sampling was conducted along river stretches exceeding 200 m where field conditions allowed, and up to three electrofishing passes were performed at each site. In shallow wadable channels, integrated anodes connected to cathodes and portable generators were used while moving in an upstream direction. Captured fish were identified to species level and measured for fork length and body weight. Visible anomalies were also recorded where present. These data were used to describe the composition, abundance, and diversity of fish communities across the investigated river sections. Species richness and community diversity were further interpreted through diversity-based indicators, including Menhinick's diversity index, which is commonly used to express species richness in relation to sample size (Whittaker, 1977).

Physico-Chemical Measurements

At each sampling location, supporting physico-chemical parameters were recorded or collected for laboratory analysis. The investigated parameters included water temperature, dissolved oxygen, oxygen saturation, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrate nitrogen ($N\text{-}NO_3$), ammonium nitrogen ($N\text{-}NH_4$), orthophosphate phosphorus ($P\text{-}PO_4$), conductivity, chloride, sulfate, pH, and selected heavy metals, namely Cd, Cu, Ni, Pb, and Zn. These parameters were selected because they are recognized as important supporting quality elements in ecological status assessment under the Water Framework Directive (European Parliament & Council of the European Union, 2000). The physico-chemical dataset was used as supporting information for ecological status interpretation and for identifying possible relationships between biological responses and environmental stressors such as nutrient enrichment, oxygen conditions, and pollution exposure (European Commission, 2003a; Álvarez-Troncoso, 2018).

Hydromorphological observations

Hydromorphological conditions were recorded as supporting field observations during the ecological assessment of the investigated river sections. The observations focused on visible channel characteristics, substrate composition, flow conditions, riparian vegetation, bank modification, local habitat heterogeneity, and evidence of anthropogenic alteration such as channelization, gravel extraction, waste disposal, and reduced riparian integrity.
However, a complete standardized hydromorphological assessment protocol was not applied consistently across all sampling sites. Therefore, hydromorphological information was not used as an independent quantitative basis for final ecological status classification. Instead, it was used as supporting qualitative evidence to help interpret biological responses and site-level ecological degradation. This approach is consistent with the role of hydromorphology as a supporting quality element under the Water Framework Directive, but it also represents an important methodological limitation of the present study.

Data analysis and ecological assessment
Biological and environmental data were interpreted within the framework of ecological status assessment proposed by the European Water Framework Directive. Macroinvertebrate metrics were used as the main biological basis for site classification, while macrophyte and fish data provided additional ecological information on habitat quality, biodiversity patterns, and the degree of ecological disturbance. Supporting physico-chemical and hydromorphological observations were considered in the interpretation of overall river condition (European Parliament & Council of the European Union, 2000; European Commission, 2003a). The ecological assessment emphasized differences between relatively undisturbed upstream or spring-fed sites and river sections exposed to stronger human pressures. Where relevant, biological metric values were compared with environmental characteristics to evaluate the consistency between observed community structure and the degree of site disturbance, following the preliminary ecological classification approach proposed for the Drini i Bardhë basin. The complete site-level dataset used for ecological status interpretation is provided in Supplementary Table S1, while the main text presents a summarized classification of sites by ecological status class.

Taxonomic identification and metric calculation
Benthic macroinvertebrates were identified primarily at the family level, because the BMWP and ASPT indices applied in this study are based on family-level tolerance scores. When possible, selected taxa were identified to genus or species level to support ecological interpretation, particularly within pollution-sensitive groups such as Ephemeroptera, Plecoptera, and Trichoptera. Taxonomic identification was carried out using standard European freshwater macroinvertebrate identification keys and the AQEM/STAR methodological framework. The Biological Monitoring Working Party score (BMWP) was calculated by summing the tolerance/sensitivity scores assigned to all macroinvertebrate families recorded at each sampling site. Families with higher sensitivity to organic pollution contribute higher scores, whereas tolerant families contribute lower scores (see Table 2). The Average Score Per Taxon (ASPT) was calculated as:
ASPT = BMWP score/number of scoring taxa
EPT richness was calculated as the total number of taxa belonging to Ephemeroptera, Plecoptera, and Trichoptera recorded at each site.

Table 2. Criteria used for preliminary ecological status classification.

Ecological status	**Biological criteria**	**Supporting interpretation**
Good	High BMWP/ASPT; presence of sensitive taxa; higher richness	Limited nutrient enrichment and limited habitat degradation
Moderate	Intermediate BMWP/ASPT; reduced sensitive taxa	Evidence of moderate nutrient or habitat pressure
Poor	Low BMWP/richness; tolerant taxa more common	Clear pollution or habitat degradation
Bad	Very low BMWP/ASPT and strongly degraded assemblage	Severe ecological disturbance

These groups were used as indicators of better ecological quality because they generally include taxa sensitive to organic pollution, oxygen depletion, and habitat degradation. Macrophyte data were evaluated using the Macrophyte Index framework described by Suárez *et al.* (2005). The index considers the indicator value of recorded macrophyte taxa and their relative abundance or coverage within the sampled river reach. In the present dataset, only Potamogeton perfoliatus and Potamogeton crispus were included among the indicator taxa used directly for index interpretation. Therefore, macrophyte-based classification was treated as supporting ecological evidence rather than as an independent final status assessment.

Because nationally intercalibrated class boundaries are not yet fully established for Kosovo rivers, the classification was treated as a preliminary ecological status assessment based mainly on macroinvertebrate metrics and supported by physico-chemical and hydromorphological evidence.

Statistical Analysis

Statistical analyses were performed to summarize biological metrics, compare ecological status classes, and evaluate relationships between biological indices and supporting physico-chemical parameters. Descriptive statistics, including mean, standard deviation, minimum, and maximum values, were calculated for macroinvertebrate abundance, number of taxa, ASPT, and BMWP score.

Before inferential analysis, the normality of biological and physico-chemical variables was assessed using the Shapiro–Wilk test. Because of the relatively small number of sampling sites and the expected non-normal distribution of several ecological variables, non-parametric tests were applied where appropriate. Differences in biological metrics among ecological status classes (Good, Moderate, Poor, and Bad) were evaluated using the Kruskal–Wallis test. When significant differences were detected, pairwise comparisons were considered to identify which ecological status groups differed from each other. Relationships between nutrient concentrations and biological indices were assessed using Spearman rank correlation. In particular, nitrate, ammonium, and phosphate concentrations were compared with BMWP and ASPT values in order to evaluate whether nutrient enrichment was associated with reduced biological quality. Spearman correlation was selected because it is suitable for small datasets and does not require normally distributed variables.

