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jgeor KURA WATCH

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WATER PROBLEMS

A special issue dedicated to pollution, water quality, ecosystem challenges and sustainable solutions related to the Kura River across Türkiye, Georgia and Azerbaijan.

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Water Quality
Pollution, monitoring and river health

Ecosystem Risks
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Policy, innovation and river management

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KURAWATCH
WATER PROBLEMS

Economy · ecology · water security · sustainable development

ABOUT THIS ISSUE

Kura Watch is a special issue of the Journal of Green Economy and Optimization Research (JGEOR) dedicated to scientific research on the Kura River and its wider basin across Türkiye, Georgia and Azerbaijan. The issue brings together interdisciplinary studies addressing water quality, pollution, ecosystem pressures, biodiversity, climate-related risks, human impacts, environmental monitoring and sustainable river management. It provides a platform for researchers, practitioners, educators and young researchers, including student-led studies that meet JGEOR's editorial and peer-review standards.

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FOREWORD FROM THE EDITOR-IN-CHIEF

One River, Shared Responsibility

Dear readers,

KuraWatch, the second special issue of JGEOR, focuses on one of the most important shared river systems of the South Caucasus. Originating in Türkiye, flowing through Georgia and Azerbaijan, and finally reaching the Caspian Sea, the Kura connects countries, ecosystems and communities through a single hydrological system. What happens upstream can influence water quality, biodiversity, agriculture and livelihoods far downstream. The Kura basin faces interconnected challenges including water-quality deterioration, changing river flow, pollution, ecosystem degradation, erosion and growing pressure on water resources. These issues require shared scientific understanding and coordinated river-basin management. UNECE has supported cooperation between Georgia and Azerbaijan on sustainable management of the Kura River, including dialogue on water protection, monitoring and transboundary management. Türkiye, Georgia and Azerbaijan each have an important role in the future of the river. Türkiye represents the headwater part of the Kura system; Georgia is a major upstream and transit country; and Azerbaijan is the principal downstream country before the river enters the Caspian Sea. This geographical continuity makes monitoring, responsible water use and cross-border scientific cooperation especially important.

"Making peace with nature requires evidence, restoration, responsible finance and decisions that recognize ecological limits."

KuraWatch also gives special place to studies developed through the **Mother Kura Program**, a research initiative for school students focused on the environmental condition and future of the Kura River. Through structured research activities, young researchers explore pollution, water use, biodiversity, climate pressures and river conservation, with selected studies further developed to meet JGEOR's editorial and peer-review requirements. The relationship between the Kura and the **green economy** is central to this issue. Freshwater ecosystems support irrigated agriculture, hydropower, drinking-water supply, tourism and natural-hazard regulation, meaning that ecological degradation can also produce economic losses and development risks. Cleaner water, efficient irrigation, restored riparian ecosystems and stronger environmental monitoring therefore represent not only conservation priorities but investments in natural capital and economic resilience. For JGEOR, KuraWatch reflects the principle that river science should connect ecology with economic responsibility. Protecting the Kura requires reliable evidence, environmental education, efficient resource use and cooperation across the basin.

Ulvi Mammadov

Editor-in-Chief · Journal of Green Economy and Optimization Research

Context sources

United Nations Economic Commission for Europe. *Projects in Caucasus — Kura River transboundary water cooperation.*

United Nations Development Programme. *Assessment of freshwater ecosystem services in the Kura–Aras River Basin.*

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Sources and environmental impacts of Kura River pollution under anthropogenic pressures in Azerbaijan

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anthropogenic pressure, environmental pollution, Kura River, plastic waste, water quality

ABSTRACT
The Kura River is Azerbaijan's principal river system and supports drinking-water supply, irrigation, hydropower, fisheries and riverine ecosystems. At the same time, its transboundary character and intensive human use make it vulnerable to multiple forms of pollution. This study examines the principal anthropogenic sources of Kura River pollution and their environmental implications by integrating two independently prepared research dossiers with a targeted review of scientific and institutional literature. The original research materials were based on desk research, qualitative observation and comparison of pollution problems; no new laboratory water-quality measurements were generated. The synthesis identifies four recurrent pressure groups: untreated municipal and industrial wastewater, domestic solid waste and plastics, agricultural runoff, and transboundary pollutant loads. These pressures are linked to deterioration of water quality, habitat stress, risks to aquatic organisms, potential effects on irrigation and soil quality, and exposure pathways relevant to human health. Recent studies corroborate several of the source-level observations, including downstream changes in Kura River mineralization, historically elevated metal concentrations at transboundary sites, and substantial plastic transport from the Kura-Aras basin toward the Caspian Sea. The results indicate that pollution control cannot rely on riverbank clean-up alone. Priority measures include wastewater treatment, solid-waste prevention, agricultural nutrient management, basin-scale monitoring and stronger transboundary coordination. The study provides a concise source-pathway-impact framework that can support environmental education, local monitoring and future empirical research on the Kura River.

INTRODUCTION
The Kura River is the largest river of the South Caucasus and the main surface-water artery of Azerbaijan. Official hydrometeorological information lists a total river length of 1,515 km and a catchment area of about 188,000 km^2, while 906 km of the river course lies within Azerbaijan (Ministry of Ecology and Natural Resources of the Republic of Azerbaijan [MENR], 2025). The river rises in northeastern Türkiye, passes through Georgia and enters Azerbaijan before discharging into the Caspian Sea. This geographical setting gives the Kura both national and transboundary importance. Its water is used for drinking-water supply, irrigation, industrial activities and hydropower, while the river and its floodplain support fish, birds and riparian vegetation. Consequently, water quality degradation in the Kura is not a single-sector problem; it affects environmental health, food production, settlements and the wider Kura-Caspian system.

Azerbaijan's water security is strongly influenced by transboundary flows. The World Bank (2024) reports that approximately 70% of the country's surface-water resources originate outside its borders and identifies pollution, inefficient irrigation and inadequate wastewater infrastructure among the principal pressures on water security. The Kura is therefore exposed to cumulative impacts generated both upstream and within Azerbaijan. Historical research documented elevated concentrations of several metals at monitoring sites close to the Georgian and Armenian borders, demonstrating the relevance of transboundary pollution pathways (Suleymanov et al., 2010). More recent monitoring has shown that the chemical character of the river also changes longitudinally, with substantially higher mineralization in the lower reaches than near the upstream border sections (Aliyev & Abduyev, 2025). These patterns illustrate why pollution must be considered at basin scale rather than only at individual settlements.

The two original research works integrated in this paper focused on practical and visible forms of human pressure on river water. They independently emphasized untreated industrial and municipal effluents, household litter and plastics, agricultural chemicals, and environmentally harmful behaviour as major sources of concern. They also linked pollution with declining water quality, stress on fish and other aquatic organisms, possible human-health risks and reduced suitability of water for agricultural use. These themes are scientifically plausible and are consistent with the pressure categories identified in regional water-management assessments, although the source projects did not include laboratory sampling or quantified pollutant loads. The present paper therefore does not reinterpret the original observations as chemical measurements; instead, it develops them into a structured qualitative assessment and evaluates them against published evidence.

The objective of this study is to identify the main anthropogenic pollution pressures highlighted by the original research materials, connect each pressure to its principal environmental pathway and likely receptor, and assess the extent to which recent scientific and institutional evidence supports those relationships. The study asks three questions: Which human activities emerge most consistently as sources of Kura River pollution? Through which pathways can these activities affect water quality and ecosystems? Which management responses are most directly aligned with the identified pressures? By answering these questions, the paper aims to preserve the practical focus of the original investigations while placing their findings within a more rigorous environmental management framework.

LITERATURE REVIEW

Pollution in the Kura-Aras basin has long been recognized as a transboundary environmental issue. Campana et al. (2012) described the basin as a setting in which water-quality and water-quantity problems are shared across Armenia, Azerbaijan and Georgia, with untreated urban wastewater, agricultural return flows and industrial activities contributing to cumulative pressures. The United Nations Development Programme (UNDP, 2013) similarly identified transboundary degradation as a priority issue requiring coordinated basin management. A later pressure and impact assessment prepared under the European Union Water Initiative Plus (EUWI+, 2021) classified water withdrawal, hydromorphological modification, untreated municipal and industrial discharges, and diffuse pollution from fertilized and pesticide-treated agricultural land among the main pressures affecting the lower Kura-Aras system. These assessments support the core argument of the original research works that human activities occurring at multiple points in the basin can combine to reduce ecological quality downstream.

Chemical monitoring provides more direct evidence of these pressures. Suleymanov et al. (2010) analyzed monthly samples from the Kura-Aras river system between 2004 and 2008 and found strong spatial differences in trace-metal concentrations. Sites close to the borders with Georgia and Armenia were among the most polluted, and several metals were transported substantially in suspended form. Although these data represent an earlier period, they remain important because they demonstrate that pollutant transport across national boundaries is measurable and that sediment-associated contamination can be relevant. More recent work by Aliyev and Abduyev (2025), based on monitoring at 14 points during 2020–2022, focused on major ions and mineralization rather than a broad suite of toxic contaminants. Their results showed a pronounced downstream rise in mineralization and changes in ionic composition, while also emphasizing continuing pressures from wastewater and tributary inputs. The contrast between historical metal contamination and newer ion-based monitoring also highlights the need for long-term, multi-parameter datasets rather than reliance on a single pollution indicator.

Solid waste and plastic pollution form a second major pressure pathway. This theme was prominent in the source research, where plastic bottles and household waste were identified as visible forms of river pollution and as materials that can fragment into smaller particles. Recent basin-scale studies strengthen this concern. Mousavi et al. (2025) estimated that large quantities of mismanaged plastic waste are generated across the Kura-Aras basin and modelled substantial annual plastic transport to the Caspian Sea. Ghaffari et al. (2025) subsequently applied field monitoring, unmanned aerial vehicle surveys and hydrodynamic modelling at the Kura delta, recording more than 600 debris items along a surveyed shoreline and demonstrating both local accumulation and transboundary origins of some plastic items. These findings move the plastic issue from a general visual concern to a measurable river-to-sea pollution pathway.

Agricultural pollution is more diffuse and therefore less visible than litter or wastewater outfalls. Fertilizers containing nitrogen and phosphorus can be transported through surface runoff or drainage water, increasing nutrient loads and, under suitable conditions, stimulating excessive algal production and oxygen depletion. The EUWI+ (2021) assessment identifies agricultural areas treated with fertilizers and pesticides as a diffuse pressure in the lower Kura-Aras system. The original research materials described the same mechanism in accessible terms, linking fertilizer wash-off with reduced dissolved oxygen and stress on aquatic organisms. Importantly, the present study treats this as a pressure pathway supported by environmental science rather than as a measured nutrient concentration in the authors' own field data.

The ecological consequences of river pollution can occur at several levels, from altered water chemistry to organism-level stress and habitat degradation. At the Kura River mouth, Yusifova et al. (2024) reported histological changes in fish gills and liver that were interpreted mainly as protective-adaptive responses and as evidence of some environmental stress factor, while genotoxic indicators did not exceed the reported norm. This result is important because it shows the need for cautious interpretation: ecological stress may be detectable even when a single biomarker or chemical parameter does not indicate extreme contamination. In parallel, the World Bank (2024) emphasizes the need for improved water-quality monitoring, wastewater treatment and pollution enforcement in Azerbaijan. Taken together, the literature supports a multi-pressure perspective in which point-source effluents, diffuse agricultural inputs, plastics, sediment-associated contaminants and reduced flows interact rather than act in isolation.

MATERIALS AND METHODS

This study used a qualitative integrative research design. The primary analytical corpus consisted of two independently prepared 2026 research dossiers addressing Kura River pollution and its environmental consequences. Both source works used online research and documentary review; they also incorporated qualitative observation, environmental images or maps, and simple problem-effect comparisons. One dossier emphasized the causes and broad environmental consequences of river-water pollution, while the second gave greater attention to agricultural chemicals, plastics, transboundary contamination, water-level pressures and possible mitigation measures. The original wording and thematic priorities were retained as the foundation of the analysis, but repeated material was consolidated and claims requiring empirical support were checked against external literature.

The analysis followed a three-stage coding procedure. First, statements in the two source works were grouped into pressure categories: (1) municipal and industrial wastewater, (2) domestic solid waste and plastics, (3) agricultural runoff and chemical inputs, (4) transboundary contaminant transfer, and (5) interacting water-quantity and hydromorphological pressures. Second, each pressure was linked to an environmental pathway, such as direct discharge, surface runoff, river transport, sediment transport or reduced dilution capacity. Third, likely receptors and impacts were classified as water-quality deterioration, aquatic-ecosystem stress, soil or irrigation effects, human exposure pathways, and downstream transfer to the Caspian Sea.

A targeted literature review was then used for triangulation. Priority was given to peer-reviewed articles and official reports directly concerning the Kura River, the Kura-Aras basin or Azerbaijan's water sector, with emphasis on sources published from 2010 to 2025.

Recent evidence was used where available, particularly for water-quality trends and plastic pollution. The study did not conduct chemical analysis, microbiological testing, flow measurement or statistically representative field sampling. Accordingly, no concentration, exceedance rate or causal effect is attributed to the authors' original observations unless supported by a cited external source. The resulting framework is interpretive and comparative, designed to identify convergent pressure-impact relationships and management priorities rather than to estimate pollutant loads.

RESULTS AND DISCUSSION

Dominant anthropogenic pressure pathways

The synthesis shows that wastewater discharges are the most direct point-source pressure identified across the research materials. Industrial effluents and untreated or insufficiently treated municipal wastewater can introduce organic matter, nutrients, oils, metals and other contaminants into the river. This pathway is consistent with the World Bank's (2024) assessment that Azerbaijan needs to modernize and expand wastewater treatment infrastructure, and with EUWI+ (2021), which identifies untreated discharges from riparian settlements and industrial enterprises as a major pressure. The environmental significance of point-source wastewater is amplified in river sections where flows are lower or where multiple discharges accumulate, because the river has less capacity to dilute incoming loads. The source works correctly emphasized prevention and treatment at the discharge point rather than relying only on downstream clean-up.

Domestic solid waste, particularly plastic, emerged as the most visible pollution pressure. The original materials described littering on riverbanks and plastic containers entering the water, and they connected long-term plastic persistence with risks to aquatic organisms. Recent empirical work at the Kura delta strongly supports this concern. Ghaffari et al. (2025) documented debris accumulation through standardized field monitoring and remote-sensing tools, while Mousavi et al. (2025) estimated substantial basin-scale plastic inputs to the Caspian Sea. These studies indicate that visible litter is not merely an aesthetic problem; it is part of a transport continuum in which mismanaged waste can move from settlements and riverbanks through the river network and ultimately accumulate in the delta or Caspian coastal environment.

Agricultural runoff represents a diffuse pressure that is harder to observe directly. The source research identified excessive use of nitrogen- and phosphorus-containing fertilizers as a potential cause of nutrient enrichment. This mechanism is consistent with the EUWI+ (2021) identification of agricultural land treated with fertilizers and pesticides as a diffuse source of pressure. Unlike a wastewater pipe, agricultural pollution may enter the river through many small runoff and drainage pathways, which complicates monitoring and enforcement. Management therefore requires source reduction, appropriate fertilizer application, drainage control and vegetated buffer zones rather than a single end-of-pipe treatment solution.

Transboundary transport cuts across all of these categories. The Kura receives water and pollutant loads from upstream territories before entering Azerbaijan, while internal tributaries and settlements add further pressures along the downstream course. Suleymanov et al. (2010) demonstrated strong spatial differences in trace metals and particularly high contamination at several border-related sites. Campana et al. (2012) and UNDP (2013) similarly framed the basin as a shared system in which water-quality management depends on cooperation. Therefore, an effective pollution-control strategy for Azerbaijan must combine domestic source control with information exchange and coordinated monitoring across the basin.

Environmental consequences and receptor pathways

The environmental effects identified in the original research can be organized into three linked receptor groups. First, aquatic ecosystems are exposed through changes in chemical quality, oxygen conditions, physical habitat and ingestion or contact with pollutants. Nutrient enrichment may increase biological oxygen demand indirectly through enhanced primary production and decomposition, while plastics can create ingestion and entanglement risks and can fragment into smaller particles. Fish and benthic organisms can also be exposed to dissolved or sediment-associated metals. Yusifova et al. (2024) found tissue-level changes in fish from the Kura River mouth area that were consistent with the presence of environmental stress, although the study did not attribute those changes to a single pollutant. This supports the use of multiple indicators when evaluating ecological condition.

Second, pollution can affect human uses of river water. The source materials emphasized drinking-water safety, irrigation and agricultural productivity. These concerns should be expressed cautiously: the present study does not measure disease incidence or crop losses. Nevertheless, the pathway is clear. Poor raw-water quality can increase treatment requirements and costs, while contaminated irrigation water may transfer salts, nutrients or other pollutants to soils and agricultural systems. The strong downstream mineralization gradient reported by Aliyev and Abduyev (2025), including much higher values in lower-river stations, shows that water-quality pressures are not spatially uniform. This reinforces the need to match water use with location-specific monitoring rather than assuming that all sections of the river have the same chemical status.

Third, pollution in the Kura has downstream consequences beyond the river itself. Because the Kura discharges to the Caspian Sea, river-borne pollutants and plastics can be transferred to deltaic and coastal environments. The Kura delta studies by Ghaffari et al. (2025) and Mousavi et al. (2025) provide direct evidence for the importance of this river-to-sea pathway. In management terms, this means that upstream waste prevention and wastewater treatment are also Caspian Sea protection measures. River and coastal policies should therefore be coordinated rather than treated as separate environmental domains.

Table 1. Main anthropogenic pressures, pathways and environmental implications identified in the synthesis

Pressure	Pathway and environmental implication
Municipal and industrial wastewater	Direct discharge to the river or tributaries can increase organic and chemical loading, raise treatment demand and create aquatic stress.
Solid waste and plastics	Littering and storm runoff transport plastics downstream, creating ingestion/entanglement hazards, fragmentation and transfer to the Kura delta and Caspian Sea.
Agricultural inputs	Runoff and drainage from cultivated land can transport nutrients and pesticides, contributing to diffuse pressure, possible oxygen stress and irrigation concerns.
Transboundary pollutants	Upstream river and sediment transport can create cumulative cross-border exposure to metals and other contaminants.
Reduced flow and hydromorphological change	Lower dilution, altered residence time and sediment transport can intensify water-quality pressures and ecological vulnerability.

Interaction between pollution and water-quantity pressures

Although the article focuses on pollution, the source research also noted declining water levels and inefficient water use. These issues matter because quantity and quality are interdependent. Reduced flow can increase the relative concentration of pollutants, reduce dilution capacity and alter sediment transport, while reservoirs and abstractions can change residence times and ecological conditions.

The World Bank (2024) identifies both water abstraction and pollution as major pressures, and EUWI+ (2021) reports significant hydromorphological and flow-related changes in the lower basin. The present synthesis therefore interprets pollution control as part of integrated river-basin management, not as an isolated waste-management task.

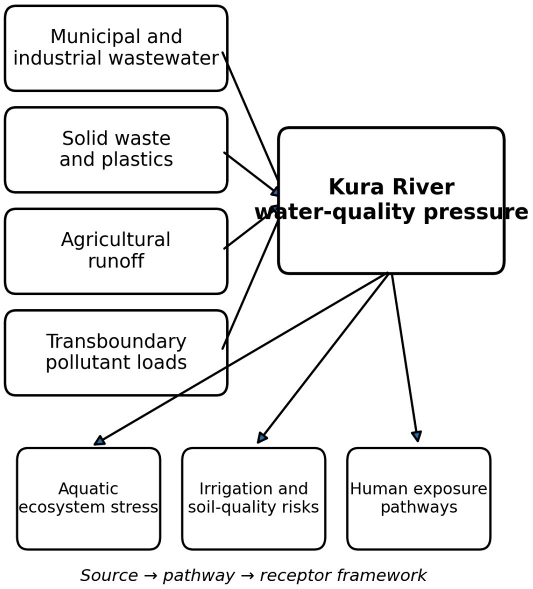

Figure 1. Source–pathway–impact framework used in the qualitative synthesis

Figure 1 summarizes the analytical logic used in the study. The framework does not assume that each pressure produces a single effect; rather, it emphasizes that several source types can converge on river water quality and can affect multiple receptors simultaneously.

Management priorities

Five management priorities emerge from the combined evidence. The first is prevention and treatment of municipal and industrial wastewater before discharge. The second is stronger solid-waste management at settlements and recreation areas along the river, combined with routine clean-up and enforcement against dumping. The third is reduction of diffuse agricultural pollution through more precise nutrient use, runoff control and riparian buffers. The fourth is a monitoring system that combines conventional chemistry with biological indicators, litter surveys and, where feasible, sediment analysis. The fifth is transboundary data sharing and coordinated basin management. These priorities directly reflect the pressures identified by the original research while also aligning with recent national and international evidence.

CONCLUSIONS

This study integrated two independent research works on Kura River pollution into a structured assessment of anthropogenic pressures, environmental pathways and management priorities. The combined analysis preserves the central observations of the original investigations: industrial and municipal wastewater, household litter and plastics, agricultural chemicals, and transboundary pollution are recurrent concerns, while the consequences extend from water quality to aquatic organisms, irrigation, human uses and the Caspian receiving environment. Scientific evidence supports the relevance of these themes. Historical monitoring documented transboundary metal contamination, recent work has shown strong downstream changes in major-ion composition and mineralization, and 2025 studies provide direct evidence that plastic waste is transported through the Kura-Aras system toward the Caspian Sea. At the same time, the evidence also demonstrates the importance of caution. The source projects did not collect laboratory water samples, and therefore their observations should not be interpreted as quantified contamination levels or causal health estimates. Their value lies in identifying practical pressure categories that can guide more rigorous monitoring. The principal implication is that Kura River protection requires source-oriented management. Wastewater must be treated before discharge, plastics and household waste must be prevented from entering the river, agricultural runoff must be reduced, and monitoring should cover chemical, biological and solid-waste indicators. Because the river is transboundary and ultimately discharges to the Caspian Sea, local action should be connected to basin-scale cooperation. Future research should combine the qualitative pressure framework developed here with georeferenced field observations, seasonal water sampling and standardized laboratory analysis so that visible pollution pressures can be linked to measurable environmental outcomes.

AUTHOR CONTRIBUTIONS

Z.A. and J.A. contributed the original research materials, problem identification and initial environmental observations. G.G. coordinated the academic integration, methodological structuring and manuscript-level review. All authors contributed to interpretation, reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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DATA AVAILABILITY

The qualitative source materials and synthesis used in this study are described within the article. No new laboratory water-quality dataset was generated.

