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jgeor KURA WATCH 2

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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
Biodiversity, habitat stress and resilience

Sustainable Solutions
Policy, innovation and river management

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KURAWATCH
WATER PROBLEMS 2

Economy · ecology · water security · sustainable development

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Kura Watch 2 is a thematic special issue of the Journal of Green Economy and Optimization Research (JGEOR) dedicated to contemporary water-related challenges affecting the Kura River and its wider basin. The issue brings together interdisciplinary studies examining the interaction between water quality, pollution, aquatic ecosystems, biodiversity, climate pressures, agricultural water use, resource efficiency and sustainable development.

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FOREWORD FROM THE EDITOR-IN-CHIEF

One River, Shared Responsibility

Dear readers,

The **Kura River Basin** is one of the most important transboundary freshwater systems of the South Caucasus and the wider Caspian region. Originating in Türkiye and flowing through Georgia and Azerbaijan before reaching the Caspian Sea, the Kura forms part of a larger basin shared by several countries. Its waters support agriculture, settlements, ecosystems, industry and other economic activities, making the river both an environmental resource and an important element of regional development [1]. At the same time, the basin faces interconnected pressures related to **water quality, pollution, inefficient water use, ecosystem degradation, climate change and growing demand for freshwater resources**. These challenges cannot be considered separately from the social and economic systems that depend on the river. Integrated water resources management therefore requires reliable scientific evidence, effective monitoring, cooperation between stakeholders and a stronger understanding of the relationship between human activity and river ecosystem health [2]. **KuraWatch 2** continues the thematic research initiative of the *Journal of Green Economy and Optimization Research (JGEOR)* by bringing together studies that examine these challenges from environmental, economic and management perspectives. Particular attention is given to water quality, anthropogenic pressures, biodiversity, water security, resource efficiency and approaches that can contribute to more sustainable management of the Kura River and its associated ecosystems.

"Protecting shared waters requires evidence, cooperation, responsible management and decisions that recognize the limits of river ecosystems."

The transboundary character of the Kura makes cooperation especially important. Environmental pressures generated in one part of a river basin may influence ecosystems and communities far beyond administrative and national boundaries. For this reason, sustainable river management depends not only on local interventions but also on shared knowledge, comparable monitoring, institutional cooperation and long-term planning. Scientific research has a central role in this process. Monitoring can reveal where pressures are increasing; ecological and economic assessments can clarify their consequences; and interdisciplinary research can help identify measures that are environmentally effective, economically realistic and socially relevant. Through **KuraWatch 2**, JGEOR aims to provide an academic platform for this evidence and to encourage further discussion on how the Kura River can be managed as a shared natural resource whose ecological condition is closely connected with water security, economic resilience and sustainable development.



Ulvi Mammadov

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

Context sources

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VOLUME 1 · SPECIAL ISSUE 3

Contents

PERPECTIVES AND COMMENTARIES

Public participation in environmental governance: Reflections on MENR Public Council meeting in October 2026 5-6
Zamin Mammadov

RESEARCH ARTICLES

The role of Tugay forests along the Kura River and ecosystem conservation 7-11
Elnur Arifzade· Aynur Mammadova · Toghrul Mammadli

The decline of the Kura River water level and the impacts of climate change, human activity and water management on environment and society in Azerbaijan 12-17
Ismayil Alaskarzada· Ummulbanu Safiyeva

Fish and aquatic biodiversity of the Kura River under pollution, flow alteration and climate pressures 18-22
Elnur Arifzade · Gunay Gojali · Ali Fatalizade · Malak Bashirova · Mahammadali Adigozalov · Rza Gurbanov · Ayla Isgandarli

Diversity of fauna and flora in the areas around the Kura River 23-27
Elnur Arifzade · Aynur Mammadova · Fidan Ibrahimzade

Drought-induced water stress and its effects on plant growth, photosynthesis and productivity 28-33
Ulvi Mammadov · Tunzala Mammadova · Mehdi Allahverdiyev

Ecological pressures on the Kura River and sustainable pathways for pollution control, water conservation and biodiversity protection 34-38
Elnur Arifzade · Aliya Jafarova · Asya B. · Mahira A. · Sadagat M.

The Kura River: Our History, Nature, and Future 39-44
Aliya Jafarova · Bunyamin Huseynli

Mother Kura - Comprehensive information about the Kura River 45-49
Elnur Arifzade · Tunzala Mammadova · Matin Alizade

The main causes of decreasing water levels in the Kura River 50-55
Tunzala Mammadova · Ilham Abdullayev

Riparian flora and fauna diversity along the Kura River and key conservation pressures 56-61
Elnur Arifzade · Gunay Gojali · Firuza Mustafazade

An investigation into the major causes of declining water availability in the Kura River Basin 62-66
Elnur Arifzade · Aynur Mammadova · Narmin Mammadli

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Public participation in environmental governance: Reflections on MENR Public Council meeting in October 2026

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Keywords
public participation; environmental governance; public councils; Azerbaijan; Aarhus Convention

ABSTRACT

This commentary reflects on the 15 October 2026 meeting of the Public Council under Azerbaijan's Ministry of Ecology and Natural Resources. Based on the meeting account, it outlines the Council's review of recent activities, discussion of priorities for late 2026 and 2027, and proposals for further dialogue with ministry bodies. The meeting is considered in light of Azerbaijan's Law on Public Participation, the Aarhus Convention and international open-government guidance. The commentary argues that public councils contribute most effectively when community concerns and local monitoring are translated into documented proposals, institutional responses and publicly accessible follow-up. It offers an agenda for strengthening environmental participation rather than presenting new empirical research or an assessment of policy impacts.

CONTEXT AND PURPOSE

Environmental decisions affect communities, ecosystems and public resources. Meaningful participation therefore requires more than occasional consultation: it requires channels through which environmental observations, civil-society expertise and public concerns can inform official priorities. Public councils can provide such a channel without replacing the responsibilities of government agencies.

On 15 October 2026, the Public Council under the Ministry of Ecology and Natural Resources of Azerbaijan convened to review its activities over the preceding six months and discuss work planned for the final quarter of 2026. The agenda also looked ahead to initiatives proposed for 2027. This article is an event-based policy commentary, not an original empirical study.

ISSUES CONSIDERED AT THE MEETING

Council Chair Mugabil Bayramov opened the meeting and invited members to present proposals. Deputy Chair Amin Mammadov summarised activities undertaken and suggested priorities for the remaining months of 2026 and the following year. Members Imran Abdulov, Zurab Israfilov, Ulvi Mammadov, Yusif Poladov and Elshad Asgarov discussed issues raising public concern and reported information from environmental monitoring undertaken by their respective organisations in different regions of Azerbaijan.

Participants proposed meetings with relevant departments and subordinate bodies of the Ministry so that identified concerns could be communicated directly to institutional leaders and opportunities for cooperation could be explored. They also agreed in principle to meet again toward the end of the year and prepare an overview of the Council's 2026 activities. These are reported discussion points and intentions, not independently verified implementation outcomes.

LEGAL AND INTERNATIONAL FOUNDATIONS

Azerbaijan's Law on Public Participation (Law No. 816-IVQ, 22 November 2013) defines public councils as consultative bodies and provides for public discussion, hearings and other participatory mechanisms. Article 7 authorises councils to gather and present civil-society proposals and, within the applicable legal framework, engage in matters related to environmental assessment. It also provides for informing the public and publishing an annual activity report. Article 8 addresses council meetings, their openness and frequency (Republic of Azerbaijan, 2013).

At the international level, Azerbaijan acceded to the Aarhus Convention on 23 March 2000. The Convention connects environmental protection with access to information, participation in decision-making and access to justice (United Nations, 1998; United Nations Treaty Collection, 2026). OECD guidance similarly distinguishes information, consultation and engagement, and stresses the value of providing feedback on how public input is considered (OECD, 2022). These are relevant benchmarks for evaluating participatory practice, without implying that the OECD guidance is legally binding in Azerbaijan.

PERSPECTIVES ON THE COUNCIL'S ROLE

Mugabil Bayramov, Chair of the Public Council — proposed statement, pending approval: *"A public council should be a consistent forum where citizens' environmental concerns are heard, discussed responsibly and communicated to the relevant authorities. The value of our work lies not simply in holding meetings, but in connecting constructive public proposals with transparent follow-up and practical cooperation."*

Ulvi Mammadov, Council member — proposed statement, pending approval: *"Public participation is most meaningful when local observations and environmental monitoring help shape decisions. Civil-society organisations can bring evidence from different regions, while open dialogue with the Ministry can help turn that evidence into focused recommendations and measurable next steps."*

FROM DIALOGUE TO FOLLOW-UP

The October meeting points to three practical priorities: recording each proposed issue with its supporting evidence; identifying the responsible institution and a realistic response timeline; and reporting back publicly on actions taken or reasons for non-adoption. A concise year-end summary could distinguish completed activities, unresolved issues and proposals carried into 2027. Such documentation would support transparency while preventing meetings alone from being mistaken for demonstrable policy impact.

For example, reports based on regional monitoring could specify the place and date of observation, the type of environmental concern, the supporting material and the relevant authority to be consulted. A shared tracking register could then distinguish issues submitted, examined, responded to and closed. This proposal does not suggest that such a system was adopted at the October meeting; it describes a possible improvement to the follow-up process. The broader ambition is consistent with Sustainable Development Goal target 16.7 on inclusive and responsive decision-making (United Nations, n.d.).



Figure 1. *Participants at the Public Council meeting, 15 October 2026. Photograph supplied for this commentary; publication permission to be confirmed.*



Figure 2. *Discussion during the 15 October 2026 Council meeting. Photograph supplied for this commentary; permission to be confirmed.*

CONCLUSION

The Public Council's 15 October meeting illustrates a practical setting for dialogue between civil society and public institutions on environmental concerns. Its longer-term significance will depend on sustained access to information, an accountable response to proposals and transparent reporting of subsequent actions. Making this feedback loop visible would align national participatory mechanisms with the wider principles of environmental governance.

EDITORIAL AND DISCLOSURE NOTES

The two attributed first-person passages are editorial drafts for the named speakers' review; they are not authenticated quotations and must be approved or replaced before publication. No new dataset was generated. The commentary does not represent an official statement of the Ministry or the Public Council.

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The role of Tugay forests along the Kura River and ecosystem conservation

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Keywords
Kura River, Tugay forests, riparian ecosystems, biodiversity conservation, restoration

ABSTRACT

Tugay forests are river-dependent riparian woodlands that form natural green corridors in arid and semi-arid landscapes. This study examines the ecological role, principal pressures, and conservation needs of Tugay forests along the Kura River in Azerbaijan, with particular attention to the Garayazi forest landscape. The research was developed from an original student project based on official online sources, scientific literature, visual materials, and qualitative comparison of past and present ecosystem conditions. The findings show that Tugay forests support biodiversity, stabilize riverbanks and soils, regulate local microclimatic conditions, and provide opportunities for recreation, environmental education, and scientific observation. The reviewed evidence also identifies tree cutting, excessive grazing, land conversion, hydrological alteration, pollution, intensive water use, drought, and climate-related stress as interconnected pressures that can weaken forest regeneration and fragment riparian habitats. Recent studies of Azerbaijan's Tugay ecosystems reinforce the importance of hydrological regime, groundwater conditions, alluvial soils, and native vegetation in maintaining ecosystem integrity. The analysis therefore supports an integrated conservation approach combining protection of existing forest stands, restoration with suitable native species, environmental-flow and water-management considerations, pollution control, grazing management, long-term monitoring, and environmental education. Tugay conservation is also relevant to the green economy because these forests function as natural infrastructure that supports biodiversity, erosion control, landscape quality, and the resilience of water- and land-dependent activities.