Where complete site-by-site environmental data were available, Principal Component Analysis (PCA) was used as an exploratory multivariate method to identify major environmental gradients among sampling sites and to examine the association between physico-chemical variables and biological quality metrics. PCA was applied only to variables measured across the same sampling sites. NMDS and CCA were not performed because a complete taxon-by-site community matrix was not available for all investigated Biological Quality Elements. Therefore, multivariate interpretation was limited to the available site-level biological and environmental variables.

3. Results

Macroinvertebrates

A total of 32 macroinvertebrate families were identified across the investigated sites of the Drini i Bardhë River basin. The most frequently represented families included Gammaridae (Amphipoda), Tabanidae (Diptera), Hirudidae (Hirudinea), Baetidae (Ephemeroptera), and Perlidae (Plecoptera). These taxa reflect a broad ecological gradient, ranging from groups relatively tolerant of organic enrichment to groups commonly associated with better ecological conditions.

The distribution of macroinvertebrate families varied among sampling locations. The highest family richness was recorded at Burim-Istog and Lumi i Plavës, indicating comparatively greater taxonomic diversity at these sites. In contrast, several sites showed lower family richness, suggesting reduced biological complexity or stronger local environmental constraints. The site-specific distribution of macroinvertebrate family richness is illustrated in Figure 2.

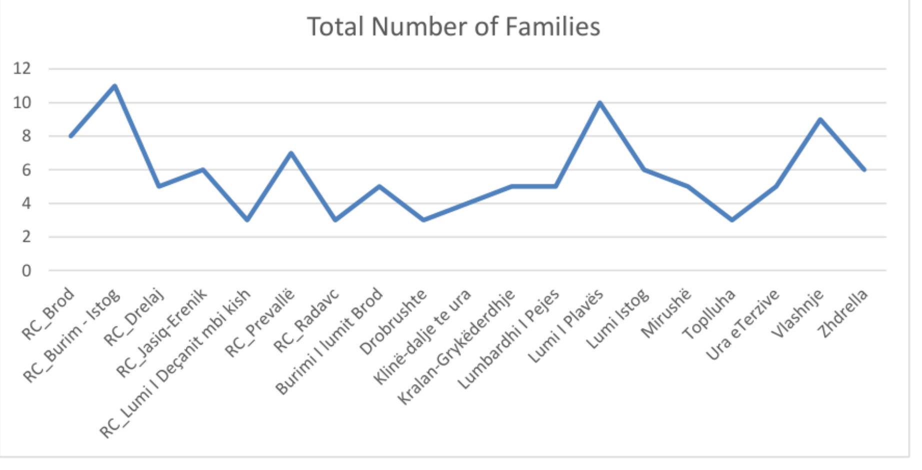

Figure 2. Number of benthic macroinvertebrate families recorded at each sampling site in the Drini i Bardhë River basin during the spring 2018 sampling campaign. Higher family richness generally indicates greater biological diversity and was used together with BMWP, ASPT, and EPT richness to support ecological status interpretation.

Macroinvertebrate-based metrics further confirmed substantial variation among sites (see Table 3). The BMWP score ranged from 10 at Lumi i Plavës to 69 at Burim-Istog, while ASPT values ranged from 2.5 to 10.0. Higher BMWP and ASPT values were generally observed at sites such as Burim-Istog, Drelaj, Jasiq-Erenik, and Lumi Istog, indicating better biological quality relative to sites with lower scores.

Table 3. Selected macroinvertebrate metrics recorded at representative sites in the Drini i Bardhë River basin.

Site	Abundance (ind./m²)	Number of taxa (n)	ASPT score	BMWP score
Burim-Istog	339	11	7.0	69
Drelaj	15	5	8.3	39
Jasiq Erenik	52	6	7.25	33
Lumi Istog	372	6	9.2	50
Zhdrella	13	6	7.0	38
Lumi i Plavës	14	4	2.5	10

Macrophytes

The macrophyte survey documented a diverse assemblage of aquatic and riparian plant taxa across 10 sampling sites in the Drini i Bardhë basin. In total, the dataset included 57 recorded taxa, covering bryophytes, algae, submerged macrophytes, emergent species, and riparian vegetation. Among the most widely represented or abundant taxa were Amblystegium fluviatile, Equisetum fluviatile, Mentha aquatica, Cladophora sp., Sparganium erectum, and Lythrum virgatum.

Figure 3. Representative submerged and emergent macrophytes recorded at the Zllakuqan location along the Lumi Istogut. The photograph illustrates aquatic and riparian vegetation used as supporting evidence for habitat condition, nutrient enrichment, and local ecological interpretation.

Differences in macrophyte richness and abundance were evident among the investigated stations. Burim-Istog and Deçan were identified as the sites with relatively high macrophyte diversity. Filamentous algae of the genus Cladophora were particularly prominent in several locations, reaching high abundance at Brod, Drelaj, Deçan, and Jasiq. The proportional representation of the most frequent macrophyte taxa across the surveyed stations is shown in Figure 4.

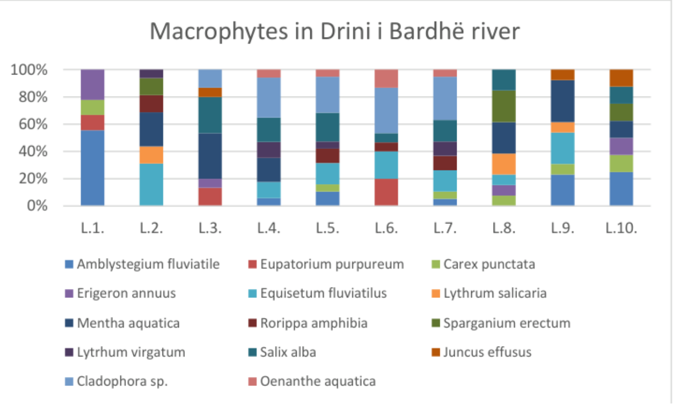

Figure 4. Distribution of selected macrophyte taxa across ten sampling sites in the Drini i Bardhë River basin during the summer 2018 field survey. Taxa occurrence and relative abundance were used to support the interpretation of macrophyte richness, coverage patterns, and potential nutrient enrichment.

With respect to the Macrophyte Index framework applied in the source assessment, only two recorded species were directly included among the indicator taxa used for index calculation: Potamogeton perfoliatus, observed at Brod and Zllakuqan, and Potamogeton crispus, recorded at Deçan and Zllakuqan. A simplified overview of selected ecologically relevant macrophyte taxa and their occurrence is provided in Table 4.