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Water security and sustainable management of the Kura River for future generations

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Kura River, sustainable water management, water conservation, water security, water-use efficiency

ABSTRACT

The Kura River is central to Azerbaijan's water security because it supports drinking-water supply, irrigation, energy production and riverine ecosystems while remaining strongly dependent on transboundary inflows. This study examines how water scarcity, inefficient use and environmental pressure are understood at the local research level and how these concerns align with contemporary water-management priorities. The paper integrates two independently prepared 2026 research dossiers with a targeted review of official and peer-reviewed literature. One source project used desk research, maps and a five-factor problem prioritization, while the second combined desk research with an exploratory questionnaire and interview material. The source-based prioritization assigned the greatest emphasis to pollution (35%), followed by water overuse (30%), climate change (20%), solid waste (10%) and riparian tree loss (5%). In the exploratory survey material, 63% identified water waste as the leading cause of depletion, 80% reported avoiding unnecessary water use, 63% selected drinking-water shortage as the principal anticipated consequence, and 49% preferred stronger oversight of water consumption as the most effective measure. Because the source files do not document the survey sample size or respondent-level data, these percentages are interpreted descriptively rather than as population estimates. The combined evidence supports an integrated strategy based on infrastructure modernization, efficient irrigation, wastewater control, rainwater and treated-water reuse, public awareness, monitoring and basin-scale cooperation. These priorities are broadly consistent with Azerbaijan's 2024–2040 National Strategy on efficient use of water resources.

INTRODUCTION

Water security is not limited to the physical availability of water. It also depends on whether sufficient water of acceptable quality can be supplied to households, agriculture, ecosystems and the economy while drought, pollution and other water-related risks remain manageable (Grey & Sadoff, 2007). This broader perspective is particularly relevant to Azerbaijan, where the Kura River is the principal surface-water artery and where water availability is shaped by both domestic demand and upstream conditions. The World Bank (2024) estimates that roughly 70% of Azerbaijan's surface-water flows originate outside the country, making national water security highly sensitive to transboundary hydrology, upstream abstraction and basin-wide environmental pressures.

The Kura River therefore connects several dimensions of sustainability at the same time. Its water is used for municipal supply, irrigated agriculture, hydropower and ecosystem maintenance, while the river and its tributaries are exposed to pollution, seasonal variability, infrastructure losses and increasing demand. The World Bank (2024) identifies irrigated agriculture as the largest water-consuming sector in Azerbaijan and notes that inefficient irrigation, aging infrastructure, pollution and drought risk remain important constraints. FAO (2021) similarly emphasizes that declining rainfall, higher temperatures, reduced runoff and old irrigation systems have intensified water-scarcity concerns, particularly because a large share of the country's usable water originates beyond its borders.

The two original research works integrated in this paper approached these issues from a future-oriented perspective. Muradzade's project focused on protecting water resources for future generations and organized the main Kura-related pressures into pollution, excessive water use, climate change, solid waste and riparian vegetation loss. Hasanova's project examined water-management strategy, irrigation losses, rainwater harvesting, alternative water use and public attitudes toward conservation. Both projects emphasized that household behavior and infrastructure management are linked: individual conservation can reduce avoidable demand, but long-term water security also requires institutional planning, irrigation modernization, water-quality protection and climate adaptation.

The objective of this study is to convert those source-level observations into a structured academic assessment of Kura River water security. Three questions guide the analysis: Which pressures are most prominent in the original research materials? What do the exploratory perception data suggest about public understanding and water-saving behavior? How do the proposed solutions correspond to current evidence and Azerbaijan's national water-management strategy? The study does not reinterpret the source percentages as nationally representative statistics; instead, it uses them as descriptive evidence and evaluates them against recent scientific and institutional literature.

LITERATURE REVIEW

Water security is increasingly treated as a coupled environmental, economic and governance problem. Grey and Sadoff (2007) define the concept around adequate quantity and quality of water for health, livelihoods, ecosystems and production together with acceptable water-related risks. This framing is useful for the Kura because scarcity cannot be separated from water quality, irrigation efficiency, drought exposure or institutional coordination. In the Kura-Aras context, Suleymanov (2025) argues that stronger basin institutions and cooperative governance are important for managing shared water resources, particularly where scarcity and transboundary dependence interact.

Recent assessments of Azerbaijan reinforce this integrated view. The World Bank's General Water Security Assessment identifies transboundary dependence, seasonal variability, inefficient irrigation, infrastructure condition and pollution as interrelated challenges and recommends stronger resource management, modernization and adoption of efficient technologies (World Bank, 2024). FAO (2021) likewise highlights old earthen canals and associated distribution losses as important obstacles to sustainable agricultural water use. Earlier research by Rzayev (2017) also concluded that irrigation-system modernization and better agricultural water management are necessary to prevent depletion under growing domestic demand and reduced transboundary inflows.

Water quantity and water quality are also connected. Aliyev and Abduyev (2025), using monitoring data from 2020–2022, documented substantial downstream changes in the Kura River's mineralization and major-ion composition. Their findings show why sustainable management cannot focus only on the volume of water stored or diverted: lower flows, wastewater inputs, agricultural drainage and tributary chemistry can alter the quality of water available for drinking, irrigation and ecosystems. Protecting the Kura therefore requires both demand-side efficiency and water-quality control.

A major institutional development is Azerbaijan's National Strategy on Efficient Use of Water Resources for 2024–2040, approved in October 2024. The strategy is organized in three stages and addresses integrated water-resource management, reliable drinking and irrigation supply, infrastructure modernization, reuse of treated water, rainwater management, drought and flood risks, and hydroecological protection (President of the Republic of Azerbaijan, 2024). Several elements correspond directly to proposals in the source projects, including rainwater collection, modernization of irrigation systems and stronger conservation awareness.

Taken together, the literature suggests that future-oriented Kura management should combine four functions: protecting the resource base, reducing avoidable demand, improving infrastructure and water-use efficiency, and strengthening governance and monitoring. The present study uses these functions as the analytical framework for organizing the original research materials and distinguishing source-derived observations from broader evidence in the literature.

MATERIALS AND METHODS

The study used an integrative qualitative design based on two independently prepared 2026 research dossiers. The first dossier, prepared by Aydan Muradzade, examined protection of water resources for future generations through online research, map and image review, and a source-level prioritization of five pressures affecting the Kura River. The second dossier, prepared by Nuray Hasanova, focused on water-management strategy and combined desk research with questionnaire and interview material, including charts on perceived causes of water depletion, personal conservation practices, expected consequences and preferred management measures.

The source materials were coded into four analytical domains: (1) water availability and climate exposure; (2) demand, irrigation and infrastructure efficiency; (3) pollution and ecosystem protection; and (4) governance, public behavior and adaptation. Muradzade's five-factor percentages were retained exactly as reported but are treated as a project-level prioritization rather than as survey estimates because the source document does not describe a statistical procedure for generating them. Hasanova's questionnaire percentages were transcribed from the original charts. The source file does not report the survey sample size, and it contains a textual reference to interviews with children aged 5–11 while separate charts display a broader age distribution. For that reason, the questionnaire results are used only as exploratory descriptive evidence and no inferential statistics are applied.

A targeted literature review was used for triangulation. Priority was given to Azerbaijan's 2024–2040 National Strategy, the World Bank's recent national water-security assessment, FAO material on agricultural water governance, and peer-reviewed studies addressing Kura-Aras governance, irrigation and water quality. The comparison assessed whether source-level concerns and proposed solutions were consistent with documented national and basin-level challenges. No new field sampling, laboratory analysis or respondent-level survey processing was undertaken for this article, and no personal identifiers were used.

RESULTS AND DISCUSSION

Water-security pressures identified in the source research

Muradzade's source project assigned the highest relative emphasis to pollution (35%) and water overuse (30%), followed by climate change (20%), solid waste (10%) and loss of riparian trees (5%). These percentages should not be interpreted as measured contributions to Kura River decline; rather, they provide a transparent record of how the original research prioritized the problem. The ranking is nevertheless consistent with the broader literature in one important respect: Azerbaijan's water-security challenge is multi-causal. The World Bank (2024) identifies abstraction, irrigation inefficiency, pollution and climate-related risk simultaneously, while the National Strategy treats infrastructure, water quality, drought and efficient use as linked management areas.

Pollution was the most strongly emphasized pressure in Muradzade's work. The project linked untreated wastewater and litter to reduced suitability of river water and ecological damage. Recent monitoring confirms that water-quality conditions vary substantially along the Kura. Aliyev and Abduyev (2025) reported a strong downstream mineralization gradient and changes in major-ion composition, demonstrating that the river cannot be treated as chemically uniform from the upstream border to the lower reaches. For management, this means that water security requires location-specific water-quality monitoring in addition to overall allocation planning.

The second major pressure was inefficient or excessive water use. Both source projects repeatedly discussed open-channel losses, outdated irrigation practices and avoidable household consumption. These concerns align closely with FAO (2021), which notes significant losses in older irrigation infrastructure, and with Rzayev (2017), who identifies irrigation modernization as central to water-resource protection in Azerbaijan's arid zones. Modernization should therefore be understood not only as an agricultural productivity measure but also as a water-security intervention that can reduce the volume withdrawn from river systems for the same productive purpose.

Climate change was the third major source theme. The student projects referred to hotter summers, lower rainfall, reduced snow availability and greater risk of future scarcity. The National Strategy itself cites projected reductions in national water resources under warming scenarios and places drought management and climate-resilient water supply among its long-term priorities (President of the Republic of Azerbaijan, 2024). Climate pressure can also amplify other problems: when flows are reduced, competing demands become more difficult to reconcile and water-quality pressures may become more consequential because dilution capacity is lower.

Source-derived prioritization and exploratory perception evidence

Table 1 preserves Muradzade's original five-factor weighting while translating each factor into a management implication. The purpose is not to quantify causal responsibility but to show how the source research connected environmental problems with proposed action. Pollution and overuse together account for 65% of the project-level emphasis, which explains why the original recommendations concentrated on wastewater control, household conservation, efficient irrigation and environmental education.

Hasanova's questionnaire material provides a complementary behavioral perspective. Among the reported responses, 63% selected water waste as the main cause of depletion, 80% stated that they avoid unnecessary water use, 63% identified drinking-water shortage as the main anticipated consequence, and 49% selected stronger oversight of water consumption as the preferred management measure. Other responses in the source charts included support for awareness activities, new technologies and penalties. Because the number and composition of respondents are not fully documented, these values should be interpreted as indicators of the concerns present in the project sample, not as estimates for Sumgait or Azerbaijan.

The perception data are still useful for understanding the logic of the original research. Respondents appear to connect water security primarily with everyday waste and future drinking-water availability, while the preferred responses combine behavioral control and public education. This is important because infrastructure investment alone cannot eliminate inefficient use if households and water users do not understand scarcity. Conversely, awareness campaigns alone cannot compensate for leakage, inefficient irrigation or untreated wastewater. Sustainable management therefore requires a combination of demand-side behavior and system-level modernization.

Table 1. Source-project problem weighting and corresponding management relevance

Pressure	Reported emphasis and management relevance
Pollution	35% — Wastewater treatment, source control and water-quality monitoring
Water overuse	30% — Demand management, leakage reduction and irrigation efficiency
Climate change	20% — Drought preparedness, climate-resilient allocation and storage
Solid waste	10% — Waste prevention, riverbank management and public awareness
Riparian tree loss	5% — Riparian restoration, erosion control and ecosystem protection

Alignment with Azerbaijan's 2024–2040 water strategy

The policy alignment between the student research and the National Strategy is notable. The strategy's first stage (2024–2027) emphasizes institutional and infrastructure improvements and includes actions on wastewater and drainage-water reuse, rainwater management, irrigation-system reconstruction, alternative drinking-water sources, drought measures and pollution-risk reduction. Its later stages extend the framework toward 2040. The source projects proposed many of the same practical directions in simpler form: rainwater harvesting, drip irrigation, reduced household waste, wastewater treatment, tree planting and stronger environmental education. This convergence suggests that the students identified management themes that are relevant beyond the school-project context.

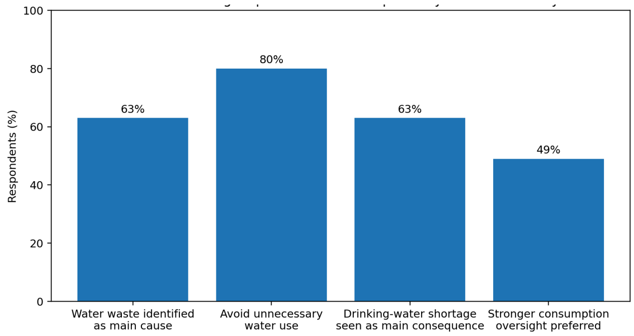

Figure 1. Selected leading responses from the exploratory water-use survey reported in the source research

Figure 1 summarizes four of the clearest majority responses recorded in Hasanova's charts. The dominant behavioral message is that respondents recognize avoidable water use as a problem and report some personal conservation behavior, yet they also expect future drinking-water shortages and favor stronger oversight. The apparent coexistence of awareness and concern implies that knowledge does not automatically resolve water insecurity. Effective management must create practical conditions in which conservation is easy, measurable and supported by infrastructure, pricing and service reliability. The figure is descriptive only because the source material does not provide the sample size or respondent-level observations.

Integrated management priorities for future generations

Five priorities emerge from the combined analysis. First, irrigation and distribution infrastructure should be modernized to reduce conveyance and application losses, supported by measurement and efficient technologies such as drip irrigation where technically and economically appropriate. Second, wastewater treatment and water-quality monitoring should protect the usable resource, especially in downstream reaches. Third, alternative and circular water sources should be expanded where feasible, including rainwater harvesting and safe reuse of treated wastewater for non-potable applications; both are explicitly reflected in the National Strategy. Fourth, drought planning and climate adaptation should connect hydrological monitoring with flexible allocation rules so that scarce water can be managed transparently during low-flow periods. Fifth, public awareness should be linked to measurable conservation practice in schools, households and agricultural communities. Because the Kura is transboundary, these domestic actions should be complemented by basin-level information exchange and cooperation. Together, these measures frame water conservation not as a single campaign but as a long-term system for protecting quantity, quality and access for future generations.

Limitations and future research priorities

The main limitation of this study is inherited from the original research materials. The first source project provides a transparent problem-weighting scheme but does not describe how the percentages were calculated; they therefore represent the author's structured prioritization rather than measured shares of hydrological or environmental causation. The second source project contains useful questionnaire charts, yet the sample size, recruitment procedure and respondent-level dataset are not documented. The textual description also refers to interviews with children aged 5–11, whereas a separate chart shows respondents from several age groups. These inconsistencies do not invalidate the educational value of the project, but they prevent statistical generalization. A future version of the research should record the exact number of participants, sampling location, age group, question wording and response counts and should preserve an anonymized dataset so that percentages can be independently verified. If minors participate, consent and school-level ethical procedures should also be documented explicitly.

A second limitation is the absence of direct hydrological and water-quality measurements in the two source dossiers. Perceptions of scarcity and observations of pollution should ideally be tested against measurable indicators such as river discharge, seasonal water level, electrical conductivity, salinity or mineralization, selected nutrients and basic water-quality parameters. Repeated observations at fixed locations would make it possible to distinguish seasonal variation from longer-term change. For a school-based monitoring programme, this need not begin with advanced laboratory analysis: standardized field sheets, georeferenced photographs, simple water-level observations and carefully selected low-cost sensors can create a reproducible baseline when quality-control procedures are followed. These observations could then be compared with official monitoring and published studies such as Aliyev and Abduyev (2025). A third priority is to connect perception research with actual water-use behavior. Household or school water-meter readings before and after an awareness intervention, for example, would allow researchers to test whether knowledge produces measurable conservation. Such a design would preserve the practical and youth-oriented character of the original projects while providing stronger evidence for future water-security planning.

CONCLUSIONS

This study integrated two original research projects into an academic assessment of Kura River water security and sustainable management. The source materials consistently identified pollution, inefficient water use, climate change, solid waste and degradation of riparian vegetation as threats to the future of the river. Muradzade's project-level weighting placed pollution and water overuse at the center of the problem, while Hasanova's exploratory questionnaire showed strong concern about water waste and future drinking-water shortage and substantial reported engagement in basic conservation behavior. These percentages are useful as descriptive project evidence but cannot be generalized because the source files do not document a survey sample size or provide respondent-level data. The wider literature nevertheless confirms the relevance of the themes identified by the students. Azerbaijan remains highly dependent on transboundary surface water, irrigated agriculture is a major user, old infrastructure can generate substantial losses, and both water quantity and quality are affected by climate, pollution and management conditions. The 2024–2040 National Strategy provides a policy framework that closely overlaps with the source recommendations, including irrigation modernization, rainwater management, wastewater reuse, drought management and stronger resource governance. The central implication is that protecting the Kura for future generations requires integrated action across infrastructure, water quality, efficient demand, climate adaptation, education and transboundary cooperation. Future work should improve the empirical basis of the school research by documenting sample design, collecting georeferenced observations and linking perception surveys with measured indicators of water use and river condition.

AUTHOR CONTRIBUTIONS

A.M. and N.H. contributed the original research materials, problem identification, source collection and preliminary analysis. N.H. also contributed the exploratory questionnaire and interview materials. T.M. provided supervision, methodological guidance, academic integration and review and editing. All authors contributed to interpretation, reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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This research received no external funding.

DATA AVAILABILITY

The source-level charts, percentages and qualitative research materials used in this synthesis are described in the article. Respondent-level survey data and a documented sample size were not available in the source files; therefore, no inferential statistical dataset is provided.

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Combined anthropogenic and climate pressures on the Kura River and their implications for water security, ecosystem sustainability and green economic resilience

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Keywords
anthropogenic pressure, climate change, ecosystem sustainability, green economic resilience, Kura River

ABSTRACT

The Kura River is a strategic water artery for Azerbaijan, supporting drinking-water supply, irrigated agriculture, energy production and aquatic and riparian ecosystems. This study integrates two independently prepared 2026 research projects to examine how anthropogenic pressures and climate-related water stress interact and what these interactions imply for water security, ecosystem sustainability and green economic resilience. The first source project used desk research, official statistics, visual observation, teacher interviews and map-based comparison to assess human impacts on the river. The second combined desk research with an exploratory survey of 25 students and family members. Survey results showed that 92% considered the Kura important for Azerbaijan, 84% recognized ecological problems, 76% reported practicing water conservation and 96% supported stronger protection measures. The source materials consistently identified inefficient irrigation, untreated wastewater, solid waste, declining water availability, climate variability and riparian degradation as interconnected pressures. Recent official and scientific evidence supports the direction of these concerns, although one source-project estimate of a 35–40% flow decline could not be independently verified from the underlying data and is therefore not treated as a measured result. The analysis shows that water efficiency, pollution control, climate adaptation, riparian restoration and transboundary cooperation are not only environmental priorities but also elements of green economic resilience because they protect agricultural productivity, ecosystem services and the reliability of water-dependent livelihoods. Integrated river-basin management is therefore essential for aligning ecological protection with resource-efficient development.

INTRODUCTION

The Kura River is the largest river system in Azerbaijan and one of the principal water arteries of the South Caucasus. Its functions extend well beyond hydrology: the river supports municipal water supply, irrigated agriculture, hydropower, fisheries, riparian habitats and economic activity across the central lowlands. This multifunctional role means that deterioration in either water quantity or quality can propagate through food production, public services, ecosystems and local livelihoods. Azerbaijan is particularly exposed because a large share of its surface-water resources forms outside the country. The Ministry of Ecology and Natural Resources reports that 67–70% of national river-water resources originate in neighboring states, while recent World Bank assessments similarly describe strong dependence on transboundary inflows (Ministry of Ecology and Natural Resources, n.d.; World Bank, 2024).

Water stress in the Kura basin is not caused by a single driver. Climate change affects snow accumulation, runoff timing, drought frequency and evaporative demand, while human activities alter water withdrawals, pollution loads, riverbank condition and the efficiency with which water is delivered to farms and settlements. The 2024 Initial National Adaptation Plan of Azerbaijan notes that flows of the Kura and Aras have declined sharply in recent years and identifies safe water supply, ecosystem protection and efficient use as major adaptation priorities (Republic of Azerbaijan, 2024). At the same time, official national monitoring indicates long-term declines in river flow and increasing competition for water as population, irrigation and economic activity expand (Ministry of Ecology and Natural Resources, n.d.).

These pressures have a direct economic dimension. Agriculture is a central component of Azerbaijan's non-oil economy and is highly exposed to drought and water scarcity. The World Bank's Country Climate and Development Report emphasizes that climate-proofing agriculture requires improved irrigation efficiency and climate-smart practices, linking water management to economic diversification and resilience (World Bank, 2023). In this paper, green economic resilience is understood as the capacity of water-dependent production and communities to withstand environmental shocks while improving resource efficiency and protecting natural capital. Under this framing, conserving Kura water and ecosystems is not separate from economic development; it is part of the infrastructure and natural-resource base on which sustainable growth depends.

The present study combines two original school-level research projects that approached the same problem from complementary directions. Ahgazade examined anthropogenic effects on the Kura ecosystem through desk research, official information, visual observation, interviews with teachers and map-based comparison. Nurulu focused on the significance of Kura water resources, ecological problems and conservation attitudes and conducted a small exploratory survey. The objective is to preserve the evidence and reasoning of both projects while placing them in a more rigorous academic framework. The analysis asks three questions: Which anthropogenic and climate pressures are emphasized in the source research? What does the exploratory survey reveal about awareness and conservation attitudes? How do these pressures affect water security, ecosystem services and green economic resilience?

LITERATURE REVIEW

The Kura–Aras system is frequently described as a coupled transboundary water-security problem because river flow, water quality, agricultural withdrawals and governance interact across national borders. Suleymanov (2025) argues that stronger basin institutions, transparency and cooperation are needed to improve water-resource management in a context of scarcity and uneven trust among riparian states. The World Bank (2024) similarly identifies transboundary dependence, irrigation demand, infrastructure condition, water pollution and climate variability as mutually reinforcing constraints on Azerbaijan's water security.

Climate change adds stress to already intensively used water systems. Azerbaijan's Initial National Adaptation Plan reports increasing concern over reduced river flows and future water availability, particularly in arid lowland areas where water-intensive agriculture is concentrated (Republic of Azerbaijan, 2024). Research in the Kur–Araz lowland also demonstrates that climate and water management can interact through soil salinity and agricultural productivity. Han et al. (2024) found that future rainfall decline could contribute to renewed salinization, creating risks for agricultural sustainability and food security. This illustrates why river-flow management, drainage and climate adaptation need to be considered together rather than as separate environmental issues.

Anthropogenic water-quality pressure is another major concern. Aliyev and Abduyev (2025) documented downstream changes in mineralization and major-ion composition in the Kura River, including the influence of the Aras confluence and more mineralized tributary waters. Such evidence supports the source projects' broader concern that pollution and reduced flows can weaken the suitability of river water for ecosystems and economic uses. Lower flow can also reduce dilution capacity, making the ecological consequences of wastewater and agricultural drainage more difficult to manage.

