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Evaluation of the Environmental Impacts of Rivers on Fisheries in Azerbaijan's Liberated Areas

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Abstract
The present study examines the impact of industrial wastewater contamination on the aquatic ecosystems of the Hakari and Bargushad rivers, with a focus on the pollution originating from the Oxchu River. The Oxchu River, primarily contaminated by effluents from copper-molybdenum production in Armenia, contributes to significant fish mortality events in its territory and Khudafarin Reservoir. Through regular monitoring and analysis, the presence of heavy metals in the water has been confirmed to negatively affect biodiversity, impairing the health of the river ecosystems. In response to these challenges, the study proposes the creation of fish farming reservoirs along the clean watercourses of the Hakari and Bargushad rivers, prior to their confluence with the Khudafarin Reservoir. These reservoirs will enhance aquaculture production and support the preservation of native fish species. Furthermore, the study highlights the potential for hydroelectric power generation in these areas, demonstrating the dual environmental and economic benefits of the proposed infrastructure. This strategy will not only improve water quality and fish stocks but also offer opportunities for water conservation and agricultural irrigation, ensuring the long-term sustainability of the river ecosystems.

Keywords: Aquatic biodiversity, Fish mortality events, Industrial wastewater contamination, Hydroecological management, Fish farming reservoirs, Water quality monitoring,

Introduction

The quality of river water is a critical component of environmental challenges, as rivers represent one of the primary sources of freshwater essential for human consumption. Historically, rivers have been utilized as convenient channels for waste disposal, resulting in widespread pollution. Given the global scarcity of freshwater and the adverse impacts of anthropogenic activities on water quality, the preservation of freshwater resources has emerged as a central priority in the 21st century. [2] The condition of surface water is a key indicator of the ecological health of these systems, offering essential insights into their capacity to sustain life. The increasing pollution of surface waters not only compromises their quality but also poses significant risks to human health, disrupts the balance of aquatic ecosystems, threatens biodiversity, and impedes socio-economic progress.

A major contributor to the degradation of aquatic ecosystems is the accumulation of heavy metals, which are inherently toxic. Some of these elements exhibit carcinogenic properties, posing serious health risks to humans. During periods of heavy rainfall, agricultural runoff, along with urban and industrial effluents, can elevate the concentrations of these harmful substances in water to hazardous levels. Additionally, the ecological health of rivers can often be assessed through the status of aquatic organisms. For example, reduced fish populations or frequent occurrences of fish mortality can serve as indicators of chemical imbalances in water composition. Observable changes in water conditions, declining fish stocks, and large-scale fish die-offs are indicative of deteriorating water quality.

In Azerbaijan, rivers flowing through territories recently liberated from occupation have been identified as heavily polluted, with serious implications for biodiversity and fish populations. Alarmingly, 75% of the population relies on these rivers as sources of drinking water, despite their failure to meet basic sanitary and hygienic standards. The consequences of neglecting this issue could be severe if immediate actions are not implemented.[13]

The ichthyofaunal diversity of the Karabakh and Eastern Zangezur regions holds significant importance. Detailed investigations into the fish species inhabiting these areas are crucial for the sustainable management of water resources and the conservation of aquatic biodiversity. For instance, in March 2021, a substantial fish mortality event involving small trout was reported in the Okchuchay River. Subsequent surveys in the Shayifli and Jahangirbeyli basins of this river in Zangilan documented the deaths of 227 goldfish and 330 shirbit fish, both of which are included in Azerbaijan’s "Red Book" of endangered species [11]

Materials and Methods

Systematic sampling and analysis of water and sediment were initiated in 2021 along the Oxchuchay River and other regional rivers to assess water quality and pollution levels. Sampling was conducted at three distinct locations along the Oxchuchay River's flow trajectory.

In 2023, monitoring efforts focused on the Oxchuchay River included the collection of 108 water samples from the upper, middle, and lower reaches. These samples underwent a total of 1,728 physicochemical analyses. Furthermore, to evaluate pollution levels, 39 sediment samples were collected, and 398 physicochemical analyses were performed to quantify heavy metal concentrations. Additionally, three ecotoxicological tests were conducted. Results highlighted elevated concentrations of zinc, iron, manganese, and copper compared to other heavy metals.

Quarterly monitoring of the Hakari River was conducted at the Balasoltanli station in Qubadli District. A total of four water samples were collected during the year, and these underwent 70 physicochemical analyses performed by Azelab LLC.

On April 13, 2024, a water sample was collected from the Lachin Boulevard area and submitted for laboratory analysis at Azecolab's labaratory on April 15, 2024 (sample identification number: 21032-01).

Between January and August 2024, the Oxchuchay River was monitored comprehensively across its upper, middle, and lower reaches. This resulted in the collection of 91 water samples, with 1,474 physicochemical analyses conducted. Sediment sampling during this period yielded additional insights into pollution levels, with 240 analyses targeting heavy metal concentrations.