With respect to the Macrophyte Index framework applied in the source assessment, only two recorded species were directly included among the indicator taxa used for index calculation: Potamogeton perfoliatus, observed at Brod and Zllakuqan, and Potamogeton crispus, recorded at Deçan and Zllakuqan. A simplified overview of selected ecologically relevant macrophyte taxa and their occurrence is provided in Table 4.

Table 4. Selected macrophyte taxa recorded in the Drini i Bardhë River basin.

Taxon	Main recorded locations	Ecological note
Amblystegium fluviatile	Radavc, Brod, Jasiq, Burimi i Brodit, Prevallë	Moss species associated with flowing waters
Equisetum fluviatile	Dobrushë, Brod, Drelaj, Deçan, Jasiq	Frequent emergent/riparian aquatic plant
Mentha aquatica	Dobrushë, Burim-Istog, Brod, Zllakuqan, Burimi i Brodit	Common in moist river margins
Cladophora sp.	Burim-Istog, Brod, Drelaj, Deçan, Jasiq	Filamentous algae; elevated cover may indicate nutrient enrichment
Potamogeton perfoliatus	Brod, Zllakuqan	Indicator species included in the Macrophyte Index
Potamogeton crispus	Deçan, Zllakuqan	Indicator species included in the Macrophyte Index

*Coverage was assessed using semi-quantitative abundance categories: present, rare, occasional, frequent, abundant, and dominant.

This limitation is important because a large number of recorded macrophyte taxa could not be directly translated into index scores. Therefore, the ecological interpretation of macrophytes was based mainly on taxa richness, coverage patterns, the occurrence of indicator species, and the presence of taxa associated with nutrient enrichment, such as filamentous algae. The restricted number of available indicator taxa reduces the precision of macrophyte-based ecological classification and may underestimate the ecological information contained in the full macrophyte assemblage.

Fish-Fauna

The ichthyofaunal survey conducted in the Drini i Bardhë River basin revealed the presence of several fish species characteristic of both mountain streams and lowland river habitats. Fish sampling was carried out using electrofishing methods at 10 sampling stations distributed throughout the basin. A diverse fish community was recorded, reflecting differences in habitat structure, water quality, flow regime, and ecological conditions among river sections. The abundance pattern of ichthyofauna by station is presented in Figure 5.

The dominant and most frequently recorded species was *Salmo trutta* m. *fariodes* (brown trout), which was mainly found in upstream and spring-fed river sections characterized by cold, well-oxygenated, and fast-flowing waters. This species was recorded at sites including Burim-Istog, Radavc, Lumbardhi i Pejës–Drelaj, Erenik–Jasiq, Mbi Kishë, Brod, and Prevallë. According to the report, *Salmo trutta* m. *fariodes* prefers temperatures between 15–18 °C and habitats with submerged rocks, vegetation cover, and strong currents.

In addition to brown trout, several cyprinid and benthic fish species were identified in lower and more heterogeneous river sections. These included:

- *Alburnoides ohridanus*
- *Barbatula sturanyi*
- *Rhodeus amarus*
- *Barbus rebeli/balcanicus*

Alburnoides ohridanus was recorded mainly in lowland areas, particularly within the Rimnik River area. The species is considered endemic to the Southeastern Adriatic Freshwater Ecoregion and represents an ecologically important component of regional biodiversity. *Barbatula sturanyi* was observed in stony and gravel-bottom habitats, particularly in the Zllakuqan–Lumi Istog area. This benthic species is associated with springs and flowing waters with coarse substrates. *Rhodeus amarus*, the only bitterling species naturally distributed in Europe, was also recorded in Zllakuqan–Lumi Istog lowland habitats. The species is considered ecologically significant because of its specialized reproductive relationship with freshwater mussels. *Barbus rebeli/balcanicus* was identified mainly in the Rimnik river sections and lower river habitats with clear water and riffles. The species is typical of Adriatic basin drainages and is adapted to flowing river ecosystems. The composition of fish fauna in the investigated sampling stations is summarized in Table 5.

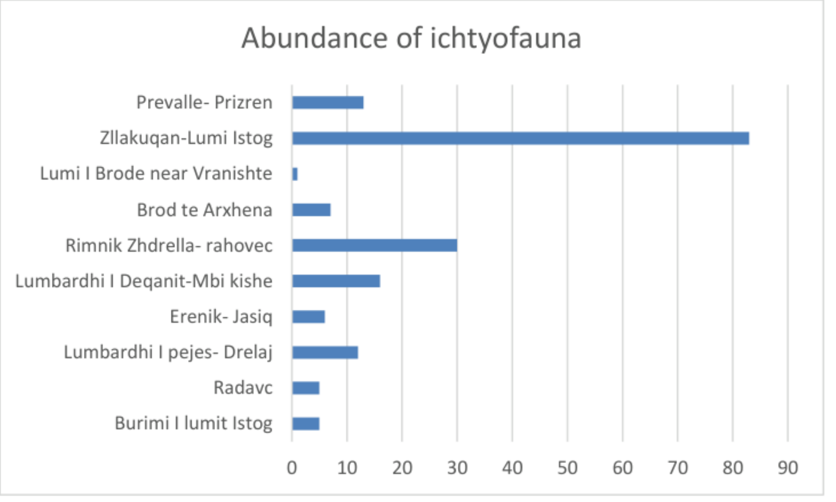

Figure 5. Abundance of fish individuals recorded across the investigated sampling stations in the Drini i Bardhë River basin during the summer 2018 electrofishing survey. Differences among stations reflect variation in habitat type, flow conditions, water quality, and longitudinal position within the basin.

Most sampling sites were dominated by a single species, particularly Salmo spp. in spring-fed and mountainous sections. In contrast, Zllakuqan-Lumi Istog showed the highest species richness and was the only station where several fish taxa co-occurred within the same sampling site. Differences in species richness among stations are illustrated in Figure 6.

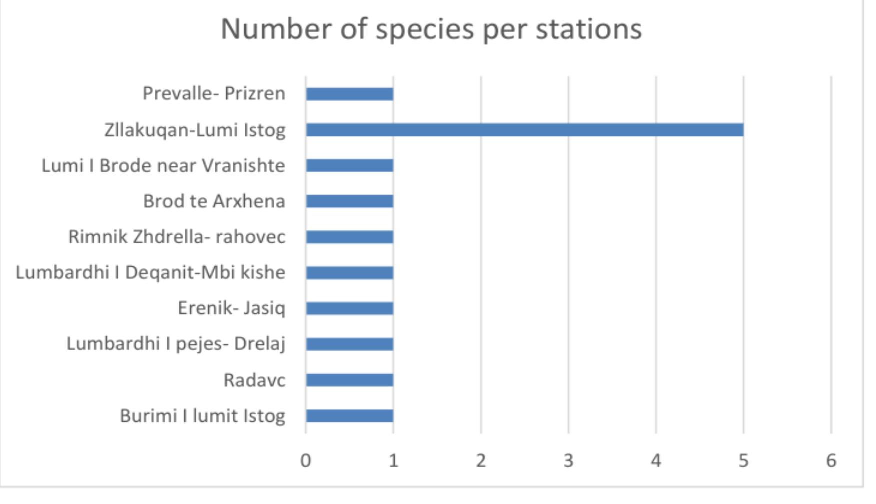

Figure 6. Number of fish species recorded per sampling station in the Drini i Bardhë River basin. Species richness was used as supporting ecological evidence to compare upstream, spring-fed, and lowland river sections.