From a green-economy perspective, water efficiency is a productivity and resilience issue. The World Bank (2023) notes that agriculture contributes less than 8% of Azerbaijan's GDP but accounts for 36% of total employment, making climate and water shocks socially important even when the sector's GDP share is comparatively modest. The same report recommends irrigation efficiency and climate-smart agriculture to protect productivity under higher temperatures and lower water availability. The National Strategy on Efficient Use of Water Resources for 2024–2040 further emphasizes integrated water management, infrastructure modernization, reuse, drought preparedness and ecosystem protection (President of the Republic of Azerbaijan, 2024).

The literature therefore supports an integrated conceptual pathway in which climate variability and anthropogenic pressure affect river flow and water quality; these changes influence habitats, irrigation reliability and ecosystem services; and the resulting environmental stress affects economic productivity and social resilience. The original student research is evaluated within this pathway, with clear separation between source-derived observations and externally verified evidence.

MATERIALS AND METHODS

The study used an integrative qualitative design based on two independently prepared 2026 research dossiers. Ahgzade's project examined the impact of human activity on the river ecosystem using online research and statistical review, official environmental information, visual observation of riverbank conditions, discussions with geography, biology and chemistry teachers, and comparison of maps and satellite imagery. The project identified inefficient irrigation, industrial and municipal wastewater, solid waste, declining flow and climate change as key pressures. It also reported a 35–40% reduction in flow near the Kura mouth relative to a stated norm; however, the underlying time series, station, baseline and calculation were not provided in the source file. That percentage was therefore retained as a source observation but excluded from verified quantitative findings.

Nurulu's project combined desk research with an exploratory survey of 25 students and family members. Four questions asked whether respondents understood the Kura's importance for Azerbaijan, believed the river faced ecological problems, practiced water conservation and supported stronger river-protection measures. The source-reported results were 92%, 84%, 76% and 96%, respectively. Because the sample was small and convenience-based, the survey is used only to describe the awareness pattern within the project group; no population-level inference is attempted.

For synthesis, both dossiers were coded into five analytical categories: (1) water abstraction and irrigation efficiency; (2) pollution and waste; (3) climate-related water availability; (4) ecosystem and riparian degradation; and (5) governance, awareness and transboundary dependence. A targeted literature review was then used to triangulate the direction of the source findings and to add an economic interpretation. Priority was given to recent official documents, peer-reviewed research and institutional assessments relevant to Azerbaijan. Green economic implications were assessed qualitatively through effects on agricultural productivity, ecosystem services, resource efficiency, water-treatment needs and the resilience of water-dependent livelihoods. No monetary valuation or cost-benefit analysis was performed because the source materials did not contain the data required for such estimates.

RESULTS AND DISCUSSION

Interacting anthropogenic and climate pressures

Both source projects portray the Kura as a system exposed to multiple pressures rather than a single isolated problem. Ahgzade places inefficient agricultural water use, wastewater discharge, household waste and weak riverbank management alongside climate-related reductions in water availability. Nurulu similarly identifies overuse, pollution, climate change and inefficient management as risks to future water security. The combined interpretation is important because the same amount of pollution can create greater ecological stress when river flow is low, while inefficient withdrawals can amplify the consequences of drought. In other words, anthropogenic and climatic pressures can reinforce one another.

The direction of the source findings is supported by official monitoring. The Ministry of Ecology and Natural Resources reports that 67–70% of Azerbaijan's river-water resources form outside the country and that water resources of the Kura and Aras are reduced by upstream use. Its monitoring summary also indicates that, compared with 1961–1990, average flow in transboundary rivers during 1991–2023 declined by approximately 9.1–21%, with even larger reductions recorded for some rivers over the most recent decade (Ministry of Ecology and Natural Resources, n.d.). These national indicators do not verify Ahgazade's specific 35–40% estimate at the Kura mouth, but they support the broader conclusion that declining flow is a real management concern.

Pollution constitutes the second pathway of interaction. The source projects describe untreated municipal and industrial wastewater, agricultural chemicals and litter as threats to river quality and aquatic life. Recent peer-reviewed evidence shows measurable downstream changes in Kura mineralization and ion composition, confirming that water quality varies significantly along the system (Aliyev & Abduyev, 2025). From a management perspective, protecting water quality increases the usable share of a scarce resource. Pollution control can therefore reduce pressure on treatment systems and help preserve the ecological functions that support fisheries, agriculture and riverine habitats.

Table 1 translates the main pressures retained from the student research into environmental and green-economy pathways. The table does not assign causal percentages. Instead, it clarifies how actions that improve water efficiency or ecosystem condition can simultaneously support climate adaptation, natural-capital protection and resource-efficient development.

Environmental awareness and conservation attitudes

Nurulu's survey provides a small but internally consistent picture of awareness. Among 25 respondents, 92% considered the Kura important for Azerbaijan and 84% believed that the river faced ecological problems. Seventy-six percent reported that they save water, while 96% supported stronger measures to protect the river. The gap between near-universal support for stronger protection and the lower share reporting personal conservation behavior suggests that environmental concern does not always translate completely into everyday practice. Because the respondents were students and family members selected for a school research project, this pattern should not be generalized to the population of Sumgait or Azerbaijan.

The survey nevertheless adds a social dimension that is often absent from purely hydrological assessments. Water-saving technologies require user acceptance, while pollution prevention depends partly on household, agricultural and industrial behavior. Public awareness can therefore complement infrastructure investment, although it cannot substitute for effective wastewater treatment, flow measurement or irrigation modernization. Green economic resilience depends on both: efficient infrastructure reduces physical losses, and informed users reduce avoidable demand and support long-term conservation measures.

Figure 1 presents the four source-reported survey indicators. The strongest response was support for additional Kura-protection measures (96%), followed by recognition of the river's national importance (92%). Recognition of ecological problems was also high (84%), while self-reported water-saving behavior was lower at 76%. This hierarchy is useful for designing education and citizen-engagement activities because it suggests that awareness is already substantial within the small study group, whereas consistent behavior may require more practical guidance, incentives and visible institutional action.

Table 1. Integrated pressure pathways identified in the source research

Pressure pathway	Source observation and green-economy relevance
Irrigation inefficiency	Outdated irrigation practices and avoidable losses — higher water productivity and more resilient agricultural output.
Pollution and waste	Wastewater, agricultural chemicals and solid waste threaten river quality — pollution control can protect fisheries, irrigation and natural capital while lowering treatment pressure.
Climate-related scarcity	Reduced flow, heat and rainfall variability increase water stress — climate-resilient allocation can lower production risk.
Riparian degradation	Loss of tugay vegetation and riverbank pressure weaken ecosystem condition — restoration protects ecosystem services, erosion control and biodiversity.
Transboundary dependence	A large share of national river flow originates outside Azerbaijan — cooperation and shared monitoring can reduce resource-security risk.

Implications for ecosystem sustainability and water security

Ecosystem sustainability is directly connected to water security because riparian vegetation, wetlands and aquatic habitats contribute to erosion control, water purification, biodiversity and the stability of riverine landscapes. Ahgazade's source project specifically emphasized restoration of tugay forests and riverbank vegetation, while Nurulu highlighted the role of the Kura ecosystem in supporting fish, birds and other species. These observations align with a nature-based interpretation of water security: protecting ecosystem condition helps maintain natural functions that engineered systems would otherwise need to replace at additional cost.

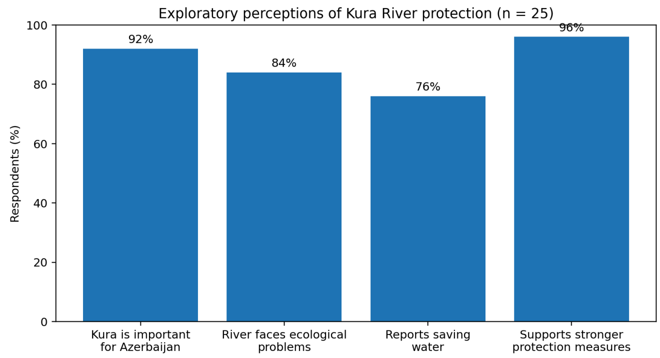

Figure 1. Source-reported environmental awareness and water-conservation responses (n = 25)

Climate pressure also influences ecosystem condition through lower flow, higher temperatures and altered seasonal water availability. Azerbaijan's adaptation planning recognizes that reduced Kura and Aras flows can make it more difficult to supply agriculture during hot months and can intensify future water-security risks (Republic of Azerbaijan, 2024). Han et al. (2024) further show that climate and water management interact with salinity in the Kur–Araz lowland. These links demonstrate that biodiversity protection, soil management, drainage and efficient irrigation should be viewed as connected components of basin resilience rather than independent sectoral tasks.

Green economic resilience and resource-efficient adaptation

The economic relevance of Kura resilience is most evident in agriculture. Water scarcity can reduce irrigation reliability, raise production risk and accelerate soil degradation, while inefficient conveyance means that part of the abstracted resource produces no economic value. The World Bank (2023) characterizes agriculture as important to Azerbaijan's non-oil economy and employment and recommends higher irrigation efficiency and climate-smart practices. For the Kura basin, this implies that drip and sprinkler systems where appropriate, canal rehabilitation, measurement of withdrawals and better scheduling can be interpreted not only as water-saving interventions but also as green-economy investments that improve the productivity of each unit of water used.

Integrated management priorities and study limitations

Five management priorities follow from the synthesis. First, irrigation modernization should reduce avoidable abstraction and increase water productivity. Second, wastewater treatment and pollution control should protect the quality of the remaining resource. Third, climate adaptation should combine drought planning, flow monitoring and flexible allocation with soil- and salinity-management measures. Fourth, riparian restoration should protect natural capital and ecosystem services. Fifth, transboundary information exchange and basin-scale cooperation should be strengthened because a large share of Azerbaijan's water originates outside national borders. These priorities are broadly consistent with the National Strategy on Efficient Use of Water Resources for 2024–2040 (President of the Republic of Azerbaijan, 2024).

The study has several limitations. The research integrates two school-level projects rather than a standardized basin-monitoring dataset. Ahgazade's visual observations and reported statistics were not accompanied by georeferenced field records or raw hydrological data, and the specific 35–40% flow-decline estimate could not be independently reconstructed. Nurulu's survey had only 25 convenience respondents and therefore cannot support population inference. The green-economic analysis is qualitative because the dossiers contain no farm-level production costs, water tariffs, treatment costs or ecosystem-service valuation. Future research should combine measured discharge and water-quality data with georeferenced field observations, larger surveys and economic indicators such as crop water productivity, avoided treatment costs and the value of ecosystem services.

CONCLUSIONS

This study integrated two original research projects to assess how human activity and climate pressure jointly affect the Kura River and why those effects matter for water security, ecosystem sustainability and green economic resilience. The source materials consistently identify inefficient irrigation, untreated wastewater, solid waste, declining water availability, climate variability and degradation of riparian ecosystems as interconnected pressures. Nurulu's exploratory survey of 25 respondents found high recognition of the Kura's importance and ecological problems and very strong support for additional protection measures, although self-reported water-saving behavior was somewhat lower. External evidence supports the direction of the students' concerns: Azerbaijan is highly dependent on transboundary surface water, recent monitoring indicates declining river flows, and climate change, salinity, pollution and irrigation inefficiency create combined risks for agriculture and ecosystems. The economic implication is that protecting the Kura is also an investment in resource efficiency and resilience. Efficient irrigation, water-quality protection, climate-smart agriculture, riparian restoration and basin cooperation can safeguard natural capital while reducing vulnerability in water-dependent production and livelihoods. The article does not claim a monetary benefit from these measures, but it demonstrates a clear pathway through which ecological protection and green economic development can reinforce one another. Future work should strengthen this pathway with measured hydrological, ecological and economic data.

AUTHOR CONTRIBUTIONS

A.A. and N.N. contributed the original research materials, problem identification, source collection and preliminary analysis. N.N. contributed the exploratory survey and its descriptive results. A.J. contributed supervision of manuscript development, methodological integration, green-economy framing, review and editing. All authors contributed to interpretation, reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

The source-level qualitative materials and the four aggregate survey percentages used in this synthesis are reported in the article. The survey included 25 respondents. Respondent-level records, raw hydrological measurements and georeferenced observation data were not available in the source files; therefore, no inferential statistical or hydrological dataset is provided.

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Rainwater harvesting as a decentralized water conservation strategy for resource efficiency and green economy transition in Azerbaijan

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Keywords
green economy, rainwater harvesting, resource efficiency, water conservation, water security

ABSTRACT

Rainwater harvesting (RWH) offers a decentralized option for supplementing conventional water supplies while improving resource efficiency and urban resilience. This study integrates three independently prepared 2026 research projects on rainwater collection and use and places their core observations within a green-economy and policy framework for Azerbaijan. The source projects consistently described a simple system architecture based on roof or surface catchment, gutters and pipes, preliminary filtration, storage, distribution for non-potable uses and, where appropriate, overflow management or groundwater recharge. They emphasized irrigation, cleaning, car washing and toilet flushing as practical applications that can substitute treated freshwater. A structured qualitative synthesis was combined with targeted verification against recent scientific literature and Azerbaijan's water-policy documents. The analysis indicates that RWH can contribute to resource efficiency through freshwater substitution, local stormwater retention and diversification of water supply. Its economic value, however, is context dependent because installation, storage, pumping, maintenance, rainfall, water tariffs and end-use demand determine financial performance. Azerbaijan's National Strategy on Efficient Use of Water Resources for 2024–2040 explicitly calls for technical-economic assessment of rainwater collection and a pilot project for its use, strengthening the policy relevance of the approach. RWH should therefore be treated not as a stand-alone solution to water scarcity but as a complementary green-economy instrument that can reduce pressure on centralized water systems and freshwater sources when locally designed, safely operated and economically assessed.

INTRODUCTION

Water scarcity, climate variability and growing demand are increasing the need for diversified water-management strategies. Conventional water-supply systems depend on rivers, reservoirs, groundwater, treatment plants and extensive distribution networks, while many urban and peri-urban activities do not require drinking-water quality. Rainwater harvesting (RWH) addresses this mismatch by capturing precipitation close to where it falls and storing it for appropriate uses. In its simplest form, an RWH system contains a catchment surface, conveyance pipes, first-flush or filtration components, storage and a distribution mechanism. Modern systems can also be integrated with drainage, infiltration and building-water networks (Campisano et al., 2017).

The three source research projects that underpin this article approached RWH from a practical conservation perspective. Abbasli described rooftop capture, filtration, storage, non-potable uses and the possibility of directing excess water to recharge structures. Gurbanov emphasized the physical components of a collection system and the use of harvested water for irrigation and household or technical purposes. Azizli similarly focused on collection from roofs, storage in tanks and uses such as garden irrigation, cleaning and other technical activities. Across the three dossiers, the central idea is recognizable and consistent: using rainwater for suitable tasks can reserve higher-quality freshwater for uses where it is genuinely required.

This conservation logic has a direct connection to the green economy. Resource efficiency seeks to generate greater social and economic value from a smaller quantity of natural resources and lower environmental pressure. RWH can support this objective by reducing demand for centrally treated water, moderating stormwater runoff and diversifying local supply. Reviews also show that the economic and environmental performance of RWH varies substantially by rainfall regime, tank size, demand profile, pumping energy, water tariffs and regulatory conditions; therefore, a system that is environmentally useful is not automatically financially attractive in every location (Campisano et al., 2017; de Sá Silva et al., 2022).

The objective of this study is to synthesize the three original research projects into an academic assessment of RWH as a decentralized water-conservation strategy for Azerbaijan. The paper asks three questions: (1) which technical and practical elements of RWH are consistently identified in the source projects; (2) through which pathways can RWH improve water-resource efficiency and green-economy resilience; and (3) what policy and economic conditions should be considered before wider implementation in Azerbaijan? The study does not estimate a national water-saving volume or financial payback because the source materials do not contain measured rainfall series, roof areas, tank costs or water-demand records.

LITERATURE REVIEW

RWH has evolved from a traditional water-storage practice into a modern component of decentralized urban water management. Campisano et al. (2017) define urban RWH broadly as the collection, storage and treatment of runoff from rooftops and other impervious surfaces for on-site use. Common applications include toilet flushing, laundry, garden irrigation, cleaning and car washing. The review also highlights that RWH can provide multiple functions beyond water supply, including stormwater attenuation and, in some configurations, support for infiltration and local microclimate management.

Water quality is a decisive design consideration. The student projects correctly recognized the need for filtration before storage or use, but scientific evidence requires a more cautious distinction between potable and non-potable applications. Harvested rainwater quality depends on atmospheric deposition, roof material, antecedent dry periods, first-flush management, storage conditions and maintenance. Potable use therefore requires treatment appropriate to local health standards, whereas many non-potable uses can be supplied with simpler treatment and separation from drinking-water networks (Campisano et al., 2017). This distinction is important for scaling RWH safely.

The environmental and economic literature increasingly frames RWH as a multi-benefit system. De Sá Silva et al. (2022) identify decentralized water security, reduced potable-water demand, stormwater control and potential water-energy benefits as major advantages, while also noting that system economics can constrain uptake. Ali et al. (2025) similarly conclude that urban RWH can support sustainable development but that performance depends on rainfall, water demand, storage capacity, climate conditions and institutional support. These findings reinforce the need to evaluate RWH as an integrated infrastructure option rather than only as a household conservation device.

Financial feasibility is particularly context specific. Investment costs include tanks, filters, gutters, pumps, plumbing and installation, while operating costs may include energy, cleaning, inspection and component replacement. Benefits may include lower purchased-water consumption, reduced pressure on centralized infrastructure and avoided or reduced stormwater-management burdens. Jin et al. (2023) show that cost-benefit results are sensitive to system capacity and financial assumptions and that public support programs can materially affect feasibility. Consequently, green-economy arguments for RWH should not rely on universal payback claims; site-specific technical-economic assessment is required.

Azerbaijan's current policy environment makes this topic especially relevant. The National Strategy on Efficient Use of Water Resources for 2024–2040 identifies alternative water sources, wastewater reuse and rainwater management as elements of water security. Its action plan specifically calls for international experience to be reviewed, a technical-economic assessment of rainwater collection and use to be conducted and one pilot project to be implemented during the 2024–2027 phase (President of the Republic of Azerbaijan, 2024). In January 2026, a state program for Baku and the Absheron Peninsula also placed water losses, wastewater and stormwater infrastructure within a long-term urban water agenda (President of the Republic of Azerbaijan, 2026). This creates a clear policy bridge between the students' conservation ideas and national resource-efficiency priorities.

MATERIALS AND METHODS

The study used an integrative qualitative design based on three author-prepared research dossiers completed in 2026. Abbasli's English-language project used online research and scientific articles to explain rooftop RWH, filtration, storage, groundwater recharge and non-potable applications, with a specific interest in reducing pressure on freshwater resources such as the Kura River. Gurbanov's Azerbaijani-language project described rainwater characteristics, catchment surfaces, gutters, filtration, reservoirs and distribution and discussed examples of international use. Azizli's Azerbaijani-language project used online research, observation and visual sources to examine collection, storage, practical uses and conservation benefits.

The source materials were first coded into six analytical categories: catchment and conveyance; filtration and water quality; storage; end uses; freshwater-substitution potential; and economic or policy implications. Statements repeated across more than one project were treated as shared source findings. Claims requiring external support were then checked against peer-reviewed review studies and official Azerbaijani policy documents. External evidence is used to validate, qualify or extend the original projects rather than to replace their structure and central reasoning.

No measured rainfall, roof area, runoff coefficient, tank volume, water bill, installation cost or household demand dataset was supplied. Accordingly, no site-specific yield or payback is calculated. For future application, potential annual harvest can be estimated conceptually as $V = P \times A \times C$, where V is harvestable volume, P is rainfall depth, A is effective catchment area and C is a runoff coefficient representing losses. The equation is included as a sizing framework only; applying it requires local rainfall and building data. Economic assessment would additionally require capital and operating costs, water tariffs, discount rate and expected system life.

RESULTS AND DISCUSSION

System architecture identified in the source research

All three source projects describe a common RWH chain beginning with precipitation falling on a roof or other suitable surface. Gutters and downpipes convey the runoff toward a filter or first-flush component, after which water enters a storage tank. The stored water is then distributed by gravity or pumping for selected uses. Abbasli additionally highlighted diversion of surplus water to recharge structures, while Gurbanov emphasized the role of roof material and pre-storage filtration. Azizli's project presented the same system in a simplified conservation format, demonstrating that the basic technical logic was understood consistently across the independent works.

Figure 1 reorganizes these source-described elements into a single operational pathway. The figure does not represent a measured installation; it is a conceptual synthesis. Its main implication is that water quality and end use should be matched. Irrigation, outdoor cleaning, vehicle washing and toilet flushing are plausible non-potable applications, whereas any potable application would require substantially stronger treatment, monitoring and compliance with public-health requirements.

The design also has an urban drainage function. Storage creates temporary detention capacity, so part of a rainfall event is retained rather than immediately entering streets or drainage networks. The benefit depends on tank size, antecedent storage, rainfall intensity and how quickly stored water is used. Campisano et al. (2017) and Ali et al. (2025) both stress that multi-purpose performance should be incorporated into system design, because a tank optimized only for water supply may perform differently from one also intended for stormwater control.

Table 1 summarizes the main pathways through which the technical elements identified by the source projects can translate into environmental and green-economy value. These are qualitative pathways rather than monetized benefits.

Resource efficiency and pressure on freshwater systems

The strongest shared finding is the substitution principle: suitable rainwater can replace treated freshwater for activities that do not require potable quality. This is important because treatment and long-distance distribution consume infrastructure capacity, chemicals and energy. When a building or institution uses harvested water for irrigation or cleaning, the same service can be provided with less demand on centralized freshwater supply. De Sá Silva et al. (2022) note that this decentralization can support water conservation and, depending on the local system, may also reduce energy use associated with public supply.

For Azerbaijan, the relevance extends beyond household savings. Abbasli explicitly connected RWH to conservation of the Kura River and other freshwater sources. The present synthesis retains this logic but frames it cautiously: a single rooftop system cannot measurably change basin-scale abstraction, yet widespread substitution of non-potable demand can contribute to a portfolio of demand-management measures. The national strategy's inclusion of alternative sources and a rainwater pilot indicates that such distributed measures are being considered within a broader resource-efficiency approach (President of the Republic of Azerbaijan, 2024).

Figure 1 also highlights overflow and recharge as optional elements. Infiltration can be useful where soil, groundwater protection and engineering conditions permit it, but it should not be treated as universally appropriate. In dense urban areas, contaminated sites, high groundwater zones or poorly drained soils, controlled drainage may be preferable. This illustrates a broader point from the literature: RWH is decentralized, but it still requires site-specific engineering and water-quality management.