Similarly, the Bargushad River was monitored every ten days during the same eight-month period. A total of 72 water samples were collected, accompanied by 1,170 physicochemical analyses. In addition, 24 sediment samples were obtained, and 240 heavy metal analyses were conducted by Azelab LLC. Among the analyzed metals, zinc, iron, manganese, and copper were found to dominate in concentration.

For the Hakari River, quarterly monitoring activities from January to August 2024 involved the collection of three water samples. These samples underwent 49 physicochemical analyses to evaluate water quality and pollution indicators.

Results and Discussion,

Fish Species Inhabiting the Karabakh and Eastern Zangezur Regions

The ichthyofauna of Karabakh and Eastern Zangezur has been predominantly studied during the mid-20th century. The most recent comprehensive scientific data on fish species inhabiting the region dates back to the 1970s, before the occupation period [12]

In total, 23 fish species belonging to four families—*Cyprinidae, Salmonidae, Gobiidae, and Nemacheilidae*—have been recorded. Approximately 75% of these species are from the Cyprinidae family, which includes semi-migratory species characterized by high diversity (17 out of 23 species). Other families include Salmonidae (e.g., river trout, Angora loach, and Kura loach), Gobiidae (e.g., Caucasian goby and golden goby), and Nemacheilidae (e.g., Caucasian stream loach). [15]

Karabakh's freshwater systems are home to 20 fish species, excluding the river trout, Kura nase, and South Caucasus stone loach.

- In the section of the Kondalanchay River flowing through Khojavend and Fuzuli districts, 14 species have been identified, including species like the Caucasian khramulya, Kura barbel, and Transcaucasian goby.
- The Gargar River in Agdam District contains eight fish species, including the Kura loach and Caucasian stream loach.
- The Tartarchay River, including the Sugovushan Reservoir in Tartar District, supports 14 fish species, such as the Angora loach and golden goby.

The aquatic systems of Eastern Zangezur are home to 22 fish species, excluding the Kura khramulya. Key rivers in this region include the Basitchay, Oxchuchay, and Hakari rivers, which host species like the river trout, Caucasian stream loach, and Transcaucasian goby.

- In the Lachin and Gubadli districts, 10 species inhabit the Hakari River, including the Kura loach and Angora loach.
- In the Kelbajar District, the Tartarchay River and Sarsang Reservoir harbor six species, including the river trout and Kura barbel.

Fish species listed in Azerbaijan's "Red Book" are notably present in these regions.

- **The river trout** is found in the upper reaches of the Tartarchay, Hakari, and Basitchay rivers, as well as in the Sarsang Reservoir.
- **The golden bleak**, another "Red Book" species, is distributed across the Basitchay, Oxchuchay, and Hakari rivers in Zangilan, Lachin, and Gubadli districts, as well as the upper reaches of the Kondalanchay in Khojaly and Fuzuli districts.

In the lower reaches of the Araz River tributaries, the khramulya is the dominant species, followed by abundant populations of bleak and barbel. The ichthyofauna of the Gargar River and its tributaries, such as Khojalychay, is similar to that of the Kondalanchay, with species like the Kura silverfish, Caucasian khramulya, and Transcaucasian goby being prominent. [16]

This comprehensive overview highlights the significant biodiversity of fish species in the Karabakh and Eastern Zangezur regions, emphasizing their ecological and conservation value.

In March 2021, a massive fish death (Small Trout) was recorded in the river. During the investigations conducted in the Shayifli and Jahangirbeyli basins of the Okchuchay River in Zangilan discovered the mass death of 227 goldfish and 330 shirbit fish included in the "Red Book" of Azerbaijan took place here. [3]

Figure 1. Mass fish mortality in the Oxchuchay observed during the year 2021

Monitoring Results of the Oxchuchay in 2021

Monitoring activities conducted on the Oxchuchay in 2021 identified significant levels of pollution, as evidenced by the results of chemical analyses. Samples collected at the border point with Armenia exhibited heavy metal and biogenic substance concentrations that exceeded permissible thresholds. Specifically, ammonium concentrations were 1.6 times higher than the standard, while manganese, iron, nickel, cadmium, and molybdenum levels were 4.0, 4.5, 5.5, 2.9, and 1.9 times higher, respectively. Water samples obtained approximately 5 km downstream near Zangilan city displayed slightly reduced concentrations compared to the upper reaches. However, these values still exceeded permissible standards, with ammonium levels 1.3 times, manganese 3.6 times, and nickel 3.4 times above the acceptable limits. [9]

In March 2021, a substantial discharge of untreated wastewater into the river caused a large-scale fish die-off (Figure 1), highlighting the severe ecological consequences of the pollution.