Table 5. Principal fish taxa recorded in the Drini i Bardhë River basin.

Species	Main occurrence in the basin	Ecological interpretation
Salmo trutta m. farioides	Radavc, Drelaj, Jasiq, Mbi Kishë, Brod, Prevallë	Associated with cold, oxygen-rich, fast-flowing waters
Barbus rebeli/balcanicus	Zhdrella, Zllakuqan	Common in lower river sections and riffle habitats
Alburnoides ohridanus	Zllakuqan	Dominant in the most diverse low-land station
Rhodeus amarus	Zllakuqan	Present in lowland habitats
Barbatula sturanyi	Zllakuqan	Associated with stony substrates and flowing waters

Ecological interpretation of fish assemblages

Fish assemblages were evaluated not only in terms of species occurrence and abundance, but also according to species richness, habitat preference, and ecological sensitivity. Species richness varied among sampling stations, with most upstream and spring-fed sites dominated by one salmonid taxon, mainly *Salmo trutta* m. *farioides*. In contrast, the Zllakuqan–Lumi Istog station showed the highest fish species richness, supporting several taxa including *Alburnoides ohridanus*, *Rhodeus amarus*, *Barbatula sturanyi*, and *Barbus rebeli/balcanicus*. This pattern indicates a longitudinal ecological gradient, where cold, fast-flowing, oxygen-rich upstream habitats are dominated by trout, while lower river sections with more heterogeneous habitat structure support a more diverse cyprinid and benthic fish assemblage. The conservation relevance of the recorded fish fauna was also considered. *Salmo trutta* is widely distributed in European freshwater systems, but local populations may be sensitive to water temperature, oxygen conditions, habitat degradation, and fragmentation of spawning habitats. *Alburnoides ohridanus* is of particular regional importance because of its restricted Balkan distribution and its association with the Drin/Ohrid freshwater system. *Rhodeus amarus* is ecologically important because its reproduction depends on the presence of freshwater mussels, making it indirectly sensitive to habitat degradation and loss of benthic habitat quality. Benthic and rheophilic taxa such as *Barbatula sturanyi* and *Barbus rebeli/balcanicus* are also relevant indicators of substrate condition, flow regime, and habitat connectivity. Habitat connectivity and anthropogenic pressures are likely to influence fish assemblage structure in the Drini i Bardhë basin. Barriers, channel modification, gravel extraction, reduced riparian vegetation, wastewater inputs, and changes in flow conditions can restrict fish movement, reduce spawning habitat, and simplify habitat structure. Such pressures may particularly affect species that require clean gravel substrates, well-oxygenated water, or longitudinal connectivity between feeding, refuge, and spawning habitats (See Table 6). Therefore, the fish community results should be interpreted as supporting evidence of ecological condition, complementing macroinvertebrate and physico-chemical indicators. The observed spatial variation in fish assemblages is consistent with previous river biodiversity studies showing that anthropogenic disturbance, habitat modification, and declining water quality reduce fish diversity and alter community composition, emphasizing the importance of integrated river management and conservation measures (Shafa *et al.*, 2023).

Table 6. Ecological and conservation interpretation of recorded fish taxa.

Species/taxon	Main habitat association	Ecological interpretation	Conservation note
Salmo trutta m. *farioides*	Cold, fast-flowing, oxygen-rich upstream waters	Indicator of relatively preserved mountain and spring-fed habitats	Widely distributed, but local populations may be affected by warming, pollution, barriers, and loss of spawning habitat
Alburnoides ohridanus	Lowland or transitional river sections with clean, well-oxygenated water and suitable substrates	Regionally important Balkan/Drin-associated taxon	Conservation-relevant because of restricted regional distribution and sensitivity to habitat degradation
Rhodeus amarus	Lowland habitats, often associated with areas supporting freshwater mussels	Indicates habitat complexity and dependence on suitable benthic conditions	Reproductive dependence on mussels makes populations sensitive to habitat and water-quality degradation
Barbatula sturanyi	Stony and gravel-bottom flowing waters	Benthic species associated with substrate quality and flow conditions	Sensitive to substrate degradation, sedimentation, and habitat alteration
Barbus rebeli/balcanicus	Flowing lower river sections and riffle habitats	Rheophilic taxon indicating the importance of flow diversity and connectivity	May be affected by barriers, channel alteration, and reduced longitudinal connectivity

Physico-Chemical Parameters

The physico-chemical assessment included temperature, conductivity, pH, dissolved oxygen, nitrate, ammonium, phosphate, and other supporting parameters relevant to ecological status evaluation. Comparisons with monitoring data from 2016 and 2017 revealed notable temporal variation across several locations. Among the most pronounced changes were increases in ammonium and nitrate concentrations at numerous sites in 2018, suggesting spatially variable nutrient enrichment across the basin. The variation of selected nutrient-related parameters over the 2016-2018 monitoring period is shown in Figures 7-9.

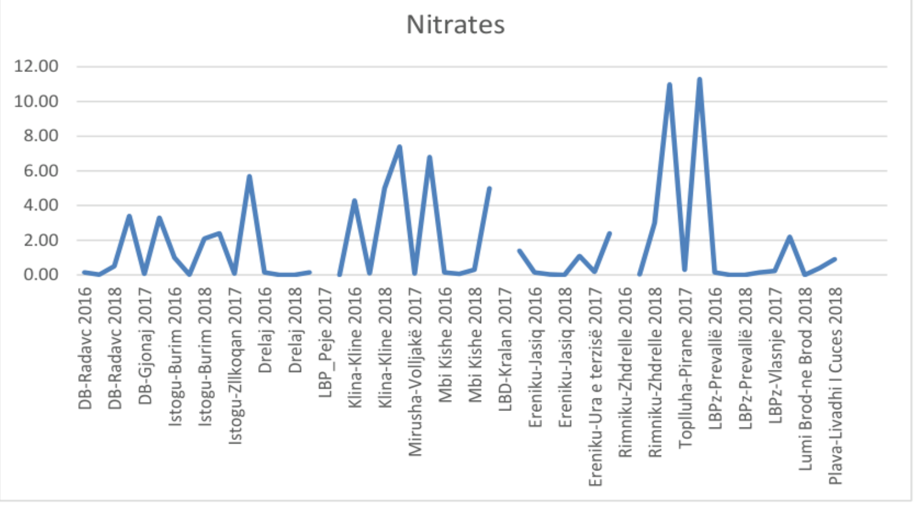

Figure 7. Variation in nitrate concentrations among selected monitoring sites in the Drini i Bardhë River basin during the 2016–2018 monitoring period. Nitrate values are expressed as nitrate nitrogen, $N\text{-}NO_3$, in mg/L, and were used to evaluate possible nutrient enrichment.