INTRODUCTION

Riparian forests are among the most important ecological interfaces in river basins because they connect flowing water, groundwater, floodplains, soils, and terrestrial habitats. In arid and semi-arid landscapes, this role is particularly visible in Tugay forests, which develop as narrow woodland belts along rivers and floodplains where water availability is higher than in the surrounding dry landscape. The original research project on which this article is based identified these forests as natural green corridors along the Kura River and emphasized their importance for wildlife, riverbank protection, and the wider ecological balance of Azerbaijan.

The Kura River is one of the principal water systems of Azerbaijan and supports settlements, agriculture, reservoirs, aquatic habitats, and riparian vegetation. Along parts of its valley, Tugay forests contain combinations of poplar, willow, elm, alder, tamarisk, oak, and shrub communities whose composition varies with hydrological regime, groundwater depth, soil conditions, salinity, and human disturbance. Recent field research confirms that Azerbaijani Tugay forests have a multilayered vegetation structure and high ecological value, while also showing sensitivity to grazing, deforestation, hydrological alteration, and other anthropogenic pressures (Gurbanov et al., 2026).

The student project also placed the Garayazi forest landscape at the center of the discussion. This is appropriate because Garayazi represents one of the best-known remaining Tugay forest areas along the Kura. Official information describes the reserve as a protected area established for the conservation and restoration of Kura Tugay forests, while botanical research has documented substantial plant diversity and changes in vegetation where forest removal, drying, and reduced soil moisture have occurred (Bayramova, 2023). These observations show that Tugay conservation is not only a question of tree cover; it depends on the maintenance of the river–floodplain–groundwater relationships that sustain the forest.

Accordingly, this study aims to preserve and develop the original student investigation by addressing three questions: What ecological functions do Tugay forests perform along the Kura River? Which natural and human pressures threaten their condition and regeneration? Which conservation and restoration measures are most consistent with the evidence available for Azerbaijan? The study also considers how the ecosystem services provided by Tugay forests can be interpreted within the broader context of sustainable resource use and green economic resilience.



Figure 1. The Kura River and its riparian Tugay forests. Source: original student research project.

LITERATURE REVIEW

2.1. Ecological characteristics of Tugay forests

Tugay forests are intrazonal riparian ecosystems: their existence is determined less by the general climate of the surrounding region than by access to river water, floodplain moisture, and shallow groundwater. Gurbanov et al. (2026) found clear ecological differentiation among Tugay forest formations in Azerbaijan according to hydrological regime, groundwater conditions, and soil salinity. Their study identified vegetation groups dominated by Populus, Salix, Ulmus, Alnus, and Tamarix, demonstrating that the Kura basin contains structurally complex riparian communities rather than a single uniform forest type.

This hydrological dependence helps explain why Tugay forests can be highly vulnerable to changes in river regulation. Reduced floodplain inundation, declining groundwater levels, or prolonged drought can limit seedling establishment and natural regeneration even where mature trees remain. Ahmadova (2026) therefore argues that restoration should not be treated as ordinary afforestation. Effective recovery requires attention to environmental flows, floodplain connectivity, groundwater, native species, and adaptive monitoring. This process-based interpretation strengthens the central argument of the original project: forest protection must be linked to responsible water and soil management.

2.2. Evidence from Garayazi and other Kura riparian forests

The Garayazi State Nature Reserve provides a locally important example. Bayramova (2023) recorded 379 species of vascular plants in the reserve and also documented rich lichen and moss diversity. The study found that the species composition of forest areas changed where tree removal was followed by drying and lower soil moisture. The student project correctly used this evidence to show that forest disturbance can alter ecological conditions beyond the immediate loss of individual trees.

Research farther downstream also supports this interpretation. Qurbanov and Ahmadova (2024) examined riparian forests along the Kura River in the Agjabadi district and described Poplar–Willow–Tamarisk formations on alluvial-meadow soils. They noted that conversion of riparian areas to agricultural land can contribute to salinization and desertification and emphasized the importance of scientifically informed restoration. Together, the Garayazi and Agjabadi evidence indicates that Tugay forests should be understood as hydrologically connected landscape systems whose conservation depends on both vegetation protection and the physical condition of the river corridor.



Figure 2. Characteristics of Tugay forests and their distribution along the Kura and Araz rivers. Source: original student research project.

2.3. Ecosystem services and natural-capital relevance

The ecological functions identified in the student project can also be interpreted as ecosystem services. Riverbank stabilization reduces erosion risk; riparian vegetation provides habitat and ecological connectivity; shade and evapotranspiration influence local microclimates; and intact forest corridors improve landscape quality for recreation, education, and research. These functions represent forms of natural infrastructure because they support ecological stability without requiring a fully engineered substitute. In a green-economy context, protecting such functions can reduce future restoration needs and strengthen the resilience of water- and land-dependent activities.

MATERIALS AND METHODS

This study used a structured qualitative review design based on the original research project prepared by Togrul Mammadli in September 2026. The source project combined three methods: online research using official information about Tugay forests and the Garayazi State Nature Reserve; review of scientific literature concerning plant diversity, ecosystem functions, and threats; and comparison of scientific findings with information from official sources. The present manuscript retains that research design and develops it into an academic article format.

The source material was organized into four analytical themes: (1) characteristics and distribution of Tugay forests; (2) ecological functions; (3) natural and anthropogenic pressures; and (4) conservation and restoration responses. The original visual materials and qualitative comparison table were retained because they form part of the student's research presentation. The five original figures are used as conceptual and illustrative evidence rather than as independent quantitative datasets.

To strengthen the literature base, the original references were reformatted in APA 7th edition style and supplemented with recent peer-reviewed research on the Kura and Araz riparian forests. Particular attention was given to distinguishing measured scientific findings from general or schematic statements. The original project explicitly noted that its past–present comparison did not provide a consistent historical forest-inventory dataset. Accordingly, no unsupported hectare losses or percentage declines are introduced in this article. The study is a literature-based ecological synthesis and does not involve new field sampling, experiments, or statistical testing.

RESULTS AND DISCUSSION

4.1. Characteristics and distribution of Tugay forests along the Kura

The original research identifies Tugay forests as riparian woodlands that occur in river valleys and floodplains under the influence of surface water and groundwater. Along the Kura, characteristic woody vegetation includes white poplar, willow, oak, alder, and various shrubs. Recent field evidence provides a more detailed botanical basis for this description. Gurbanov et al. (2026) reported multiple Tugay formation groups across the Kura basin and showed that vegetation structure differs with moisture and salinity conditions. Qurbanov and Ahmadova (2024) similarly documented Poplar–Willow–Tamarisk communities in the Agjabadi section of the Kura corridor.

The visual synthesis in Figure 2 captures an important spatial idea from the student project: Tugay forests should be viewed as elongated ecological corridors associated with the Kura–Araz river system rather than isolated forest patches. Corridor continuity matters because wildlife movement, seed dispersal, riverbank stability, and habitat connectivity all depend on the relationship between separate riparian fragments. Fragmentation can therefore reduce ecological function even before complete forest loss occurs.

4.2. Biodiversity, soil protection, microclimate, and educational value

Four ecological roles were emphasized in the student research and are retained in Figure 3. First, Tugay forests provide habitat and feeding areas for birds, mammals, reptiles, insects, and plant communities. Second, their root systems bind riverbank soils and can reduce erosion, while vegetation slows surface runoff and supports soil structure. Third, shade and evapotranspiration can create cooler and more humid conditions within the forest than in surrounding open landscapes. Fourth, Tugay corridors have cultural, educational, recreational, and scientific value because they provide accessible settings for observing river ecology.

These functions are mutually reinforcing. For example, bank stabilization helps maintain riparian habitat, while intact vegetation can improve the conditions required for natural regeneration. The biodiversity value documented in Garayazi is particularly important: Bayramova (2023)

reported hundreds of vascular plant species and substantial cryptogam diversity, indicating that the conservation value of these forests extends well beyond the dominant tree layer. This supports the student project's conclusion that protecting the forest cover helps maintain food webs and broader ecosystem relationships.



Figure 3. Ecological role of Tugay forests in biodiversity conservation, soil and riverbank protection, climate regulation, recreation, and education. Source: original student research project.

4.3. Main pressures and qualitative evidence of ecosystem decline

The student project identifies five main pressure groups: deforestation, overgrazing, changes in river flow and water use, pollution, and climate change. This framework is consistent with recent literature. Gurbanov et al. (2026) identify grazing, deforestation, and hydrological alteration as major drivers of degradation, while Ahmadova (2026) highlights reduced floodplain inundation, groundwater decline, grazing pressure, land conversion, and technogenic impacts. The agreement between the student synthesis and recent research indicates that Tugay degradation should be understood as a multi-driver process.

Tree cutting and agricultural conversion directly reduce forest cover. Overgrazing can suppress young tree recruitment and compact soils, slowing recovery. Water abstraction and river regulation can alter the moisture regime on which floodplain forests depend. Pollution from household waste, untreated wastewater, and agricultural chemicals can degrade river and riparian habitat quality. Finally, drought and rising climatic stress can weaken already fragmented stands. These pressures can interact; for example, a forest exposed to both reduced moisture and grazing may have less capacity to regenerate after disturbance than a forest affected by either pressure alone.



Figure 4. Main threats to Tugay forests identified in the original project: deforestation, overgrazing, hydrological change, pollution, and climate-related stress. Source: original student research project.

The source project also included a schematic comparison of past and present conditions (Figure 5). This image is useful as a conceptual representation of the direction of change reported in the literature, but it should not be interpreted as a measured time series. The original author explicitly cautioned that the illustration does not constitute official forest-inventory data. This distinction is important for research integrity: qualitative evidence can identify plausible trends and mechanisms without supporting precise claims about area loss or rates of decline.

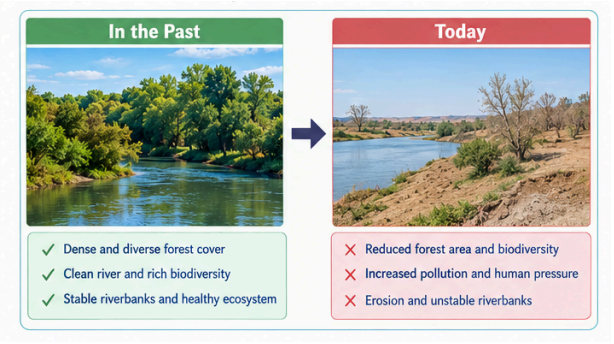


Figure 5. Schematic comparison of past and present Tugay forest conditions. The visual is qualitative and should not be treated as official forest-inventory data. Source: original student research project.

Table 1. Qualitative comparison of Tugay forest conditions retained from the original student research

Indicator	Past period (approx. 1960–1980)	Present period (2020–2025)	Assessment
Integrity of forest cover	Relatively extensive and connected	Thinning and fragmentation in some locations	Trend towards decline
Natural regeneration	More favourable where the water regime was suitable	Drought, grazing, and soil changes may weaken regeneration	Pressure has increased
Plant diversity	Natural plant communities across the area	Species composition may change in disturbed areas	Varies by location
Riverbank erosion	Dense root systems helped stabilise the banks	Areas with reduced vegetation are more vulnerable	Risk may increase
Human impact	More limited in some areas	Land use, water abstraction, and pollution exert pressure	Impact may intensify

Table 1 preserves the qualitative comparison developed in the original research. Its value is not in providing precise historical measurements but in organizing a set of ecological expectations that can be tested with future monitoring. The table suggests that loss of forest connectivity, weaker regeneration, altered species composition, greater erosion exposure, and increasing human pressure are linked outcomes. A scientifically stronger future version of this comparison would require repeated forest-cover mapping, permanent vegetation plots, groundwater measurements, river-flow records, and consistent indicators collected across the same locations and seasons.