The primary contributor to this pollution is the Zangezur Copper-Molybdenum Combine, located on the Armenian side of the river. The facility discharges untreated waste from copper and molybdenum production directly into the river, resulting in contamination levels that significantly exceed ecological and health standards. These elevated pollution levels render the river’s water resources unsuitable for use and contravene environmental regulations. A notable portion of this plant is owned by the German company *Cronimet*. Additionally, the

Gafan Ore Processing Plant contributes further to the river's pollution through the release of heavy metals, compounding the environmental degradation. The cumulative effect of these pollutants not only devastates the river's aquatic ecosystem but also poses significant risks to human health. [8]

The consumption of water contaminated with heavy metals and other pollutants is associated with serious health risks. Documented impacts include gastrointestinal disorders, renal and skeletal tissue damage, as well as cardiovascular and neurological system dysfunctions. These findings underscore the urgent need for remediation measures to mitigate the environmental and public health hazards posed by the ongoing contamination of the Oxchuchay.

The Oxchuchay River serves as a significant conduit for the disposal of waste generated by mining activities in Armenia. The river's water quality has deteriorated to such an extent that it has become inhospitable to aquatic life, with no viable organisms able to survive in its highly polluted environment. Given that the Oxchuchay flows into the Araz River, the second largest watercourse in the South Caucasus, the contamination from the Oxchuchay has substantial implications for the overall water quality of the Araz River.

As a critical tributary of the Kura River, the Araz River plays an essential role in the region's hydrology, particularly as the primary source of irrigation for agricultural lands in Azerbaijan. However, recent significant declines in water quality in the Araz River—attributable in large part to the pollution from the Oxchuchay—have resulted in adverse effects on both domestic water use and agricultural irrigation. These changes pose serious risks to public health and agricultural productivity, underscoring the need for urgent measures to address the ongoing contamination and restore the water quality of these interconnected river systems. [7]

In 2024, a comprehensive water quality analysis was conducted at the Shayifli point of the Oxchu River, involving the collection of 24 water samples and 390 corresponding physicochemical analyses. The results revealed that pollution levels at this site exceeded the permissible concentration limits by factors ranging from 1.4 to 2.0, with the most significant pollution observed during the second ten-day period of March.

Ammonium ion (NH4) concentrations were found to be elevated, ranging from 1.8 to 4.4 times above the allowable limits, with the highest concentrations recorded during the second ten-day period of January and the first ten-day period of February. Among the heavy metals, manganese (Mn) concentrations were found to be 1.1 to 4.0 times higher than the permissible levels, peaking in January. Molybdenum (Mo) concentrations were also elevated in January, with levels 1.1 to 1.2 times above the acceptable limit. Furthermore, iron (Fe) concentrations exceeded the permissible limits by 1.2 times in the third ten-day period of March.

Particular concern, changes in the water environment were noted in February, when a foul odour emanated from the river and visible household and industrial waste was observed flowing from upstream sources. These changes prompted the initiation of intensive monitoring activities to assess the extent of pollution and its potential impact on the river's ecosystem and water quality. This ongoing monitoring effort aims to provide a clearer understanding of the pollution dynamics within the Oxchu River and inform future mitigation strategies.

From February 2nd to 10th, water samples were collected four times a day, at regular intervals, from the Burunlu region of the Oxchu River. These analyses were conducted on dates when the highest levels of contaminated water were discharged from Armenian territory. As a result, it was confirmed that during copper-molybdenum production, untreated wastewater was directly discharged into the river, poisoning the local biodiversity. The daily results of the water quality analysis are summarized as follows: [11]

Table 1. Analytical Results from the Okhchu River – Burunlu Region, Collected between February 2nd and 10th, 2024

№	Component Name	Unit of Measurement	02,02,24	03.02.24	05.02.24	06.02.24	09.02.24	10.02.24
1	Hydrogen Index	pH	7,2	7,13	6,9	7	7,35	7,44
2	Dissolved Oxygen	mqO_2/L	5,4	6,7	4,8	4,2	7,4	9
		%	54,0	67	52	47	82	99
3	Electrical Conductivity	$x10^{-3}$ ^{c}m/sm µcm/cm	1547,0	1608	1691	1745	1264	706
4	Chemical Oxygen Demand (**COD)**	mg-ekv/l	14,0	14,6	16,19	16,42	10,35	6,12
5	Chloride Ion, Cl^-	mg/l	20,6	19,14	19,49	19,14	16,31	14,9
6	Sulfate Ion, SO_4^{2-}	mg/l	381,6	391,2	411,9	416,9	204,3	140
7	Ammonium Ion, NH_4^+	mg/l	2,3	1,5	2,19	0,57	1,17	1,59
8	Nitrite Ion, NO_2^-	mg/l	0,8	0,7	0,87	0,99	0,64	0,24
9	Nitrate Ion, NO_3^-	mg/l	7,1	7,72	5,99	5,97	7,92	4,18
10	Zinc, **Zn**	mkg/l	63,7	79,3	25,4	58,8	29,2	35,1
11	Iron, **Fe**	mkg/l	68,3	143,0	36,3	67,7	82,1	213
12	Lead,**Pb**	mkg/l	0,443	0,938	0,173	0,125	0,183	0,141
13	Nickel,**Ni**	mkg/l	0,4	0,9	7,0	0,962	3,07	1,77
14	Molybdenum,**Mo**	mkg/l	222,0	226,0	159,0	235	149	39
15	Manganese,**Mn**	mkg/l	328,0	255,0	118,0	295	254	223
16	Copper,**Cu**	mkg/l	12,5	18,6	44,8	10,6	11,5	14,8