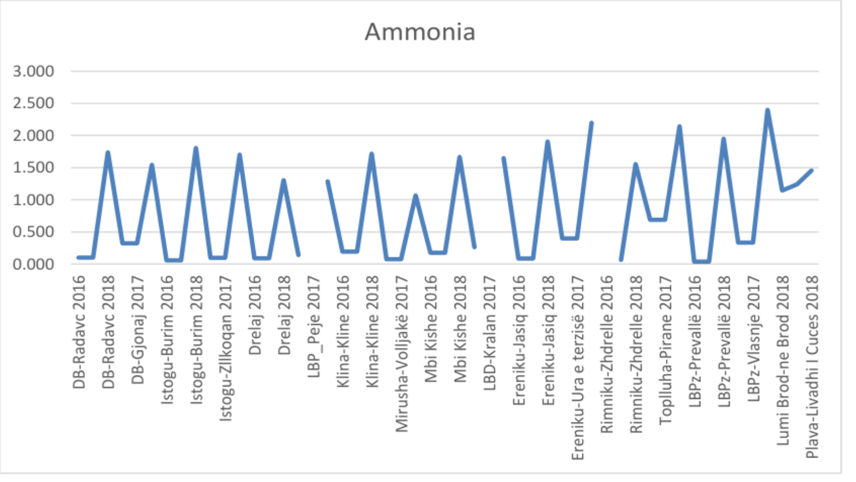

Figure 8. Variation in ammonium concentrations among selected monitoring sites in the Drini i Bardhë River basin during the 2016–2018 monitoring period. Ammonium values are expressed as ammonium nitrogen, N-NH_4, in mg/L, and were used as supporting evidence of organic pollution or wastewater influence.

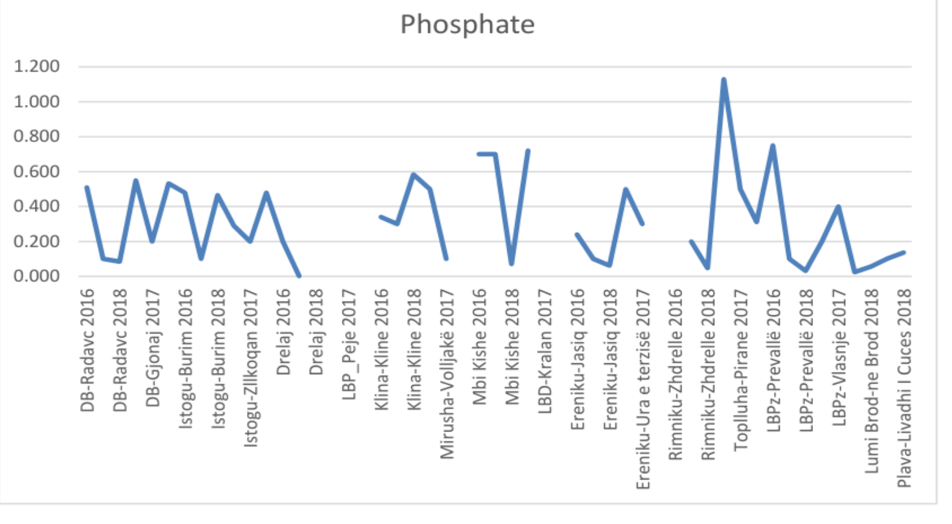

Figure 9. Variation in phosphate concentrations among selected monitoring sites in the Drini i Bardhë River basin during the 2016–2018 monitoring period. Phosphate values are expressed as orthophosphate phosphorus, P-PO_4, in mg/L, and were used to assess nutrient enrichment and possible eutrophication pressure.

A summary of the most important physico-chemical observations reported for selected sites is presented in Table 7. Elevated ammonium levels were among the most recurrent findings, while increases in nitrates and phosphates were particularly notable at sites such as Zllakuqan, Klinë, and Burim-Istog.

Table 7. Selected physico-chemical changes reported in 2018 compared with previous monitoring years.

Site	Main observation
Radavc	Higher dissolved oxygen; higher nitrate and ammonium; lower phosphate
Zllakuqan	Higher nitrate, ammonium, and phosphate
Vlashnje	Higher nitrate and ammonium
Klinë-dalje te ura	Higher nitrate, ammonium, and phosphate
Mbi Kishë	Higher dissolved oxygen; higher nitrate and ammonium
Zhdrella	Higher conductivity; higher dissolved oxygen; higher nitrate and ammonium
Piranë	Higher nitrate and ammonium
Burim-Istog	Higher dissolved oxygen; higher nitrate and ammonium

Ecological Status Classification

The preliminary ecological status classification exercise, based primarily on macroinvertebrate metrics and supported by physico-chemical and hydromorphological observations, was applied to 19 river sites. The results showed a wide ecological gradient across the Drini i Bardhë basin, ranging from Good to Bad overall ecological status. Four sites were classified as having Good ecological status: Burim-Istog, Drelaj, Jasiq-Erenik, and Lumi Istog. Five sites were classified as Moderate: Kralan-Grykëderdhje, Mirushë, Zhdrella, Prevallë, and Burimi i Lumit Brod. The majority of sites were assigned to the Poor ecological status class, while Lumi i Plavës was classified as Bad (see Table 8). A full site-by-site matrix of biological metrics, supporting quality elements, and final status is provided in Supplementary Table S1.

Table 8. Ecological status classification of selected sites in the Drini i Bardhë River basin.