Table 1. Resource-efficiency and green-economy pathways of rainwater harvesting

RWH dimension	Resource-efficiency and economic pathway
Freshwater substitution	Reduces demand for treated freshwater and may lower water-service costs where tariffs and demand justify investment
Stormwater storage	Provides distributed detention and may reduce burden on urban drainage during suitable events
Irrigation support	Diversifies supply, protects treated water for higher-value uses and supports urban green infrastructure
Overflow and recharge	Can support local recharge and reduce runoff, subject to groundwater and soil safeguards
Financial feasibility	Site-specific economics depend on rainfall, demand, storage size, tariffs, energy use and possible incentives

Economic relevance and green economy transition

The economic case for RWH is broader than a household water bill. At user level, harvested rainwater can reduce consumption of metered mains water where tariffs and demand are sufficient to create savings. At system level, distributed storage can reduce peak demand on centralized supply and contribute to stormwater management. At environmental level, lower abstraction pressure can help protect natural capital embodied in rivers, reservoirs and groundwater. These benefits are consistent with green-economy principles because they seek to maintain services while using fewer treated freshwater resources and reducing pressure on public infrastructure.

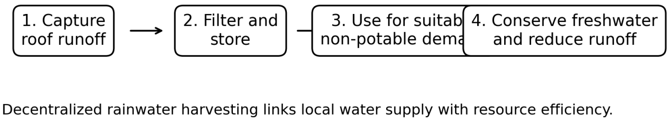

Figure 1. Conceptual rainwater harvesting pathway synthesized from the three source projects

Financial viability should nevertheless be stated carefully. The student dossiers describe RWH as inexpensive or capable of substantial savings, but they do not provide bills, equipment quotations or life-cycle costs that would permit those claims to be quantified. Published evidence shows mixed economic outcomes. Campisano et al. (2017) identify economic constraints as a major determinant of implementation, while Jin et al. (2023) demonstrate that tank sizing, inflation, discounting and public support can alter cost-benefit results. The economically appropriate question for Azerbaijan is therefore not whether RWH is always cheaper, but where it creates the greatest combined water-saving, drainage and resilience value per unit of investment.

Policy relevance and implementation priorities for Azerbaijan

The 2024–2040 National Strategy provides unusually direct policy support for this research topic. The action plan includes rainwater management and use, international benchmarking, technical-economic assessment and a pilot project. It also places alternative water sources within a broader program of infrastructure modernization and water-loss reduction (President of the Republic of Azerbaijan, 2024). This means that future school, municipal or building-scale demonstrations can be linked to a national policy agenda rather than presented only as environmental awareness activities.

Practical implementation framework and study limitations

Five priorities emerge from the combined evidence. First, RWH should initially target non-potable uses with predictable demand, such as irrigation, cleaning and toilet flushing. Second, roof and storage-water quality should be managed through first-flush diversion, filtration and regular maintenance. Third, tanks should be sized using local rainfall and demand data rather than generic assumptions. Fourth, economic appraisal should include capital cost, maintenance, pumping energy, water tariff savings and stormwater benefits where they can be valued. Fifth, pilot systems in schools or public buildings could combine water saving with environmental education while generating measured data for later scaling.

The study is limited by the nature of the underlying projects. They are educational research dossiers rather than engineering trials. No physical RWH system was monitored, no water-quality samples were analyzed and no measured economic dataset was available. Some numeric savings stated in the original projects could not be reconstructed from raw data and are therefore not repeated as findings. The green-economy discussion is qualitative and does not claim a specific payback period, national water-saving volume or reduction in Kura abstraction. Future work should instrument a pilot building, record rainfall and tank levels, measure non-potable demand and water quality, and conduct a full life-cycle cost assessment.

CONCLUSIONS

This study integrated three original research projects into an academic assessment of rainwater harvesting as a decentralized strategy for water conservation, resource efficiency and green economy transition in Azerbaijan. The source projects converge on a technically coherent system comprising catchment, conveyance, filtration, storage and distribution, with irrigation, cleaning, vehicle washing and toilet flushing among the principal non-potable applications. Scientific literature supports the central conservation logic but also shows that performance depends on rainfall, demand, storage design, water quality, maintenance and economic conditions. The key green-economy contribution of RWH is its potential to substitute treated freshwater for suitable uses, diversify local supply and provide additional stormwater-management value. Azerbaijan's National Strategy on Efficient Use of Water Resources for 2024–2040 strengthens the relevance of this approach by explicitly requiring technical-economic assessment and a rainwater-use pilot project. RWH should therefore be developed as a complementary element of integrated water management rather than as a universal substitute for conventional supply. The next research step should move from descriptive assessment to monitored pilot systems that quantify water yield, quality, operating cost and avoided mains-water demand under Azerbaijani conditions.

AUTHOR CONTRIBUTIONS

T.A., H.G. and Z.A. contributed the original research materials, topic development, source collection and preliminary assessment of rainwater-harvesting methods and uses. A.M. contributed supervision of manuscript integration, methodological framing, green-economy interpretation, review and editing. All authors contributed to interpretation, reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study is a qualitative synthesis of three author-prepared research dossiers and published literature. No primary hydrological, water-quality or cost dataset was generated. The source-level descriptive materials supporting the synthesis are contained in the authors' original research files; no separate numerical dataset is available.

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Biodiversity and conservation challenges in the Kura–Caspian aquatic system and their implications for ecosystem services and the green economy

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Keywords
aquatic biodiversity, ecosystem services, green economy, Kura–Caspian system, sturgeon conservation

ABSTRACT

The Kura River, its riparian habitats, the Kura delta and the Caspian Sea form an interconnected ecological system that supports freshwater and marine biodiversity while also providing ecosystem services with economic and social value. This study integrates two independently prepared 2026 research projects on riverside flora and fauna and on fish and other aquatic animals, and develops their observations within an ecosystem-services and green-economy framework. The source projects identified Tugai riparian vegetation, riverine fish communities, sturgeons and the Caspian seal as important components of regional biodiversity and emphasized pollution, overfishing, habitat degradation, plastic waste and climate-related water change as major pressures. A structured qualitative synthesis was combined with targeted verification against recent peer-reviewed literature and institutional sources. The analysis shows that biodiversity loss cannot be treated as a separate conservation issue because ecological degradation can weaken fisheries, habitat regulation, bank stability, nature-based recreation and other services on which water-dependent economic activity relies. Recent Caspian research further indicates that cumulative stressors and falling water levels threaten sturgeon and seal habitat as well as fisheries and coastal infrastructure. Conservation therefore has a green-economy dimension: sustainable harvest rules, habitat restoration, pollution prevention, circular waste systems, responsible aquaculture and adaptive protected-area planning can protect natural capital while supporting resilient livelihoods. The study concludes that biodiversity protection in the Kura–Caspian system should be integrated with water, fisheries and economic planning rather than addressed through isolated species-level interventions.

INTRODUCTION

River and inland-sea ecosystems are not only reservoirs of biological diversity; they are forms of natural capital that support water regulation, food production, fisheries, recreation, habitat connectivity and local livelihoods. In Azerbaijan, the Kura River links inland freshwater habitats and riparian landscapes with the Caspian Sea. Its ecological condition therefore matters beyond the river channel itself. Changes in water quantity, pollution, habitat structure and biological communities can be transmitted downstream and can influence the condition of the Kura delta and the wider Caspian system.

The two source research projects used in this article examine complementary parts of this continuum. Djumayeva focused on flora and fauna along the Kura riverside, identifying fish, riparian shrub communities and Tugai forest habitats as characteristic elements and emphasizing pollution and declining water conditions as ecosystem pressures. Sadikhova focused on fish and other aquatic animals, with particular attention to Caspian sturgeons, the Caspian seal, plastic pollution, overfishing, habitat destruction and conservation measures. Her research also highlighted the social and economic consequences of declining aquatic biological resources.

This combined perspective is relevant to the green economy because biodiversity underpins services that conventional economic accounting often treats as free inputs. Riparian vegetation stabilizes banks, regulates microclimates and supports habitat connectivity, while aquatic food webs sustain fisheries and other ecosystem functions. In the Kura–Aras basin, earlier ecosystem-services analysis explicitly connected freshwater biodiversity and ecosystem condition with hydropower, irrigated agriculture, drinking-water supply, nature-based tourism and natural-hazard regulation (Flores & Abbasov, 2015). Biodiversity degradation can therefore transfer ecological costs into production systems and public infrastructure.

The objective of this study is to synthesize the original research materials into an academic assessment of biodiversity and conservation challenges in the Kura–Caspian aquatic system and to interpret their implications for ecosystem services and green economic resilience. Three questions guide the analysis: (1) which biodiversity components are emphasized by the source projects; (2) which interacting pressures most directly threaten those components; and (3) which conservation responses can protect both ecological functions and the economic benefits derived from natural capital? No population census, fish-catch dataset or monetary valuation was generated by the source projects, so the paper does not estimate species abundance, fishery revenue or the monetary value of ecosystem services.

LITERATURE REVIEW

Recent research confirms the ecological importance of riparian Tugai forests in Azerbaijan. Gurbanov et al. (2026) describe these forests as high-diversity, multilayered ecosystems whose composition is strongly shaped by hydrological regime, groundwater conditions and soil salinity. They also identify grazing, deforestation and hydrological alteration as important drivers of degradation. Ahmadova (2026) similarly emphasizes bank stabilization, microclimate regulation, habitat connectivity and biodiversity support as key functions of Tugai forests and argues that restoration must recover river–floodplain–groundwater processes rather than rely on simple tree planting.

At the aquatic end of the system, Caspian sturgeons illustrate the connection between biodiversity and economic incentives. Pueppke et al. (2023) describe Caspian sturgeons as ecologically and economically important but critically threatened by illegal and unregulated fishing, loss of spawning and feeding habitat, pollution and climate-related environmental change. The authors also note growing interest in aquaculture as one tool for reducing harvest pressure on wild stocks, while stressing that recovery of self-sustaining populations requires coordinated habitat and fisheries governance.

Caspian biodiversity is affected by multiple stressors rather than a single driver. Bodini et al. (2024) examined the decline of kilkas, sturgeons and seals through a cumulative-stressor framework and showed that interacting perturbations can produce system-wide depletion. Lahijani et al. (2024) likewise identify physical alteration, pollution, overfishing and climate change as concurrent drivers of declining bioresources. This evidence supports the broad structure of the source projects, but it also requires caution: individual percentages and causal claims reported in educational dossiers should not be treated as measured regional statistics unless supported by traceable datasets.

Climate-driven changes in the Caspian Sea add a further conservation and economic dimension. Court et al. (2025) show that continued sea-level decline can disrupt habitats used by sturgeon and the endemic Caspian seal, reduce the effectiveness of static protected-area boundaries and create serious risks for fisheries, ports and other coastal infrastructure. Their analysis demonstrates that biodiversity policy and economic adaptation cannot be separated: conservation areas, fishing grounds and infrastructure may all shift as shorelines retreat.

The green-economy perspective therefore extends beyond species protection. It includes sustainable fisheries, pollution prevention, circular material systems that reduce plastic leakage, restoration of riparian natural capital, adaptive spatial planning and forms of aquaculture that reduce pressure on depleted wild stocks. The original Sadikhova project proposed deposit-return approaches, stronger quota control, protected spawning areas and aquaculture, while the Djumayeva project emphasized river clean-ups, reduced chemical pollution and public awareness. These proposals provide a practical basis for linking biodiversity conservation to resource efficiency and low-impact economic activity.

MATERIALS AND METHODS

The study applied an integrative qualitative design based on two author-prepared research dossiers completed in 2026. Djumayeva's project, 'Fauna and flora diversity in riverside area', examined Kura riverside species, Tugai vegetation, fish communities, pollution and visible ecosystem change using online sources, research papers and image-based comparison. Sadikhova's project, 'The status, problems, and conservation ways of fish and other aquatic animals', used literature and document analysis, qualitative and quantitative comparison of reported trends, and visual observation of solid waste and plastics along Absheron coastal areas. The present article retains the thematic content of both works while restructuring it into a unified analytical framework.

The source materials were coded into five categories: biodiversity components; ecosystem services; anthropogenic pressures; climate and hydrological pressures; and conservation or green-economy responses. Claims from the source projects were separated into descriptive observations, proposed solutions and quantitative statements. Quantitative claims that lacked a reconstructable dataset or traceable source were not repeated as findings. Targeted literature verification was then conducted using peer-reviewed research and institutional material on Tugai forests, Caspian sturgeons, Caspian seals, cumulative ecosystem stress, sea-level decline and freshwater ecosystem services.

The study is a synthesis rather than a biological survey. No new fish sampling, vegetation plot, laboratory water-quality analysis, catch assessment or economic valuation was conducted. Accordingly, the results describe relationships and policy implications rather than estimating population sizes or causal effect magnitudes. This approach is appropriate for preserving the original research contribution while avoiding unsupported numerical precision.

RESULTS AND DISCUSSION

Biodiversity structure across the Kura–Caspian continuum

The source projects portray biodiversity as a connected river–riparian–marine system. Djumayeva identifies fish such as carp, catfish, pike and barbel alongside mammals and riparian shrub and forest communities, with particular emphasis on Tugai vegetation. These observations align with recent research showing that Tugai forests along the Kura basin contain diverse Populus, Salix, Ulmus, Alnus and Tamarix communities and depend strongly on hydrological connectivity (Gurbanov et al., 2026). Their value is not limited to species lists: riparian vegetation contributes to bank stabilization, habitat continuity and local environmental regulation.

Sadikhova extends the biodiversity frame downstream to the Caspian Sea, where sturgeons, kilka and the endemic Caspian seal are used as examples of species embedded in wider food-web and habitat relationships. Pueppke et al. (2023) confirm the severe conservation status of Caspian sturgeons, while IUCN (2021) identifies fishing-gear mortality, habitat degradation, disturbance and climate-related loss of breeding ice as major concerns for the Caspian seal. The Kura–Caspian perspective is therefore useful because river condition, spawning access, delta habitats, coastal change and marine food webs are ecologically connected even when individual species occupy different parts of the system.

Figure 1 organizes this relationship as a qualitative pathway. It does not represent measured flows or monetary values. Instead, it shows how biodiversity components can be affected by common pressures and how ecological change can propagate into ecosystem-service and green-economy outcomes.

Table 1 summarizes the principal biodiversity-service relationships retained from the source research and strengthened through recent literature. The table illustrates why a conservation strategy based only on charismatic species would be incomplete: the same interventions that support sturgeon or seal conservation can also protect fisheries, riparian functions, water-dependent livelihoods and resilience.

Multiple pressures and cumulative ecosystem risk

Pollution is the most consistently identified pressure across both source projects. Djumayeva discusses municipal wastewater, industrial contaminants and river pollution, while Sadikhova emphasizes plastics, industrial discharges and oil-related pollution. The scientific literature supports treating these pressures cumulatively rather than independently. Lahijani et al. (2024) show that bioresource decline in the Caspian is linked to a combination of pollution, physical alteration, overexploitation and climate change; Bodini et al. (2024)

similarly demonstrate that multiple concurrent stressors can help explain simultaneous depletion of kilkas, sturgeons and seals.

Overexploitation and habitat alteration add direct pressure to biological populations. Sturgeon recovery is especially difficult because migratory fish require functioning spawning routes and because high commercial value creates persistent incentives for illegal harvest (Pueppke et al., 2023). The source projects' recommendations for stronger control, protected spawning periods and reporting of destructive fishing are therefore consistent with contemporary conservation priorities. At the same time, reduced river flow, dams, shoreline development and falling Caspian water levels can alter habitat even when fishing pressure is controlled.

Climate and hydrological change further complicate management. Court et al. (2025) project that substantial sea-level decline can reduce shallow habitats important to sturgeon and Caspian seals and can shift or eliminate current conservation areas. These changes create a moving-target problem: fixed protected boundaries may cease to cover the ecosystems they were intended to protect. Adaptive conservation planning is therefore needed alongside pollution control and fisheries enforcement.

Table 1. Biodiversity, ecosystem-service and green-economy relationships in the Kura–Caspian system

Biodiversity component	Ecosystem-service and green-economy relevance
Tugai riparian forests	Bank stabilization, habitat connectivity, microclimate regulation, carbon storage and support for nature-based recreation
River and reservoir fish communities	Food resources, recreational and commercial fishing, food-web function and indicators of aquatic ecosystem condition
Kura delta and spawning corridors	Nursery and spawning habitat, biodiversity connectivity and support for renewable fishery resources
Caspian sturgeons and food web	High-value renewable biological capital, fisheries, aquaculture development and cultural value
Caspian seal and coastal habitats	Flagship biodiversity, ecosystem integrity, conservation tourism and justification for adaptive spatial protection

Ecosystem services and green-economy implications

The economic meaning of biodiversity in the Kura–Caspian system is best understood through ecosystem services rather than through unsupported monetary estimates. Healthy riparian forests help stabilize banks, regulate local hydrology and maintain habitat; functioning rivers support water supply, agriculture and reservoirs; and aquatic biodiversity supports fisheries, food webs and nature-based recreation. Flores and Abbasov (2015) explicitly assessed freshwater ecosystem services in the Kura–Aras basin in relation to hydropower and also considered drinking-water supply, irrigated agriculture, nature-based tourism and natural-hazard regulation. Ecological degradation can therefore impose indirect economic costs by weakening these services.

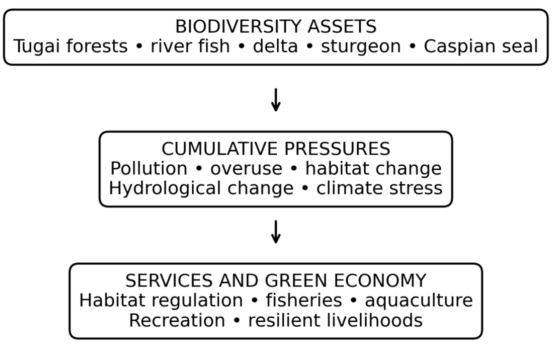

Figure 1. Conceptual biodiversity, pressure and green-economy pathway in the Kura–Caspian aquatic system

Fisheries provide the clearest direct economic link. Sturgeon conservation is not only a biodiversity issue because these species have historically carried high commercial value, while overexploitation and illegal trade have contributed to their decline (Pueppke et al., 2023). A green-economy approach changes the objective from maximizing extraction to maintaining renewable biological capital. Sustainable quotas, traceable supply chains, seasonal protection and enforcement can preserve future resource value, while responsible aquaculture may provide production without placing equivalent pressure on wild populations. However, aquaculture should complement rather than substitute for habitat recovery.

Conservation instruments for natural capital and circular resource management

The two source projects contain several measures that can be organized into a green-economy policy package. First, habitat restoration and environmental-flow management can protect Tugai forests and river–floodplain connectivity. Second, pollution prevention and modern wastewater treatment reduce ecological damage before it enters the river and sea. Third, deposit-return and other circular material systems can reduce leakage of bottles and packaging into aquatic environments. Fourth, fisheries governance should combine monitoring, anti-poaching enforcement, protected spawning areas and scientifically informed harvest rules. Fifth, education and community clean-up activities can strengthen stewardship and lower local litter pressure.

Economic resilience, implementation priorities and study limitations

Conservation investment can also be interpreted as risk reduction. Court et al. (2025) show that Caspian sea-level decline threatens both ecological areas and human infrastructure, illustrating how environmental deterioration can create simultaneous biodiversity and economic losses. For Azerbaijan, priority should therefore be given to interventions with multiple benefits: restoring riparian buffers, reducing untreated discharges, protecting spawning corridors, improving fishery traceability and developing adaptive protected areas. These measures protect natural capital while supporting fisheries, water-dependent production and resilient local livelihoods.

The study has important limitations. The underlying research projects are educational dossiers, not standardized biodiversity surveys. Species lists were not generated from systematic sampling, and the coastal observations did not include quantified litter density or biological abundance. Several numerical statements in the source files could not be independently reconstructed and are therefore excluded. No monetary ecosystem-service valuation or fishery revenue analysis was undertaken. Future research should combine field biodiversity inventories, water-quality monitoring, fishery and aquaculture statistics, habitat mapping and ecosystem-service valuation so that ecological and economic priorities can be assessed within a common decision framework.

CONCLUSIONS

This study integrates two original research projects into a unified assessment of biodiversity and conservation challenges across the Kura–Caspian aquatic system. The combined evidence highlights a connected natural-capital base composed of riparian Tugai habitats, freshwater fish communities, delta and spawning areas, Caspian sturgeons and the wider marine food web that includes the endemic Caspian seal. Pollution, overexploitation, habitat alteration, hydrological change and climate-driven water-level decline act together and can weaken both biodiversity and the ecosystem services on which economic activity depends. The green-economy implication is that conservation is an investment in productive natural capital rather than a cost external to development. Habitat restoration, sustainable fisheries, responsible aquaculture, pollution prevention, circular waste systems, adaptive protected areas and public stewardship can jointly protect ecological functions and support resilient livelihoods. Because the present study is qualitative, the next step should be a monitored Kura–Caspian biodiversity and ecosystem-services assessment that combines biological indicators with fishery, tourism, water-management and restoration-cost data.

AUTHOR CONTRIBUTIONS

K.D. and A.S. contributed the original research materials, topic development, source collection and preliminary assessment of riverside biodiversity, aquatic species, ecological pressures and conservation options. A.M. contributed supervision of manuscript integration, methodological framing, ecosystem-services and green-economy interpretation, review and editing. All authors contributed to interpretation, reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study is a qualitative synthesis of two author-prepared research dossiers and published literature. No new biological sampling, water-quality dataset, fish-catch dataset or monetary ecosystem-service valuation was generated. The descriptive source materials supporting the synthesis are contained in the authors' original research files.

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Irrigation inefficiency and water distribution losses as drivers of Kura River depletion and agricultural resource inefficiency in Azerbaijan

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Keywords
agricultural water use, green economy, irrigation efficiency, Kura River, water distribution losses

ABSTRACT

The Kura River is a strategic water source for Azerbaijan, where irrigated agriculture depends heavily on reliable conveyance and efficient field application. This study integrates two independently prepared research works on Kura River depletion and agricultural water-use problems and places their observations within a resource-efficiency and green-economy framework. The source materials identify excessive irrigation withdrawals, leakage from aging distribution networks, widespread use of conventional surface irrigation, drainage and salinity problems, and weak coordination of water management as major drivers of water loss and agricultural vulnerability. A structured qualitative synthesis was combined with verification against recent World Bank, FAO, national policy and peer-reviewed sources. The World Bank's 2024 water-security assessment estimates average irrigation water received at about 7.03 billion m^3 per year against crop water consumption of about 2.33 billion m^3, implying a potential national-level difference of around 67%, while overall irrigation-system efficiency was estimated at 37%. These figures support the central argument of the original research that losses occur both during conveyance and at farm level. Economically, such inefficiency raises the amount of water that must be abstracted and delivered, increases exposure to shortages, and can reduce farm productivity through poor timing, salinity and waterlogging. Modernized canals, metering, drip and sprinkler systems, improved drainage and allocation planning are therefore not only technical measures but green-economy investments in water productivity, agricultural resilience and natural-capital protection.