During the monitoring conducted from January to August 2024, a total of 91 water samples were collected from the Okhcu River. In addition, sediment samples were also gathered, and 240 physicochemical analyses focusing on heavy metals were performed. The analysis revealed that the concentrations of zinc, iron, manganese, and copper exceeded the levels of other heavy metals present in the river. These findings suggest a significant variation in the contamination profile, with these particular metals being the most prevalent pollutants in the water and sediment samples. The data provides critical insights into the extent of anthropogenic impact on the river's ecosystem, especially concerning the accumulation of heavy metals. Further studies and mitigation efforts are necessary to address these pollution levels and prevent further ecological degradation. [11]

- **Bargushad River**

The analysis of heavy metal concentrations in the Bargusad River for the Gubadli region from January to August reveals significant variations in levels. Below are the key findings based on the data collected:

Table 2. Summary of Heavy Metal Concentrations in the Bargusad River (Gubadli Region)

	January	February	March	April	May	June	July	August
Mn	788	788	644	691	573	545	536	612
Co	6.5	4.22	2.04	12.04	8.05	5.96	6.96	6.29
Pb	2.44	3.25	4.12	18.3	14.7	11.04	9.88	12.66
Ni	9.77	6.44	5.11	2.07	5.06	3.83	8.99	4.56
Cr	7.01	4.55	3.44	26.9	31	25.4	20.4	27.4
Mo	4.55	0	0	0	0	0	0	0
Fe	24630	29360	25320	23,5	24,68	28760	21890	24780
Zn	44.4	31.7	36.05	63.6	59.8	47.8	53.6	39.5
Cu	40.55	29.7	20.04	45.6	40.3	47.6	53.4	35.6

The Bargusad River demonstrates persistently elevated concentrations of manganese and iron, with levels consistently surpassing the established permissible limits. This ongoing exceedance suggests significant ecological risks, potentially affecting aquatic life and the broader ecosystem. Additionally, a marked increase in lead concentrations during the month of April underscores the need for in-depth investigations to identify and assess the sources of contamination, as well as the pathways through which these pollutants may enter the river system. In contrast, concentrations of other heavy metals analyzed remain within the acceptable thresholds, indicating that the pollution may be localized rather than indicative of a regionwide issue. Given these findings, it is crucial to implement continuous monitoring to track pollution levels, assess trends, and inform mitigation strategies aimed at preserving the ecological integrity of the Bargusad River.