Ecological status	Sites
Good	Burim-Istog; Drelaj; Jasiq-Erenik; Lumi Istog
Moderate	Kralan-Grykëderdhje; Mirushë; Zhdrella; Prevallë; Burimi i Lumit Brod
Poor	Radavc; Drobrushte; Brod; Lumi i Deçanit mbi Kishë; Ura e Terzive; Vlashnje; Top-lluha; Klinë-dalje te ura; Lumbardhi i Pejës
Bad	Lumi i Plavës

The summarized ecological status classes presented in Table 5 are based on the complete site-level classification matrix provided in Supplementary Table S1. This supplementary table includes the main biological metrics used for classification, including macroinvertebrate abundance, number of taxa, ASPT, and BMWP score, together with supporting physico-chemical and hydromorphological information and the final ecological status assigned to each sampling site. Supplementary Table S1 therefore provides the detailed evidence behind the summarized Good, Moderate, Poor, and Bad ecological status categories presented in the main text. Its inclusion allows the reader to verify how individual site-level metric values contributed to the final ecological interpretation.

Statistical analysis

Descriptive statistical analysis was performed using the ecological classification dataset from 19 sampling sites in the Drini i Bardhë River basin. The results showed substantial spatial variability in macroinvertebrate-based ecological metrics among the investigated sites. Macroinvertebrate abundance ranged from 4 to 372 ind./m², with a mean value of 72.05 ± 109.77 ind./m². The number of taxa ranged from 3 to 11, with an average of 5.11 ± 1.91 taxa per site. ASPT values varied between 2.5 and 10.0, with a mean of 6.28 ± 1.73, while BMWP scores ranged from 10 to 69, with an average of 30.47 ± 13.97 (see Table 9). These values indicate a high degree of spatial variation in biological quality across the investigated river sections. The distribution of ecological status classes showed that 9 sites (47.4%) were classified as Poor, 5 sites (26.3%) as Moderate, 4 sites (21.1%) as Good, and 1 site (5.3%) as Bad. This indicates that the majority of investigated sites did not achieve Good ecological status. Sites classified as Good ecological status had the highest mean BMWP score (47.75) and ASPT value (7.94), whereas the site classified as Bad had the lowest BMWP score (10) and ASPT value (2.5). Poor-status sites had a mean BMWP score of 22.78, confirming reduced biological quality in more impacted river sections.

Table 9. Descriptive statistics of macroinvertebrate-based ecological metrics

Metric		Mean ± SD	Minimum	Maximum
Abundance	ind. m^{-2}	72.05 ± 109.77	4	372
Number of taxa	n	5.11 ± 1.91	3	11
ASPT	score	6.28 ± 1.73	2.5	10.0
BMWP	score	30.47 ± 13.97	10	69

Pearson correlation analysis showed a strong positive relationship between BMWP score and number of taxa ($r = 0.91$, $p < 0.001$), indicating that sites with higher taxonomic richness generally had better biological quality. A moderate positive correlation was also observed between BMWP score and macroinvertebrate abundance ($r = 0.72$, $p < 0.001$). The relationship between BMWP and ASPT was positive but weaker ($r = 0.44$, $p = 0.062$), suggesting that BMWP was influenced more strongly by taxonomic richness than by average sensitivity score alone. ASPT showed no meaningful relationship with the number of taxa ($r = 0.08$, $p = 0.754$), indicating that ASPT reflects the average ecological sensitivity of recorded taxa rather than taxonomic richness itself. The available statistical results support the interpretation that macroinvertebrate-based metrics, particularly BMWP score and taxa richness, were effective in distinguishing ecological differences among sampling sites in the Drini i Bardhë River basin. Higher BMWP, ASPT, and taxa richness values were generally associated with better ecological status classes, while lower values corresponded to more degraded sites (see Tables 10, 11, and 12). These findings confirm the usefulness of Biological Quality Elements, especially benthic macroinvertebrates, as indicators of ecological condition in the basin.

Table 10. Distribution of ecological status classes

Ecological status	Number of sites(n)	Percentage (%)
Good	4	21.1%
Moderate	5	26.3%
Poor	9	47.4%
Bad	1	5.3%

Additional statistical analyses, including non-parametric comparison of ecological status groups and relationships between nutrient concentrations and biological indices, should be interpreted with caution because complete site-by-site physico-chemical datasets were not available for all sampling locations and years. Similarly, multivariate analyses such as NMDS and CCA were not applied because a complete taxon-by-site community matrix was not available for all Biological Quality Elements. Therefore, the statistical interpretation in the present study is based primarily on descriptive statistics and correlation analysis of available macroinvertebrate-based metrics, while future monitoring should include complete biological and environmental datasets suitable for more robust inferential and multivariate analyses.

Table 11. Mean biological metrics by ecological status class

Ecological status	Mean abundance (ind. m^{-2})	Mean number of taxa (n)	Mean ASPT score	Mean BMWP score
Good	194.50	7.00	7.94	47.75
Moderate	63.60	6.00	6.09	35.00
Poor	28.78	4.33	6.07	22.78
Bad	14.00	4.00	2.50	10.00

Table 12. Pearson correlation between biological metrics

Variables	Pearson r	p-value
BMWP vs. number of taxa	0.91	<0.001
BMWP vs. abundance	0.72	<0.001
BMWP vs. ASPT	0.44	0.062
ASPT vs. number of taxa	0.08	0.754

Overall, the statistical analysis confirms that macroinvertebrate-based metrics, especially BMWP and taxa richness, were effective in distinguishing ecological differences among sampling sites in the Drini i Bardhë River basin. These findings support the use of Biological Quality Elements as reliable indicators for ecological status assessment.

4. Discussion

The results of the present study revealed considerable spatial variation in the ecological condition of the Drini i Bardhë River basin, reflecting the influence of both natural environmental heterogeneity and anthropogenic pressures. Biological Quality Elements, particularly benthic macroinvertebrates, proved to be effective indicators of ecological status, supporting the applicability of integrated biological assessment approaches recommended under the European Water Framework Directive (European Parliament and Council of the European Union, 2000). Macroinvertebrate assemblages showed clear differences among sampling sites, with upstream and spring-fed locations generally exhibiting higher BMWP and ASPT values compared to downstream and anthropogenically influenced river sections. Sites such as Burim–Istog, Drelaj, and Jasiq–Erenik were characterized by the presence of pollution-sensitive taxa, including representatives of Ephemeroptera and Plecoptera, indicating relatively favorable ecological conditions. Similar patterns have been documented in other Balkan river systems, where upper mountain streams commonly support more diverse and sensitive macroinvertebrate communities due to lower pollution loads and better habitat quality (Kerovec *et al.*, 1998; AQEM Consortium, 2002). In contrast, sites classified as Poor or Bad ecological status displayed reduced taxonomic richness and lower biological index values, suggesting ecological degradation associated with nutrient enrichment, habitat alteration, and organic pollution. The observed macroinvertebrate responses are consistent with findings from previous studies conducted in Kosovo and neighboring regions. Zhushi Etemi et al. (2020) reported significant correlations between physico-chemical parameters and biotic indices within the White Drin basin, emphasizing the sensitivity of macroinvertebrate communities to nutrient and oxygen-related disturbances. Similarly, Korça and Demaku (2022) identified increased concentrations of several pollutants along the Drini i Bardhë River, particularly in areas affected by urban and agricultural activities. The elevated ammonium and nitrate concentrations recorded at several sites in the present study support these observations and indicate the continuing influence of untreated wastewater discharges and diffuse pollution sources. Macrophyte distribution patterns also reflected environmental variability among the investigated sites. The occurrence of taxa such as *Cladophora* sp. at several locations may indicate increased nutrient availability, since filamentous algae are frequently associated with eutrophic conditions and elevated phosphorus concentrations (Dodds and Welch, 2000). However, the relatively limited number of indicator macrophyte species available for index calculation reduced the precision of macrophyte-based ecological classification in the current assessment. This limitation highlights the need for further macrophyte-focused surveys in Kosovo rivers, including seasonal monitoring and refinement of regional indicator species lists.