INTRODUCTION

Agricultural production in Azerbaijan is strongly linked to irrigation, especially in the Kura–Araz lowland and other dry or seasonally water-limited areas. The Kura River supports irrigation, municipal supply, energy and ecosystems, yet the same river is subject to growing pressure from climate variability, abstraction and inefficient distribution. For agriculture, the central management problem is not only how much water is available at the river but how much of the withdrawn water reaches fields at the right time and is used productively.

The two source research works used in this article approach the issue from complementary directions. Amrullayeva examined the non-systematic use of the Kura River, emphasizing agricultural overuse, distribution leaks and the absence of fully coordinated basin governance. Shahpalangli focused on agricultural water use and identified open-channel seepage, evaporation, traditional surface irrigation, poor drainage and salinity as constraints that lower the effectiveness of irrigation. Both works proposed modernization through canal rehabilitation, drip and sprinkler irrigation, better scheduling and stronger water management.

These concerns have direct economic significance. Water lost before reaching crops still requires abstraction, storage, conveyance and management, while unreliable supply can reduce yields or force farmers to irrigate at suboptimal times. Inefficient irrigation can also raise groundwater levels and salinity, converting a water-management problem into land degradation and future production costs. In a green-economy framework, reducing these losses means increasing output and resilience per unit of natural resource rather than simply expanding water withdrawals.

The objective of this study is to synthesize the original research materials into an academic assessment of irrigation inefficiency and distribution losses as drivers of Kura River depletion and agricultural resource inefficiency. The study asks three questions: (1) where do the principal irrigation losses occur; (2) how do those losses affect agricultural and environmental performance; and (3) which modernization measures offer the strongest combined water-security, economic and green-economy benefits? The source projects did not conduct farm-level flow measurements or a cost-benefit survey; therefore, quantitative values used in the discussion are drawn only from traceable published sources.

LITERATURE REVIEW

Recent national evidence confirms that irrigation inefficiency is a structural water-security issue. The World Bank (2024) estimates that average irrigated land in Azerbaijan is about 1.02 million ha compared with an average irrigable area of 1.54 million ha. Its Water Accounting Tool assessment reports average crop water consumption of approximately 2.33 billion m^3 per year against about 7.03 billion m^3 of irrigation water received, potentially indicating losses of roughly 67% at national level. The same assessment estimates overall irrigation-system efficiency at 37%, with major losses attributed to leakage and seepage from aging infrastructure.

A 2026 agricultural-economics study reaches a similar conclusion. Mustafayeva et al. (2026) identify water losses in agricultural conveyance as a major constraint on sectoral efficiency and argue that improving irrigation infrastructure and water-saving technologies is central to agricultural water security. The study frames the problem economically: scarce water should be managed so that the value generated per unit of water rises rather than relying on higher withdrawals to compensate for inefficient delivery.

The physical consequences of irrigation inefficiency extend beyond water volume. Han et al. (2024) show that water management and drainage conditions are closely linked to soil salinity and agricultural productivity in the Kur-Araz lowland. Their analysis demonstrates that salinity dynamics can materially affect the sustainability of agricultural production. This supports the concern in the source projects that seepage, high groundwater and poor drainage can convert conveyance losses into soil-quality losses.

Water-saving modernization is also embedded in national policy. Azerbaijan's National Strategy on the Efficient Use of Water Resources, approved in October 2024, sets priorities for integrated management, efficient water use, improved irrigation-water provision and water security (President of the Republic of Azerbaijan, 2024). In 2026, implementation responsibilities were further updated, showing that water-sector reform remains active. The strategy provides a policy context for canal rehabilitation, monitoring, efficient irrigation technologies and improved allocation.

At basin scale, technical efficiency also depends on governance. Suleymanov (2025) emphasizes the importance of stronger institutional arrangements for the Kura-Aras basin, while Amrullayeva's original literature review likewise identified fragmented management as a factor that can complicate allocation and planning. FAO AQUASTAT further notes that irrigation withdrawals commonly exceed crop water requirements because losses occur during distribution and application, reinforcing the need to distinguish between water diverted from a source and water productively consumed by crops (FAO, 2025).

MATERIALS AND METHODS

The study used an integrative qualitative design based on two author-prepared research dossiers completed in 2026. Amrullayeva's work was a literature-based investigation of Kura River depletion, agricultural overuse, transboundary management and distribution leakage. Shahpalangli's work examined agricultural water use, open-channel losses, modern irrigation methods, drainage, salinity and farmer-oriented recommendations. Their original themes, terminology and proposed solutions were retained as the foundation of the synthesis.

The source material was coded into five analytical categories: water abstraction and agricultural demand; conveyance and distribution losses; field-level irrigation efficiency; soil and drainage consequences; and economic and green-economy implications. Claims with numerical values were checked against traceable institutional or peer-reviewed sources. Where the original works reported percentages without a verifiable underlying dataset, those values were not reproduced as measured national statistics.

External verification used the World Bank's 2024 Azerbaijan water-security report, the 2024 National Strategy on the Efficient Use of Water Resources, FAO AQUASTAT materials, recent peer-reviewed work on soil salinity and agricultural water efficiency, and the Kura-Aras basin governance literature already cited by Amrullayeva. The study does not estimate causal effects, farm profits or payback periods for irrigation equipment. The economic assessment is interpretive and focuses on resource productivity, avoided losses, production risk and resilience.

RESULTS AND DISCUSSION

Conveyance losses and the scale of agricultural water inefficiency

Both source works identify the distribution network as a critical point of loss. Amrullayeva describes leakage from poorly maintained channels and pipes, while Shahpalangli emphasizes seepage from open canals and evaporation before water reaches crops. The national-scale evidence is consistent with this diagnosis. World Bank (2024) estimates average irrigation water received at 7.03 billion m^3 per year and crop water consumption at 2.33 billion m^3, implying a potential difference of about 67%. The report cautions that the difference reflects system-wide losses and accounting limitations rather than a single measured leakage rate, but it nonetheless demonstrates a large efficiency gap.

The same assessment estimates national irrigation-system efficiency at approximately 37%, with substantial regional variation. This is economically important because low conveyance and field efficiency increase the amount of water that must be diverted to deliver a given amount of effective crop water. In a water-scarce system, this raises competition between users and reduces the buffer available during drought or low-flow periods. The source projects' recommendation to rehabilitate canals and improve distribution is therefore strongly supported by recent evidence.

Figure 1 compares average irrigation water received with estimated crop water consumption in the World Bank assessment. The figure should be read as a resource-efficiency indicator, not as a direct financial-loss calculation. The difference includes conveyance losses, field application losses, return flows, measurement uncertainty and other system effects.

Table 1 links the main loss mechanisms identified in the source research to their agricultural, economic and green-economy implications.

Field application, crop productivity and the economics of water-saving technology

Traditional surface irrigation can deliver water unevenly and may require larger withdrawals than localized systems when management is weak. Shahpalangli's work therefore prioritizes drip and sprinkler irrigation. These technologies can improve control over timing and application, particularly when combined with soil-moisture monitoring, pressure regulation and appropriate crop scheduling. Their value is not simply the physical volume of water saved; it is the possibility of producing more reliable output with less water diverted from rivers and reservoirs.

The green-economy benefit arises from higher resource productivity. Water-saving technology can reduce exposure to shortages, support higher-value production where technically suitable and lower the need for continual expansion of supply infrastructure. However, modernization also requires capital, maintenance, filtration, energy and technical skills. For that reason, investment decisions should be crop- and location-specific. The objective is not to replace every surface-irrigation system but to target the sections of the network and farms where the economic value of reduced losses is greatest.

Azerbaijan's 2024 National Strategy supports this direction by prioritizing efficient use, irrigation reliability and integrated management. From an optimization perspective, the policy challenge is to allocate rehabilitation funds between main canals, secondary networks, on-farm systems, drainage and digital monitoring so that marginal water savings and production benefits are maximized.

Table 1. Irrigation inefficiency pathways and green-economy responses in the Kura-dependent agricultural system

Inefficiency pathway	Green-economy response
Aging or unlined conveyance network	Canal lining or piping, rehabilitation and metering
Poorly controlled surface irrigation	Drip or sprinkler systems where suitable and soil-moisture scheduling
Weak drainage and high groundwater	Drainage maintenance and groundwater monitoring
Limited measurement and allocation data	Digital monitoring and seasonal water accounting
Fragmented basin and sectoral coordination	Integrated governance and coordinated allocation

Seepage, groundwater and salinity as hidden production costs

Conveyance loss is not always a simple disappearance of water; some seepage can recharge groundwater. In poorly drained agricultural areas, however, excessive recharge can raise the water table and contribute to salinity. Amrullayeva's source work explicitly links leakage, rising groundwater and salinization, while Shahpalangli emphasizes drainage maintenance and careful scheduling. Han et al. (2024) provide peer-reviewed evidence that water management and drainage conditions are important determinants of soil salinity and agricultural productivity in the Kur-Araz lowland.

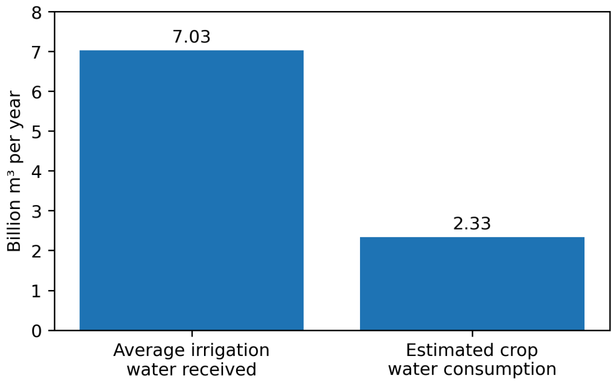

Figure 1. Average irrigation water received and estimated crop water consumption in Azerbaijan based on World Bank (2024)

Salinization has a clear economic pathway: degraded soils may require additional drainage, leaching, land reclamation or crop substitution and can reduce the productivity of existing farmland. This means that investments in canal rehabilitation and drainage can yield joint benefits by conserving water and protecting land capital. A green-economy strategy should therefore assess water efficiency together with soil condition rather than treating irrigation and land degradation as separate policy fields.

Integrated modernization priorities for agricultural water security

The combined evidence supports a phased modernization package. First, high-loss conveyance sections should be identified through metering, water accounting and condition surveys, followed by lining, piping or targeted rehabilitation where justified. Second, drip or sprinkler systems should be expanded where crop value, soil conditions and farm scale support their operation. Third, drainage and groundwater monitoring should be maintained to prevent water-saving interventions from creating new salinity risks. Fourth, water delivery schedules should reflect crop demand rather than fixed routine allocation. Fifth, digital measurement and transparent water accounting should connect river abstraction, canal delivery and field use.

Economic resilience, governance and study limitations

The economic case for improving irrigation efficiency is strongest when water scarcity, infrastructure deterioration and agricultural dependence occur together. Reduced distribution losses can lower the volume that must be abstracted for the same productive use, protect a larger share of river flow for other sectors and ecosystems, and improve the reliability of farm supply. At basin scale, stronger institutional coordination can also reduce uncertainty in allocation and improve planning, as emphasized by Suleymanov (2025). These outcomes fit a green-economy model in which infrastructure investment increases productivity while reducing pressure on natural capital.

The study has limitations. The two underlying research works are qualitative educational dossiers rather than standardized hydraulic audits. They contain useful problem identification and practical observations but no direct measurements of canal seepage, farm-level application efficiency, crop yield response or investment cost. Some percentages in the original Shahpalangli material were not linked to traceable datasets and were therefore excluded from the quantitative results. Future research should combine canal flow measurements, farm water accounts, remote sensing, soil salinity data and cost-benefit analysis so that irrigation investments can be prioritized according to both water savings and economic returns.

CONCLUSIONS

This study integrates two original research works into a unified assessment of how irrigation inefficiency and water-distribution losses contribute to Kura River depletion and agricultural resource inefficiency in Azerbaijan. The source research correctly identifies conveyance leakage, traditional irrigation, drainage constraints and weak management as interconnected pressures. Recent evidence strengthens that diagnosis: the World Bank's 2024 assessment estimates a large gap between irrigation water received and crop water consumption and an overall irrigation-system efficiency of about 37%. The implication is both environmental and economic. Excessive losses increase the water that must be withdrawn, reduce resilience during scarcity, and can contribute to salinity and declining land productivity. Modernized conveyance, metering, localized irrigation, improved scheduling and drainage management should therefore be treated as green-economy investments that raise water productivity while protecting river and soil natural capital. The next research step should be a farm- and canal-level economic assessment that identifies where each unit of investment produces the greatest combination of water savings, yield stability and ecosystem benefit.

AUTHOR CONTRIBUTIONS

I.A. and H.S. contributed the original research materials, topic development, source collection and preliminary assessment of Kura River use, irrigation losses, agricultural water management and proposed solutions. N.B. contributed supervision, conceptual integration, methodological framing, economic and green-economy interpretation, review and editing. All authors contributed to interpretation, reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study is a qualitative synthesis of two author-prepared research dossiers and published secondary sources. No new farm survey, canal-flow dataset, crop-yield experiment or financial dataset was generated. Quantitative values used in the article are taken from the cited published sources, while the original descriptive research materials are contained in the authors' project files.

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Hydroecological degradation of the Kura River through water quality pressures and its implications for ecosystem services and local green economy development

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Keywords
ecosystem services, green economy, hydroecology, Kura River, water quality

ABSTRACT

The Kura River is Azerbaijan's principal surface-water artery and supports drinking-water supply, irrigated agriculture, energy production and aquatic ecosystems. This study integrates two educational research projects that approached hydroecological degradation from complementary scales: a literature-based assessment of Kura River water quality and flow pressures, and a local field-monitoring project in Padar village that examined visible pollution, environmental awareness and a low-cost filtration model. The synthesis was verified against recent peer-reviewed and institutional evidence and interpreted through ecosystem-services and green-economy perspectives. Recent monitoring for 2020–2022 shows a strong downstream mineralization gradient in the Kura, rising from about 349 mg/L at I Shikhli to more than 3,000 mg/L at Neftchala, while the local project documented plastic litter near the village, organic and fertilizer residues near pasture areas, and improved visual clarity after mechanical filtration through sand, gravel and activated carbon. The filter experiment demonstrates physical pre-treatment only and does not establish drinking-water safety. Economically, declining water quality can increase treatment and monitoring needs, constrain irrigation suitability, intensify salinity-related production risks and weaken fisheries, recreation and other ecosystem services. The combined evidence supports prevention-oriented water management, stronger wastewater control, community monitoring and resource-efficient local interventions as components of Azerbaijan's green-economy and water-security agenda.

INTRODUCTION

The Kura River functions simultaneously as an ecological corridor, a source of drinking and irrigation water, a hydropower resource and a foundation for settlements and productive activity in Azerbaijan. This multifunctional role makes water quality an environmental and economic issue rather than a purely chemical one. When pollution, salinity and altered flow reduce the suitability of river water, the consequences extend from aquatic organisms to farms, municipal treatment systems, public health, fisheries and local livelihoods. Hydroecological degradation therefore represents a loss of natural-capital quality as well as a threat to water security.

The two source research works used in this article examine that problem at different scales. Ismayıl's project focused directly on the Kura River and assembled evidence on transboundary pollution, wastewater discharge, flow alteration, mineralization and ecological effects. Karimova's project was carried out in Padar village, Khachmaz, at a local water body that is not a direct Kura tributary. Its relevance is therefore not as a measurement of Kura water quality, but as a community-scale demonstration of pollution pressures, field observation, environmental awareness and practical mitigation within Azerbaijan's wider connected water environment. This distinction is retained throughout the analysis so that local observations are not incorrectly generalized to the Kura basin.

The economic dimension is central to the journal scope. Polluted or highly mineralized water can require additional treatment before municipal use, reduce the flexibility of irrigation, contribute to salinity risks and weaken ecosystem services that support fisheries, recreation, landscape quality and local well-being. These are economic pathways even when a monetary valuation is unavailable. In a green-economy framework, the objective is to maintain or increase social and productive value while reducing pollution loads, material waste and pressure on aquatic natural capital.

The study therefore asks three questions: (1) what water-quality and hydroecological pressures are supported by the combined source materials and recent evidence; (2) what can local field monitoring and low-cost interventions contribute without overstating their scientific scope; and (3) how do water-quality improvements connect to ecosystem services, resource efficiency and local green-economy development?

LITERATURE REVIEW

Recent peer-reviewed monitoring substantially strengthens the water-quality observations contained in the original Kura research. Aliyev and Abduyev (2025) analysed seasonal samples collected in 2020–2022 along the Kura in Azerbaijan and found a persistent downstream increase in mineralization and major ions. Mean mineralization increased from approximately 349 mg/L at I Shikhli to

404 mg/L at Mingachevir, 777 mg/L at Sabirabad, 921 mg/L at Salyan and 3,086 mg/L at Neftchala. The same study reports that the lower river changes from calcium-bicarbonate to sodium-sulfate water and links this pattern to tributary inflows, wastewater, mineralized groundwater, the Aras confluence and interaction with Caspian water near the mouth.

The basin context is intrinsically transboundary. UNECE (2011) identifies wastewater discharge, agricultural pressure, hydromorphological modification and inadequate infrastructure as recurrent pressures in the Kura-Aras system. Strosser et al. (2017) further argue that stronger Georgia-Azerbaijan cooperation can generate economic, environmental and social benefits, even though complete monetary valuation is constrained by data gaps. This literature supports the source project's emphasis on upstream-downstream interdependence while avoiding attribution of individual pollution events without traceable monitoring evidence.

Water quality is also connected to the national economy through water-dependent agriculture and infrastructure. The World Bank (2024) notes that Azerbaijan relies heavily on transboundary inflows and that irrigated agriculture is a major water user and an important sector for employment, livelihoods and economic diversification. In this context, poor water quality can create indirect costs through treatment requirements, irrigation limitations, soil degradation and lower resilience to drought. The relevant economic concept is therefore not only the price of water, but the productivity and ecosystem value generated per unit of safe and usable water.

National policy increasingly reflects this linkage. The National Strategy on the Efficient Use of Water Resources for 2024–2040 prioritizes integrated management, efficient use, reliable water-supply and sanitation services, irrigation provision and water security. Azerbaijan 2030 also places efficient resource use and a clean environment within the national green-growth priority. For the Kura River, these objectives imply that pollution prevention, monitoring, wastewater treatment and efficient allocation should be evaluated together rather than as isolated environmental measures.

At the local scale, community monitoring and environmental education can complement formal systems by identifying visible litter hotspots, fertilizer residues and behavioural problems that are often missed by infrequent technical sampling. Such initiatives cannot replace laboratory analysis or regulatory enforcement, but they can reduce local waste leakage, generate environmental awareness and support low-cost preventive action. The Padar village project is interpreted in this limited but useful role.

MATERIALS AND METHODS

The study used an integrative qualitative design based on two author-prepared research dossiers completed in 2026. The first dossier, prepared by Ismayıl, synthesized official monitoring information, dissertation-based hydroecological material and conference sources on the Kura River. It focused on water-quality deterioration, flow change, industrial and municipal wastewater, agricultural pressure, dams and downstream mineralization. The second dossier, prepared by Karimova, documented a school-based field project in Padar village using visual monitoring, simple physical observations, a 15-respondent awareness survey, cartographic review and a classroom filtration model.

Karimova's field team reported monitoring at three locations, but the source results table contains interpretable findings for two points only. Point A, close to the village, was classified by the project team as critically highly polluted because of polyethylene bags and plastic bottles. Point B, near a pasture area, contained organic waste and fertilizer residues and was classified as moderately polluted, with eutrophication identified as the principal ecological risk. The project also tested a layered mechanical filter made of plastic housing, sand, gravel and activated carbon and reported improved visual clarity of turbid water. No microbiological, chemical or potability test was supplied.

For external verification, the synthesis used Aliyev and Abduyev (2025), the World Bank's 2024 water-sector assessment, UNECE basin assessments, the OECD study of transboundary cooperation and Azerbaijan's current water and green-growth policy framework. Quantitative values were included only where they were traceable to these sources. The 15-person survey is acknowledged as part of the original project design, but item-level response frequencies were not available in the dossier and were therefore not statistically analysed. The economic assessment is interpretive and does not estimate treatment costs, farm-income losses or ecosystem-service monetary values.

RESULTS AND DISCUSSION

Downstream water-quality deterioration and hydroecological pressure

The strongest verified quantitative pattern is the downstream rise in mineralization. Aliyev and Abduyev (2025) report mean values increasing from about 349 mg/L at I Shikhli to more than 3,000 mg/L at Neftchala. This confirms the central concern of Ismayıl's original research that the lower Kura faces substantially greater hydrochemical stress than the river near the Georgian border. The pattern is not attributable to a single source: the peer-reviewed study identifies the combined influence of tributaries, wastewater discharges, the Aras River, mineralized groundwater and Caspian mixing near the estuary.

The hydroecological consequence is a progressive narrowing of water-use options. Higher salinity and major-ion concentrations can reduce the suitability of water for some irrigation conditions, intensify soil-salinity management requirements and complicate treatment for municipal use. From an ecosystem perspective, the same river sections are exposed to altered chemical conditions alongside hydrological regulation and habitat fragmentation. The source work also discusses historical reductions in downstream flow and migration barriers associated with dams; these observations are retained qualitatively because the original numerical comparisons were not accompanied by a fully traceable primary dataset.

Figure 1 presents selected mean mineralization values from the 2020–2022 monitoring dataset reported by Aliyev and Abduyev (2025). The steep increase below the middle reaches should be interpreted as a water-quality gradient, not as a direct measure of toxicity or economic loss.

Table 1 combines the Padar village field evidence with the intervention evidence from the classroom filter trial. The purpose is to preserve the original project observations while separating visible pollution indicators from laboratory water-quality claims.

Local pollution observations, environmental awareness and low-cost filtration

The Padar project identifies two common local pathways by which human activity can degrade small water bodies: plastic litter near settlements and nutrient-rich organic or fertilizer residues near pasture areas. These observations are site-specific, but the mechanisms are consistent with wider water-management literature. Plastics create persistent physical pollution and can fragment into smaller particles, while nutrient inputs can stimulate eutrophication and oxygen stress. The project's value lies in showing how visible pollution can be classified through structured school-based monitoring and translated into cleanup and awareness actions.

The 15-respondent survey demonstrates an attempt to include community perceptions, but the absence of item-level frequencies prevents quantitative interpretation. Similarly, the low-cost filter improved visual clarity, which is a meaningful demonstration of sediment and particle removal, but it cannot be treated as a drinking-water treatment result. Activated carbon, sand and gravel may improve physical appearance and adsorb some compounds under controlled conditions, yet safe water requires validated treatment, disinfection and chemical and microbiological testing. This distinction is important for responsible environmental education.