4.4. Conservation and restoration priorities

The student project proposed seven practical measures: stronger protection against illegal tree cutting; restoration with native tree and shrub species; management of excessive grazing; prevention of waste and untreated wastewater discharge; consideration of the water regime required by Tugay vegetation; regular monitoring of forest cover, species, erosion, and water quality; and environmental education in schools and communities. These proposals remain well aligned with the recent scientific literature.

However, restoration should be sequenced according to the dominant ecological pressure. Where hydrological disconnection is the principal problem, planting alone is unlikely to succeed without adequate floodplain moisture or groundwater. Where grazing prevents recruitment, temporary exclusion and protection of young vegetation may be required. Where pollution is severe, water-quality improvement should accompany habitat restoration. Ahmadova (2026) similarly recommends a driver-based restoration logic that links pressures to ecological processes, measurable indicators, and appropriate interventions.

Monitoring is essential because restoration success cannot be judged by planting numbers alone. Useful indicators include survival and regeneration of native trees and shrubs, canopy and understory cover, continuity of riparian habitat, groundwater depth, bank erosion, water quality, and evidence of repeated disturbance. Remote sensing can help identify changes in forest extent and fragmentation, while field surveys are needed to confirm species composition and regeneration status. Combining both approaches would directly address the evidence gaps recognized in the original student project.

4.5. Relevance to ecosystem services and the green economy

The importance of Tugay forests extends beyond biodiversity conservation. Riverbank protection, soil stabilization, habitat connectivity, local climate regulation, recreational value, and landscape quality are ecosystem services that contribute to human well-being and the resilience of economic activities. In this sense, Tugay forests are a form of natural capital. Degradation can increase future costs by creating greater demand for erosion control, habitat restoration, water-quality management, and landscape rehabilitation.

Conservation therefore has a resource-efficiency dimension. Maintaining natural riparian functions can complement engineered river management and reduce the need to replace lost ecosystem services after degradation occurs. Restoration projects can also support environmental education, ecological monitoring, native-plant production, and low-impact recreation. The green-economy value of Tugay forests should not be reduced to a single monetary estimate; rather, it lies in maintaining ecological functions that underpin long-term water, land, and community resilience.

4.6. Protected-area management, community stewardship, and monitoring

The Garayazi landscape illustrates why protected areas can act as conservation anchors for the wider Kura riparian corridor. A reserve can protect a core area of Tugay vegetation, but ecological processes do not stop at administrative boundaries. Groundwater conditions, river flow, grazing pressure, pollution, and land use in surrounding areas can influence the condition of protected forest stands. This means that reserve management should be linked with broader river-basin planning and with the condition of adjacent floodplain habitats. The original project's emphasis on protection rules, restoration, and monitoring is therefore most effective when these actions are coordinated rather than implemented as isolated measures.

Community stewardship is another important part of this approach. The student project recommended environmental education in schools and local communities and proposed involving students in nature-conservation activities. Such participation can support formal management by improving awareness of illegal dumping, tree cutting, uncontrolled grazing, and other visible pressures. School-based monitoring cannot replace professional ecological surveys, but it can build long-term environmental literacy and encourage careful observation of changes in vegetation, riverbanks, and waste accumulation. This is particularly relevant for a river system whose conservation depends on decisions made by many users across a large geographic area.

A practical monitoring framework could combine several levels of evidence. Satellite imagery can be used to track changes in forest extent, fragmentation, and vegetation condition over time. Field surveys can then verify species composition, regeneration, canopy cover, and signs of grazing or cutting. Hydrological observations are needed to understand whether areas of weak regeneration correspond to reduced floodplain inundation or changes in groundwater. Water-quality measurements can identify whether pollution is an additional stressor. When these datasets are collected repeatedly at the same locations, conservation managers can distinguish short-term seasonal variation from longer-term ecosystem change.

Monitoring should also be connected directly to restoration decisions. For example, low seedling survival may indicate that planting density or species selection is inappropriate, but it may also signal that water availability is insufficient or grazing remains uncontrolled. Similarly, increased bank erosion may reflect loss of vegetation, altered flow, or both. Adaptive management requires managers to use monitoring results to revise interventions rather than simply repeating the same activity. This approach is consistent with the restoration principles proposed by Ahmadova (2026) and provides a scientific extension of the student project's recommendation to compare ecological indicators across years.

4.7. Research limitations and priorities for future evidence

The main limitation of the present study is its reliance on secondary information and qualitative comparison. The original project was designed as a student investigation and did not include permanent vegetation plots, laboratory water analysis, groundwater monitoring, or a georeferenced forest inventory. The figures summarize ecological concepts and reported pressures but do not constitute independent measurements. The past–present comparison is therefore best interpreted as a hypothesis-generating framework rather than a quantitative reconstruction of Tugay forest change.

A second limitation concerns spatial variation. Conditions in Garayazi cannot automatically be generalized to every section of the Kura River. The basin contains different soils, climatic conditions, levels of water regulation, land-use patterns, and vegetation communities. Recent research demonstrates that Tugay formations differ across Azerbaijan in response to hydrology, groundwater, and salinity (Gurbanov et al., 2026). Future studies should therefore compare several river sections using the same field protocol, allowing local differences to be separated from basin-wide patterns.

A third research priority is the development of measurable restoration criteria. Future work could record native seedling density, survival rates, canopy continuity, vegetation-layer structure, invasive or disturbance-tolerant species, soil moisture, groundwater depth, bank-erosion indicators, and water-quality variables. Where reliable historical imagery is available, remote-sensing analysis could quantify forest-cover change and fragmentation. These measurements would make it possible to evaluate whether restoration is recovering ecosystem function rather than only increasing the number of planted trees.

Finally, future research could assess ecosystem services in a way that connects ecological condition with practical decision-making. This may include non-monetary indicators such as erosion protection, habitat connectivity, recreational use, educational value, and resilience of adjacent land uses. Where appropriate, economic valuation could later estimate avoided restoration or erosion-control costs. Such work would strengthen the link between Tugay conservation and green-economy planning while keeping biodiversity and ecosystem integrity as the primary objectives.

CONCLUSIONS

This study confirms the central conclusion of the original student research: Tugay forests along the Kura River are ecologically significant riparian systems whose conservation depends on the interaction of vegetation, water regime, soils, biodiversity, and human activity. The forests provide habitat, stabilize riverbanks, influence local microclimates, and create educational, recreational, and scientific value. Evidence from Garayazi and other Kura riparian areas supports the importance of these functions and shows that Tugay communities can contain substantial botanical diversity.

The principal threats are interconnected. Deforestation, agricultural conversion, grazing, hydrological alteration, pollution, intensive water use, drought, and climate-related stress can jointly weaken forest regeneration and fragment habitat. Conservation should therefore combine protection of existing stands with native-species restoration, appropriate grazing management, pollution control, hydrological considerations, long-term monitoring, and environmental education. The qualitative figures and comparison table retained from the original project provide a useful

framework for understanding these relationships, but they are not substitutes for standardized forest-inventory data.

Future research should establish repeatable monitoring sites along the Kura River and combine remote sensing with field-based vegetation, groundwater, erosion, and water-quality measurements. Such evidence would allow changes in Tugay condition to be quantified over time and would support stronger evaluation of restoration investments. Protecting Tugay forests should ultimately be understood as both biodiversity conservation and investment in natural infrastructure that contributes to sustainable water and land management in Azerbaijan.

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The decline of the Kura River water level and the impacts of climate change, human activity and water management on environment and society in Azerbaijan

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Keywords
Kura River, climate change, water scarcity, water quality, water management

ABSTRACT

The Kura River is a transboundary water system whose quantity, quality, and ecological condition are closely connected to water security in Azerbaijan. This study develops an original school research project into a structured academic synthesis of the interacting causes and consequences of declining water availability in the Kura River. The analysis is based on secondary research using government and international reports, scientific literature, maps, photographs, and recent peer-reviewed studies. Three research questions guide the paper: how climate change, human activity, and water-management systems influence water availability; how pollution affects ecosystems and human use of the river; and why Tugay riparian forests are important for ecological resilience. The evidence indicates that water scarcity should not be attributed to a single driver. Climatic variability, drought and evaporative demand interact with irrigation withdrawals, conveyance losses, reservoir regulation, pollution, and transboundary management constraints. Water-quality deterioration further reduces the effective availability of water suitable for drinking, irrigation, ecosystems, and recreation. Riparian Tugay forests provide bank stabilization, habitat connectivity, and landscape functions, but depend on appropriate flow and groundwater conditions. The study concludes that efficient irrigation, leakage reduction, wastewater treatment, monitoring, ecosystem restoration, nature-based solutions, and basin-scale cooperation should be pursued together. These measures also have green-economy relevance because they protect natural capital, reduce avoidable resource losses, and strengthen the resilience of agriculture and water-dependent communities.

INTRODUCTION

Freshwater availability is determined by more than the physical volume of water in a river. Reliability across seasons, water quality, infrastructure performance, ecological condition, and the ability of institutions to allocate and protect the resource all influence whether water can meet human and environmental needs. These dimensions are especially important in transboundary basins, where upstream climate conditions, storage, abstraction, wastewater discharge, and land use can influence downstream users. The Kura River is therefore both a hydrological system and a socio-economic resource whose condition affects agriculture, settlements, energy production, biodiversity, and local livelihoods in Azerbaijan.

The original research project by Safiyeva (2026) examined the decline of the Kura River water level through three connected questions. First, it considered how climate change, human activity, and water-management systems contribute to reduced water availability and what consequences follow for society and the environment. Second, it examined pollution sources and their effects on biodiversity and human health. Third, it investigated the ecological role of Tugay forests along the Kura and the measures required for their preservation. This three-part structure is retained in the present article because it captures the interaction between water quantity, water quality, and riparian ecosystem condition.

The student project correctly recognized that the problem cannot be explained by climate change alone. Recent technical assessments likewise describe Azerbaijan as highly dependent on transboundary surface-water inflows and identify irrigation demand, infrastructure inefficiency, reservoir regulation, pollution, and climatic stress as important water-security pressures (World Bank, 2024). Monitoring of the Kura in Azerbaijan also demonstrates that water quality changes markedly along the river, with increasing mineralization and major-ion shifts toward the lower reaches (Aliyev & Abduyev, 2025). These findings reinforce the need to separate, but also jointly assess, water quantity and water quality.

The objective of this study is to preserve and academically develop the student's original analysis while distinguishing documented evidence from illustrative or historical claims. The paper evaluates the principal drivers of declining water availability, discusses environmental and socio-economic consequences, examines pollution and Tugay forest degradation, and identifies integrated management responses. Particular attention is given to green-economy implications, including resource efficiency, natural capital, nature-based solutions, environmental monitoring, and the resilience of water-dependent economic activities.



Figure 1. Map of the Kura River Basin retained from the original student research project. Source: EU Water Initiative Plus (EUWI+ East).

LITERATURE REVIEW

2.1. Climate variability, river flow, and water availability

The Kura River's flow regime is influenced by precipitation, snow accumulation and melt, temperature, tributary inflows, reservoir storage, and water withdrawals. The original project cited earlier climate scenarios showing strong warming and precipitation changes for Azerbaijan. Those values are useful as evidence of how climate risk was framed in earlier assessments, but they should not be treated as current forecasts because they were based on older emissions scenarios. A more robust interpretation is that higher temperature can increase evaporative demand, while changes in precipitation and snowmelt can alter both the quantity and timing of runoff. The consequences of these changes depend on how reservoirs, irrigation systems, and water allocation operate during wet and dry periods.

The World Bank (2024) describes water scarcity in Azerbaijan as a combined institutional, infrastructure, and resource-management challenge. Its assessment highlights the country's dependence on transboundary flows and the need to improve irrigation efficiency, water accounting, infrastructure, and institutional coordination. This is consistent with the student project's central argument that climatic stress can be amplified when irrigation losses and weak coordination increase the amount of water that must be abstracted to meet a given demand.

