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Biodiversity and distribution of selected freshwater mollusks and crayfish along a mineralization gradient in the Zarafshan River, Uzbekistan

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Abstract. *Boymurodov K, Yunusov K, Izzatullaev Z, Raximov M, Boymurodov S, Djalilov F, Khasanov N, Egamkulov A, Otakulov B, Suyarov S, Aliyev B, Mirzamurodov O, Saboxiddinov B, Jabborova T, Khorazov S, Saidkulov J, Mustafoyev Z. 2026. Biodiversity and distribution of selected freshwater mollusks and crayfish along a mineralization gradient in the Zarafshan River, Uzbekistan. Biodiversitas 27 (4): d270425. https://doi.org/10.13057/biodiv/d270425.* The Zarafshan River basin is characterized by a distinct hydro-chemical gradient shaped by intense urbanization and industrial activity, which significantly impacts its biological integrity. This study evaluates the taxonomic diversity and distribution of four key freshwater macroinvertebrate families (Unionidae, Corbiculidae, Lymnaeidae, and Astacidae) along a documented mineralization gradient in the Zarafshan River basin. Field surveys were conducted from 2023 to 2025 at 12 sampling stations representing varying anthropogenic pressures. Taxonomic composition was analyzed alongside hydro-chemical parameters, including Total Dissolved Solids (TDS) and nutrient levels. A total of 11 species, belonging to 3 classes, 4 orders, 4 families, and 7 genera, were identified. Data analysis revealed a marked decline in both species' richness and individual density as water mineralization increased from 300 mg/L (Site Z1) to 1600 mg/L (Site Z4). Ecological classification identified the predominance of phytophilic (5 species, 45.4%) and peloreophilic (3 species, 27.3%) groups. Faunistic similarity analysis, using Jaccard and Ochiai indices, showed the highest similarity between stations K1 and A2 (Ochiai 0.95), while the lowest similarity was recorded between the most impacted stations Z4 and K4 (Jaccard 0.45). The observed spatial shifts in community structure suggest that elevated mineralization and organic loading are primary drivers of macroinvertebrate distribution in the basin. These findings characterize the environmental tolerances of the target taxa, providing foundational data for developing future bioindication frameworks in the Zarafshan River ecosystem.

Keywords: Anthropogenic impact, macrozoobenthos, Ochiai, species richness, total dissolved solids

INTRODUCTION

Freshwater macroinvertebrates, including mollusks and crustaceans, are fundamental components of aquatic ecosystems, fulfilling critical roles in nutrient cycling and water self-purification (Tsybekmitova et al. 2025). Among these, selected families such as Unionidae, Corbiculidae, Lymnaeidae, and Astacidae are highly valued as bioindicators due to their specialized ecological adaptations and sensitivity to environmental shifts (Dildar et al. 2025). While global records identify over 150,000 hydrobiont species, maintaining the stability of their populations is increasingly vital for the ecological balance of inland water bodies (Baymuradov et al. 2021). The accelerating anthropogenic pressure on freshwater systems, characterized by chemical pollution and habitat transformation, is likely associated with a decline in aquatic biodiversity (Naselli-Flores et al. 2023; Pazilov et al. 2026).

In particular, the discharge of industrial and agricultural effluents leads to elevated mineralization and salt content, which may influence the community structure and survival of historically established hydro-fauna. Understanding the correlation between these hydro-chemical gradients and the transformation of macroinvertebrate assemblages warrants investigation to prevent the local disappearance of rare and sensitive species (Boymuradov et al. 2024; Gavrilaş et al. 2025; Medetov 2025b). Historically formed hydro-faunal species in natural water bodies are of particular importance, and changes in their biotopes under the influence of anthropogenic and technogenic factors are leading to the transformation of hydro-biont fauna and the disappearance of rare species. Therefore, it is of great scientific and practical importance to determine changes in the populations of aquatic organisms in areas under strong anthropogenic influence (Liu et al. 2023; Medetov et al. 2025a). In recent years, the expansion of urbanization and the increase in water mineralization due to increased water pollution by industrial and agricultural wastes have become some of the main factors affecting the diversity of aquatic organisms (Varatharajan et al. 2025). Most industrial enterprises are located near rivers, which leads to water pollution as a result of the untreated discharge of industrial waste (Ma et al. 2022).

The Zarafshan River, stretching over 781 km through a basin of 41,680 km², presents a distinct anthropogenic gradient shaped by intense urbanization and industrial activity. Key tributaries, the Akdarya (131 km) and Karadarya (111 km), receive runoff from major urban centers, including Samarkand and Kattakurgan. This geographical and industrial framework creates a complex hydro-chemical environment, where the downstream accumulation of untreated waste potentially alters the biological integrity of the river system (Yunusov et al. 2024; Uralov et al. 2025).

Despite previous studies on various animal groups in the Zarafshan oasis, there is currently limited faunistic and ecological information regarding the specific distribution of Unionidae, Corbiculidae, Lymnaeidae, and Astacidae under these differing hydro-chemical conditions (Mamanov et al. 2024; Alimova et al. 2025; Naydenov et al. 2025).

To address this gap, the present study focuses on four selected families: Unionidae, Corbiculidae, Lymnaeidae, and Astacidae. The rationale for selecting these specific taxa is based on several ecological criteria. First, these families represent different functional feeding groups (filter-feeders, scrapers, and omnivorous scavengers), providing a holistic view of benthic community health. Second, unlike smaller, highly mobile or transient aquatic insects, these mollusks and crayfish are characterized by long life cycles and limited mobility (sedentary or semi-sedentary). This makes them superior bioindicators, as their population structures and densities integrate the cumulative effects of environmental stress over several years. Third, their high biomass and role in calcium carbonate cycling (in the case of mollusks) make them fundamental to the river's structural complexity and nutrient dynamics.

The objective of this study was to evaluate the taxonomic composition and ecological status of these selected families across 12 stations in the Zarafshan basin. We hypothesized that stations subject to higher mineralization and cumulative anthropogenic influence would exhibit reduced species richness, lower individual density, and decreased faunistic similarity compared to less-impacted upstream sites.