Fish assemblages demonstrated longitudinal ecological differentiation within the basin. The fish community results provide additional ecological evidence for the spatial gradient observed across the basin. The dominance of *Salmo trutta* m. *farioides* in upstream and spring-fed sites reflects the presence of cold, well-oxygenated, fast-flowing habitats that are generally associated with better ecological conditions. In contrast, the higher species richness recorded at Zllakuqan–Lumi Istog suggests greater habitat heterogeneity in lower river sections, where cyprinid and benthic species can coexist. However, fish assemblages are strongly influenced not only by water quality but also by hydromorphological conditions and longitudinal connectivity. Barriers, channel modification, gravel extraction, sedimentation, riparian degradation, and wastewater inputs may reduce spawning habitat, restrict movement, and alter community composition. The presence of regionally important taxa such as *Alburnoides ohridanus* and habitat-sensitive species such as *Barbatula sturanyi* and *Barbus rebeli/balcanicus* highlights the need to integrate fish-based indicators, conservation status, and connectivity assessment into future monitoring programs in the Drini i Bardhë basin. (Karr, 1981; Schiemer and Waidbacher, 1992). Nevertheless, anthropogenic pressures such as habitat fragmentation, hydromorphological alteration, and pollution may intensify these ecological transitions and reduce habitat suitability for sensitive fish species.

The physicochemical results further supported the biological assessment. Increased ammonium, nitrate, and phosphate concentrations at several locations indicate localized nutrient enrichment and possible wastewater influence. Although dissolved oxygen values remained relatively favorable at some upstream sites, downstream areas exposed to urban and agricultural pressure exhibited signs of ecological stress. Similar relationships between nutrient enrichment and biological degradation have been documented throughout European freshwater ecosystems (Allan, 2004; European Commission, 2003). The heterogeneous spatial distribution of physico-chemical parameters observed in the present study suggests that local pollution sources and land-use patterns strongly influence river condition within the basin. The absence of a complete standardized hydromorphological assessment represents an important limitation of the present study. Hydromorphological conditions, including channel form, substrate structure, flow diversity, bank stability, riparian vegetation, and longitudinal connectivity, can strongly influence macroinvertebrate, macrophyte, and fish communities. For example, reduced habitat heterogeneity, channel modification, gravel extraction, or degradation of riparian zones may reduce the availability of suitable microhabitats for sensitive macroinvertebrate taxa and may also affect fish spawning, shelter, and movement. Therefore, some of the biological degradation observed in Poor and Bad status sites may reflect not only nutrient enrichment and organic pollution, but also local hydromorphological disturbance.

Because hydromorphological information was used only as qualitative supporting evidence, the final ecological classification should be interpreted with caution. The lack of a full hydromorphological scoring system limits the ability to separate the effects of water quality pressures from physical habitat degradation. Future ecological monitoring in the Drini i Bardhë River basin should therefore include a standardized hydromorphological protocol applied at all biological sampling sites. This would improve the reliability of ecological status classification and would provide a stronger basis for identifying restoration priorities, especially in river sections affected by channel alteration, reduced riparian vegetation, and habitat fragmentation. The ecological patterns observed in the Drini i Bardhë River basin are consistent with findings from other river systems in the Balkans and wider Europe, where upstream and less disturbed river sections generally support more sensitive biological communities, while downstream and urban-influenced reaches show signs of biological degradation. Similar responses have been reported in karstic and mountain rivers of the Balkan region, where macroinvertebrate richness and the presence of sensitive Ephemeroptera, Plecoptera, and Trichoptera taxa are closely associated with better habitat quality, lower organic pollution, and more natural flow conditions (Kerovec *et al.*, 1998; AQEM Consortium, 2002). At a broader European scale, river sections affected by wastewater discharge, agricultural runoff, channel alteration, and reduced riparian integrity commonly show a decline in sensitive taxa and an increase in more tolerant organisms (Allan, 2004; Skoulikidis *et al.*, 2009). Therefore, the spatial gradient recorded in the Drini i Bardhë basin reflects a pattern that is not only local but also consistent with ecological responses documented in other European river monitoring studies. The link between nutrient enrichment and biological degradation can be explained through several ecological mechanisms. Elevated concentrations of ammonium, nitrate, and phosphate may stimulate excessive algal and macrophyte growth, particularly filamentous algae such as *Cladophora* sp., which were recorded at several sites. Increased algal biomass can alter habitat structure, reduce substrate availability, and contribute to stronger daily fluctuations in dissolved oxygen. In addition, organic enrichment and wastewater inputs may increase microbial decomposition and oxygen demand, creating less favorable conditions for oxygen-sensitive macroinvertebrates and fish. As a result, sensitive groups such as Ephemeroptera, Plecoptera, and Trichoptera may decline, while more tolerant taxa become relatively more common. This mechanism helps explain why sites with higher nutrient pressure and stronger anthropogenic influence generally showed lower BMWP scores, reduced taxa richness, and poorer ecological status.

The results also have important implications for the implementation of the European Water Framework Directive in Kosovo. Under the WFD, ecological status classification should be based primarily on Biological Quality Elements and supported by physico-chemical and hydromorphological quality elements. The present study shows that benthic macroinvertebrates can provide a useful and sensitive basis for assessing ecological condition in the Drini i Bardhë basin. However, the results also indicate that Kosovo still needs more complete and standardized monitoring procedures, including type-specific reference conditions, nationally adapted class boundaries, broader seasonal datasets, and better integration of macrophytes, fish fauna, hydromorphology, and physico-chemical parameters. Reference or near-reference sites such as Burim–Istog, Drelaj, Jasiq–Erenik, and Prevallë should be protected and used as ecological benchmarks for future classification and monitoring.