Table 1. Field observations and practical intervention evidence from the Padar village project

Evidence / observation	Hydroecological and green-economy interpretation
Padar point A – polyethylene bags and plastic bottles; project classification: critically high visible pollution	Persistent litter pressure; habitat and amenity degradation; recurring cleanup burden and material leakage
Padar point B – organic waste and fertilizer residues; project classification: moderate	Nutrient-loading and eutrophication risk; need for manure and fertilizer management near water bodies
Classroom layered filter – sand, gravel and activated carbon	Visual clarity improved; useful as physical pre-treatment demonstration, but not evidence of potable water
Lower Kura – strong downstream mineralization gradient in published 2020–2022 monitoring	Greater treatment and irrigation-management pressure; risk to ecosystem services and local economic resilience

Water-quality degradation as an economic and ecosystem-services issue

Hydroecological degradation generates economic exposure through several connected channels. First, lower raw-water quality can increase monitoring and treatment requirements before municipal use. Second, higher salinity and mineralization can reduce irrigation flexibility and contribute to soil-management costs in already water-stressed agricultural areas. Third, degraded aquatic habitat can weaken fisheries and other provisioning services. Fourth, littered or polluted riverbanks reduce recreational and landscape value. These pathways do not prove a specific monetary loss in the present study, but they show why water-quality protection is an investment in productive and social assets rather than an environmental expense alone.

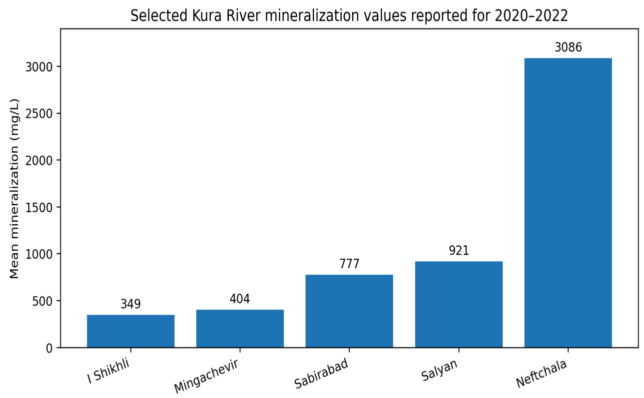

Figure 1. Selected mean mineralization values along the Kura River reported by Aliyev and Abduyev (2025) for 2020–2022

The sharp lower-river increase is particularly relevant to green-economy planning because natural capital becomes less productive when more resources are needed to make water usable or when land, fisheries and recreation lose ecological quality. Prevention can therefore have a double return: avoiding degradation costs while preserving ecosystem services. This logic is consistent with the World Bank's recommendation to strengthen water-quality monitoring, water accounting and the valuation of water as an economic resource within integrated management.

Green-economy responses from basin infrastructure to community action

The combined evidence supports a layered response. At basin and municipal level, priorities include reliable wastewater collection and treatment, monitoring of tributaries and industrial discharges, transparent water-quality data, pollution-control enforcement and coordinated transboundary management. At agricultural level, nutrient management and efficient irrigation can reduce return-flow pollution and pressure on the river. At community level, litter prevention, organized shoreline cleanup, school monitoring and bilingual awareness materials can address visible local pressures. Low-cost filters can be used for education and pre-treatment demonstrations, but not as substitutes for regulated drinking-water systems.

Local green economy development, governance and study limitations

Local green-economy development can build on water stewardship without requiring large industrial projects. Cleaner riverbanks and reliable water quality support recreation, small-scale nature tourism, fisheries-related livelihoods, greener public spaces and lower cleanup burdens. School and community projects can also strengthen environmental skills and create demand for waste sorting, recycling, monitoring services and resource-efficient technologies. These benefits become more durable when local initiatives are connected to municipal services and national water policy rather than remaining one-off campaigns.

The study has important limitations. The two underlying works are educational research projects rather than standardized hydrochemical surveys. The Padar field site is not a Kura monitoring station and should not be used to infer Kura water quality. The source file lists three field points but reports interpretable results for only two; survey response distributions are unavailable; and the filtration experiment lacks chemical and microbiological measurements. The article therefore uses verified published data for quantitative Kura claims and treats the student observations as descriptive local evidence. Future work should add georeferenced sampling, repeated seasonal measurements, basic physicochemical parameters, laboratory testing and cost-benefit assessment of treatment and pollution-prevention options.

CONCLUSIONS

This study integrates a Kura-focused hydroecological review with a local field-monitoring project to show how water-quality degradation connects environmental condition, ecosystem services and green-economy resilience. Verified 2020–2022 evidence confirms a pronounced downstream mineralization gradient, with mean mineralization rising from about 349 mg/L at I Shikhli to more than 3,000 mg/L at Neftchala. The local Padar project independently demonstrates visible plastic and nutrient-related pollution pressures and shows the educational value of structured monitoring and simple filtration experiments. However, the filter result is limited to visual clarification and the local field observations cannot be generalized to the Kura River. The practical implication is that effective protection requires action at multiple levels: wastewater control and basin monitoring, efficient agricultural practices, transboundary coordination, local litter prevention and environmental education. From a green-economy perspective, such measures protect natural capital by maintaining usable water, reducing avoidable treatment and cleanup pressures and sustaining agriculture, fisheries, recreation and community well-being. Future research should combine school and citizen-science engagement with standardized laboratory monitoring and explicit economic valuation of water-quality improvements.

AUTHOR CONTRIBUTIONS

L.I. contributed the original Kura River hydroecological research material, source collection and preliminary synthesis. G.K. contributed the local field-monitoring project, pollution classification, survey design, practical filtration model and project documentation. G.G. contributed supervision, conceptual integration, methodological framing, economic and green-economy interpretation, review and editing. All authors reviewed the final manuscript and approved the submitted version.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study synthesizes two author-prepared educational research dossiers and publicly available secondary sources. No new laboratory water-quality dataset or economic valuation dataset was generated. The Padar project reported descriptive field observations and a 15-respondent survey, but item-level survey frequencies and laboratory measurements were not included in the source dossier. Quantitative Kura River values used in this article are taken from the cited published sources.

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Transboundary pollution and ecological degradation in the Kura–Araz river system and their implications for water security and green economic resilience

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Keywords
green economy, Kura–Araz, transboundary pollution, water security, river basin management

ABSTRACT
The Kura–Araz river system is central to Azerbaijan's water security, irrigated agriculture, settlements, biodiversity and regional economic resilience. This study integrates two educational research projects that examined river pollution, declining water availability, biodiversity pressure and practical responses from complementary perspectives. The source materials were synthesized with peer-reviewed and institutional evidence and interpreted through water-security and green-economy frameworks. The combined evidence identifies a pressure chain that begins with transboundary and domestic wastewater, industrial and mining emissions, agricultural runoff, solid waste, flow regulation and climate-related water scarcity. Published studies confirm that the Kura–Araz system is exposed to spatially uneven metal pollution and that Azerbaijan depends heavily on transboundary inflows, while recent national water-sector assessments emphasize increasing scarcity and the need for more efficient institutions, monitoring and investment. The original student works also highlight biodiversity loss, degradation of riparian habitats, risks to fisheries and agriculture, and the importance of public awareness, riverbank protection and modern treatment systems. Economically, deteriorating water quality and quantity can increase treatment and monitoring needs, constrain irrigation, reduce ecosystem-service value and weaken rural and urban resilience. The study concludes that basin-scale monitoring, wastewater treatment, efficient irrigation, transboundary cooperation and environmental education should be treated as mutually reinforcing investments in natural capital and Azerbaijan's green economic transition.

INTRODUCTION
The Kura–Araz river system is the principal transboundary freshwater network of the South Caucasus and a strategic natural asset for Azerbaijan. It supports municipal water supply, irrigated agriculture, hydropower, industry, fisheries, riparian habitats and the Caspian Sea receiving environment. This multifunctional role means that river degradation affects not only ecological condition but also food production, public services, human health and regional development. The World Bank (2024) estimates that 78% of Azerbaijan's runoff enters through the transboundary Kura and Araz rivers, underscoring the country's downstream dependence on water quantity and quality formed beyond its borders.

The two source research projects used in this article approach the problem from complementary angles. Muradli's project focused on the contemporary ecological condition of the Kura and Araz, emphasizing transboundary pollution, heavy metals, phenols, petroleum-related pollutants, biodiversity and health risks. The "Kürün səsi" group project examined pollution, declining flow, salinity intrusion, biodiversity loss, dams, agricultural pressure and proposed solutions such as basin cooperation, efficient irrigation, wastewater treatment, rainwater harvesting and environmental awareness. Both projects therefore treat the river as a coupled ecological and socio-economic system rather than as an isolated watercourse.

The economic dimension is especially important for a green-economy interpretation. Water-quality deterioration can raise treatment and monitoring requirements; reduced flow can intensify competition among irrigation, household and ecosystem needs; biodiversity loss can weaken fisheries and recreation; and salinity or pollution can reduce the productive value of water and land. The World Bank's green-growth analysis for Azerbaijan identifies water and waste management, resource efficiency and climate-smart agriculture among measures capable of improving both environmental performance and economic resilience (World Bank, 2022).

This study asks three questions: (1) which transboundary and domestic pressures on the Kura–Araz system are consistently supported by the student source materials and external evidence; (2) how do these pressures propagate through water quality, hydrology, biodiversity and human use; and (3) which responses can jointly improve water security, ecosystem condition and green economic resilience?

LITERATURE REVIEW
Transboundary contamination in the Kura–Araz basin has long been

documented scientifically. Suleymanov et al. (2010), using repeated sampling from the Azerbaijan part of the basin, found substantial spatial differences in trace-metal concentrations and reported that sites near the borders with Armenia and Georgia were among the most polluted. The study also showed that a large share of several metals was transported with suspended matter, demonstrating that water quality cannot be understood only through dissolved concentrations.

More recent evidence adds a downstream water-quality perspective. Aliyev and Abduyev (2025) analyzed monitoring data from 14 points along the Kura for 2020–2022 and found marked changes in major-ion composition and mineralization along the river. Their analysis also identifies industrial, municipal and untreated wastewater discharges as continuing pressures. These findings support the pollution pathways identified in the student projects, while also showing why individual source claims about exact exceedance multiples require verification against monitoring datasets.

Integrated basin management has become a central institutional response. The EU Water Initiative Plus river-basin work for the Kura upstream of Mingachevir applied Water Framework Directive principles to water-body delineation, pressure assessment, monitoring and programme-of-measures planning (EUWI+, 2021). The related River Basin Management Plan included an economic analysis of water use and of proposed measures, explicitly linking ecological objectives to cost recovery, investment and water-service planning.

Azerbaijan's broader water-security context strengthens this linkage. The World Bank (2024) identifies high dependence on transboundary inflows, climate-related scarcity, infrastructure inefficiencies and the need for improved water accounting, wastewater performance and institutional coordination. The Country Climate and Development Report likewise stresses that water scarcity and climate pressures can affect agriculture, livelihoods and economic diversification, making resilient water management part of long-term development strategy (World Bank Group, 2023).

The literature therefore suggests a combined framework in which pollution control, hydrological resilience, ecosystem protection and economic efficiency are mutually dependent. For a downstream country, prevention and cooperation upstream can reduce treatment and restoration burdens downstream, while domestic investments in wastewater treatment, efficient irrigation and monitoring protect the productive value of natural capital.

MATERIALS AND METHODS

The study used an integrative qualitative synthesis of two author-prepared educational research dossiers completed in 2026. The first source was a 13-page presentation by Nihat Muradli on pollution and environmental effects in the Kura and Araz basins. It drew on monitoring reports, scientific literature, laboratory information and field observations and organized evidence around pollutants, ecosystem effects, human health and management responses. The second source was a 15-page project prepared by Asya B., Mahira A. and Sadaqat M. under the "Kürün səsi" group. It examined transboundary pollution, declining river flow, biodiversity, salinity intrusion, dams, agricultural water use, community awareness and proposed interventions.

Because the educational source documents contain several graphs and percentages without an attached raw dataset or complete calculation notes, those figures were not treated as independently verified statistical evidence. Instead, the study retained their qualitative direction and research questions and checked the main mechanisms against external sources. Exact quantitative claims were used only where they could be supported by peer-reviewed or institutional evidence. External verification relied primarily on Suleymanov et al. (2010), EUWI+ (2021), the World Bank (2022, 2024), the World Bank Group (2023) and Aliyev and Abduyev (2025).

The synthesis classified evidence into five pressure categories: transboundary industrial and mining pollution; domestic wastewater and solid waste; agricultural runoff; declining flow and water scarcity; and hydromorphological change from reservoirs and dams. For each category, ecological consequences and plausible economic channels were identified. The analysis is interpretive rather than a monetary valuation, and it does not estimate causal effect sizes or aggregate economic losses.

RESULTS AND DISCUSSION

Transboundary and domestic pollution as a coupled basin pressure

Both educational projects identify transboundary pollution as a defining characteristic of the Kura–Araz system. This framing is consistent with the basin geography: upstream urban, industrial, mining and agricultural activities can affect water entering Azerbaijan. Suleymanov et al. (2010) provides strong empirical support for this mechanism, documenting elevated trace-metal pollution at border-influenced sites and showing that the pollutant burden varies sharply across the basin. Muradli's source project additionally emphasizes phenols, petroleum products and untreated wastewater, while the "Kürün səsi" project highlights industrial discharge, sewage and agricultural chemicals.

Domestic pressures within Azerbaijan remain important as well. Aliyev and Abduyev (2025) identify untreated or insufficiently treated municipal and industrial wastewater as continuing contributors to Kura water-quality degradation. This matters because transboundary and domestic pollution interact: imported pollution can enter a river already subject to local wastewater, runoff and solid-waste pressures, while lower flows can reduce dilution capacity. The policy implication is therefore not to treat upstream and domestic sources as competing explanations, but as cumulative pressures requiring coordinated management.

Table 1 summarizes the main pressure pathways retained from the two educational studies and shows how they connect to ecological condition and green-economy resilience.

Water scarcity, flow alteration and biodiversity consequences

The second major theme is the interaction between hydrological decline and pollution. The World Bank (2024) reports that water availability in Azerbaijan is declining under rising upstream demand and climate change, while national dependence on transboundary inflows remains high. Lower river flow can intensify ecological stress by reducing dilution, changing habitat availability and increasing competition among municipal, agricultural and environmental water uses. Both student projects recognize this compound risk and connect it to hotter and drier conditions, water abstraction and reservoir regulation.

Biodiversity impacts follow through several pathways. The source projects discuss degradation of riparian vegetation, pressure on sturgeon and other fish, disruption of migration by dams, eutrophication and loss of habitat quality. While the source documents do not provide a standardized biological monitoring dataset, these mechanisms are consistent with the broader basin-management literature, which treats ecological status and hydromorphology as core dimensions of river health (EUWI+, 2021).

The economic relevance is direct because fisheries, erosion control, water purification, recreation and landscape quality are ecosystem services with social and productive value.

Table 1. Main pressure pathways and their implications for the Kura–Araz river system

Pressure / source evidence	Environmental, water-security and green-economy implication
Transboundary industrial and mining pollution; trace metals documented at border-influenced sites	Toxic stress, sediment contamination and reduced aquatic habitat quality; greater monitoring and treatment burden; cross-border externalities require coordinated prevention.
Municipal wastewater, industrial effluent and solid waste	Organic loading, oxygen stress, litter and degraded riverbank condition; higher treatment and cleanup needs and lower amenity and ecosystem-service value.
Agricultural fertilizers, pesticides and inefficient irrigation	Nutrient loading, eutrophication risk and reduced environmental flows; lower water productivity and weaker farm resilience.
Climate-related scarcity, upstream abstractions and reservoir regulation	Lower dilution capacity, altered habitat and stronger competition among water users; greater need for water accounting, efficiency and adaptive allocation.
Dams and hydromorphological modification	Interrupted fish migration and altered flow regime; trade-offs among energy, irrigation and ecosystem services requiring basin-level optimization.

Water security and green economic resilience

River degradation creates economic exposure through water treatment, agriculture, infrastructure and natural-capital loss. Poorer raw-water quality can require more intensive monitoring and treatment before use. Water scarcity can reduce irrigation reliability, while salinity and pollution can lower the suitability of water for crops and soils. In rural economies, these effects can interact with already variable climate conditions and raise the importance of efficient irrigation, leakage reduction and water accounting. Agriculture is especially sensitive because irrigated production is a major water user in Azerbaijan and an important source of employment and non-oil economic activity (World Bank, 2024).

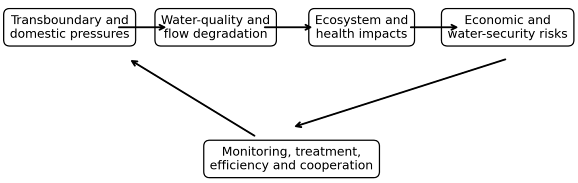

Figure 1. Integrated pathway from river-basin pressures to green-economy responses

The framework in Figure 1 shows that environmental and economic effects are not separate endpoints. Pollution and hydrological pressure first change water quality and flow, then affect ecosystems, health and productive uses, and finally generate costs or lost benefits through treatment, irrigation constraints, degraded fisheries and reduced ecosystem services. Green-economy responses work in the opposite direction by preventing pollution, increasing resource efficiency and protecting natural capital.

Priority responses from treatment and monitoring to basin cooperation

The combined evidence supports a layered response. First, wastewater collection and treatment should be improved in urban and industrial centers because prevention is generally more resource-efficient than repeated downstream cleanup. Second, agricultural measures should reduce fertilizer runoff and improve irrigation efficiency. Third, monitoring should combine chemical, biological and hydrological indicators and use basin-scale information systems that can detect changing risks. EUWI+ (2021) and the World Bank (2024) both emphasize integrated planning, monitoring and stronger institutional capacity as foundations for more resilient water management.

Transboundary governance, green skills and study limitations

Transboundary cooperation is indispensable because downstream water security cannot be achieved solely through domestic measures. Shared monitoring protocols, data exchange, pollution-event notification and coordinated basin planning can reduce uncertainty and improve investment decisions. The educational projects also place unusual emphasis on public awareness and “green skills”, including school-based water education, riverbank cleanups and responsible household behavior. These actions are not substitutes for infrastructure or regulation, but they can support compliance, community monitoring and long-term stewardship.

The study has several limitations. The two source projects are educational research products rather than standardized basin-monitoring studies, and some of their charts and percentage claims lack accessible raw data. For that reason, the present article uses them primarily to preserve the students’ problem framing, observations and proposed solutions, while quantitative interpretation relies on independently traceable literature. No monetary valuation, laboratory resampling or causal modeling was performed. Future work should integrate standardized water-quality data with economic valuation of treatment costs, irrigation losses and ecosystem-service benefits.

CONCLUSIONS

This study integrates two student-led research projects to examine how transboundary pollution, domestic wastewater, agricultural runoff, water scarcity and hydromorphological change interact in the Kura–Araz river system. External evidence confirms that the basin is exposed to spatially uneven metal pollution, strong dependence on transboundary inflows and increasing water-security pressure. The combined analysis shows that ecological degradation has economic consequences through higher treatment and monitoring needs, irrigation risk, biodiversity loss and weakened ecosystem services. From a green-economy perspective, the most effective response is a portfolio rather than a single intervention: stronger wastewater treatment, efficient irrigation, basin-scale monitoring, water accounting, transboundary cooperation, riverbank and habitat protection, and sustained environmental education. These measures protect water as natural capital while reducing avoidable downstream costs and supporting agriculture, public health and resilient local development. The original educational projects provide a valuable foundation for awareness and problem identification, but future research should pair such engagement with standardized monitoring datasets and explicit economic assessment.

AUTHOR CONTRIBUTIONS

N.M. contributed the original Kura–Araz pollution research, source collection and preliminary environmental synthesis. A.B., M.A. and S.M. contributed the original Kura ecological-problems project, visual synthesis, proposed solutions and survey design. T.M. contributed supervision, methodology development, academic structuring, literature integration and writing—review and editing. All authors reviewed and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study synthesizes two author-prepared educational research dossiers and publicly available secondary sources. No new laboratory sampling was undertaken. Several source-project graphics were not accompanied by raw datasets; therefore, their exact percentages were not used as independently verified quantitative evidence. The cited institutional and peer-reviewed sources are publicly accessible through the referenced publishers and organizations.

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Riparian biodiversity of the Kura River and its role in ecosystem services and local green economy development

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Keywords
ecosystem services, green economy, Kura River, riparian biodiversity, Tugai forests

ABSTRACT

Riparian ecosystems along the Kura River combine riverine vegetation, wetlands, fish communities, birds, mammals and reptiles within a narrow ecological corridor that supports both biodiversity and human well-being. This study develops an academic synthesis from an author-prepared research project on the fauna and flora of the Kura River and interprets its findings through ecosystem-services and local green-economy perspectives. The source project identified Tugai forests, reed and aquatic vegetation, fish, migratory and resident birds, semi-aquatic mammals and reptiles as characteristic components of the riverside system, while emphasizing declining water levels, pollution and flow regulation by dams as major pressures. The study combines this original material with recent research on Azerbaijan's Tugai forests, riparian restoration and Kura-related ecosystem services. Results show that riparian biodiversity is economically relevant because it contributes to bank stabilization, habitat continuity, water regulation, fisheries potential, recreation and nature-based tourism. Degradation therefore represents not only an ecological loss but also a weakening of natural capital that supports local development. The analysis indicates that restoring river–floodplain connectivity, protecting Tugai vegetation, improving pollution control, maintaining environmental flows and supporting low-impact recreation can generate joint ecological and economic benefits. The paper concludes that Kura riparian biodiversity should be treated as productive natural infrastructure within Azerbaijan's green-economy transition, while future work should add standardized field inventories, habitat mapping and ecosystem-service valuation.

INTRODUCTION

Riparian zones are among the most multifunctional parts of river systems because they connect flowing water, floodplains, soils, vegetation and terrestrial habitats. Their ecological value is expressed through biodiversity, bank protection, nutrient cycling, habitat connectivity and hydrological regulation. Their economic value is less visible but equally important: healthy river corridors can support fisheries, agriculture, recreation, tourism and the long-term stability of land and water resources. For this reason, riparian biodiversity can be interpreted as a form of natural capital rather than as an environmental feature separate from economic development.

The Kura River is especially important in this context. It is the largest river system crossing Azerbaijan and supports extensive lowland landscapes, settlements and productive activities before reaching the Caspian Sea. The original research project by Imanli and Ismayil examined the fauna and flora associated with the Kura riverside and organized the system into several components: Tugai forests, wetland and aquatic vegetation, fish communities, riverside birds, mammals and reptiles. The project also identified declining water levels, pollution and dams as pressures capable of weakening this ecological structure.