2.2. Water quality as a component of usable water availability

Declining water quality does not necessarily reduce river discharge, but it can reduce the effective quantity of water suitable for drinking, irrigation, industry, recreation, or ecosystem functions. Aliyev and Abduyev (2025) analysed Kura River samples collected during 2020–2022 and reported a strong downstream increase in mineralization and major-ion concentrations. Their work provides direct monitoring evidence that river chemistry changes substantially between the Georgian border and the lower Kura.

Reservoir-scale evidence adds another layer to this picture. Arifzade (2026) synthesized nutrient, microbial, and major-ion records from Mingachevir Reservoir and the Middle Kura cascade, demonstrating the value of bringing dispersed monitoring evidence together when assessing hydroecological pressure. For the present study, this supports an important distinction: physical water scarcity, chemical deterioration, and ecological stress are different processes, yet all can reduce water security when they occur simultaneously.

Pollution pathways extend beyond dissolved ions and conventional wastewater indicators. Mammadov et al. (2026) reviewed microplastic pollution and coastal anthropogenic pressure in the Caspian Sea basin, highlighting the wider downstream context into which river-borne waste and pollutants may ultimately be transferred. The Kura should therefore be understood not only as an inland water resource but also as part of a connected river–reservoir–Caspian system.

2.3. Tugay forests, ecosystem services, and nature-based solutions

The student project identified Tugay forests as natural green corridors that stabilize riverbanks, support biodiversity, and depend on seasonal flooding and shallow groundwater. Recent research confirms that Azerbaijan's riparian Tugai forests are hydrologically dependent ecosystems with complex vegetation structure and high biodiversity value (Gurbanov et al., 2026). Ahmadova (2026) further emphasizes that successful restoration requires recovery of the river–floodplain–groundwater processes that enable long-term regeneration, rather than tree planting alone.

This ecological interpretation is closely related to nature-based solution and green-finance approaches. Qadimli and Mammadov (2026b) used remote sensing to prioritize nature-based solutions and green-finance needs for ecosystem restoration in Shahdag National Park, illustrating how spatial evidence can support investment decisions for ecological recovery. Their framework is relevant to the Kura corridor because riparian restoration can similarly be treated as investment in natural infrastructure that protects soils, biodiversity, landscape quality, and ecosystem resilience.

Green-economy value can also emerge through low-impact recreation, education, and tourism when ecological limits are respected. Qadimli and Mammadov (2026a) connected ecosystem sustainability, ecotourism, and green finance in Akhar-Bakhar National Park, while Qadimli et al. (2026) mapped blue-green tourism potential in the Central Aran region and identified high water-related suitability around the Mingachevir Reservoir and Kura corridor. These studies do not imply that tourism should be prioritized over water security or conservation; rather, they demonstrate that healthy river landscapes can generate additional social and economic value when ecosystem protection remains the primary condition.

MATERIALS AND METHODS

This study used a structured qualitative secondary-research design. The primary source was the 2026 research project prepared by Ummulbanu Safiyeva at European Azerbaijan School. The original project reviewed reports and publications from government institutions, environmental organizations, scientific studies, educational sources, maps, photographs, and other online materials. It did not conduct laboratory analysis, hydrological measurement, field sampling, or a primary survey. The present manuscript therefore treats the source project as a literature-based synthesis rather than an empirical monitoring study.

The original material was reorganized around three analytical themes corresponding to the student's research questions: (1) climate, human activity, and water-management pressures on

water availability; (2) pollution, biodiversity, and human-use risks; and (3) Tugay forest functions and conservation. A fourth cross-cutting theme—green-economy and resource-efficiency implications—was added to connect the evidence to the scope of the Journal of Green Economy and Optimization Research.

All four substantive visual materials from the student project were retained. Figure 1 presents the Kura basin, Figure 2 documents visibly low water conditions, Figure 3 shows the river at Salyan, and Figure 4 illustrates another low-water condition. These images are treated as contextual visual evidence and not as quantitative measurements. The source project's older scenario values and broad pollution percentages were also handled cautiously: they are discussed as claims or historical assessments where relevant, but are not repeated as current measured conditions unless supported by recent evidence.

The reference list was converted to APA 7th edition style and strengthened with recent peer-reviewed studies and technical reports. The review prioritized evidence on Kura water quality, Mingachevir hydroecology, Tugay forest ecology, water-sector efficiency, nature-based restoration, blue-green development, and Caspian pollution. No new statistics were calculated from the photographs or maps, and no causal contribution was assigned to an individual pressure where the reviewed evidence did not support such attribution.

RESULTS AND DISCUSSION

4.1. Interacting drivers of declining water availability

The student research identifies climate change, human water use, and water-management systems as interacting drivers of declining Kura water availability. This remains the most defensible overall interpretation. Climate-related reductions in runoff or higher evaporative demand can decrease natural supply, while irrigation withdrawals and conveyance losses increase pressure on the water that remains. Reservoirs can redistribute flow across seasons, and poorly coordinated abstraction can intensify shortages during low-flow periods. The combined outcome depends on location and time; therefore, a single basin-wide percentage cannot be assigned to climate change, irrigation, or reservoirs without matched hydrological and water-use data.

The original project gave particular attention to irrigation inefficiency, water-supply losses, and the challenge of balancing supply and demand. These points align with the World Bank's 2024 assessment, which calls for stronger water-sector institutions, improved monitoring and accounting, and more efficient irrigation and service delivery. From a green-economy perspective, efficiency matters because avoidable conveyance losses represent both environmental pressure and economic waste: more water must be diverted, pumped, stored, or treated to deliver the same useful quantity to end users.

The student project also documented the contrast between flood risk in 2010 and severe low-water concern in 2020. This contrast is analytically important because it shows why river management must address variability rather than only long-term averages. Infrastructure and institutions must cope with both excess water and scarcity. Drought preparedness, seasonal storage, transparent allocation, and environmental-flow considerations are therefore complementary rather than competing objectives.



Figure 2. Visibly low water conditions along the Kura River, retained from the original student research project. Source: AZERTAG, as cited in the source project.

4.2. Environmental, social, and economic consequences

Reduced water availability can affect households, farms, ecosystems, and local economies at the same time. The source project emphasizes risks to crop production, food security, access to clean water, and biodiversity. These linkages are particularly relevant in irrigated landscapes, where lower supply during hot and dry periods may coincide with peak agricultural demand. Water scarcity can also increase competition among users and make existing infrastructure losses more costly.

The economic significance of the Kura is broader than irrigation alone. Qadimli et al. (2026) show that the Kura River–Mingachevir Reservoir corridor has blue-green tourism and recreation potential in the Central Aran region. This means that degraded water quality, shoreline condition, or riparian habitat can reduce not only ecological value but also opportunities for recreation and local green development. Conversely, water-security investments that improve ecological condition may create co-benefits for landscape quality, environmental education, and low-impact tourism.

These relationships support a natural-capital interpretation of river management. Water, wetlands, riparian forests, and river landscapes provide services that would be costly or impossible to replace fully through engineered infrastructure. Protecting those assets can therefore be understood as a form of preventive economic policy rather than as an environmental expense isolated from development.

4.2.1. Integrated pressure–response framework

Taken together, the reviewed evidence identifies five linked management priorities. Climate variability and drought require adaptive allocation, drought planning, storage efficiency, and climate-resilient agriculture. Irrigation demand and distribution losses require modernization, leakage reduction, scheduling, and transparent water accounting. Wastewater and agricultural runoff require treatment, nutrient management, monitoring, and pollution prevention. Reservoir and flow regulation require integrated operation with attention to downstream ecological needs. Riparian degradation requires Tugay restoration and nature-based solutions that protect natural infrastructure.

The value of this framework is that each intervention can generate benefits across more than one sector. Irrigation modernization can reduce unnecessary abstraction; wastewater treatment can improve

both public-health protection and ecosystem condition; and riparian restoration can simultaneously strengthen biodiversity, riverbank stability, and landscape quality. This integrated logic is more consistent with green-economy planning than isolated single-sector responses because it treats water, ecosystems, and economic activity as connected components of the same river system.

4.3. Pollution, water quality, and downstream connectivity

The original project identifies untreated industrial wastewater, municipal sewage, agricultural runoff, and mining activity as major pollution pathways. Recent monitoring provides stronger evidence for the broader concern. Aliyev and Abduyev (2025) documented pronounced downstream changes in mineralization and major-ion composition along the Kura in Azerbaijan. The study does not support attributing every chemical change to pollution alone because tributary inflows, groundwater interactions, salinity, and natural hydrochemistry also contribute; however, it confirms that water quality varies substantially along the river and requires sustained monitoring.

Arifzade (2026) reaches a complementary conclusion at reservoir scale by synthesizing nutrient, microbial, and major-ion evidence for Mingachevir Reservoir. Together, these studies show why monitoring programs should integrate flow, chemistry, microbial indicators, and land-use pressures. Concentration data alone cannot establish pollutant load, and water-quality deterioration cannot automatically be used as proof of lower discharge. Matching water-quality observations with flow records would allow future research to distinguish concentration effects from changes in total pollutant transport.



Figure 3. Kura River at Salyan, Azerbaijan, retained from the original student research project. Source: Encyclopaedia Britannica, as cited in the source project.

The downstream connection to the Caspian Sea increases the significance of pollution prevention. Mammadov et al. (2026) show that the Caspian basin is exposed to growing anthropogenic pressure from waste, urbanization, transport, tourism, and recreational activity, with microplastics emerging as an additional concern. River-borne material is only one part of this regional pollution system, but the Kura's role as a major inflow means that improved solid-waste management, wastewater treatment, and catchment monitoring can contribute to both river and coastal environmental objectives.

4.4. Tugay forests as ecological buffers and natural infrastructure

The student project's third research question focuses on Tugay forests, and this component materially strengthens the article because it connects water management with riparian ecology. The source correctly emphasizes bank stabilization, erosion control, biodiversity, and dependence on seasonal flooding and shallow groundwater. Recent ecological research confirms that Tugai forests in Azerbaijan are structured by hydrology, soils, salinity, and disturbance, and that river regulation, abstraction, grazing, and land conversion can reduce their integrity (Gurbanov et al., 2026; Ahmadova, 2026).

These forests can be understood as natural infrastructure. Their root systems help stabilize alluvial banks; vegetation provides habitat and ecological connectivity; and riparian cover contributes to landscape quality and local microclimatic regulation. When floodplain moisture declines or vegetation is repeatedly removed, these services weaken and the cost of restoration may increase. The logic of nature-based solutions developed by Qadimli and Mammadov (2026b) is therefore relevant: spatially targeted restoration can direct limited financial resources toward locations where ecological recovery generates the greatest combination of biodiversity, erosion-control, and resilience benefits.

The green-finance and ecotourism framework proposed for Akhar-Bakhar National Park by Qadimli and Mammadov (2026a) also offers a useful caution. Economic use of natural landscapes is sustainable only when visitor access, infrastructure, and investment are compatible with ecosystem sensitivity. Applied to the Kura corridor, restoration should prioritize ecological function first, with recreation or tourism treated as a secondary co-benefit rather than the primary objective.



Figure 4. River and riparian landscape retained from the original student research project as an illustration of the ecological character of the Kura basin. Source: AzerNews, as cited in the source project.

4.5. Integrated management priorities and limitations

The source project proposed modernization of irrigation, reduction of distribution losses, wastewater treatment, drought-resistant agricultural practices, improved water storage, riparian forest restoration, environmental water releases, and regional cooperation. The present review supports this broad package but adds a sequencing principle: interventions should be selected according to the dominant pressure in each river section. Areas affected primarily by conveyance losses require

infrastructure and accounting reforms; pollution hotspots require source control and treatment; and degraded floodplains require hydrological and vegetation restoration.