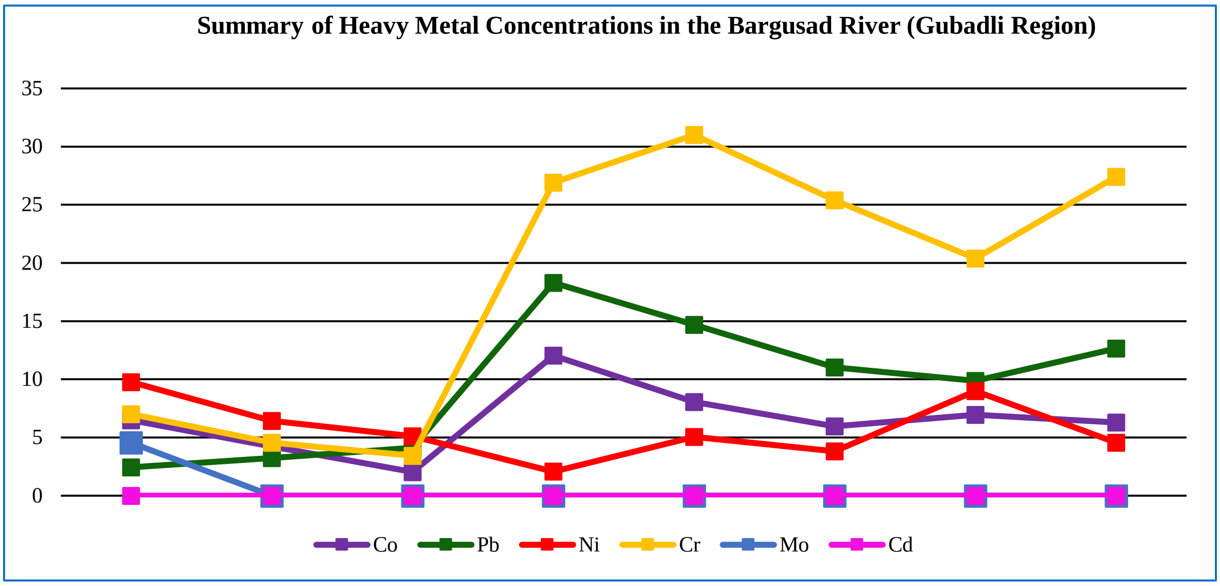
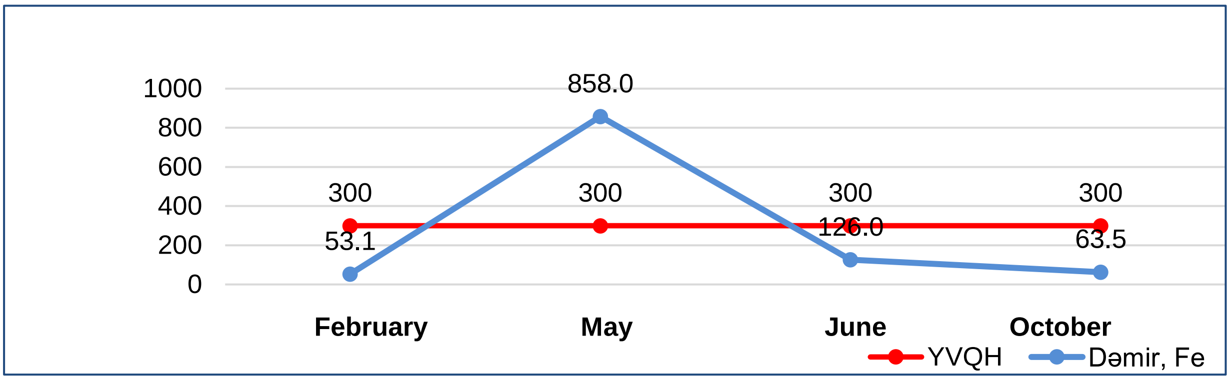


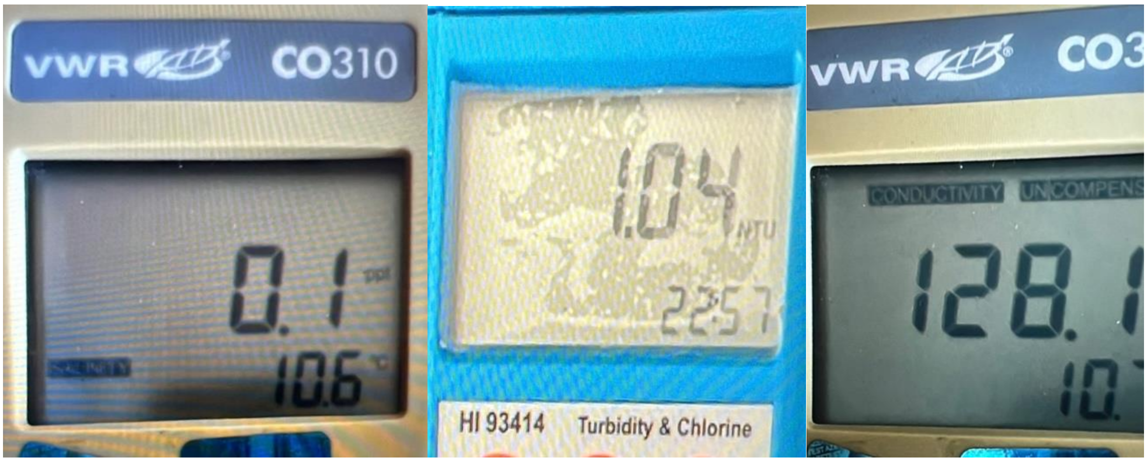
Figure 2. Dynamics of Heavy Metal Concentrations in the Bargusad River in Gubadli Region from January to August

- **Hakari river**

In 2023, based on the analysis results from the Balasoltanli village area in the Qubadli region along the Hekari River, only the concentration of iron (Fe) exceeded the permissible threshold, reaching 2.9 times the allowable limit in the second quarter. All other determined indicators remained within the acceptable concentration levels.

Figure 3. **Change dynamics of iron (Fe) in Hekarichay's water environment for 2023**





a) b) c)

Figure 5. Analytical Results for the Hakari River Conducted in January 2024
(a) Salinity measurements in parts per thousand (ppt), reflecting the concentration of dissolved salts; (b) Turbidity levels (NTU) and chlorine concentration, indicating the presence of suspended particles and potential chlorination byproducts; (c) Electrical conductivity (µS), representing the river's capacity to conduct electrical current, which correlates with ion concentration

In January 2024, an analysis of river water was conducted in the laboratory of AUAC. The results indicated a turbidity of 1.04 NTU (Figure 5 (b)), measured using a turbidimeter; an electrical conductivity of 128.1 µS (Figure 5 (c)), determined with a conductometer; and a salinity of 0.1 ppt (Figure 5 (a)),.