Recent research confirms that Azerbaijan's Tugai forests are ecologically distinctive riparian ecosystems whose composition depends on flooding, shallow groundwater, alluvial soils and salinity conditions. They provide habitat for diverse plant and animal communities while also performing functions such as bank stabilization and local microclimate regulation (Gurbanov et al., 2026; Ahmadova, 2026). These functions create a direct bridge to green economy thinking because natural systems can reduce environmental risk and sustain economic activities without requiring continuous replacement by engineered infrastructure.

This study therefore asks three questions: (1) which biodiversity components are emphasized in the original Kura River research project; (2) how do these components contribute to ecosystem services and local economic value; and (3) which management actions can protect riparian natural capital while supporting green-economy development? The analysis does not treat the educational project as a standardized biodiversity census. Instead, it preserves the authors' observations and thematic structure, verifies major ecological mechanisms against recent literature and develops an ecosystem-services interpretation suitable for an interdisciplinary journal.

LITERATURE REVIEW

Tugai forests are the core riparian vegetation type of the Kura lowlands. Gurbanov et al. (2026) describe them as intrazonal ecosystems characterized by multilayered vegetation and strong dependence on hydrological regime, groundwater conditions and soil salinity. Dominant and characteristic groups include Populus, Salix, Ulmus, Alnus and Tamarix. The same study emphasizes that river regulation, intensive water abstraction, agricultural expansion, deforestation, overgrazing, invasive species and climate change have reduced the extent and ecological integrity of these forests.

Field-based research from the Kura riparian zone in Agjabadi provides additional evidence. Qurbanov and Ahmadova (2024) documented poplar–willow–tamarisk communities on alluvial-meadow soils and argued that conversion of riparian forests to agricultural land can contribute to salinization and desertification. Their work is particularly relevant to the present study because it links plant-community structure with the need for ecological management and restoration in the Kura corridor.

Restoration research also shows that Tugai recovery cannot be reduced to tree planting alone. Ahmadova (2026) argues that effective restoration requires re-establishing the coupled river–floodplain–groundwater processes that support recruitment and long-term vegetation persistence. In economic terms, this matters because poorly designed restoration can consume resources without recovering the ecosystem functions that justify investment.

The Kura–Aras basin has also been examined through an ecosystem-services lens. Flores and Abbasov (2015) assessed freshwater ecosystem services in relation to hydropower and other water-dependent uses, demonstrating that water management decisions involve ecological as well as economic trade-offs. More recently, Zeynalova and Asgarova (2026) showed that the Kura riverfront in Mingachevir has potential for green tourism through waterfront landscapes, fishing, birdwatching and recreation, while stressing that ecological monitoring, resource-efficient services and waste management are necessary if tourism growth is to remain sustainable.

Together, these studies support a natural-capital framework for riparian biodiversity. Vegetation, wetlands and wildlife are not isolated conservation objects; they form a service-producing system whose condition affects erosion control, landscape quality, ecological connectivity, fisheries and recreation. This framework provides the basis for interpreting the original student project within a green-economy context.

MATERIALS AND METHODS

The study used an integrative qualitative design based on a 13-page educational research presentation prepared by Zahra Imanli and Farah Ismayil in 2026. The original project, titled 'Kür Çayı Ətrafında Fauna və Flora', aimed to examine plant and animal communities associated with the Kura River and to identify ecological threats and conservation measures. Its structure covered the river's geographical setting, Tugai forests, tree and shrub species, wetland and aquatic vegetation, fish, riverside birds, mammals and reptiles, current environmental pressures and selected conservation responses.

The source material was coded into four analytical categories: biodiversity components, ecosystem functions, major pressures and conservation responses. Plant and animal examples were retained when they were explicitly named in the source project. However, the project's visual labels describing relative fish abundance were not treated as measured population statistics because no sampling protocol or underlying dataset was supplied. The analysis therefore focuses on presence, ecological role and management relevance rather than on abundance estimates.

To strengthen academic interpretation, the source project was compared with recent peer-reviewed and institutional evidence on Azerbaijan's Tugai forests, riparian restoration, ecosystem services and sustainable riverfront tourism. No new field sampling, laboratory analysis, wildlife census or monetary valuation was conducted. The resulting study is a structured synthesis intended to preserve the original research contribution while avoiding unsupported quantitative claims.

RESULTS AND DISCUSSION

Biodiversity structure of the Kura riparian corridor

The original project presents the Kura riverside as a vertically and horizontally connected ecological corridor. The vegetation component begins with Tugai forests and identifies white willow, white poplar, Tugai oak, oleaster and tamarisk among characteristic woody plants. Wet and slow-flowing zones are represented by reed beds, water lilies and other dense shoreline vegetation. These habitats create structural diversity from the river edge to the floodplain and provide feeding, breeding, shelter and movement spaces for wildlife.

The fauna section identifies fish, birds, mammals and reptiles as complementary parts of the system. The source project names sturgeon, carp, pike-perch and other fish; grey heron, black pelican, pheasant and purple swamphen among birds; and otter, nutria, wild boar, river turtle, water snake, wolf, fox and jackal among mammals, reptiles and predators. These records should be interpreted as an educational inventory rather than a verified species census, but they correctly emphasize the ecological diversity associated with river, wetland and woodland habitats.

Recent botanical studies support the project's emphasis on the Tugai zone. Gurbanov et al. (2026) found high species diversity and multilayered structure in Kura-basin riparian communities, while Qurbanov and Ahmadova (2024) documented poplar–willow–tamarisk formations in the Agjabadi sector. This agreement between the educational project and field literature strengthens the interpretation of riparian vegetation as the physical framework supporting much of the corridor's biodiversity.

Tugai forests as natural infrastructure and ecosystem-service providers

The source project describes Tugai forests as green corridors that protect riverbanks from erosion and provide shelter for animals. These functions have direct ecosystem-service significance. Vegetation can stabilize alluvial banks, reduce soil loss, create shade, maintain habitat continuity and contribute to local microclimate regulation. Ahmadova (2026) similarly identifies bank stabilization, habitat connectivity, biodiversity support and microclimate regulation as important Tugai functions.

From a green-economy perspective, such functions can be understood as natural infrastructure. When riparian buffers reduce erosion or maintain habitat, they help preserve the productive condition of land and water without requiring equivalent engineered interventions. This does not mean that ecological functions can always be assigned a simple monetary value, but it does mean that their degradation can create real costs through bank instability, poorer water quality, habitat loss and reduced recreational attractiveness.

Table 1. Riparian biodiversity components and their ecosystem-service and green-economy relevance

Biodiversity component	Ecosystem-service and green-economy relevance
Tugai forests and riparian trees	Erosion control, habitat connectivity, microclimate regulation, landscape quality and restoration value
Wetland and aquatic vegetation	Bird nesting habitat, wetland structure, aesthetic value and nature-based recreation
Fish communities	Food-web function, fisheries potential, recreational fishing and indicators of aquatic condition
Riverside birds	Biodiversity value, birdwatching potential and indicators of wetland habitat quality

Biodiversity component	Ecosystem-service and green-economy relevance
Mammals and reptiles	Habitat-integrity value, ecological connectivity and conservation-based recreation

The original project identifies three principal pressures: declining water levels, pollution and dams. Reduced flow can affect floodplain moisture, wetland persistence and the hydrological conditions required by Tugai vegetation. Pollution can reduce habitat quality for aquatic organisms and weaken the recreational and aesthetic value of the river corridor. Dams and flow regulation can modify natural hydrology and interrupt fish migration. These pressures are mutually reinforcing because hydrological alteration can make riparian ecosystems more sensitive to pollution and climate stress.

The literature confirms this multi-pressure interpretation. Gurbanov et al. (2026) identify reservoir construction, river regulation, water abstraction, agricultural expansion and climate change as important drivers of Tugai degradation. Qurbanov and Ahmadova (2024) further show that land conversion and inappropriate restoration approaches can weaken the ecological resilience of riparian forests. Biodiversity management therefore requires attention to the hydrological system, not only to individual species.

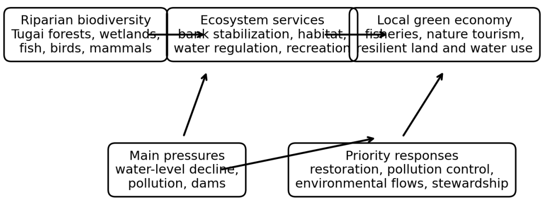

Figure 1. Conceptual pathway from Kura riparian biodiversity to ecosystem services and local green-economy value

Figure 1 summarizes the central relationship developed in this study. Riparian biodiversity produces ecosystem services, those services support locally relevant economic functions, and environmental pressures can weaken both. Restoration, pollution control, environmental-flow management and stewardship can reverse part of this pathway by protecting natural capital before ecological losses become higher social and economic costs.

Local green-economy opportunities linked to riparian biodiversity

Local green-economy value can emerge through several channels. First, healthy fish habitats can support renewable fishery and recreational-fishing opportunities when extraction remains within ecological limits. Second, bird-rich wetlands and visually attractive riverfront landscapes can support low-impact recreation, birdwatching and nature tourism. Zeynalova and Asgarova (2026) show that the Kura riverfront in Mingachevir already has potential for boating, fishing, birdwatching and other river-oriented tourism, but that ecological monitoring and resource-efficient services are essential for sustainability.

Third, restoration itself can be viewed as green investment. Re-establishing native riparian vegetation, controlling erosion, improving waste management and protecting floodplain connectivity can strengthen natural infrastructure while creating demand for ecological monitoring, nursery production, restoration work and environmental education. The economic objective is not to commercialize every ecosystem component, but to maintain the ecological assets on which resilient local development depends.

Conservation priorities and study limitations

The evidence supports five practical priorities: protect remaining Tugai forest fragments; maintain hydrological conditions that allow floodplain and wetland habitats to function; reduce untreated waste and chemical pollution; preserve fish-migration and habitat connectivity where possible; and expand community stewardship and environmental education. Protected-area management and artificial propagation can contribute to species conservation, but they should complement rather than replace river-corridor restoration and pollution prevention.

The study has important limitations. The original research project is an educational presentation rather than a standardized field inventory. Species presence was not verified through a reproducible sampling protocol, and the relative fish-abundance graphic was not accompanied by raw data. No habitat-area measurements, population trends or monetary ecosystem-service values were generated. Future research should combine georeferenced vegetation plots, bird and fish surveys, water-quality monitoring, habitat mapping and valuation of recreation, erosion protection and other ecosystem services.

CONCLUSIONS

The Kura River's riparian biodiversity forms a connected natural-capital system rather than a collection of isolated species. The original research project highlights Tugai forests, wetland vegetation, fish, birds, mammals and reptiles as characteristic elements of this corridor, while identifying water-level decline, pollution and dams as major pressures. Recent literature supports the ecological importance of Tugai vegetation and shows that its persistence depends on river–floodplain hydrology, groundwater and appropriate restoration. The green-economy implication is clear: protecting riparian biodiversity also protects services that support land stability, fisheries, recreation, nature tourism and resilient water-dependent livelihoods. Conservation should therefore be designed as investment in natural infrastructure. Priority actions include Tugai restoration, pollution prevention, environmental-flow and connectivity management, low-impact tourism, ecological monitoring and public stewardship. Because this study is qualitative, the next stage should integrate field biodiversity inventories with ecosystem-service and local economic data so that conservation priorities can be evaluated through both ecological and development criteria.

AUTHOR CONTRIBUTIONS

Z.I. and F.I. contributed the original research concept, source collection, biodiversity inventory, visual synthesis and preliminary assessment of Kura riparian flora, fauna, ecological pressures and conservation measures. A.J. contributed supervision, methodological framing, academic structuring, ecosystem-services and green-economy interpretation, and writing—review and editing. All authors reviewed and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study is a qualitative synthesis of an author-prepared educational research project and published literature. No new biological sampling, laboratory water-quality dataset, wildlife census or monetary ecosystem-service valuation was generated. The descriptive source material supporting the synthesis is contained in the authors' original research file.

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Human pressures on Kura River riparian ecosystems and the role of Tugai forests in biodiversity conservation and green economic resilience in Azerbaijan

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Keywords
biodiversity, green economy, Kura River, riparian ecosystems, Tugai forests

ABSTRACT

Riparian ecosystems of the Kura River combine aquatic habitats, floodplain vegetation and Tugai forests that support biodiversity, water regulation, soil stability and local economic activity. This study integrates two author-prepared research projects: one examining the effects of human activities on river ecosystems and another assessing the ecological importance of Tugai forests. The source studies identify industrial effluents, agricultural chemicals, household waste, riparian deforestation, dams, water-resource decline and climate-related stress as major pressures. They also emphasize the role of Tugai forests in erosion control, habitat provision, soil protection, microclimate regulation and landscape quality. The present article preserves these original findings and interprets them through an ecosystem-services and green-economy framework, supported by recent literature on the Kura River and Azerbaijani Tugai forests. Results show that human pressures can simultaneously reduce water quality and weaken the natural infrastructure provided by riparian forests, creating ecological and economic exposure for agriculture, water supply, recreation and local livelihoods. Priority responses include wastewater control, more efficient agricultural inputs, riparian restoration, environmental-flow management, ecological monitoring and environmental education. The study concludes that Tugai conservation should be integrated into river-basin management as an investment in biodiversity, natural capital and long-term green economic resilience.

INTRODUCTION

River ecosystems are simultaneously ecological networks and resource systems. They provide water for households, agriculture, industry and energy while supporting aquatic organisms, riparian vegetation and floodplain biodiversity. When human pressures alter water quality, flow regime or riverbank vegetation, the effects extend from species and habitats to agricultural productivity, treatment requirements, recreation and local well-being. For this reason, river protection increasingly requires an integrated perspective that connects ecological condition with natural capital and resource efficiency.

The Kura River is especially important in Azerbaijan because its river corridor supports settlements, agricultural land, reservoirs and extensive riparian habitats. Two educational research projects form the core evidence of this paper. Rustamli (2026) focused on the effects of human activity on river ecosystems, identifying industrial discharges, agricultural chemicals, household waste, deforestation and dams as major pressures. Hamidov (2026) examined Tugai forests along the Kura–Araz system, emphasizing their biodiversity, soil-protection, climate-regulation and social value.

Recent scientific evidence supports the ecological mechanisms identified in both source studies. Gurbanov et al. (2026) describe Azerbaijani Tugai forests as biodiversity-rich riparian systems dependent on river hydrology, shallow groundwater and alluvial conditions, while identifying deforestation, grazing, river regulation, irrigation abstraction and climate change as major degradation pressures. Ahmadova (2026) further argues that restoration requires recovery of river–floodplain–groundwater processes rather than simple tree planting.

This study therefore asks three questions: (1) how do the human pressures identified by the source research affect Kura River ecological condition; (2) what ecosystem services are provided by Tugai forests; and (3) how can river and riparian management contribute to green economic resilience? The study does not introduce new field measurements. Instead, it combines the two student research works, preserves their core findings and develops a structured interpretation using recent academic evidence.

LITERATURE REVIEW

Human activities affect river ecosystems through both direct pollution and physical alteration. Industrial and municipal wastewater can change chemical and biological water quality, while agricultural runoff can transport fertilizers and pesticides into surface waters. Solid waste creates additional habitat and landscape pressures. Flow regulation and dam construction can modify sediment transport, seasonal discharge and fish migration. Rustamli's source research organizes these mechanisms into a practical pressure framework and links them to biodiversity decline and ecosystem imbalance.

For the Kura River, recent water-quality monitoring demonstrates that chemical conditions vary substantially along the Azerbaijani reach. Aliyev and Abduyev (2025) found a consistent downstream increase in mineralization during 2020–2022 and reported that tributary inputs, agricultural runoff, wastewater and natural hydrochemical processes all contribute to the observed pattern. Their study reinforces the source project's broader conclusion that water quality is shaped by interacting human and natural factors rather than a single pollution source.

Tugai forests represent the riparian component of this system. Gurbanov et al. (2026) identify multilayered Populus-, Salix-, Ulmus-, Alnus- and Tamarix-dominated communities within Azerbaijan's river corridors and emphasize their importance for biodiversity, nutrient cycling, bank stabilization, soil fertility, carbon sequestration and local microclimate regulation. These functions correspond closely to the ecological roles identified in Hamidov's source research.

The restoration literature adds an important management dimension. Ahmadova (2026) describes Tugai recovery as a driver-based process involving environmental flows, floodplain connectivity, groundwater conditions, protected areas and adaptive monitoring. This perspective is economically relevant because healthy riparian systems can function as natural infrastructure, reducing erosion risk, supporting landscape quality and maintaining ecological conditions on which agriculture, recreation and other water-dependent activities depend.

The Kura–Aras basin has also been examined through ecosystem-services approaches. Flores and Abbasov (2015) show that freshwater ecosystem services contribute to hydropower, irrigated agriculture, drinking-water supply, tourism and natural-hazard regulation. This provides a useful framework for interpreting Tugai forests and river quality as productive natural capital within a green economy.

MATERIALS AND METHODS

The study used an integrative qualitative design based on two educational research projects prepared in 2026. The first, by Zeynab Rustamli, examined human impacts on river ecosystems through online research, scientific-source review and comparison of environmental information. The second, by Eldar Hamidov, examined the ecological importance of Tugai forests using books, online sources, maps, images and comparative observation. Hamidov also reported observations of rivers and water sources in Quba; these were treated as comparative environmental observations rather than direct field measurements of the Kura River.

The two source documents were coded into four analytical groups: pressure sources, river responses, Tugai ecosystem functions and conservation responses. Pressure categories included industrial and household waste, agricultural chemicals, deforestation, water abstraction, dams, hydrological alteration and climate-related stress. Tugai functions included habitat provision, erosion control, soil protection, carbon-related functions, microclimate regulation and recreational landscape value.

Quantitative graphics from the source documents were used cautiously. Percentage shares shown in Hamidov's illustrative pressure chart were not treated as measured statistics because no sampling design or underlying dataset was provided. Likewise, internally inconsistent area figures presented in a conservation infographic were not used for numerical inference. The analysis therefore preserves the authors' qualitative findings while avoiding unsupported quantitative claims. Recent peer-reviewed literature was used to verify ecological mechanisms and strengthen interpretation.

RESULTS AND DISCUSSION

Human pressure pathways affecting the Kura River ecosystem

The combined source research identifies a multi-pressure river system. Rustamli emphasizes industrial effluents, agricultural fertilizers and pesticides, household plastics and waste, riparian deforestation and dams. Hamidov adds water scarcity, climate change, river-regime alteration and agricultural expansion. Together, these pressures affect water quality, habitat continuity, bank stability and the ability of riparian ecosystems to maintain ecological balance.

Industrial and household pollution primarily act through water-quality deterioration and physical habitat degradation. Agricultural chemicals reach rivers through runoff and can affect aquatic organisms and ecological processes. Deforestation and agricultural conversion remove protective vegetation, while dams and water abstraction alter natural flow. These mechanisms interact rather than operate independently: reduced flow can increase ecological sensitivity to pollution, while vegetation loss can intensify erosion and weaken the buffering capacity of riverbanks.

The recent Kura monitoring study by Aliyev and Abduyev (2025) supports the importance of cumulative downstream pressures. Their 2020–2022 data show substantial changes in mineralization and major-ion composition along the river. The present study does not attribute these changes to one source, but the evidence confirms that river management must consider tributaries, wastewater, agricultural runoff and natural hydrochemistry together.

Tugai forests as biodiversity refuges and natural infrastructure

Hamidov's research identifies Tugai forests as river-dependent ecosystems occurring along floodplains and moist riverbanks. The source study highlights poplar, willow, plane trees and shrubs, as well as the role of these forests as habitat for birds and other animals. It also emphasizes erosion control, soil fertility, air quality and microclimate regulation.

These observations are consistent with recent field-based research. Gurbanov et al. (2026) show that Tugai forests in Azerbaijan support high floristic diversity and complex vegetation structure and perform functions such as bank stabilization, soil-fertility maintenance, hydrological regulation, carbon sequestration and habitat provision. This means that Tugai forests can be interpreted as natural infrastructure: their ecological condition influences both biodiversity and the reliability of water- and land-dependent economic activities.

Table 1. Integrated pressure–ecosystem service framework for Kura River and Tugai management

Pressure / process	Ecosystem-service and green-economy implication
Industrial and household waste	Higher monitoring and treatment needs; lower amenity value; prioritize wastewater and solid-waste control
Agricultural chemicals and intensive water use	Resource inefficiency and external costs; improve input efficiency, irrigation and riparian buffers
Riparian deforestation and land conversion	Loss of natural infrastructure; restore and protect Tugai vegetation
Dams and hydrological alteration	Trade-offs among irrigation, energy and ecosystem services; use environmental-flow management

Pressure / process	Ecosystem-service and green-economy implication
Climate-related drought and declining water availability	Higher water-security risk; combine conservation, efficient use and adaptive management

Both source studies link ecosystem degradation to biodiversity loss. Rustamli notes that poorer water quality and altered river conditions can reduce fish and other aquatic organisms, while Hamidov emphasizes habitat loss in Tugai forests. Biodiversity decline also has an economic dimension because it can weaken fisheries potential, reduce landscape and recreational value, and impair the natural regulation functions provided by riparian vegetation.

From a green-economy perspective, the key issue is not simply the number of species lost but the deterioration of ecosystem services. If riverbanks become less stable, water quality deteriorates or floodplain vegetation disappears, additional engineered treatment, erosion control or restoration may be required. Preventing degradation can therefore be economically preferable to repeated remediation.

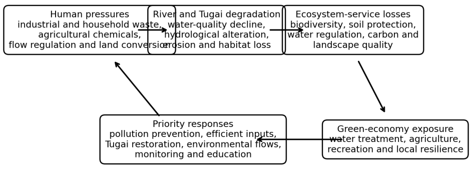

Figure 1. Integrated pathway from human pressures to Tugai ecosystem-service loss and green-economy responses

Figure 1 summarizes the combined logic of the two source studies. Human pressures first affect river water quality, flow and riparian habitat. Tugai degradation then reduces biodiversity and ecosystem services. The resulting losses create exposure for agriculture, water supply, recreation and local resilience. Green-economy responses aim to interrupt this chain through prevention, restoration and more efficient resource use.

Conservation and restoration priorities

The two source projects propose complementary solutions. Rustamli emphasizes wastewater treatment, reduced agricultural chemical use, solid-waste control, riparian phytomelioration, environmental education and stronger environmental oversight. Hamidov emphasizes water saving, public awareness, ecological education, rainwater use, tree planting, pollution prevention and conservation of Tugai forests.

Recent restoration literature suggests that these actions should be organized around ecological processes. Ahmadova (2026) argues that Tugai restoration requires environmental flows, floodplain connectivity, groundwater recovery and adaptive monitoring. Therefore, tree planting should be combined with hydrological management and protection from repeated land conversion or grazing pressure.

Green economic resilience and local development

Tugai conservation can support green economic resilience in several ways. Healthy riparian vegetation protects soils and riverbanks, supports biodiversity and improves landscape quality. Cleaner river environments can reduce water-treatment pressure and strengthen conditions for agriculture, recreation and nature-based tourism. Hamidov's source research explicitly links protected natural landscapes with tourism potential, while Rustamli connects river degradation with risks to agriculture and economic activity.