Monitoring is the link between these interventions. A stronger evidence system would combine hydrological stations, reservoir-operation data, abstraction records, water chemistry, microbial indicators, remote sensing of riparian vegetation, and transparent reporting. This would make it possible to evaluate whether efficiency measures reduce total withdrawals, whether pollution controls improve usable water quality, and whether restoration improves ecosystem condition over time.

Several limitations must be recognized. The underlying project is a secondary-research study and does not generate new field measurements. Some statistics and scenario values in the original document were drawn from older institutional sources and are not suitable for direct interpretation as current conditions. The photographs provide contextual evidence but cannot quantify water-level change. Finally, the review integrates studies with different spatial scales and methods. Future research should therefore use matched time-series data on discharge, withdrawals, reservoir operations, climate, and water quality to separate the relative contributions of different pressures more reliably.

CONCLUSIONS

The Kura River's declining water availability is best understood as a combined climate, demand, infrastructure, water-quality, and ecosystem-management challenge. The original student research identified the main elements of this system: drought and warming, intensive water use, inefficient irrigation and distribution, reservoir regulation, pollution, and degradation of Tugay forests. Recent scientific and technical evidence supports this integrated interpretation while also showing the importance of avoiding single-cause explanations. Water quality must be assessed separately from discharge, and ecological condition must be considered alongside the amount of water available to users.

The most effective management strategy is therefore a portfolio of mutually reinforcing actions: reduce avoidable irrigation and network losses; improve wastewater treatment and pollution prevention; strengthen hydrological and water-quality monitoring; manage reservoirs and abstractions with greater attention to seasonal and ecological needs; restore riparian forests using hydrologically informed nature-based solutions; and improve transboundary data exchange and coordination. These measures also support green economic resilience because they protect natural capital, improve resource efficiency, and reduce the long-term costs associated with degraded water quality, erosion, biodiversity loss, and unreliable water supply.

The student project's strongest contribution is its recognition that water scarcity, pollution, and riparian ecosystem decline are not separate problems. They are connected parts of one river system. Future research should preserve this integrated perspective while adding standardized field measurements, geospatial analysis, and economic valuation so that ecological restoration and water-efficiency investments can be prioritized on the basis of measurable environmental and social benefits.

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Fish and aquatic biodiversity of the Kura River under pollution, flow alteration and climate pressures

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aquatic biodiversity, fish conservation, Kura River, pollution, green economy

ABSTRACT

The Kura River supports a diverse aquatic community that includes fish, benthic organisms, mollusks, crustaceans, plankton and semi-aquatic mammals, while also sustaining fisheries, water supply and other ecosystem services. This study develops a five-author school research project into a structured academic synthesis of aquatic biodiversity and the pressures affecting river organisms. The original project used online research, textbooks, visual materials, Google Earth and NASA WorldWind, and focused on fish and other aquatic animals, pollution, changing water levels, overfishing and climate-related stress. The present article preserves the project's original organism profiles and visual diagrams while comparing them with recent peer-reviewed and regional evidence. The literature confirms that the Kura supports multiple freshwater fish taxa and that its aquatic biota is exposed to interacting water-quality, habitat, flow and exploitation pressures. Recent studies document downstream hydrochemical changes, fish-health stress at the Kura mouth, parasite occurrence in freshwater fish, and broader Caspian sturgeon conservation concerns. The numerical decline diagrams prepared in the original project are retained for transparency but are treated as illustrative indices rather than verified population time series because the underlying raw dataset was not available. The study concludes that pollution prevention, fishery control, habitat and riparian protection, ecological monitoring and restoration should be pursued together. These measures also have green-economy relevance because aquatic biodiversity supports fisheries, recreation, landscape value and the natural capital on which resilient local development depends.

INTRODUCTION

Aquatic biodiversity is a central indicator of river health because fish, invertebrates, plankton and semi-aquatic mammals respond to changes in water quality, flow, habitat structure and food-web condition. Rivers also connect ecological and economic systems. Healthy fish communities support food resources and recreational value, benthic organisms contribute to nutrient cycling, and riparian-aquatic interactions help maintain the ecological functions on which settlements and water-dependent activities rely. For the Kura River, these relationships are especially important because the river links upstream catchments, reservoirs, agricultural landscapes, urban areas, the lower Kura floodplain and finally the Caspian Sea.

The original student project examined the condition of fish and other aquatic organisms in the Kura River. Its three research questions asked which fish and aquatic animals occur in the river, which factors influence their condition, and which measures are needed to protect them. The project identified sturgeons, carp, bream, catfish, mullet, crustaceans, mollusks, plankton, river crayfish and otter as representative components of the river ecosystem. It also emphasized pollution, changes in water level, excessive or illegal fishing, temperature change and broader climate pressures as the most important threats.

Recent scientific evidence supports the need for a multi-pressure interpretation. Aliyev and Abduyev (2025) documented substantial downstream changes in mineralization and major-ion composition along the Kura in Azerbaijan, while Arifzade (2026) synthesized nutrient, microbial and major-ion pressure signals in Mingachevir Reservoir. At the biological level, Mamedova and Karanis (2024) examined 170 fish specimens from Mingachevir Reservoir and the Kura estuary and recorded multiple freshwater and euryhaline fish taxa, confirming that the basin supports diverse fish communities whose health can be investigated directly. Yusifova et al. (2024) further identified histological signs of environmental stress in fish collected from the Kura River mouth seashore zone.

The objective of this article is to preserve the students' original research logic and visual work while strengthening the ecological interpretation and reference base. The analysis distinguishes source-project observations from independently measured evidence, evaluates pollution, flow alteration, exploitation and climate-related pressures, and connects aquatic biodiversity conservation with fisheries, ecosystem services, restoration finance and blue-green development.

LITERATURE REVIEW

The Kura River and the adjacent Caspian system contain fish communities with ecological and economic significance. Mamedova and Karanis (2024) sampled fish from Mingachevir Reservoir and the

Kura estuary and reported eight fish species from four families in their study material, including Caspian roach, Kura bleak, freshwater bream, common carp, silver Prussian carp, European perch, golden grey mullet and Caspian bighead goby. Their work is important here not because it provides a full inventory of Kura fish biodiversity, but because it demonstrates that recent field-based biological sampling is available for several components of the aquatic community.

Sturgeons require particular conservation attention. Pueppke et al. (2023) review the Caspian basin and note that its anadromous sturgeon species are critically endangered, with population decline linked to illegal and unsustainable fishing, habitat loss and fragmentation, water pollution and climate-related pressures. Their detailed case study focuses on the Ural River rather than the Kura, so its quantitative findings should not be transferred directly to Azerbaijan. Nevertheless, the mechanisms it identifies—especially blocked migration, degradation of spawning habitat and fishery pressure—are relevant to understanding why sturgeons are sensitive indicators of river-basin management.

Water quality creates another pathway of biological pressure. Aliyev and Abduyev (2025) measured water chemistry at multiple points along the Kura during 2020–2022 and found increasing mineralization toward the lower river, with strong spatial changes in sulfate, chloride and sodium-potassium concentrations. Arifzade (2026) provides a complementary hydroecological synthesis for Mingachevir Reservoir, emphasizing that nutrient, microbial and major-ion signals should be interpreted together. Fish health can respond to such multi-factor conditions: Yusifova et al. (2024) reported gill and liver changes in fish from the Kura mouth seashore, while Mamedova and Karanis (2024) documented natural parasite infections in freshwater fish and noted that host condition and water pollution may influence occurrence.

Aquatic conservation also extends beyond chemical pollution. Mammadov et al. (2026) show that the wider Caspian basin is exposed to anthropogenic pressure from waste, urbanization, transport, tourism and microplastic pollution. Because the Kura is a major river entering the Caspian, actions that reduce plastic and wastewater leakage within the river basin can contribute to both freshwater and coastal environmental objectives. This basin-to-coast perspective is especially relevant for migratory species and for organisms occupying the river-estuary transition.

Finally, biodiversity has a direct relationship with the green economy. Qadimli et al. (2026) identify blue-green tourism potential in the Central Aran economic region, where the Kura-Mingachevir water landscape supports recreation and nature-based development. Qadimli and Mammadov (2026a) similarly link ecosystem sustainability with green-finance-based ecotourism, while Qadimli and Mammadov (2026b) demonstrate how spatial assessment can identify priorities for nature-based restoration and green finance. These studies do not measure Kura fish populations, but they provide an economic framework for understanding why healthy aquatic and riparian ecosystems should be treated as natural capital rather than as isolated conservation objects.

MATERIALS AND METHODS

The study is based on a 21-page group research presentation prepared in 2026 by Əli Fətəlizadə, Mələk Bəşirova, Məhəmmədəli Adıgözəlov, Rza Qurbanov and Ayla İsgəndərli. The original project used three principal methods: online research, review of textbooks and other literature, and visual analysis of photographs and maps. The students also used Google Earth and NASA WorldWind to develop a visual understanding of the Kura River and collected images of selected aquatic organisms. No field sampling, laboratory water-quality analysis, fish census or direct population monitoring was reported.

For the present article, the source material was coded into four categories: (1) aquatic organisms identified by the students; (2) environmental pressures; (3) conservation responses; and (4) visual evidence. The source-project organism descriptions were preserved where they represented the students' own synthesis. Statements that could be checked against recent scientific literature were compared with peer-reviewed studies on Kura water chemistry, fish health, fish parasites and Caspian sturgeon conservation.

The original project contains two sets of percentage diagrams and one long-term decline graph. These figures were retained because they represent a substantive part of the students' analytical effort. However, the underlying raw data, sampling design and traceable statistical series were not supplied in the project. Accordingly, the percentages are treated in this article as illustrative relative indices created for the original school project, not as independently verified abundance estimates or official population statistics. They are discussed for their conceptual value and methodological limitations rather than used to calculate trends.

The reference list was expanded in APA 7th edition style using recent peer-reviewed and regional sources. In addition to biodiversity and water-quality literature, the analysis incorporates studies on ecosystem sustainability, nature-based restoration, green finance, blue-green tourism and Caspian microplastic pressure in order to connect the ecological findings with JGEOR's green-economy and optimization scope.

RESULTS AND DISCUSSION

4.1. Aquatic organisms identified in the source project

The student project presents the Kura as a multi-trophic aquatic ecosystem rather than as a fish-only habitat. Fish receive the greatest attention, with sturgeons, carp, bream, catfish, mullet and other groups discussed as components of the food web and as species of human interest. The project also identifies crustaceans, mollusks and plankton as organisms that contribute to nutrient cycling, food availability and water-related ecological processes. River crayfish are highlighted as organisms associated with cleaner water, while the otter is presented as a semi-aquatic predator whose presence depends on functioning river habitat.

The broad ecological structure identified by the students is consistent with recent Kura-based biological research. Mamedova and Karanis (2024) directly examined several fish species from the reservoir-estuary continuum, while the source project extends attention to invertebrates and semi-aquatic mammals. The two lines of evidence are complementary: the peer-reviewed study provides field-confirmed fish material, whereas the school project offers a wider ecosystem-oriented classification.

Table 1. Aquatic organisms emphasized in the original student project

Organism / group	Ecological role and principal pressure identified in the source project
Sturgeons	High conservation value; the project associates their decline with fishing pressure, pollution and habitat change.
Carp, bream, catfish and mullet	Common fish groups used to illustrate food-web, fisheries and habitat functions; vulnerable to declining water quality and altered flow.
Crustaceans, mollusks and plankton	Represent benthic and lower-trophic components that support food webs and nutrient cycling; sensitive to contamination and habitat disturbance.
River crayfish	Used in the project as an example of an organism associated with cleaner water and benthic habitat quality.