At the same time on April 13, 2024, a sample was taken from the area known as Lachin Boulevard and submitted for analysis at Azecolab's laboratory (number 21032-01) on April 15, 2024.

Table 3. Parametrs of some analysis taken from Lachin boulevard region

Test Parameter	**Unit**	**Result**	**WHO Guideline**	**EPA Standard**	**Notes**
Nitrate (NO3)	mg/L	1.7	≤ 50 mg/L	≤ 10 mg/L	High levels can cause methemoglobinemia (blue baby syndrome) and other health issues.
Sulphate (SO4)	mg/L	14.3	≤ 250 mg/L	≤ 250 mg/L	Excessive sulphate can cause gastrointestinal issues and affect water taste.
Nickel (Ni)	µg/L	3.8	≤ 0.07 mg/L	≤ 0.1 mg/L	Nickel in drinking water should be kept low to avoid health risks.
Copper (Cu)	µg/L	3.32	≤ 2.0 mg/L	≤ 1.3 mg/L	High copper levels can cause gastrointestinal problems and discoloration of water.
Lead (Pb)	µg/L	<0.01	≤ 0.01 mg/L	≤ 0.015 mg/L	Lead is highly toxic, and even low levels can be harmful, especially to children.
COD	mg/L	6.01	≤ 25-50 mg/L	Not directly regulated	COD is generally more relevant for surface water; low levels are preferred for water quality.
BOD5	mg/L	4,00	≤ 5-10 mg/L	Not directly regulated	BOD5 is more relevant for surface water; low levels are preferable for drinking water quality.

Nickel (Ni): The concentration of nickel measured at 3.8 µg/L exceeds the World Health Organization (WHO) guideline of ≤ 0.07 mg/L and is approaching the United States Environmental Protection Agency (EPA) standard of ≤ 0.1 mg/L. Given the potential health implications associated with prolonged exposure to elevated nickel levels, it is imperative to address this issue. Nickel is a known carcinogen and can have detrimental effects on renal and respiratory systems, thus necessitating further investigation and remediation efforts.

Copper (Cu): The recorded concentration of copper at 3.32 µg/L surpasses both the WHO guideline of ≤ 2.0 mg/L and the EPA standard of ≤ 1.3 mg/L. Excessive copper concentrations are associated with gastrointestinal disturbances, liver and kidney damage, and may also compromise water quality. Therefore, these elevated levels warrant immediate attention, including further investigation to identify potential sources of contamination and the implementation of appropriate remedial measures to mitigate the risks to public health and the environment.

Lead (Pb): The lead concentration, measured at <0.01 µg/L, falls well within the stringent guidelines set by both the WHO and EPA. This result is favorable, as lead is a highly toxic metal, especially harmful to vulnerable populations, such as children and pregnant women. The low lead concentration indicates minimal risk in terms of lead contamination, but continued vigilance is essential to ensure that levels remain below permissible thresholds.

While the majority of analyzed parameters remain within the safe limits set by regulatory bodies, particular attention must be given to the elevated concentrations of nickel and copper. Continuous monitoring is critical to track trends in metal contamination and to evaluate the efficacy of mitigation strategies. A combination of analytical techniques, including ion chromatography (IC), inductively coupled plasma mass spectrometry (ICP-MS), spectrophotometric methods, and respirometric methods, were employed to ensure comprehensive and accurate results.

Table 4. Methods of analysis

PP Code	Test Parameter	Test Unit	Ref Method	Technique	LOD	MU, %
1380A04	Nitrate (NO3)	mg/L	ASTM_D4327	IC	0.016	9
1380A05	Sulphate (SO4)	mg/L	ASTM_D4327	IC	0.02	8
2005A18	Nickel (Ni)	µg/L	EPA_6020B	ICP-MS	0.02	2
2005A19	Copper (Cu)	µg/L	EPA_6020B	ICP-MS	0.11	2
2005A30	Lead (Pb)	µg/L	EPA_6020B	ICP-MS	0.01	2
3022A01	COD	mg/L	ASTM_D1252B	Spectrophotometric	4	11
3030A01	BOD5	mg/L	SM_5210D	Respirometric	1	14

The Limit of Detection (LOD) standards, along with the Measurement Uncertainty (MU), were determined.

Further investigations are needed to identify potential pollution sources and implement corrective measures to safeguard water quality and public health in the long term. At the same time, pollution has negative impact for fisheries industry development in these territories.