MATERIALS AND METHODS

Study area and sampling design

The study was conducted at 12 sampling stations across the Zarafshan River basin, Uzbekistan, specifically selected to represent a distinct hydro-chemical and anthropogenic gradient. The stations were categorized into: Reference sites (Z1, K1): Upper reaches with minimal human interference and low mineralization; Agricultural zones (A2, K2): Areas affected by irrigation runoff; Urban/Industrial zones (Z3, A4, K3, K4): Sites downstream of Samarkand and Kattakurgan, subject to high nutrient loading and industrial effluents; Lentic habitats (A3): Reservoir conditions with altered hydro-morphology (Table 1).

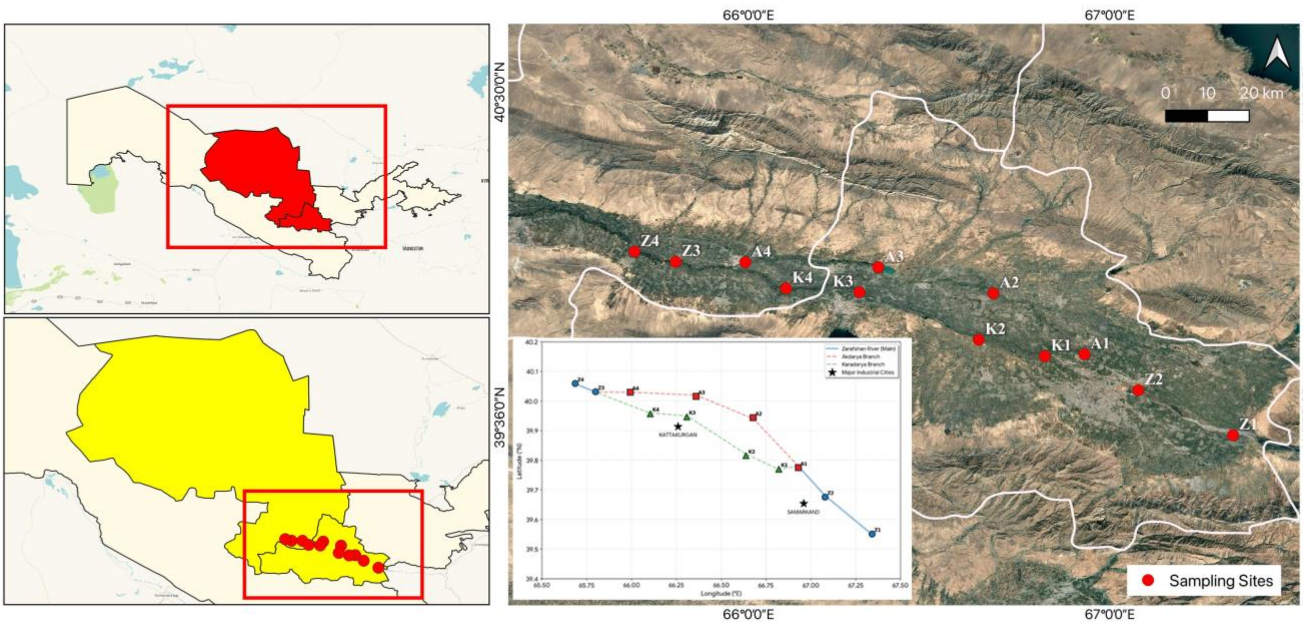

Figure 1. Map of research areas in the Zarafshan River basin, Uzbekistan

Table 1. Characteristics of the research stations in the Zarafshan River basin

River	Location	Location name	Coordinate	Description and anthropogenic gradient
Zarafshan	Z1	Chubot	39°33'06.3"N 67°20'27.6"E	Upper reach, reference site with minimal human impact
	Z2	National nature reserve-Zarafshan	39°40'34.5"N 67°04'43.1"E	Protected area, moderate anthropogenic pressure
	Z3	Narpay	40°01'54.3"N 65°47'55.1"E	Urbanized area, high nutrient and organic loading
	Z4	Paxtachi	40°03'34.6"N 65°41'04.6"E	Lower reach, maximum mineralization and industrial influence
Akdarya	A1	Kalandar	39°46'32.1"N 66°55'47.2"E	Branch source, relatively low pollution levels
	A2	Boybuta	39°56'39.4"N 66°40'39.1"E	Agricultural zone, runoff influence
	A3	Akdarya Reservoir	40°00'58.2"N 66°21'33.6"E	Lentic conditions, hydro-morphological alteration
	A4	Yangirabod	40°01'48.6"N 65°59'28.0"E	Downstream of urban centers, high mineralization
Karadarya	K1	Saydan	39°46'14.2"N 66°49'12.8"E	Natural flow, foothills zone, low mineralization
	K2	Aksulat	39°48'57.2"N 66°38'14.8"E	Moderate agricultural and domestic impact
	K3	Kattakurgan	39°56'50.3"N 66°18'24.8"E	Near major industrial city, elevated pollution risk
	K4	Kattaming	39°57'27.7"N 66°06'14.6"E	Final reach, cumulative anthropogenic stress

Hydro-chemical analysis

Water samples were collected seasonally (February, April, July, and October) using 2 L sterile bottles. To ensure accuracy, three replicates were taken at each station, and the values presented in Table 2 represent the annual mean values. Dissolved Oxygen (DO) was measured in situ using a portable oximeter (expressed in mg/L; previous µg/mL units were corrected to align with UzDSt 950:2011 standards). Concentrations of nitrite nitrogen (NO_2-N) and ammonium nitrogen (NH_4-N) were determined spectrophotometrically following Parsons et al. (1984). NO_2-N was measured using the sulfanilamide method at 543 nm, and NH_4-N was determined via the indophenol blue method at 640 nm using EMC-30PC-UV Spectrophotometer. BOD_5: BOD_5 was determined using the standard 5-day incubation method at 20°C in the dark, according to the American Public Health Association (APHA 1975) protocols. Water mineralization was measured as Total Dissolved Solids (TDS) using gravimetric analysis. Samples were filtered through a 0.45 µm membrane filter, evaporated, and the residue was dried at 105°C to a constant weight.

Sample collection

Material selection and processing were carried out using the method of Izzatullayev (2019) and Shashi et al. (2023). To ensure a robust and reproducible dataset, seasonal sampling surveys were conducted over a three-year period (2023-2025). Each station was visited four times annually (February, April, July, and October), totaling 12 sampling events per site. At each visit, 3 biological replicates were collected per habitat type (benthic substrate and aquatic vegetation), resulting in a total of 2,160 biological records (individual specimens analyzed). Standardization of sampling effort was maintained across all stations to ensure comparability of density data.