Otter	Semi-aquatic predator representing habitat connectivity, prey availability and the ecological integrity of river margins.

4.2. Pollution and hydroecological pressure

Pollution is the most prominent pressure in the original project. The students identify industrial discharges, household waste and agricultural chemicals as pathways that can reduce water quality and harm fish and other aquatic organisms. This source-based framing is supported by recent hydrochemical research, although the mechanisms need to be interpreted carefully. Aliyev and Abduyev (2025) show that chemical composition changes substantially along the Kura, but they also emphasize contributions from tributaries, groundwater interactions and natural mineralization. Thus, downstream deterioration cannot be attributed to one pollutant source without matched concentration and load data.

The same caution applies to reservoir conditions. Arifzade (2026) synthesizes nutrient, microbial and major-ion evidence for Mingachevir Reservoir and shows that hydroecological pressure is multidimensional. For aquatic organisms, this matters because fish can respond to combinations of salinity, nutrients, oxygen conditions, microbial contamination and other stressors rather than to a single variable. The fish-health study by Yusifova et al. (2024) reinforces this point: histological changes in gills and liver indicated the presence of environmental stress, but the observed tissue responses did not by themselves identify one causal pollutant.

Plastic pollution adds a further dimension. The original project specifically mentions household waste, while Mammadov et al. (2026) document microplastic and broader anthropogenic pressures in the Caspian Sea basin. A river-to-sea management perspective is therefore appropriate. Preventing plastic leakage, improving solid-waste collection and controlling wastewater upstream can reduce direct habitat degradation in the Kura while also limiting downstream transport toward the Caspian.

4.3. Flow alteration, spawning habitat and climate pressure

The project identifies changing water levels as a second major pressure, particularly because lower water can reduce or dry shallow breeding areas. This mechanism is ecologically plausible even though the source project did not measure discharge or spawning habitat directly. River organisms are adapted to seasonal patterns of depth, velocity, temperature and connectivity, so changes in flow can alter feeding areas, refuge habitats and reproductive opportunities.

For migratory sturgeons, connectivity is particularly important. Pueppke et al. (2023) show at Caspian-basin scale that dams, habitat fragmentation, pollution and unsustainable harvest have contributed to severe sturgeon decline. Their emphasis on the Ural River should not be treated as a Kura-specific population estimate, but the ecological mechanism is transferable: species that must move between marine feeding grounds and river spawning habitats are highly vulnerable when migration routes and spawning conditions are disrupted.

Climate-related temperature and drought pressures can intensify these effects. Warmer water can change oxygen demand, metabolism and seasonal habitat suitability, while prolonged low-flow periods can reduce dilution capacity and concentrate some water-quality problems. Because the Kura is regulated and heavily used, climatic and management pressures are likely to interact. Future fish-biodiversity studies should therefore pair biological sampling with discharge, temperature, dissolved oxygen and water-quality measurements.

4.4. Original project diagrams and evidence limitations

The students created comparative diagrams to communicate perceived long-term decline in selected fish and other aquatic organisms. These visuals are an important part of the project and are retained below. The first set compares relative indices for sturgeon, carp and bream, and for otter and river crayfish. The second graph presents an overall biodiversity decline trajectory. Because the source project does not provide the raw time series, sampling locations, census method or a reproducible statistical source, the numerical percentages cannot be treated as measured abundance trends in this article.

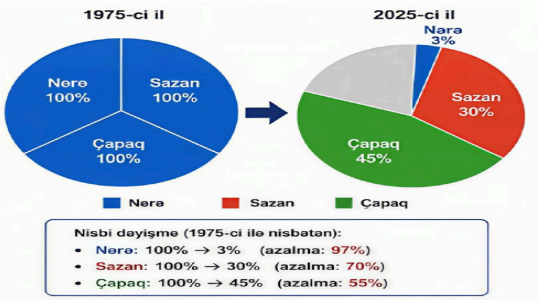


Figure 1a. Student-prepared relative-change diagram for selected fish groups, retained from the original project. Percentages are illustrative source-project indices and are not treated here as independently verified population estimates.

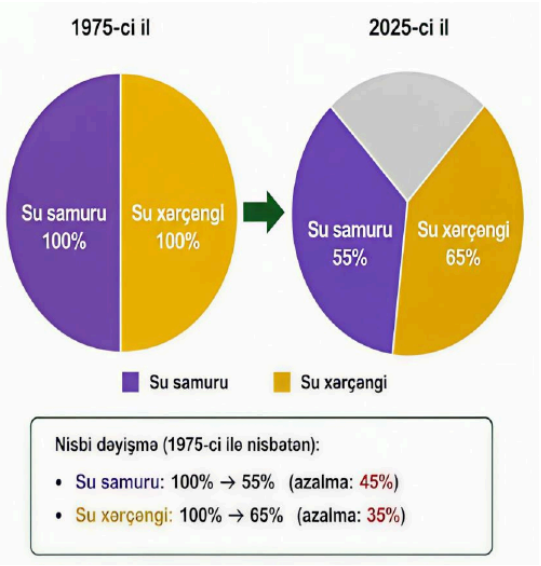


Figure 1b. Student-prepared relative-change diagram for otter and river crayfish, retained from the original project. Values are preserved as presented by the students but are not used as empirical census data.

Retaining the diagrams while explicitly limiting their evidentiary status serves two purposes. First, it preserves the students' original analytical work. Second, it demonstrates an important research principle: a visual trend is only as reliable as the underlying data and method. In a future version of this research, the same figures could be rebuilt from official fishery statistics, standardized monitoring surveys or repeated field counts, with clear units, confidence limits and documentation of sampling effort.

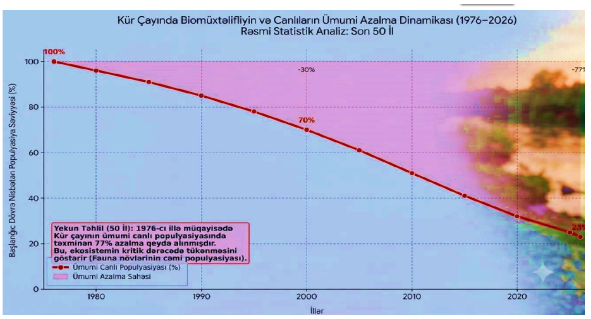


Figure 2. Overall biodiversity-decline graphic retained from the original student project. The trend line is treated as an educational visualization because the underlying statistical series was not supplied.

4.5. Fisheries, ecosystem services and green-economy relevance

The source project already recognizes that aquatic organisms matter to people as well as to ecology. Fish can support food supply and fisheries, while invertebrates and plankton contribute to food-web functioning and ecosystem processes. Healthy river habitats also sustain recreational and educational uses. This provides a direct bridge to the green economy, where biodiversity is considered part of the natural capital that supports economic activity without being exhausted or degraded.

The Central Aran assessment by Qadimli et al. (2026) is relevant because it identifies blue-green tourism potential linked to the Kura-Mingachevir water landscape. Aquatic biodiversity can strengthen such value by improving the ecological quality and attractiveness of riverfront environments, but tourism must not create additional waste, disturbance or fishing pressure. Qadimli and Mammadov (2026a) similarly emphasize that ecotourism opportunities depend on ecosystem sustainability and appropriate green financing.

Restoration finance is equally important. Qadimli and Mammadov (2026b) show how remote sensing and nature-based-solution prioritization can guide restoration investment. Applied to the Kura, comparable logic could be used to identify degraded riparian sections, spawning areas, erosion hotspots or habitat-connectivity bottlenecks where restoration yields multiple benefits. Funding directed toward pollution control, riparian buffers, habitat rehabilitation and monitoring can therefore protect fisheries and biodiversity while also reducing future environmental-management costs.

The source project's conservation message is therefore economically relevant: degradation of aquatic biodiversity can weaken food resources, recreational value, environmental education opportunities and the resilience of water-dependent communities. Green-economy planning should not monetize every species individually, but it should recognize that ecosystem degradation creates real costs and that preventive conservation can be more efficient than repeated remediation.

4.6. Conservation priorities and future monitoring

The students propose four principal responses: reduce pollution, strengthen restrictions on illegal or excessive fishing, create or protect ecological refuge zones, and expand environmental education. These recommendations remain appropriate, but the evidence reviewed here suggests that they should be implemented as a coordinated monitoring-and-management package. Pollution control should combine wastewater treatment, agricultural runoff reduction and solid-waste prevention. Fishery management should distinguish between species and life stages and should be supported by transparent catch and abundance data. Habitat protection should include both aquatic refuges and riparian zones because shoreline vegetation, shallow-water habitats and channel connectivity are ecologically linked.

Monitoring should move beyond visual observation alone. A stronger future design would sample fish communities at standardized sites in Mingachevir Reservoir, middle and lower Kura reaches and the estuary; record abundance or catch-per-unit-effort; measure water temperature, dissolved oxygen, conductivity, nutrients and selected pollutants; and document riparian and spawning habitat condition. Such a design would allow the students' original diagrams to be replaced with reproducible time series and would help determine which pressures are most strongly associated with biological change.

The study has several limitations. It is a secondary-research synthesis and contains no original field census, laboratory measurements or verified historical abundance series. Some organism names in the source project are broad common-name categories rather than taxonomically resolved species. The illustrative decline percentages cannot be validated from the documentation available. These limitations do not invalidate the project's ecological logic, but they mean that conclusions should focus on pressure pathways, conservation priorities and research needs rather than on precise population-loss percentages.



Figure 3. Educational species and Kura River visual panel prepared for the original student project and retained to preserve the students' visual contribution.

CONCLUSIONS

The original student research correctly frames the Kura River as a living ecosystem in which fish, invertebrates, plankton and semi-aquatic mammals are linked through habitat, food webs and water quality. The strongest source-based findings are qualitative: pollution, altered water levels, fishing pressure and climate-related stress can affect aquatic organisms, and conservation requires both direct species protection and protection of the river environment.

Recent scientific literature strengthens this interpretation. Field research confirms diverse fish communities in the Kura basin, water-quality studies document substantial spatial hydrochemical change, fish-health studies identify biological stress signals near the river mouth, and Caspian-basin research demonstrates the severe conservation vulnerability of sturgeons. At the same time, the students' percentage diagrams cannot be interpreted as verified population statistics because the underlying datasets are unavailable. Preserving the diagrams with this limitation makes the article both faithful to the original work and methodologically transparent.

The most defensible management priorities are pollution prevention, controlled and science-based fisheries, protection of aquatic and riparian habitats, restoration of degraded areas, environmental education and long-term ecological monitoring. These actions also support green economic resilience by protecting fisheries, recreation, ecosystem services and the natural capital associated with the Kura-Mingachevir-Caspian water system. Future research should combine standardized biological sampling with water-quality and hydrological monitoring so that changes in aquatic biodiversity can be quantified and linked to specific pressures with greater confidence.

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Diversity of fauna and flora in the areas around the Kura River

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Kura River, Tugay forests, riparian ecosystems, biodiversity conservation, restoration

ABSTRACT

The Kura River and its riparian corridor support a mosaic of aquatic, riverbank and floodplain habitats that provide living space for plants, fish, birds, amphibians, reptiles, insects and small mammals. This study develops an original school research project into a structured academic assessment of fauna and flora diversity around the Kura River. The source project used observation, photographs, maps and online and book-based research to classify representative organisms and compare biodiversity among in-water, riverbank and nearby-land habitats. The student identified reeds, grasses, algae, willow trees, aquatic plants and shrubs together with fish, frogs, turtles, birds, insects and small mammals, and prepared descriptive tables, a classification chart, seasonal river photographs and a river-course map. These materials are retained in the present article as the primary source evidence. The findings indicate that habitat heterogeneity is central to biodiversity: aquatic and riverbank zones were classified as high-diversity environments, while nearby land was classified as medium-high. Pollution, plastic and other waste, removal of riverside vegetation, habitat modification and inefficient water use were identified as principal threats. Recent Kura research supports the importance of water quality, riparian vegetation and ecosystem restoration. The discussion further links biodiversity conservation to ecosystem services, blue-green tourism, nature-based solutions and green finance. The study concludes that protecting the Kura requires integrated water-quality management, riparian restoration, waste prevention, environmental education and systematic biodiversity monitoring.