Monitoring, restoration and evidence needs

An integrated monitoring framework should connect river water quality with riparian vegetation condition. Water-quality stations can track mineralization, nutrients, selected pollutants and seasonal change, while remote sensing can be used to identify loss, fragmentation or recovery of Tugai vegetation along the floodplain. Field plots are then needed to verify changes in tree and shrub composition, regeneration and bank condition. This combination is consistent with the restoration logic proposed by Ahmadova (2026), which emphasizes adaptive monitoring rather than one-time planting. It also responds directly to the two source projects: Rustamli highlights pollution and human pressure, whereas Hamidov emphasizes forest condition, biodiversity and conservation.

Restoration priorities should be selected according to the dominant pressure in each river section. Where untreated wastewater is the main problem, pollution prevention and treatment should precede habitat enhancement. Where river regulation or excessive abstraction limits floodplain moisture, environmental-flow and groundwater conditions become central. Where Tugai vegetation has been removed by land conversion or repeated disturbance, native riparian restoration and protection from renewed clearing are more appropriate. This pressure-specific approach avoids treating all degraded sites as identical and improves the likelihood that restoration expenditure will recover functioning ecosystem services.

Future evaluation should also include economic indicators so that ecological improvement can be connected to green-development outcomes. Useful measures include changes in raw-water treatment requirements, irrigation-water suitability, erosion-control expenditure, restoration costs, recreational use, habitat condition and the maintenance of productive agricultural land near the river corridor. The present study does not assign monetary values to these services, but identifying them creates a framework for later cost-benefit or natural-capital assessment. In this way, biodiversity monitoring can inform not only conservation decisions but also investment choices concerning water security and local resilience.

The main limitation is that both source studies are educational research projects rather than standardized field investigations. Neither provides a reproducible Kura-wide sampling design, laboratory water-quality dataset or monetary ecosystem-service valuation. Their strongest contribution is therefore conceptual and diagnostic. Future studies should combine georeferenced water-quality monitoring, vegetation mapping, biodiversity surveys and economic valuation of erosion protection, recreation and other ecosystem services.

CONCLUSIONS

Combining the two source studies reveals a clear relationship between human pressure on the Kura River and the condition of its Tugai forests. Industrial and household waste, agricultural chemicals, deforestation, dams, water abstraction and climate-related stress can affect water quality, flow, riparian habitat and biodiversity. Tugai forests, in turn, provide ecosystem services that include erosion control, habitat, soil protection, carbon-related functions, microclimate regulation and landscape value. Their degradation therefore represents both an ecological loss and a weakening of natural capital. The most effective response is an integrated approach combining pollution prevention, efficient agricultural inputs, environmental-flow management, Tugai restoration, monitoring and ecological education. Treating riparian conservation as an investment in natural infrastructure can align biodiversity protection with water security, resource efficiency and green economic resilience in Azerbaijan.

AUTHOR CONTRIBUTIONS

Z.R. contributed the original research on human pressures affecting river ecosystems, including industrial, agricultural, household, riparian and dam-related impacts. E.H. contributed the original research on Tugai forest ecology, biodiversity, ecosystem functions, threats and conservation measures. N.B. contributed supervision, methodological integration, academic structuring, ecosystem-services and green-economy interpretation, and writing—review and editing. All authors reviewed and approved the final manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

DATA AVAILABILITY

This study is a qualitative synthesis of two author-prepared educational research projects and published literature. No new laboratory water-quality dataset, biodiversity census or monetary ecosystem-service valuation was generated.

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Hydroecological pressure signals in Mingachevir Reservoir: A retrospective synthesis of nutrient, microbial and major-ion evidence from the Middle Kura cascade

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Keywords
Mingachevir Reservoir; Kura River; water quality; microbial abundance; nutrients; mineralization; reservoir monitoring

ABSTRACT

Mingachevir Reservoir is the principal regulating water body of Azerbaijan's Middle Kura cascade, yet much of its hydroecological evidence remains dispersed across legacy monitoring tables and local studies. This paper consolidates station-level microbial observations, nutrient records, spatial hydrochemical measurements and major-ion profiles reported in a 2023 master's dissertation, recalculates internally inconsistent summary values from the underlying station data, and interprets the historical baseline against recent Kura River research published in 2025. Seasonal mean microbial abundance was higher in 2015 than in 1982 in all four seasons, with the largest relative difference in winter (68%). Nutrient records for 1987–2009 indicated pronounced enrichment episodes, particularly for nitrite and phosphorus, although differences in historical analytical protocols require cautious interpretation. Along the Shikhli–Salyan transect, the mean sum of major ions declined through the reservoir cascade, reaching its lowest value at Mingachevir (approximately 560 mg L−1), before increasing downstream to approximately 1,066 mg L−1 at Salyan. Within-reservoir contrasts showed lower transparency and higher mineralization, chloride and iron near the dam zone. Recent studies confirm that mineralization and microbial contamination remain relevant concerns in the Kura system. The combined evidence supports a risk-based monitoring design integrating seasonal field sampling, microbial indicators, nutrients, major ions and satellite-supported observations. The paper provides a transparent historical benchmark rather than claiming contemporary field status.

INTRODUCTION

Large reservoirs are hybrid socio-ecological infrastructures. They buffer seasonal discharge, generate electricity, supply irrigation networks and reduce flood peaks, but they also interrupt sediment transport, alter residence times, reorganize thermal and oxygen regimes, and retain or transform nutrients and contaminants. These processes are especially important in semi-arid basins where flow regulation and consumptive use interact with climate variability. The Kura–Aras basin is a prominent example because upstream pressures are transmitted across borders and accumulate toward lowland Azerbaijan (Mamedov et al., 2005; IPCC, 2023).

Mingachevir Reservoir, impounded on the Kura River in the early 1950s, is the largest reservoir in the South Caucasus and the central storage component of Azerbaijan's water–energy–food system. Its functions include hydropower production, regulation of the Middle and Lower Kura, irrigation supply through the Upper Karabakh and Upper Shirvan canals, fisheries and recreation. This multifunctionality raises the cost of ecological deterioration: changes in water quality affect not only aquatic biota but also downstream agriculture, potable-water treatment and infrastructure operation.

Earlier studies described the reservoir's microbiological regime, nutrient dynamics, organic pollution and major-ion composition, but the evidence is fragmented and often presented in tables without integrated interpretation (Salmanov & Ansarova, 2016a, 2016b). Some historical series contain inconsistent decimal notation or summary rows that do not reproduce the reported station observations. At the same time, recent research along the Kura has renewed attention to major-ion trends and faecal-indicator organisms, demonstrating the continuing relevance of mineralization and microbial safety in 2025 (Abduyev et al., 2025; Aliyev & Abduyev, 2025). A transparent synthesis is therefore useful both for preserving the historical baseline and for designing contemporary monitoring.

This study asks three questions: (1) what seasonal and temporal pressure signals are visible in the legacy microbial and nutrient records; (2) how does major-ion concentration vary along the Middle–Lower Kura cascade; and (3) which monitoring priorities follow when the historical evidence is evaluated alongside recent literature? The objective is not to label the present-day reservoir condition from old measurements. Instead, the study reconstructs an auditable baseline, identifies robust patterns and uncertainties, and proposes a monitoring architecture suitable for current reservoir management.

LITERATURE REVIEW

Reservoir water quality is governed by the interaction of catchment inputs, hydraulic residence time, stratification, sediment exchange and operational drawdown (Thornton et al., 1990; Wetzel, 2001). Damming can reduce suspended loads and temporarily retain nutrients, while longer residence time may favour algal growth and oxygen depletion. The direction of change is therefore parameter-specific: a reservoir may attenuate downstream mineral loads while simultaneously accumulating organic matter or supporting microbial growth. Global river research also shows that flow regulation interacts with pollution, habitat fragmentation and consumptive use, so multi-parameter assessment is preferable to reliance on a single index (Vörösmarty et al., 2010; Grill et al., 2019).

For the Kura–Aras basin, water-quality pressures arise from municipal wastewater, agriculture, industry, mining and altered flow regimes. The transboundary character of the system complicates source attribution and requires comparable monitoring protocols (Mamedov et al., 2005). Historical Azerbaijani research documented substantial changes in the physical, chemical and microbiological characteristics of Middle Kura reservoirs and highlighted the role of seasonality, pollution inputs and internal sediment processes (Mammadov, 2004; Salmanov & Ansarova, 2016b).

Two recent studies materially update this context. Aliyev and Abduyev (2025) analysed major ions at 14 Kura River sites and reported spatial variability in mineralization, including the influence of downstream pollution and hydrogeochemical inputs. Abduyev et al. (2025) assessed total coliforms, Escherichia coli, enterococci and total viable counts, showing that microbiological surveillance remains necessary along the river. These studies do not replace reservoir-specific sampling, but they confirm that the pressure categories present in the historical Mingachevir record remain management-relevant.

Climate change adds a further layer of uncertainty. Higher temperatures intensify evaporation and can strengthen stratification, while shifts in precipitation and snowmelt affect inflow volume, dilution and pollutant transport (IPCC, 2023). In regulated basins, ecological interpretation should therefore combine water chemistry and microbiology with hydrology, meteorology and remote sensing. Such integration is consistent with contemporary risk-based monitoring, which allocates higher sampling frequency to periods and locations with a greater probability of threshold exceedance.

MATERIALS AND METHODS

Study area and evidence base

Mingachevir Reservoir lies on the Kura River in north-western Azerbaijan, upstream of Mingachevir city and downstream of the Shamkir and Yenikend reservoirs. The reservoir regulates flow toward the Lower Kura and supplies major irrigation canals. The analysed evidence was extracted from the master's dissertation "Investigation of the ecological indicators of Mingachevir Reservoir" (Arifzade, 2023). Four internally coherent datasets were selected: eight-station seasonal microbial observations for 1982 and 2015; nutrient concentrations for 1987–2009; three within-reservoir hydrochemical observations; and three-observation major-ion profiles at six locations from Shikhli to Salyan. Tables lacking numerical content or adequate variable definitions were excluded.

Data harmonization and analysis

Decimal commas were converted to decimal points, units were retained as reported, and station-level values were transcribed without interpolation. For the microbial dataset, seasonal means were recalculated from the eight station values because the reported summer 1982 summary (12.3) was inconsistent with the underlying observations; the reproducible mean is 18.375. Relative difference was calculated as RD = ((M2015 − M1982)/M1982) × 100. Because the original microbial unit was not consistently defined, results are reported as "legacy units" and interpreted comparatively rather than against health standards.

The nutrient series was plotted on a logarithmic axis because values span several orders of magnitude. No formal trend test was applied: the series contains only six irregularly spaced years and may combine changing analytical procedures. For the major-ion profile, the arithmetic mean and observed range were calculated from three values at each location. The within-reservoir matrix included transparency, oxygen saturation, mineralization, chloride and iron. Each variable was standardized as z = (x − mean)/standard deviation solely to visualize relative spatial contrast; raw values remain printed within the heat map.

Interpretation followed a weight-of-evidence approach. A pattern was considered comparatively robust when it was reproduced across stations or aligned with recent peer-reviewed Kura studies. Isolated extreme values were treated as signals requiring verification, not as definitive exceedances. All calculations and figures were produced from the dissertation tables; no values were inferred from photographs or charts.

RESULTS AND DISCUSSION

Seasonal microbial signal

Recalculated seasonal means were higher in 2015 than in 1982 across all seasons (Figure 1). Winter increased from 7.1 to 12.0 legacy units (68.4%), spring from 13.6 to 15.3 (11.9%), summer from 18.4 to 21.9 (19.0%) and autumn from 17.5 to 20.9 (19.3%). The warm-season maximum in both years is consistent with temperature-sensitive microbial activity and longer effective residence time. The large relative winter difference is also important because it suggests that contamination and biological activity cannot be assumed to disappear outside the recreational season.

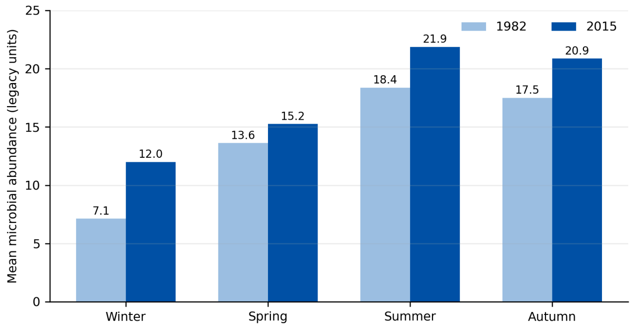

Figure 1. Recalculated seasonal mean microbial abundance at eight Mingachevir Reservoir stations, 1982 and 2015. Source: author's calculations from Arifzade (2023).

The comparison should not be interpreted as a statistically controlled 33-year trend because the record contains only two cross-sections and lacks uncertainty estimates. Nevertheless, the station-consistent increase provides a defensible historical pressure signal. Recent Kura sampling based on total coliforms, E. coli, enterococci and viable counts similarly identifies microbiological contamination as an active management concern (Abduyev et al., 2025). A modern programme should replace undefined aggregate counts with method-specific indicators, detection limits and quality-control blanks.

Nutrient enrichment episodes

The 1987–2009 nutrient record shows substantial temporal variability (Figure 2). Ammonium-N increased from 0.003 mg L−1 in 1987 to 0.25 mg L−1 in 2007 before declining to 0.08 mg L−1 in 2009. Reported nitrite-N rose sharply and remained elevated after 1993, reaching 3.59 mg L−1 in 2007. Phosphorus peaked at 0.80 mg

L−1 in the same year, whereas nitrate-N reached its highest recorded value (0.13 mg L−1) in 2004. The co-occurrence of ammonium and phosphorus maxima in 2007 is compatible with an episodic loading signal, but the magnitude of the nitrite values also raises the possibility of differing laboratory methods, units or transcription conventions.

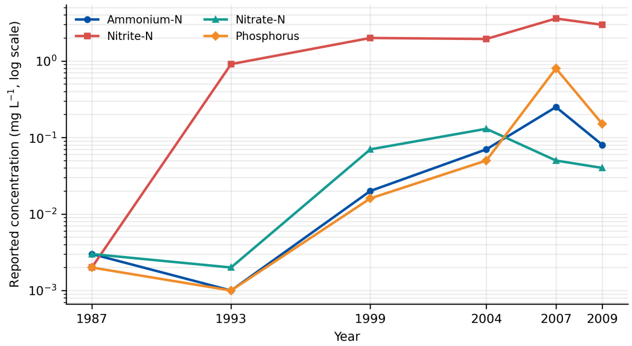

Figure 2. Reported nutrient concentrations in Mingachevir Reservoir, 1987–2009. A logarithmic axis is used because the legacy values span several orders of magnitude. Source: Arifzade (2023).

These uncertainties are scientifically consequential. Without metadata on sampling depth, preservation, analytical method and detection limit, old nutrient values should not be compared mechanically with current regulatory thresholds. Their value is instead diagnostic: they identify nitrogen species and phosphorus as parameters that require renewed, quality-assured sampling. Monthly sampling should be intensified during spring inflow, summer stratification and autumn turnover, with paired surface and near-bottom samples at deep stations.

Longitudinal major-ion pattern

The major-ion sum displayed a clear longitudinal structure (Figure 3). The mean fell from approximately 984 mg L−1 at the Kura–Shikhli station to 655 mg L−1 in Shamkir, 586 mg L−1 in Yenikend and 560 mg L−1 in Mingachevir Reservoir. It then increased to 799 mg L−1 at Zardab and 1,066 mg L−1 at Salyan. The observed range was widest at Shikhli and Salyan, while Mingachevir showed the narrowest range among the six locations. This pattern is consistent with dilution, mixing and retention within the reservoir cascade followed by downstream accumulation from saline groundwater, return flows, evaporation and anthropogenic inputs.

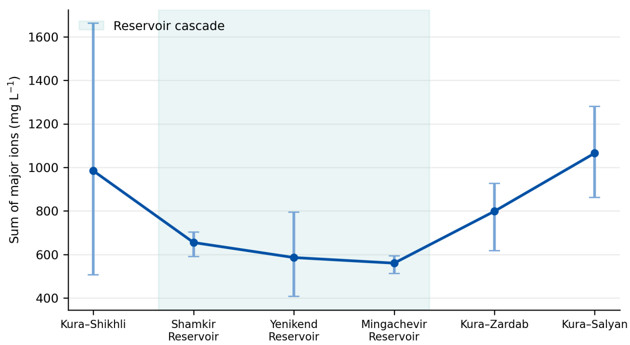

Figure 3. Mean and observed range of the sum of major ions along the Kura–reservoir cascade. Each location contains three legacy observations. Source: author's calculations from Arifzade (2023).

The recent 14-site analysis of Aliyev and Abduyev (2025) strengthens this interpretation by documenting contemporary spatial variability in Kura River major ions and increasing mineralization in downstream reaches. The agreement is notable because the datasets differ in date and sampling design. It supports the use of specific conductance and major ions as low-cost sentinel variables, while isotope or mixing-model work would be needed to separate geological, irrigation-return and wastewater sources.

Table 1. Sum of major ions along the Middle–Lower Kura profile (mg L−1).

Location	Mean	Minimum	Maximum
Kura–Shikhli	984	506	1,662
Shamkir Reservoir	655	590	703
Yenikend Reservoir	586	408	795
Mingachevir Reservoir	560	512	593
Kura–Zardab	799	618	926
Kura–Salyan	1,066	862	1,280

Within-reservoir spatial contrasts

The three-zone snapshot reveals a coherent gradient for several parameters (Figure 4). Transparency decreased from 1.8 near the city-adjacent station to 1.0 in the dense-vegetation zone and 0.5 near the dam. Over the same sequence, mineralization increased from 290 to 450 mg L−1, chloride from 14 to 37 mg L−1 and iron from 0.04 to 0.08 mg L−1. Oxygen saturation was lowest in the dense-vegetation zone (65%) and highest near the dam (92%), illustrating that chemical concentration and oxygen status need not vary in parallel.

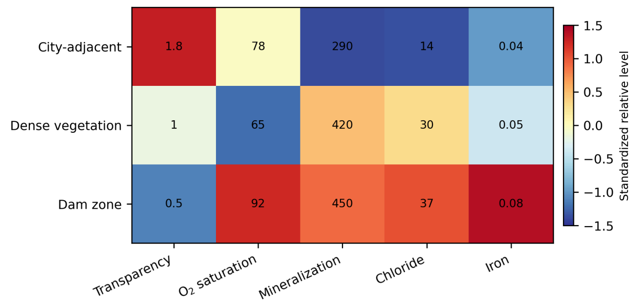

Figure 4. Standardized relative levels of selected hydrochemical indicators across three reservoir zones; cell labels show the original reported values. Source: Arifzade (2023).

Because each zone is represented by one legacy observation, the gradient cannot establish a permanent spatial ranking. It nevertheless provides a practical basis for stratified sampling: an inflow or city-adjacent station, vegetated littoral stations, a deep central station, and dam forebay surface and bottom stations. Sampling only at the dam would miss the lower oxygen signal in vegetated water and would not distinguish local from catchment-scale pressure.

Table 2. Minimum monitoring design proposed for Mingachevir Reservoir.

Component	Core variables	Recommended frequency
Hydrology	Level, inflow, outflow, residence time	Continuous / daily
Field profile	Temperature, pH, EC, DO, turbidity	Monthly; depth-resolved
Nutrients	NH_4-N, NO_2-N, NO_3-N, TN, PO_4-P, TP	Monthly; biweekly in summer
Microbiology	E. coli, enterococci, total coliforms	Monthly; event-based
Major ions	HCO_3^-, SO_4^{2-}, Cl^-, Ca^{2+}, Mg^{2+}, Na+K	Quarterly
Remote sensing	Water extent, turbidity proxy, chlorophyll proxy	Monthly cloud-free scenes

Management implications and limitations

The synthesis points to three management priorities. First, monitoring should be seasonal and depth-resolved. The microbial maximum in warm seasons and the potential for internal loading during stratification or turnover make annual grab sampling inadequate. Second, reservoir observations should be interpreted within the cascade. The decline and subsequent downstream rise in major ions show that an apparent improvement within Mingachevir does not guarantee lower exposure farther downstream. Third, data governance is as important as parameter coverage. Every observation should include coordinates, depth, date and time, hydrological state, method, detection limit, laboratory quality-control information and a stable data identifier.

The principal limitation is the age and heterogeneity of the source data. The study cannot determine the reservoir's current compliance status, estimate causal effects of dam operation, or distinguish changes in environmental conditions from changes in analytical technique. Some original units and sampling protocols were incompletely documented. Recalculation corrects an arithmetic inconsistency but cannot repair missing metadata. The visualized patterns should therefore guide contemporary sampling and hypothesis formation rather than substitute for new field evidence.

A stronger next phase would combine at least two full hydrological years of standardized field measurements with Sentinel-2 or Landsat observations and operational water-level data. Relationships between reflectance-based turbidity or chlorophyll proxies and laboratory measurements should be locally calibrated. Event-based samples after high inflow, wastewater incidents or rapid drawdown would improve attribution. Such a system would connect ecological protection with hydropower, irrigation reliability and treatment-cost reduction, aligning reservoir management with green-economy objectives.

CONCLUSIONS

This study converted dispersed dissertation tables into an integrated hydroecological baseline for Mingachevir Reservoir and the Middle–Lower Kura cascade. Four findings are central. Microbial abundance was higher in 2015 than in 1982 in every season, with the largest relative difference in winter. The nutrient series contained marked enrichment episodes, especially for nitrite and phosphorus, but methodological uncertainty prevents direct regulatory interpretation. The sum of major ions declined through the cascade to a mean of about 560 mg L^{-1} at Mingachevir and then rose downstream to about 1,066 mg L^{-1} at Salyan. Within the reservoir, lower transparency and higher mineralization, chloride and iron were reported toward the dam zone, while the lowest oxygen saturation occurred in dense vegetation.

Recent 2025 studies of Kura River ions and microbial indicators show that these historical pressure categories remain relevant. The appropriate response is not to treat legacy values as contemporary status, but to use them to design a reproducible monitoring network. A minimum system should integrate continuous hydrology, depth-resolved field profiles, nutrients, method-specific microbial indicators, quarterly major-ion analysis and calibrated satellite observations. This combination would allow managers to detect seasonal risk, separate reservoir retention from downstream re-enrichment and target interventions where environmental and economic benefits are greatest.

AUTHOR CONTRIBUTIONS

The author was responsible for conceptualization, data curation, formal analysis, visualization, interpretation, writing—original draft, and writing—review and editing.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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This research received no external funding.

DATA AVAILABILITY

All numerical data analysed in this article are reproduced in the tables and figures or are available in the underlying master's dissertation cited as Arifzade (2023). No new field dataset was generated.

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