For larger bivalves (Unionidae) and crayfish (Astacidae) in wadeable areas (up to 1.5 m depth), a standardized 1 m^2 quadrat was used. All individuals within the plot were collected manually or using a hydrobiological shovel. For deep-water habitats, in areas exceeding 2 m (e.g., A3 reservoir), a Petersen dredge (0.025 m^2) was employed. Density was then extrapolated to ind./m^2.

For small gastropods (Lymnaeidae) and Corbiculidae associated with aquatic vegetation, a standardized frame net (matrap) with a fixed sampling area of 0.25 m^2 (50 cm ×50 cm) and a mesh size of 0.5 mm was used. To ensure the consistency of the results and minimize collector bias throughout the study period (2023-2025), all sampling procedures were performed by the same group of trained researchers. Collected vegetation was thoroughly washed in the net to ensure all associated macroinvertebrates were captured, with results integrated into the total area-based density estimates (ind./m^2).

Samples were sieved (0.5 mm mesh), fixed in 70-75% ethanol, and transported to the laboratory. Voucher specimens were deposited in the Zoological Collection of Samarkand State University of Veterinary Medicine, Livestock and Biotechnologies for taxonomic verification. Ethical approval was not specifically required for this study as it focused on non-protected freshwater invertebrates. However, all sampling procedures followed the ethical guidelines for aquatic research and biodiversity conservation standards.

Species identification

Species were identified using morphological and anatomical characters (hinge structure for Bivalvia, shell aperture and copulatory apparatus for Gastropoda, and rostrum/chelae morphology for Astacidae). Keys by Starobogatov et al. (2004) and Izzatullayev (2019) were utilized. Identification was strictly morphological; no molecular components were applied in this study. While morphological identification remains a foundational tool in malacology, we acknowledge the absence of molecular genetic analysis (DNA barcoding) in this study. Future research incorporating Cytochrome Oxidase I (COI) gene sequencing would further refine the taxonomic resolution, especially for cryptic species complexes within the Unionidae family.

Ecological analysis

Species were categorized into ecological groups based on substrate and flow preference (Izzatullayev 2019). Peloreophile: Inhabiting silted substrates in flowing water; Phytophile: Associated with aquatic vegetation; Reophile: Preferring fast-flowing oxygenated water; Telmatophile: Inhabiting stagnant, marshy waters; Phytoreophile: Living on plants in flowing water; Pelolimnophile: Preferring silted bottoms in stagnant water.

Density determination

The density of individuals in the population was determined by the method of Izzatullayev (2019). In this case, the samples were collected from plots with a size of 1 m^2.

Data analysis

The Ochiai Index was calculated using the following formula (Bolton 1991):

$$\mathrm{OI} = \frac{a}{\sqrt{(a+b)(a+c)}}$$

Where, a, b and c: The number of species in each area.

The Kulczinsky index was calculated using the following formula (Sant et al. 2017; Zokirova et al. 2025):

$$K = \frac{1}{2}\left(\frac{c}{a+c} + \frac{c}{b+c}\right)$$

Where, c: is the number of common elements shared by both samples, a: is the number of elements unique to the first sample, b: is the number of elements unique to the second sample.

The Jaccard coefficient was calculated using the following formula (Akramov et al. 2025; Narzullayev and Subbotin 2025):

$$S_j = \frac{j}{(a+b-j)}$$

Where, j: The number of species common to both areas, a and b: The number of species in each area.

The Chekanovsky-Sørensen coefficient was calculated using the following formula (Uralov et al. 2025; Istamkulova et al. 2025):

$$S = \frac{2a}{2a+b+c}$$

Where, a: The number of species common to both areas, b and c: The number of species in each area.

The similarity dendrogram was constructed using the Paleontological Statistics (PAST) 4.0.7 program (Ergasheva et al. 2024; Kudratov et al. 2024).

RESULTS AND DISCUSSION

Hydro-chemical gradient and water quality

The hydro-chemical analysis reveals a pronounced spatial gradient along the Zarafshan River and its tributaries, characterized by a progressive increase in mineralization and nutrient loading from upstream to downstream stations (Table 2). A critical finding of this study is the rise in TDS, which serves as a primary proxy for the mineralization gradient. At the reference station (Z1), the water remains relatively dilute, with a mean TDS of 300±25 mg/L. However, as the river traverses through urbanized and industrial hubs, mineralization levels escalate sharply, reaching a peak of 1600±120 mg/L at Z4. This nearly five-fold increase indicates cumulative salt loading, likely stemming from irrigation return flows and industrial effluents. Similar trends were observed in the Akdarya (A4: 1500 mg/L) and Karadarya (K4: 1300 mg/L) branches, confirming that the lower reaches of the entire basin are subject to high salinity stress. The dramatic increase in TDS at station Z4 (1600 mg/L) is primarily attributed to the cumulative discharge of collector-drainage waters from surrounding agricultural fields and untreated industrial effluents from the Samarkand and Kattakurgan industrial hubs. This mineralization gradient acts as a chemical barrier, restricting the distribution of salt-sensitive species.

Table 2. Mean annual values of hydro-chemical parameters at the sampling stations (2023-2025)

Station	O_2 (mg/ L)	Biological oxygen demand (BOD_5) (mg O_2/L)	Phenols (mg/L)	Nitrate nitrogen (mg/L)	Nitrite nitrogen (mg/L)	TDS (mg/L)
Z1	7.6±0.4	1.2±0.2	<0.001	0.02±0.01	0.12±0.04	300±25
Z2	7.2±0.3	1.8±0.3	0.001	0.05±0.02	0.25±0.05	500±40
Z3	5.8±0.5	3.6±0.4	0.003	0.15±0.04	0.85±0.12	1200±95
Z4	5.2±0.6	4.2±0.5	0.005	0.28±0.06	1.15±0.15	1600±120
A1	6.8±0.4	2.1±0.2	0.002	0.08±0.03	0.45±0.08	800±60
A2	6.3±0.4	2.6±0.3	0.002	0.14±0.04	0.68±0.10	1280±90
A3	5.9±0.5	3.1±0.4	0.003	0.22±0.05	0.84±0.12	1435±105
A4	5.4±0.5	3.8±0.4	0.004	0.32±0.05	1.25±0.18	1500±110
K1	7.4±0.3	1.5±0.2	0.001	0.04±0.01	0.22±0.04	1120±85
K2	6.8±0.4	2.3±0.3	0.003	0.11±0.03	0.46±0.07	1190±90
K3	6.2±0.4	3.1±0.4	0.004	0.18±0.04	0.70±0.10	1250±95
K4	5.6±0.4	3.9±0.5	0.006	0.25±0.05	0.95±0.14	1300±105

Note: Data are presented as Mean±Standard Deviation (SD). TDS: Total dissolved solids

The dissolved oxygen (DO) levels showed an inverse relationship with anthropogenic pressure. While upstream stations maintained healthy oxygenation (Z1: 7.6±0.4 mg/L), downstream sites exhibited a marked decline, with DO dropping to 5.2±0.6 mg/L at Z4.