INTRODUCTION

Freshwater river corridors are biodiversity systems composed of several connected habitats rather than a single channel of flowing water. The open-water zone, riverbank, wet margins, floodplain vegetation and adjacent land each provide different combinations of food, shelter, breeding sites and movement routes. This habitat diversity allows plants and animals with different ecological requirements to coexist. The student research that forms the basis of this article approached the Kura River from precisely this perspective by examining fauna and flora in the water, on the riverbank and in nearby areas.

The Kura River is the principal river system of the South Caucasus and an important natural resource for Azerbaijan. Its ecological importance is inseparable from its social and economic functions because the river supports agriculture, settlements, water supply, recreation and landscapes. The source project therefore treated biodiversity not as an isolated list of species but as part of a river environment that also supports human activities. This framing is consistent with contemporary freshwater conservation approaches, which emphasize that healthy river ecosystems sustain both wildlife and human livelihoods (World Wildlife Fund [WWF], n.d.; United Nations Environment Programme [UNEP], n.d.).

The original project posed three questions: which fauna and flora occur around the Kura River; how environmental conditions affect their diversity; and which environmental problems threaten the river ecosystem. It identified pollution, waste, excessive water use, habitat destruction and removal of riverside vegetation as major pressures. Recent Kura research adds further context. Aliyev and Abduyev (2025) documented strong spatial changes in mineralization and major-ion composition along the river in Azerbaijan, while Arifzade (2026) synthesized nutrient, microbial and major-ion pressure signals in Mingachevir Reservoir. These studies reinforce the student project's central argument that water quality and habitat condition are fundamental to biodiversity.

The objective of this article is to preserve and academically develop the student's original classifications, tables, photographs and map while placing them within recent evidence on riparian vegetation, water quality, conservation and green-economy relevance. The article does not transform the source project into a species census or field experiment. Instead, it treats the student's observations and classifications as descriptive research evidence and clearly separates them from externally verified scientific findings.

LITERATURE REVIEW

Freshwater ecosystems contain an unusually high concentration of biological diversity relative to their global area. National Geographic Society (2026) describes rivers, streams, wetlands and associated habitats as systems where plants, animals, microorganisms, soils and water interact, while WWF (n.d.) emphasizes the importance of freshwater landscapes for both biodiversity and human livelihoods. These broader sources are consistent with the student project's

emphasis on vegetation, fish, amphibians, birds, insects and small mammals as interconnected components of river environments.

For the Kura River specifically, riparian vegetation is a key structural component. Gurbanov et al. (2026) documented high floristic diversity and multilayered vegetation in Azerbaijan's Tugai forests and identified hydrological alteration, deforestation, grazing and other anthropogenic pressures as major degradation drivers. Qurbanov and Ahmadova (2024) likewise described riparian forest communities along the Kura in Agjabadi and emphasized their conservation and restoration significance. These findings support the student's classification of reeds, grasses, willow trees, shrubs and aquatic vegetation as ecologically important rather than merely decorative elements of the riverside landscape.

Water quality provides a second line of evidence. Aliyev and Abduyev (2025) showed that Kura water chemistry changes markedly along the Azerbaijani reach, with substantial downstream increases in mineralization. Arifzade (2026) demonstrated that the Middle Kura cascade should be interpreted through combined nutrient, microbial and major-ion evidence. Together, these studies explain why the student project's simple statement that "clean water" is associated with more plants and animals is directionally meaningful, even though the project did not conduct laboratory measurements.

Pollution can also move across connected aquatic systems. Mammadov et al. (2026) identified microplastic and broader anthropogenic pressure in the Caspian Sea basin, demonstrating the importance of waste prevention and coordinated monitoring. Because the Kura ultimately reaches the Caspian Sea, management of solid waste and plastic leakage within the river corridor has relevance beyond local riverbank aesthetics.

Biodiversity conservation also has an economic dimension. Qadimli and Mammadov (2026a) connect ecosystem sustainability with green-finance-based ecotourism in Akhar-Bakhar National Park; Qadimli and Mammadov (2026b) use remote sensing to prioritize nature-based solutions and green-finance needs in Shahdag National Park; and Qadimli et al. (2026) link blue-green landscapes to sustainable tourism priorities in Central Aran. Although these studies address different locations and methods, they provide a framework for interpreting the Kura's riparian biodiversity as natural capital that can support recreation, environmental education, landscape quality and resilient local development.

MATERIALS AND METHODS

This article is based on an 11-page student research project prepared by Fidan Ibrahimzade in 2026. The original project used three methods explicitly stated by the author: observation, online research, and analysis of photographs or maps. It also drew on books and educational sources and included four structured tables, photographs of river habitats and organisms, a seasonal photo series, a map of the Kura's course, survey questions and interview questions.

The source material was reorganized into four analytical components: (1) fauna and flora examples; (2) habitat-based biodiversity comparison; (3) environmental pressures and conservation responses; and (4) seasonal and spatial context. The article retains the student's original categories and descriptive ratings. No species names were added to the source tables unless supported by the source project itself, and no new field observations were invented.

The numerical classification in the source project—three aquatic plant types, four riverbank plant types, four fish types, four bird types, three amphibian/reptile types and four insect types—is explicitly presented by the student as a simple classification of researched examples, not as a scientific count of all species in a particular river. The same interpretation is maintained here. The "High" and "Medium-High" biodiversity labels are also treated as descriptive source-project categories rather than measured biodiversity indices.

The survey and interview questions prepared by the student are acknowledged as part of the research design; however, the source file does not contain completed questionnaires, respondent characteristics or interview transcripts. Therefore, no survey or interview results are reported. External literature was used only to contextualize and evaluate the ecological meaning of the student's findings. All references were standardized to APA 7th edition.

RESULTS AND DISCUSSION

4.1. Fauna and flora identified in the original project

The first result of the source project is a simple but useful inventory separating flora and fauna. The flora category contains reeds, grasses, algae, willow trees, water plants and shrubs, while the fauna category contains fish, frogs, turtles, birds, insects and small mammals. This structure captures both aquatic and riparian biodiversity and reflects the idea that river biodiversity extends beyond organisms living directly in the water.

Table 1. Examples of flora and fauna retained from the original student project

Flora (plants)	Fauna (animals)
Reeds	Fish
Grasses	Frogs
Algae	Turtles
Willow trees	Birds
Water plants	Insects
Shrubs	Small mammals

The ecological importance of these groups becomes clearer when compared with riparian research from Azerbaijan. Gurbanov et al. (2026) show that river-dependent plant communities provide habitat, bank stabilization, nutrient cycling and local microclimate functions. Thus, the student's emphasis on riverbank plants as food and shelter for animals is consistent with contemporary understanding of riparian ecosystem services.

4.2. Habitat-based biodiversity comparison

The student divided the river environment into three zones: in-water habitat, riverbank habitat and nearby land. The in-water and riverbank zones were both classified as "High" biodiversity, while nearby land was classified as "Medium-High." These ratings are qualitative rather than calculated indices, but they express an important ecological concept: habitat heterogeneity can support different organism groups across a short spatial gradient.

Table 2. Original habitat-based biodiversity comparison

River area	Examples of organisms	Biodiversity
In the water	Fish, algae, aquatic plants, insects	High
Riverbank	Grasses, reeds, trees, birds, frogs	High
Nearby land	Trees, shrubs, insects, mammals	Medium-High

Riverbanks are especially important because they connect aquatic and terrestrial food webs. Vegetation can provide nesting, refuge and feeding space, while roots and stems influence erosion and bank stability. This interpretation is supported by the Tugai literature and by restoration research emphasizing that riparian vegetation must be considered together with river hydrology rather than as an isolated green strip (Qurbanov & Ahmadova, 2024; Gurbanov et al., 2026).

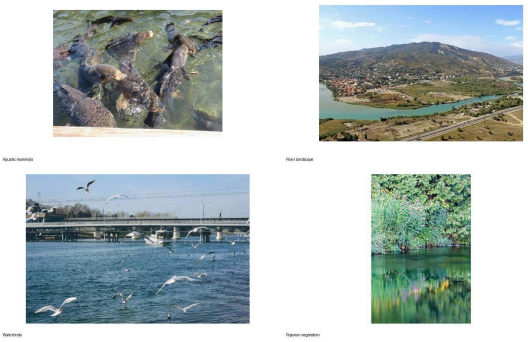


Figure 1. Original source-project photographs illustrating aquatic mammals, a river landscape, waterbirds and riparian vegetation. Images are retained from the student project; original image-source attribution should be verified before final publication.

4.3. Descriptive organism classification and seasonal context

The source project also summarized the number of organism types used in its examples. As the student explicitly noted, these values are not species counts and should not be interpreted as abundance or richness estimates. Their value is pedagogical: they show that the research considered multiple biological groups rather than focusing on a single taxon.

Table 3. Number of organism types identified in the original research classification

Category	Number of types
Aquatic plants	3
Riverbank plants	4
Fish	4
Birds	4
Amphibians/reptiles	3
Insects	4

The seasonal photo series prepared by the student adds a second type of ecological context. Winter, spring, summer and autumn scenes demonstrate that the river landscape changes visibly through the year. The accompanying source text associates spring with higher water conditions related to snowmelt and rainfall, summer with more stable but variable levels, and autumn with changes in riparian vegetation. These descriptions were not based on a measured seasonal hydrograph, so they are retained as qualitative observations rather than quantitative hydrological results.

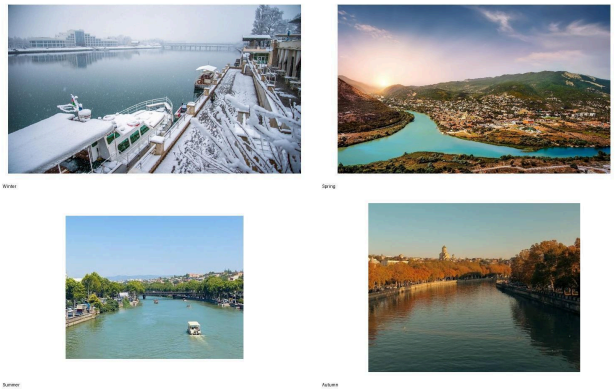


Figure 2. Seasonal Kura River photographs retained from the original student project: winter, spring, summer and autumn. The images are used as qualitative environmental context, not as a standardized seasonal monitoring series.

4.4. River course, human use and environmental pressures

The project maps the Kura from northeastern Türkiye through Georgia and Azerbaijan to the Caspian Sea and lists several human uses, including recreation, farming, fishing and transport. This geographical framing is important because ecological condition is influenced by cumulative pressures along the river corridor. The student's concluding data table also notes continuous water movement, seasonal changes and the coexistence of urban and rural surroundings.