From a management perspective, the findings indicate that restoration and protection measures should focus on both water quality improvement and habitat rehabilitation. Priority actions should include improving municipal wastewater treatment, reducing untreated discharges into rivers, controlling diffuse agricultural runoff, and limiting nutrient inputs from

settlements and farming areas. In addition, river management should address hydromorphological pressures by reducing uncontrolled gravel extraction, protecting riparian vegetation, restoring degraded riverbanks, and maintaining longitudinal connectivity for fish movement. Sites classified as Poor or Bad ecological status should be prioritized for targeted restoration, while sites classified as Good should be protected from further degradation. Long-term monitoring should be expanded to include repeated seasonal sampling of macroinvertebrates, macrophytes, fish, nutrients, and hydromorphological conditions at the same sites. Such an integrated approach would strengthen ecological status classification, support WFD-aligned water management, and provide a scientific basis for sustainable river basin planning in Kosovo. The ecological status classification demonstrated that only a limited number of investigated sites achieved Good ecological status, while most sites were classified as Moderate or Poor. This pattern is comparable to findings reported in many transitional and developing river monitoring systems within Southeastern Europe, where insufficient wastewater treatment infrastructure and increasing anthropogenic pressure continue to affect freshwater ecosystems (Skoulikidis *et al.*, 2009). The classification results also emphasize the importance of identifying and protecting reference or near-reference sites such as Burim–Istog and Prevallë, which may serve as ecological benchmarks for future monitoring and restoration programs.
Despite the valuable ecological information generated by this study, several limitations should be acknowledged. First, the monitoring campaign was conducted within a relatively limited temporal framework, restricting the ability to capture seasonal variability in biological communities and water quality conditions. Second, hydromorphological assessment was not fully standardized according to all WFD requirements, which may reduce the precision of integrated ecological classification. Finally, some biological quality elements, particularly macrophytes and fish fauna, would benefit from broader spatial and temporal sampling coverage.
The statistical analysis further supported the ecological interpretation of the investigated sites. Considerable spatial variability was observed among sampling locations, particularly in macroinvertebrate abundance, taxa richness, BMWP, and ASPT values. The strong positive correlation between BMWP score and taxa richness ($r = 0.91$) demonstrated that sites with greater biological diversity generally exhibited better ecological quality. Similarly, the positive relationship between BMWP and macroinvertebrate abundance indicated that biologically richer communities were associated with more favorable environmental conditions. The predominance of Poor and Moderate ecological status classes within the basin further reflects the influence of anthropogenic pressures on river ecosystem integrity. These findings are consistent with previous studies emphasizing the sensitivity of macroinvertebrate-based indices to organic pollution and habitat degradation in European river systems (AQEM Consortium, 2002; Zhushi Etemi *et al.*, 2020).

Overall, the present study demonstrates that Biological Quality Elements provide a valuable basis for ecological assessment in the Drini i Bardhë River basin, but also highlights the need for a more standardized and integrated monitoring framework. The ecological degradation observed at several sites is likely the result of combined pressures, including nutrient enrichment, wastewater influence, habitat alteration, and reduced hydromorphological integrity. Future river basin management in Kosovo should therefore combine biological monitoring with concrete restoration measures, improved wastewater infrastructure, protection of reference sites, and the development of basin-specific ecological classification thresholds in accordance with the principles of the Water Framework Directive.

5. Conclusion

The present study provides an integrated ecological assessment of selected river sections within the Drini i Bardhë River basin through the application of Biological Quality Elements supported by physico-chemical and hydromorphological parameters. The results demonstrated substantial spatial variation in ecological condition across the investigated sites, reflecting differences in both natural habitat characteristics and anthropogenic pressure intensity. Macroinvertebrate communities proved to be highly sensitive indicators of ecological quality and represented the most informative biological component for ecological status classification. Sites such as Burim–Istog, Drelaj, and Jasiq–Erenik exhibited comparatively high BMWP and ASPT values and supported pollution-sensitive taxa, indicating relatively good ecological conditions. In contrast, several downstream and human-impacted locations showed reduced taxonomic richness and lower biological index values, suggesting ecological degradation associated with nutrient enrichment, habitat alteration, and wastewater influence. Macrophyte and fish fauna assessments complemented the macroinvertebrate results by revealing clear ecological differences among river sections. Upstream and spring-fed habitats supported assemblages characteristic of cold, well-oxygenated waters, while lower river reaches exhibited more heterogeneous communities influenced by local environmental pressures. The occurrence of filamentous algae and increased nutrient concentrations at some sites further indicated localized eutrophication processes. Future monitoring in the Drini i Bardhë River basin should include a more complete macrophyte assessment protocol, with regionally adapted indicator values for Kosovo rivers. This would allow a larger proportion of recorded taxa to contribute directly to ecological status classification and would improve the integration of macrophytes as a Biological Quality Element under the Water Framework Directive. Physicochemical analyses revealed elevated concentrations of ammonium, nitrate, and phosphate at several sampling locations, confirming the influence of anthropogenic activities such as untreated wastewater discharge, agricultural runoff, and hydromorphological disturbance. Although some upstream sites maintained favorable oxygen conditions and relatively preserved ecological integrity, many river sections were classified as Moderate or Poor ecological status, while Lumi i Plavës was identified as having Bad ecological status. Overall, the findings confirm that Biological Quality Elements constitute an effective and reliable tool for ecological assessment of river ecosystems within the Drini i Bardhë basin and support their applicability within the framework of the European Water Framework Directive. The study also highlights the necessity of strengthening long-term ecological monitoring, improving wastewater treatment infrastructure, protecting reference river sections, and developing basin-specific ecological classification systems adapted to Kosovo's environmental conditions. Future research should focus on expanding seasonal and long-term monitoring, refining regional biological indices, and integrating more comprehensive hydromorphological assessment methods in order to improve the accuracy and reliability of ecological status classification and support sustainable river basin management in Kosovo. Future monitoring should also integrate a complete and standardized hydromorphological assessment at all sampling sites, because physical habitat condition, channel modification, flow diversity, riparian integrity, and connectivity are essential supporting elements for interpreting biological quality and for developing effective river restoration measures.

Supplementary Materials

The following supporting information can be downloaded at:
https://onlinejbs.com/index.php/jbs/libraryFiles/downloadPublic/403

Conflict of interests

The authors declare that they have no conflicts of interest that could have influenced the conduct, analysis, or presentation of the research.

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