The observed hydro-chemical profile suggests that the Zarafshan River undergoes a transformation from a "clean-water" mountain-foothill system to a "highly mineralized/ eutrophic" lowland system. While some parameters remain within the broad limits of national standards, the cumulative effect of high TDS and nutrient loading appears to be the primary driver of the documented decline in macroinvertebrate diversity. These findings align with recent studies in Central Asian River basins (Ma et al. 2020; Rakhimov et al. 2025), where mineralization exceeding 1000 mg/L has been identified as a critical tipping point for benthic community restructuring.

Species composition

As a result of the identification of materials collected from the Zarafshan River and its tributaries, 11 species of hydrobionts belonging to the families Astacidae, Unionidae, Corbiculidae, and Lymnaeidae belonging to 3 classes, 4 orders, 4 families, and 7 genera, were recorded in the study area (Table 3).

The observed patterns of biodiversity in the Zarafshan River basin are consistent with previous regional and extra-regional hydrobiological surveys. Boymuradov et al. (2021) have previously documented that the freshwater malacofauna of Uzbekistan is highly susceptible to habitat modification. This is further corroborated by recent data from the neighboring Amu Darya River, where Rakhimov et al. (2025) reported a reduction in the species richness of the target families (Unionidae, Corbiculidae, Lymnaeidae, and Astacidae) from 15 to 12 species in the middle and lower reaches following transit through urbanized zones.

Our findings mirror this downstream biodiversity decline, where cumulative anthropogenic stress from Samarkand and Kattakurgan likely acts as a similar environmental filter to that observed in the Amu Darya. Furthermore, while Aliyev (2021) reported a much broader diversity of 431 hydrobiont species (including 30 molluscan species) in the rivers of Azerbaijan, the specific taxonomic structure of the Zarafshan (particularly the dominance of 11 species within the 4 families studied) indicates a high level of regional specialization. The consistent decrease in species richness along the mineralization gradient in both the Zarafshan and Amu Darya highlights a cross-basin ecological response to salinity and nutrient loading in Central Asian lotic systems.

Taxon composition

When analyzing the taxon composition of hydrobiont species belonging to the families Unionidae, Corbiculidae, Lymnaeidae and Astacidae in the Zarafshan River and its tributaries, it was revealed that representatives of the class Gastropoda predominate in this river. Among the species, 6 species were recorded as belonging to this class. When comparing the species in the order section, it was found that most of them belong to the orders Liimmoriniformes (6 species) and Unionifarmes (2 species). Among the families, Lymnaeidae (6 species) was recorded as the most species-rich family, while the least species (1 species) belonged to the family Astacidae. Analysis of hydrobiont species in the genus section showed that the genus Lymnaea (3 species) clearly predominates in the Zarafshan River and its tributaries. In addition, 2 species each from the genera *Corbicula* and *Radix*, and 1 species each from the genera *Synanodonta*, *Anodonta*, *Galba*, and *Pontastacus* were recorded (Figure 2).

The taxonomic structure identified in the Zarafshan River basin presents an interesting contrast to other regional and extra-regional riverine systems. For instance, Golovatyuk et al. (2023) investigated the macrozoobenthos of 17 small rivers in the southern East European Plain, identifying over 100 species; however, their findings included only 11 gastropod and 4 bivalve species. In comparison, our study documented a significantly higher proportion of Gastropods (6 species of Gastropoda), representing 54.5% of the total target taxa.

Table 3. Checklist of selected freshwater mollusks and crayfish along a mineralization gradient in the Zarafshan River, Uzbekistan

Class	Order	Family	Genus	Species
Bivalvia (Linne, 1758)	Unioniformes (Stoliczka, 1871)	Unionidae (Rafinesque, 1820)	*Sinanodonta* (Modell, 1944)	*Sinanodonta woodiana* (I. Lea, 1834)
			Anodonta (Lamarck, 1799)	*Anodonta anatina* (Linnaeus, 1758)
	Cardiida (Ferussac, 1822)	Corbiculidae (Gray, 1847)	*Corbicula* (Meqerle, 1811)	*Corbicula fluminalis* (O. F. Müller, 1774) *Corbicula tibetensis* (Prashad, 1929)
Gastropoda (Cuvier, 1795)	Lymnaeiformes (Pcelintsev, 1863)	Lymnaeidae (Rafinesque, 1815)	*Lymnaea* (Lamarck, 1799)	*Lymnaea stagnalis* (Linnaeus, 1758) *Lymnaea fragilis* (Linnaeus, 1758) *Lymnaea subfragilis* (A. d'Orbigny, 1852)
			Galba (Schrank, 1803)	*Galba truncatula* (O. F. Müller, 1774)
			Radix (Montfort, 1810)	*Radix auricularia* (Linnaeus, 1758) *Radix bactriana* (T. Hutton, 1849)
Malacostraca (Latreille, 1802)	Decapoda (Latreille, 1802)	Astacidae (Latreille, 1802)	*Pontastacus* (Bott, 1950)	*Pontastacus leptodactylus* (Eschscholtz, 1823)