Integrated Utilization Plan for the Water Resources of the Bargushad and Hekari Rivers

Currently, the water resources of the Hekari and Bargushad Rivers are utilized to a very limited extent. Based on the hydrological confluence of the rivers, the annual water resource of the Bargushad River is estimated at 500 million cubic meters (excluding the 250 million cubic meters used in Armenian territory), while the annual water resource of the Hekari River is also estimated at 500 million cubic meters. Therefore, the total flow entering the Araz River from these rivers each year is approximately 1.0 billion cubic meters. [9]

The Bargushad River, with a length of 178 km and a drainage basin area of 2711 km², originates from the northern slope of the Zangezur mountain range, from Zalxa Lake located at an altitude of 3040 meters. The river enters the territory of Azerbaijan near the village of Eyvazlar in the Qubadli region, where it merges with the Hakari River near the village of Qaralar, and ultimately flows into the Araz River. At the point where it merges with the Hakari River, the average annual discharge of the river is 24.0 m³/s.

The Bargushad River is mainly regulated within Armenian territory before entering Azerbaijan, which results in minimal sedimentation and suspended matter in the river's flow, allowing clear water to enter the country. Seasonal fluctuations in the river's flow, especially in spring and autumn, are generally not significant. The sustainable utilization of the water resources of the Bargushad River in the following manner could facilitate rapid economic development in the region:

- Construction of the "Baxtiyarli" reservoir near the Baxtiyarli village, with a volume of up to 70 million cubic meters;
- Construction of the "Baxtiyarli-1" Hydroelectric Power Station (HPS) with a capacity of 10.5 MW using the 120.0 m drop in the riverbed between Eyvazli village and the Baxtiyarli reservoir;
- Measures for utilizing up to 250.0 million cubic meters of the river's total water resource for ecosystem conservation and irrigation below the reservoir;
- Directing up to 250.0 million cubic meters of the river's water resource for the irrigation of agricultural lands in the Zangilan and Jabrail regions.
- These reservoirs will help to improve water quality for fishes which lives in this region

These proposed developments could significantly enhance the region's economic potential through improved water resource management, agricultural productivity, and hydroelectric energy production

In order to optimize the utilization of the river's water resources, the construction of the "Baxtiyarli" reservoir is proposed, located above the city of Qubadli at an elevation of 540 meters above sea level. Based on preliminary hydrological reports, it is planned that up to 250.0 million cubic meters of the total water resources of the Bargushad River will be stored and preserved in the river channel below the newly constructed "Baxtiyarli" reservoir. This water will be utilized for ecosystem conservation and local use.

The proposed reservoirs will be instrumental in enhancing the water quality for the aquatic species residing within this region. By regulating hydrological flow and mitigating sedimentation, these reservoirs are expected to contribute significantly to the stabilization of the aquatic ecosystem. Such interventions will facilitate the creation of a more conducive environment for aquatic life, characterized by optimized oxygen levels, diminished pollutant concentrations, and the enhancement of habitats essential for the survival and proliferation of fish populations. Furthermore, the sustained regulation of water flow and quality will foster biodiversity preservation and bolster the overall ecological health of the aquatic system, thereby supporting both fish communities and the broader surrounding ecosystem. [14]

The Hakari River, with a length of 113 km and a catchment area of 2570 km^2, originates from the southern slope of the Mixtoken mountain range at an elevation of 2580 meters. It meets the Bargushad River near Qaralar village in Qubadli district (at an elevation of 340 meters above sea level), forming the Bazar River. At the confluence with the Bazar River, the annual water resource of the Hakari River is estimated at 500.0 million cubic meters. The average annual flow rate of the river (at the Abdallar site, before the confluence with the Zabux River) is estimated to be 10.2 m^3/s. The primary water resource (up to 300.0 million cubic meters) of the river originates from the confluence of the Shalva and Hocazsu Rivers at an elevation of 950 meters. [10]

To enhance the efficient use of the river's water resources, it is deemed appropriate to utilize the annual flow volume (approximately 270.0 million cubic meters) formed at the confluence of the Shalva and Hocazsu Rivers within the country's boundaries for public water supply. To achieve this, the construction of a "Hakari" reservoir with a volume of 70.0 million cubic meters is proposed at this location.

As we know, the level of pollution in the Oxchu River has caused contamination in the Khudafarin reservoir, resulting in the mass mortality of fish. Therefore, to protect biodiversity and enhance fish stocks in the cleaner waters of the Hakari and Bargushad rivers, it is advisable to regulate the flow of water from these rivers towards the Khudafarin reservoir. To this end, the construction of a "Hakari-Bargushad" reservoir with a total volume of 60-70 million cubic meters at the confluence of these rivers at 340 meters above sea level is considered ecologically acceptable. This new reservoir will provide favorable conditions for the increase of indigenous fish species and will also allow for the use of part of the water accumulated throughout the year for irrigation purposes. The Master Plan for the utilization of water resources from the Bargushad and Hakari rivers for the development of fisheries is presented in Figure 4.