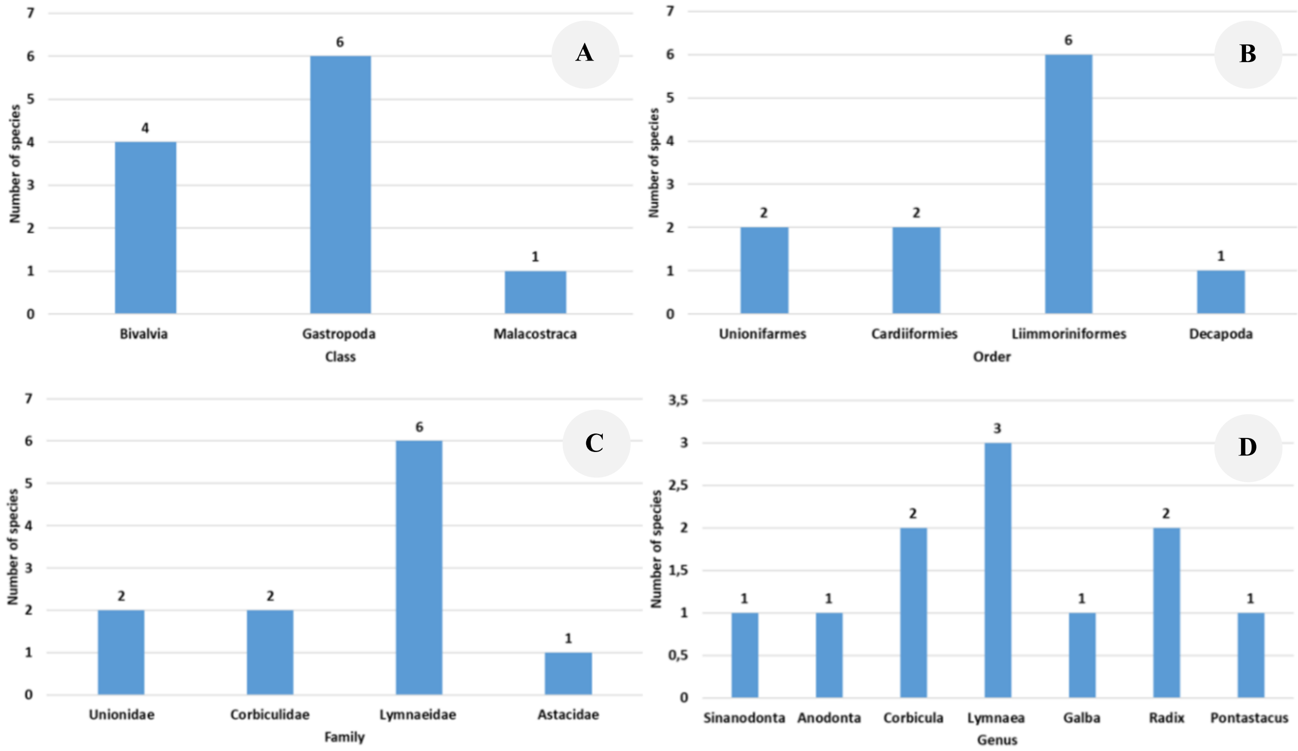

Figure 2. Taxon composition of selected freshwater mollusks and crayfish along a mineralization gradient in the Zarafshan River, Uzbekistan. A. Class, B. Order, C. Family, D. Genus

This higher prevalence of bivalves, particularly within the Unionidae and Corbiculidae families, underscores the unique ecological conditions of the Zarafshan basin, where silted substrates and moderate flow velocities provide optimal habitats for large-bodied filter feeders. While the overall dominance of molluscan fauna across these geographically distinct regions suggests a broad ecological convergence in riverine macroinvertebrate assemblages, the specific enrichment of bivalve diversity in our study emphasizes the high biological productivity and specialized niche availability within the Zarafshan's mid-stream reaches. These comparative data further validate the reliability of our taxonomic records and highlight the regional distinctiveness of the Zarafshan's benthic community.

Similarity of species composition

Determining the degree of similarity of species composition at selected stations in the study area is of particular importance in faunistic studies. In this study, the distribution of species of the families Unionidae, Corbiculidae, Lymnaeidae and Astacidae was determined at 12 stations in the Zarafshan River and its tributaries (Table 4).

The analysis of species richness (S) across the 12 sampling stations reveals a clear response to the documented mineralization and nutrient loading gradient (Table 5). The highest taxonomic diversity was recorded at stations Z2 (S): 10 and K1 (S): 10, which represent protected or structurally stable foothills with lower hydro-chemical profiles. Within the Akdarya branch, species richness remained relatively stable at (S): 9 across stations A1, A2, and A3. In contrast, a marked decline in richness was observed at the most heavily impacted downstream stations subjected to intense salinity and industrial stress: species richness dropped to a minimum of (S): 8 at station Z4 on the Zarafshan mainstem, (S): 8 at station A4 (Akdarya), and (S): 8 at station K4 (Karadarya). This spatial distribution confirms that species richness is inversely correlated with Total Dissolved Solids (TDS), showing a significant loss of biological integrity in the lower reaches.

This spatial distribution confirms that species richness is inversely correlated with TDS. As mineralization increased from 300 mg/L to 1600 mg/L along the Zarafshan mainstem, approximately 11.1% of the target taxa were lost, particularly sensitive species within the Corbiculidae and Lymnaeidae families (such as *Corbicula fluminalis* and *Lymnaea stagnalis*, which were completely excluded at site Z4). The stable richness in the Akdarya branch (A1-A3) suggests that lentic conditions and localized habitat complexity may partially buffer the negative effects of mineralization, although the overall trend remains downward towards the lower reaches (A4, (S): 8).

The obtained data allowed us to assess the similarity of the species composition of the families Unionidae, Corbiculidae, Lymnaeidae, and Astacidae in the areas of the Zarafshan River and its tributaries with different levels of industrialization, urbanization, and anthropogenic impact (Table 6). According to the Ochiai index, the minimum level of species similarity (0.63) was noted between the heavily impacted downstream areas Z4 and K4, while the maximum similarity (0.95) was recorded between reference/

agricultural stations K1 and A2 (excluding the absolute identical match of 1.00 between K1 and K2). In this regard, an identical trend was observed in the data obtained according to the Kulczynski index, where the Z4-K4 similarity was likewise 0.63. Furthermore, according to the Jaccard index, the similarity coefficient between Z4 and K4 dropped to its absolute lowest matrix value of 0.45. The values calculated via the Chekanovsky-Sørensen index (0.63 for Z4-K4) fully substantiated and mirrored the above-mentioned faunistic differentiation trends across the environmental gradient (Table 6).

The similarity dendrogram created based on the identified data is shown in Figure 3. Analysis of the data in Table 5 and Figure 3 based on the data in Table 2 showed that the increase in salts in the chemical composition of water and the increase in mineralization led to a decrease in the species composition of hydrobionts in the water.

Density and ecological groups

Individual density significantly decreased along the longitudinal river profile. At the upstream reference site Z1, the dominant bivalve *Sinanodonta woodiana* reached a mean density of 1.8 ind./m², whereas at the highly mineralized station Z4, its density sharply dropped to 0.6 ind./m² (Table 7). Across the Zarafshan River basin, the macroinvertebrate community is numerically dominated by *S. woodiana* (0.6-1.8 ind./m² depending on local water chemistry), *L. stagnalis* (1.0-1.8 ind./m²), *Galba truncatula* (0.8-1.7 ind./m²), and *Radix auricularia* (0.6-1.3 ind./m²) (Table 7). Unlike the more resilient pulmonate gastropods, large sedentary bivalves (Unionidae) and the freshwater crayfish *Pontastacus leptodactylus* exhibit high sensitivity to heavy siltation and elevated chemical parameters, resulting in localized population collapse or complete exclusion at the most degraded stations (Z4, K4).

In the Zarafshan River and its tributaries, species belonging to the families Astacidae, Corbiculidae, Unionidae, Lymnaeidae and are adapted to live in various biotopes. Based on the characteristics of the biotopes from which their samples were collected, hydrobionts were divided into 6 ecological groups (Figure 4).

Table 4. Distribution of species across research stations of species across research stations

Species	Zarafshan				Akdarya				Karadarya			
	Z1	Z2	Z3	Z4	A1	A2	A3	A4	K1	K2	K3	K4
Sinanodonta woodiana	+	+	+	+	+	+	+	+	+	+	+	+
Anodonta anatina	+	+	+	+	+	+	+	+	+	+	+	+
Corbicula fluminalis	+	+	-	-	+	+	-	-	+	+	+	+
Corbicula tibetensis	+	+	+	+	+	+	+	+	+	+	+	-
Lymnaea stagnalis	+	+	+	-	+	+	+	+	+	+	+	+
Lymnaea fragilis	+	+	+	+	+	+	+	+	+	+	+	+
Lymnaea subfragilis	+	+	+	-	-	-	+	-	-	-	+	+
Galba truncatula	+	+	-	+	-	-	-	+	+	+	+	+
Radix auricularia	-	+	+	+	+	+	+	+	+	+	-	+
Radix bactriana	-	-	+	+	+	+	+	+	+	+	-	-
Pontastacus leptodactylus	+	+	+	+	+	+	+	-	+	+	+	-

Notes: +: recorded, -: not recorded

Table 5. Summary of species richness across sampling stations in the Zarafshan River basin, Uzbekistan

River	Code	Station	Species richness (S)	Mineralization (TDS, mg/L)
Zarafshan	Z1	Chubot	9	300
	Z2	National nature reserve-Zarafshan	10	500
	Z3	Narpay	9	1200
	Z4	Paxtachi	8	1600
Akdarya	A1	Kalandar	9	800
	A2	Boybuta	9	1280
	A3	Akdarya Reservoir	9	1435
	A4	Yangirabod	8	1500
Karadarya	K1	Saydan	10	1120
	K2	Aksulat	10	1190
	K3	Kattakurgan	9	1250
	K4	Kattaming	8	1300

Table 6. Similarity coefficients of selected freshwater mollusks and crayfish along a mineralization gradient in the Zarafshan River, Uzbekistan

Research area	Z1	Z2	Z3	Z4	A1	A2	A3	A4	K1	K2	K3	K4
Ochiai index												
Z1	1											
Z2	0.95	1										
Z3	0.78	0.84	1									
Z4	0.71	0.78	0.82	1								
A1	0.78	0.84	0.89	0.82	1							
A2	0.78	0.84	0.89	0.82	1	1						
A3	0.78	0.84	1,00	0.82	0.89	0.89	1					
A4	0.71	0.78	0.82	0.88	0.82	0.82	0.82	1				
K1	0.84	0.90	0.84	0.89	0.95	0.95	0.84	0.89	1			
K2	0.84	0.90	0.84	0.89	0.95	0.95	0.84	0.89	1,00	1		
K3	1,00	0.95	0.78	0.71	0.78	0.78	0.78	0.71	0.84	0.84	1	
K4	0.82	0.89	0.71	0.63	0.71	0.71	0.71	0.75	0.78	0.78	0.82	1
Kulczinsky index												
Z1	1											
Z2	0.95	1										
Z3	0.78	0.84	1									
Z4	0.71	0.79	0.83	1								
A1	0.78	0.84	0.89	0.83	1							
A2	0.78	0.84	0.89	0.83	1,00	1						
A3	0.78	0.84	1,00	0.83	0.89	0.89	1					
A4	0.71	0.79	0.83	0.88	0.83	0.83	0.83	1				
K1	0.84	0.90	0.84	0.90	0.95	0.95	0.84	0.90	1			
K2	0.84	0.90	0.84	0.90	0.95	0.95	0.84	0.90	1,00	1		
K3	1,00	0.95	0.78	0.71	0.78	0.78	0.78	0.71	0.84	0.84	1	
K4	0.83	0.90	0.71	0.63	0.71	0.71	0.71	0.75	0.79	0.79	0.83	1
Jaccard index												
Z1	1											
Z2	0.9	1										
Z3	0.64	0.73	1									
Z4	0.55	0.64	0.70	1								
A1	0.64	0.73	0.80	0.70	1							
A2	0.64	0.73	0.80	0.70	1,00	1						
A3	0.64	0.73	1,00	0.70	0.80	0.80	1					
A4	0.55	0.64	0.70	0.78	0.70	0.70	0.70	1				
K1	0.73	0.82	0.73	0.80	0.90	0.90	0.73	0.80	1			
K2	0.73	0.82	0.73	0.80	0.90	0.90	0.73	0.80	1,00	1		
K3	1,00	0.90	0.64	0.55	0.64	0.64	0.64	0.55	0.73	0.73	1	
K4	0.70	0.80	0.55	0.45	0.55	0.55	0.55	0.60	0.64	0.64	0.70	1
Chekanovsky-Sørensen index												
Z1	1											
Z2	0.95	1										
Z3	0.78	0.84	1									
Z4	0.71	0.78	0.82	1								
A1	0.78	0.84	0.89	0.82	1							
A2	0.78	0.84	0.89	0.82	1,00	1						
A3	0.78	0.84	1,00	0.82	0.89	0.89	1					
A4	0.71	0.78	0.82	0.88	0.82	0.82	0.82	1				
K1	0.84	0.90	0.84	0.89	0.95	0.95	0.84	0.89	1			
K2	0.84	0.90	0.84	0.89	0.95	0.95	0.84	0.89	1,00	1		
K3	1,00	0.95	0.78	0.71	0.78	0.78	0.78	0.71	0.84	0.84	1	
K4	0.82	0.89	0.71	0.63	0.71	0.71	0.71	0.75	0.78	0.78	0.82	1