The development of an aquaculture facility is envisioned within the reservoir to be constructed at the confluence of the Hakari and Bargushad Rivers. This facility will be integrated with the Khudafarin Reservoir through a fish migration infrastructure designed to facilitate the movement of aquatic species. The planned infrastructure will enable the annual transfer of up to 60-70 million cubic meters of water from the newly established reservoir to the Khudafarin Reservoir, thereby promoting the natural migration patterns of fish species. [4]

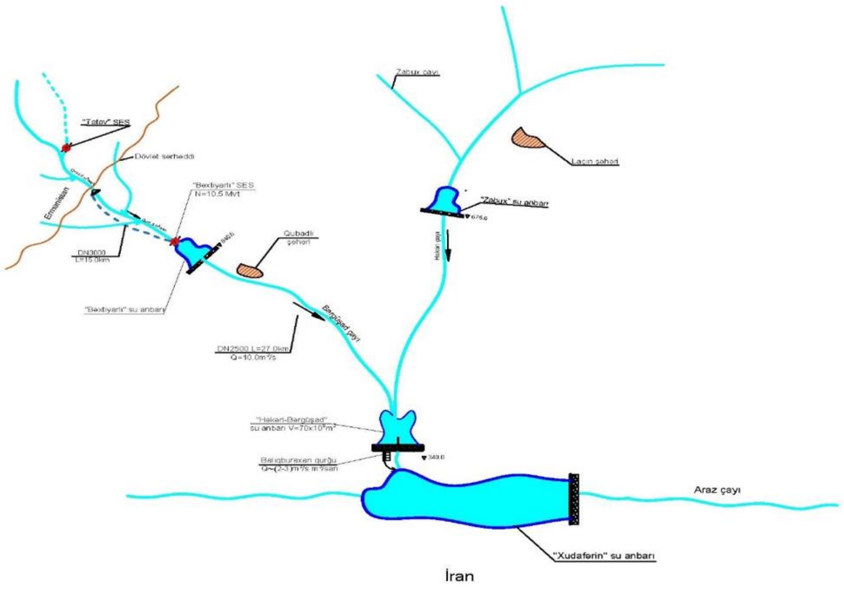


Figure 4. Strategic Framework for the Sustainable Utilization of Water Resources from the Bargushad and Hakari Rivers for Fisheries Enhancement.

This integrated system will serve as a critical tool for preserving and enhancing the biodiversity of the Hakari and Bargushad river ecosystems. Moreover, it will play a pivotal role in mitigating the adverse effects of the highly polluted waters from the Oxchu River, which has been linked to significant fish mortality events in the Khudafarin Reservoir. By incorporating this infrastructure, the contamination risks associated with the inflow of polluted waters into the Hakari and Bargushad Rivers will be effectively managed, ensuring the long-term ecological stability and vitality of these aquatic ecosystems. [18]

Conclusion

The Oxchu River water, primarily contaminated by effluents from copper-molybdenum production activities in Armenia, has been identified as a significant source of pollution, leading to recurrent fish mortality events in both the Oxchu River and the Khudafarin Reservoir, particularly during the month of March. Regular monitoring and analytical assessments have confirmed that the presence of heavy metals in the water has detrimental effects on the aquatic biodiversity, poisoning the ecosystem due to the discharge of industrial wastewater.

To mitigate these challenges and promote sustainable fisheries development, the establishment of reservoirs along the pristine watercourses of the Hakari and Bargushad rivers is recommended. These reservoirs, created prior to the rivers confluence with the Khudafarin Reservoir, would provide a controlled environment for fish farming, thereby enhancing local aquaculture potential. Moreover, these reservoirs hold considerable potential for hydroelectric power generation, offering dual benefits for both fisheries and energy production.

The fluctuating flow of the Bargushad River, regulated predominantly within Armenian territory before entering the Republic of Azerbaijan, varies between 11-33 m^3/s throughout the day. In this context, it is deemed ecologically beneficial to regulate the residual flows of the Hakari and Bargushad rivers, releasing them into the Khudafarin Reservoir to support biodiversity conservation and the enhancement of fish stocks. The construction of the "Hakari-Bargushad" reservoir, with a total capacity of 60-70 million cubic meters at the confluence of these rivers, would create optimal conditions for the proliferation of native fish species, while also enabling the use of accumulated water for irrigation purposes.

Ultimately, the development of the "Hakari-Bargushad" reservoir is a strategically sound solution for mitigating the adverse impacts of highly polluted waters from the Oxchu River. By preventing the contamination of the Hakari and Bargushad rivers, this initiative will contribute significantly to the preservation of their ecological integrity, ensuring the long-term sustainability of both the aquatic ecosystem and the surrounding agricultural landscapes.

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