Analysis of ecological groups showed that phytophiles (5 species, 45.4%), that is, species distributed among plants, and peloreophiles (3 species, 27.3%), that is, species living among fine bottom sediments, predominate among the species identified in the region. This indicates that most hydrobionts in the river use plants and muddy substrates under flowing water as their habitat. The observed reduction in species richness and density suggests that elevated mineralization and organic loading act as primary limiting factors for Unionidae and Astacidae in the Zarafshan basin. Unlike the more tolerant Lymnaeidae, large bivalves are sensitive to sediment toxicity and nutrient enrichment. While these correlations are strong, the direct causal link between specific pollutants (e.g., heavy metals or phenols) and mortality requires further toxicological validation. From a conservation perspective, the preservation of upstream reference sites (Z1, K1) is critical for maintaining the regional species pool and the potential recolonization of restored downstream reaches.

The predominance of phytophilic species (5 species, 45.4%) is linked to the increased siltation and organic enrichment in the middle and lower reaches of the Zarafshan River. The slower flow velocity and elevated sedimentation of fine-grained particles create ideal microhabitats for these species, which are specifically adapted to burrowing in soft, muddy substrates.

The distribution of Unionidae species is heavily impacted by anthropogenic factors, particularly water level fluctuations caused by irrigation management and hydro-technical installations. These sedentary filter-feeders are highly vulnerable to desiccation during sudden level drops and to sediment toxicity from urban runoff, which explains their marked decline in the most impacted downstream segments (Z4, K4) (Bird et al. 2022).

The observed patterns of macroinvertebrate community restructuring in the Zarafshan River basin align with broader regional trends documented in Central Asian aquatic systems. A key finding of this study is the pronounced response of taxonomic richness and density to the mineralization gradient, a phenomenon similarly observed by Bazarova et al. (2024) in saline lake ecosystems. Their research highlighted that salinity acts as a primary environmental filter, where exceeding specific ionic thresholds leads to a sharp decline in individual density and the formation of specialized, salt-tolerant assemblages. Our results extend this observation to lotic environments, suggesting that Total Dissolved Solids (TDS) concentrations exceeding 1000 mg/L serve as a critical tipping point for the survival of sensitive bivalve and decapod species in the Zarafshan River.

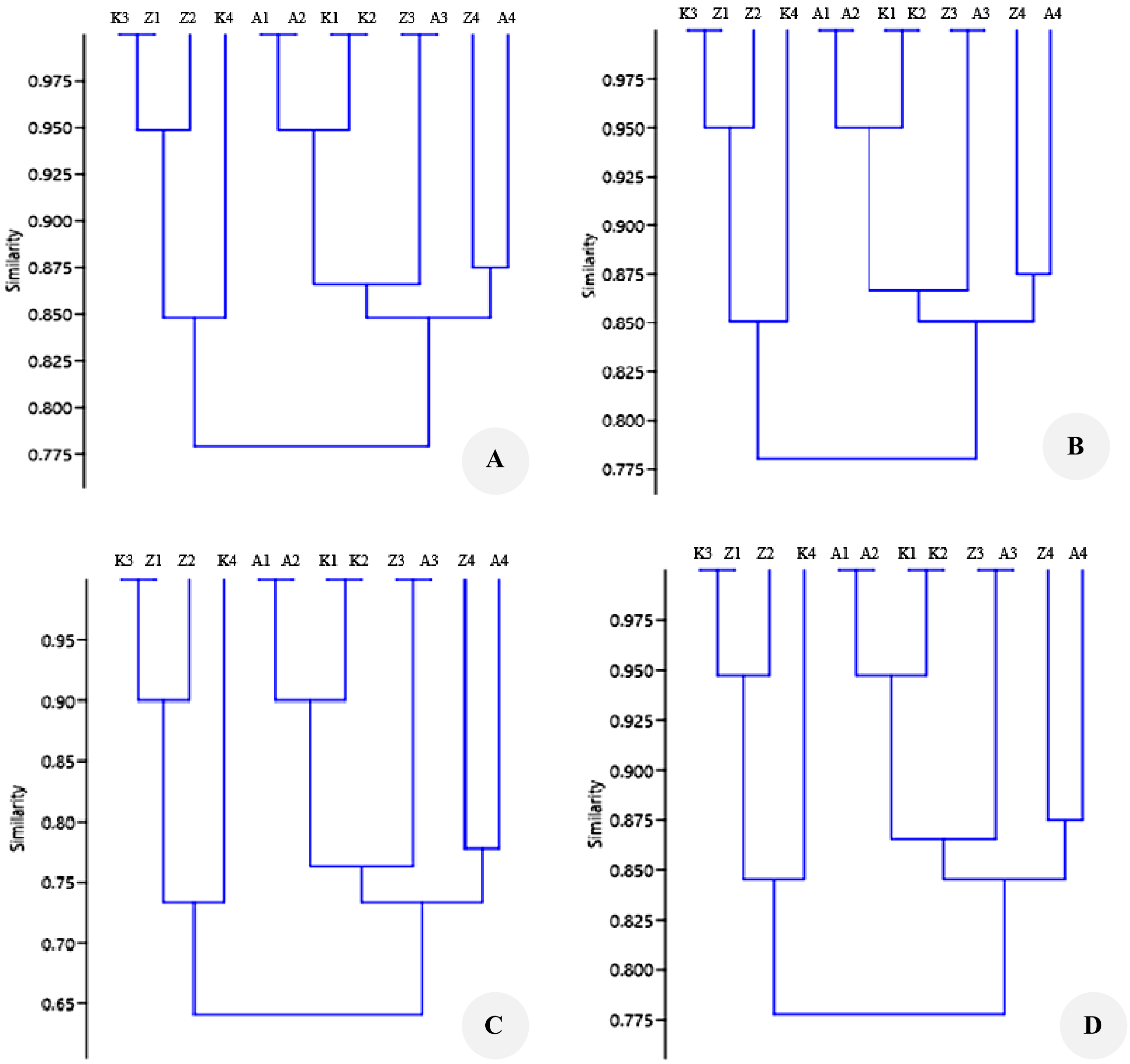

Figure 3. Dendrograms of faunistic similarity for selected freshwater mollusks and crayfish across the sampling stations. A. Ochiai index, B. Kulczynski index, C. Jaccard index, D. Sørensen-Dice (Chekanovsky-Sørensen) index

Table 7. Density (ind./m^2) and ecological groups of selected freshwater mollusks and crayfish along a mineralization gradient in the Zarafshan River, Uzbekistan

Species	Zarafshan				Akdarya				Karadarya				Ecological groups
	Z1	Z2	Z3	Z4	A1	A2	A3	A4	K1	K2	K3	K4	
Sinanodonta woodiana	1.8	1.4	1.0	0.6	1.2	1.0	1.0	0.8	1.4	1.2	1.1	1.0	Peloreophile
Anodonta anatina	0.8	0.6	0.4	0.2	0.7	0.4	0.2	0.1	0.3	0.2	0.2	0.1	Pelolimnophile
Corbicula fluminalis	0.9	1.0	0.7	-	1.2	1.0	-	-	1.0	0.7	-	0.2	Peloreophile
Corbicula tibetensis	0.7	0.6	0.6	0.4	0.8	0.8	0.5	0.5	0.7	0.6	0.3	-	Peloreophile
Lymnaea stagnalis	1.8	1.5	1.0	-	1.5	1.3	1.0	1.0	1.2	1.0	1.0	1.0	Phytophile
Lymnaea fragilis	1.0	1.3	0.8	0.6	1.2	1.0	1.0	0.7	1.0	1.0	0.9	0.8	Phytophile
Lymnaea subfragilis	0.8	0.8	0.6	-	-	-	0.5	-	-	-	0.8	0.5	Phytophile
Galba truncatula	1.7	1.5	-	1.0	-	-	1.3	1.0	1.0	0.8	0.8	0.8	Telmatophile
Radix auricularia	-	1.3	1.0	0.8	1.0	1.0	0.8	0.8	1.0	0.8	-	0.6	Phytoreophile
Radix bactriana	-	-	0.6	0.6	0.8	0.8	1.0	0.7	0.6	0.6	-	-	Phytophile
Pontastacus leptodactylus	0.8	1.0	1.0	0.7	1.1	1.0	1.0	-	1.0	0.8	0.8	-	Phytophile

Notes: -: not recorded

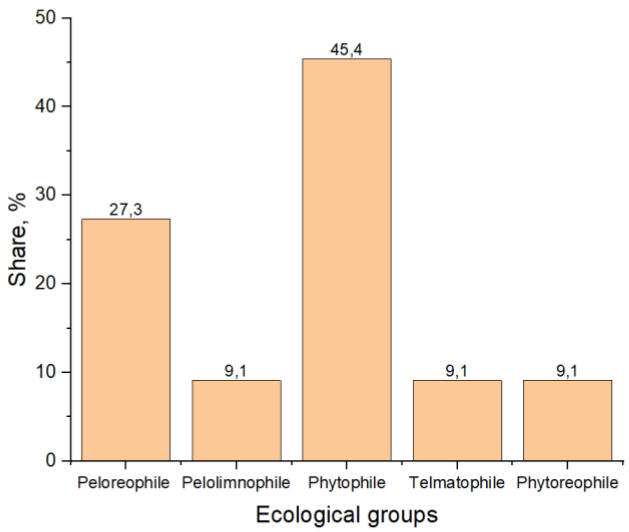

Figure 4. Ecological groups of selected freshwater mollusks and crayfish along a mineralization gradient in the Zarafshan River, Uzbekistan

Furthermore, the substrate preferences identified in our study provide a meaningful contrast to neighboring river systems. While Rakhimov et al. (2025) reported that hydrobionts in the Amu Darya are predominantly associated with sandy biotopes (supporting up to 10 species), our findings indicate a clear dominance of peloreophilic and phytophilic groups in the Zarafshan basin. This discrepancy is likely attributable to the distinct hydro-morphological and anthropogenic characteristics of the Zarafshan's middle and lower reaches. Extensive siltation and organic enrichment, driven by agricultural runoff and municipal discharges, create specialized ecological niches that favor silt-dwelling and vegetation-associated taxa over those preferring high-energy, sandy substrates.

Synthesizing these observations, it is evident that the synergistic effect of water hydrochemistry (specifically TDS and nutrient loading) and substrate heterogeneity are the fundamental determinant shaping the ecological structure of riverine macroinvertebrates. While sandy substrates may support higher diversity in more pristine or high-energy systems like the Amu Darya, the sediment-heavy and highly mineralized conditions of the Zarafshan basin primarily favor resilient, peloreophilic communities. These results underscore the importance of considering both chemical stressors and habitat alterations when assessing the ecological health and restoration potential of human-impacted river basins in Central Asia.

In conclusion, this study characterizes the taxonomic structure and spatial distribution of 4 key macroinvertebrate families (Unionidae, Corbiculidae, Lymnaeidae, and Astacidae) along the longitudinal profile of the Zarafshan River basin. Our findings document a total of 11 species (belonging to 3 classes and 7 genera), with the family Lymnaeidae exhibiting the highest species richness (6 species). The results demonstrate a strong negative association between increasing water mineralization and the biological integrity of these assemblages. As Total Dissolved Solids (TDS) escalated from 300 mg/L at reference sites to 1600 mg/L at heavily impacted stations, we observed a marked decline in both taxonomic richness and individual density. This community restructuring is further reflected in the Jaccard similarity index (0.45 between Z4 and K4), highlighting the fragmented faunistic composition of the lower reaches. The predominance of peloreophilic and phytophilic groups (8 species combined) suggests that siltation and organic enrichment are major environmental filters shaping the current benthic landscape of the Zarafshan River. While the documented correlations between mineralization and community decline are robust, this study is limited by the absence of direct toxicological assays; therefore, the observed patterns should be interpreted as strong ecological associations rather than definitive proof of pollutant-driven causation. Furthermore, while these families appear to be promising candidates for bioindication due to their sedentary nature and sensitivity to hydro-chemical shifts, a formal bioindication framework (including specific tolerance scores and index calibration) remains to be developed for the region. This study underscores the need for integrated water resource management to mitigate the impacts of salinity and organic loading on the

Zarafshan River's unique biodiversity, particularly for the sensitive Unionidae and Astacidae populations.

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