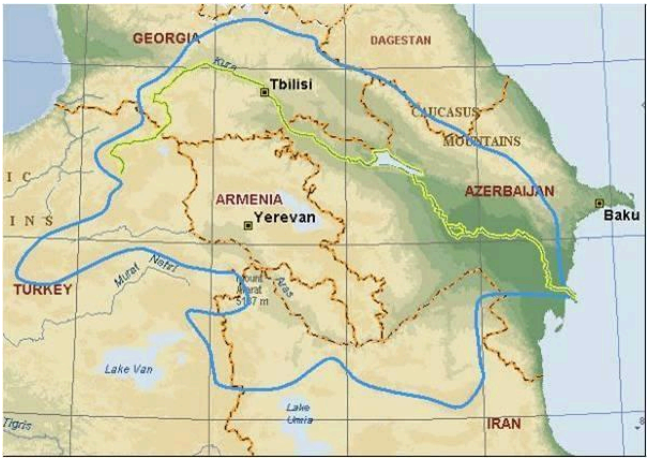


Figure 3. Kura River course map retained from the original student project. The source project uses the map to illustrate the river's transboundary path from Türkiye through Georgia and Azerbaijan to the Caspian Sea.

Table 4. Conclusive observations retained from the original project

Observation	Result
River direction	From higher land towards lower land
Water movement	Usually flows continuously
River surroundings	Can include urban and rural areas
Human activities	Recreation, farming, fishing and transport
Seasonal changes	Water levels can change during the year

The principal environmental pressures identified by the student are water pollution, plastic and other waste, habitat destruction and cutting of riverside trees. Recent scientific evidence strengthens this diagnosis. Arifzade (2026) shows that hydroecological pressure in Mingachevir Reservoir involves multiple water-quality dimensions, and Aliyev and Abduyev (2025) demonstrate major spatial changes in Kura hydrochemistry. At the wider basin scale, Mammadov et al. (2026) show that plastic-related anthropogenic pressure remains an important monitoring challenge in the Caspian system. The student's recommendation to keep rubbish and plastic away from rivers therefore has direct relevance to contemporary pollution-prevention priorities.

4.5. Conservation, ecosystem services and green-economy relevance

The student's solutions include reducing waste, saving water, planting trees and other vegetation near rivers, reducing pollution, organizing clean-up activities, protecting natural areas and expanding environmental education. These actions can be organized into three management levels. First, pollution prevention addresses the immediate quality of water and habitat. Second, riparian restoration strengthens natural infrastructure through vegetation, bank stability and habitat connectivity. Third, education and stewardship build long-term public support for river protection.

The restoration dimension aligns with nature-based solution approaches. Qadimli and Mammadov (2026b) demonstrate how ecosystem degradation can be spatially assessed to prioritize restoration and green-finance needs. While their study concerns Shahdag National Park rather than the Kura corridor, the management principle is transferable: environmental investment is more effective when restoration priorities are linked to measurable ecosystem condition. In the Kura context, future restoration planning could combine vegetation mapping, bank-condition assessment, water-quality monitoring and biodiversity surveys.

The river also has potential economic value through ecosystem services and low-impact recreation. Qadimli and Mammadov (2026a) show how ecosystem sustainability can be linked with ecotourism and green finance, while Qadimli et al. (2026) identify blue-green tourism opportunities in Central Aran. For the Kura, healthy riverbank vegetation, birdlife, clean water and attractive landscapes can support environmental education, birdwatching, walking routes and other nature-based activities. These benefits depend on ecological limits: tourism should not increase waste, disturbance or pressure on sensitive habitats.

The source project ends with a conservation message calling for collective protection of the Kura River. Retaining this element is important because environmental education is part of the original research effort. In an academic context, the message can be interpreted as a stewardship principle: scientific evidence, individual behaviour and institutional management need to operate together if freshwater biodiversity is to be maintained.

4.6. Environmental education and proposed primary-data instruments

The source project did not end with desk research alone; it also prepared a short survey and an interview guide intended to explore public interaction with rivers and perceptions of environmental change. This component is methodologically important because it shows an attempt to connect ecological information with human behaviour and local knowledge. The questions address river visitation, recreational use, perceptions of cleanliness, observation of litter, willingness to join clean-up activities, perceived changes through time, seasonal variation and local river-care priorities. No completed responses were included in the source file, so these instruments cannot be analysed as empirical results in the present article.

For future development, the same questions could be administered using a documented sampling strategy and basic respondent information, followed by transparent coding of responses. Perception data could then be compared with direct observations of litter, riparian vegetation condition and water-quality measurements. This would convert the student's exploratory instrument into a mixed-method monitoring design and would also strengthen environmental education by allowing young researchers to compare community perceptions with measurable river conditions.

Table 5. Survey and interview questions prepared in the original student project

Instrument	Question
Survey	How often do you visit a river?
Survey	What do you usually do when you visit a river?
Survey	Do you think rivers in your area are clean?
Survey	Have you ever seen litter near a river?
Survey	Would you join a river clean-up activity?
Interview	How has the river changed over the years?
Interview	What is the biggest change you have noticed?
Interview	How do local people use the river?
Interview	Are there any seasonal changes in the river?
Interview	What should people know about caring for the river?

Because the source project explicitly distinguishes its organism counts from scientific species censuses, a similar principle should guide future human-data collection: results should be reported only after the sampling frame, respondent number and analysis procedure are documented. This preserves the educational strength of the original work while improving reproducibility and research integrity.

4.7. Proposed framework for repeatable school-led biodiversity monitoring

The original project already contains the core elements of a monitoring programme: defined research questions, habitat categories, organism groups, photographs, a map, seasonal observations, and proposed survey and interview instruments. The main step needed to move from descriptive research to repeatable ecological monitoring is standardization. Each observation should be linked to a fixed location, date, weather condition and method so that changes can be compared through time rather than inferred from unrelated photographs or online examples.

A practical school-led design could use three fixed habitat stations representing the river channel, riverbank and nearby land. At each station, students could record visible plant groups, birds, insects and other fauna using the same observation period and the same field sheet. Photographs should be taken from fixed viewpoints, and simple water observations such as temperature, transparency and visible litter could be recorded with the same units. Where equipment and supervision are available, pH, electrical conductivity and dissolved oxygen would add useful hydroecological context. These measurements should be treated as educational monitoring unless validated under a formal scientific protocol.

Repeat monitoring would also allow the student's seasonal interest to become analytically stronger. Observations made in winter, spring, summer and autumn could be compared using the same locations and categories. Such a design would make it possible to distinguish real seasonal change from differences caused by changing sites or observation effort. It would also create a transparent record that could later be compared with professional monitoring of the Kura and Mingachevir system, including hydroecological evidence summarized by Arifzade (2026).

This framework would preserve the accessibility of the student's original approach while improving reproducibility. It would also support a longer-term green-economy perspective because repeat ecological information can help identify where restoration, waste-control or low-impact recreational investment is most appropriate. As shown in the restoration and blue-green tourism studies of Qadimli and Mammadov (2026a, 2026b) and Qadimli et al. (2026), environmental planning is strongest when conservation priorities are tied to spatially explicit evidence rather than broad assumptions.

CONCLUSIONS

This study preserves and develops a student-led assessment of fauna and flora around the Kura River. The original work identified representative aquatic and riparian plants, fish, amphibians, reptiles, birds, insects and small mammals; distinguished in-water, riverbank and nearby-land habitats; and classified the first two as high-diversity environments. Its photographs, seasonal observations, map and four data tables demonstrate a broad ecosystem perspective and constitute

the principal evidence retained in the present article. The strongest conclusion is that river biodiversity depends on both water condition and the integrity of the surrounding riparian environment.

The source project's conservation recommendations are consistent with recent research: pollution and plastic leakage should be reduced, water use should be more efficient, riverbank vegetation should be protected and restored, and environmental monitoring should be strengthened. These measures also have green-economy relevance because biodiversity and healthy river landscapes provide natural-capital benefits through ecosystem services, recreation, environmental education and potential blue-green tourism. The principal limitation is methodological: the project is descriptive and does not contain standardized species sampling, completed survey data or calculated biodiversity indices. Future work should therefore combine the student's habitat-based framework with georeferenced field observations, standardized flora and fauna inventories, water-quality measurements and repeat seasonal monitoring.

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Drought-induced water stress and its effects on plant growth, photosynthesis and productivity

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Keywords
drought stress, plant physiology, photosynthesis, salinity, agricultural productivity

ABSTRACT

Drought-induced water stress is a major environmental constraint on plant growth because it affects water relations, root architecture, leaf development, photosynthesis, respiration, mineral nutrition and ultimately biomass and yield. This article develops an original student research project on ecological stress into a structured review focused on plant responses to water deficit, while retaining the project's core explanations and four original visual materials. The source work examined drought avoidance and tolerance strategies, abscisic-acid-mediated stomatal responses, changes in leaf area and root morphology, reductions in photosynthetic activity, respiratory and metabolic adjustments, and the additional pressure created by soil salinity. The present study reorganizes these observations thematically and compares them with peer-reviewed evidence on drought physiology, root responses and salinization in the Kura–Araz lowland. The review shows that water stress affects plants through interacting morphological and physiological pathways rather than through a single mechanism. Moderate adaptation can include deeper or reconfigured roots, reduced leaf area and osmotic adjustment, whereas severe or prolonged stress can restrict carbon assimilation, nutrient acquisition and productivity. Salinity may compound these effects by creating osmotic and ionic stress. In Azerbaijan, these processes are relevant to water-efficient agriculture, soil management and the resilience of landscapes connected to the Kura system. The article concludes that efficient irrigation, salinity control, drought-tolerant crop selection, monitoring and ecosystem-based restoration are complementary components of green and climate-resilient agricultural development.

INTRODUCTION

Plants continuously adjust to environmental conditions, but water shortage is among the strongest constraints on their growth and productivity. Water is required for cell expansion, nutrient transport, stomatal regulation, photosynthesis and the maintenance of tissue hydration. When soil water becomes insufficient, plants experience a cascade of responses that may begin with stomatal closure and reduced leaf expansion and can progress to altered root growth, pigment loss, metabolic disruption and premature senescence. The original student research prepared by Mehdi Allahverdiyev approached these processes through the broader concept of ecological stress and identified water deficit, salinity and temperature as particularly important environmental stressors.

A central contribution of the source project is its attempt to connect whole-plant morphology with internal physiology. It discusses drought avoidance by succulents and ephemeral plants, changes in root systems, reduction of leaf area, abscisic acid (ABA) signalling, stomatal closure, lower carbon dioxide assimilation, changes in chlorophyll, respiration and mineral nutrition. The project also extends the analysis from water deficit to soil salinity, recognizing that irrigated agriculture may face combined water and salt stress rather than one pressure in isolation.

These themes are relevant to Azerbaijan because agricultural production in the Kura–Araz lowland is closely connected to irrigation, drainage and soil-water management. Han et al. (2024) demonstrated that salinity dynamics in the Kur-Araz lowland are influenced by the interaction of climate and water management and warned that future re-salinization could threaten agricultural sustainability. At the same time, hydroecological evidence from the Middle Kura system indicates that water quality itself is a management concern, adding another layer to the relationship between water availability, soil condition and productive landscapes (Arifzade, 2026).

The objective of this article is therefore to preserve the student's original physiological and ecological reasoning, retain the four visual materials included in the project, and reorganize the work as an evidence-based review of drought and associated salinity stress. The article asks how water deficit affects plant growth, root and leaf morphology, photosynthesis, respiration and mineral nutrition; how salinity can compound these responses; and how these mechanisms relate to resource-efficient and green agricultural development.

LITERATURE REVIEW

Plant water relations provide the physiological foundation for understanding drought response. Lambers et al. (1998) describe plant performance as the outcome of linked water, carbon and nutrient processes, while Blum (2011) emphasizes that drought resistance must be interpreted in relation to stress timing, intensity and the maintenance of yield. This perspective is important because "drought

tolerance" is not a single trait. Plants may escape drought through shorter life cycles, avoid dehydration through reduced water loss or greater water uptake, or tolerate lower tissue water status through osmotic and metabolic adjustment.

Recent studies strengthen the source project's emphasis on roots. Sun et al. (2024), using 997 effect sizes from 76 studies, found that severe and extreme drought can reduce root length, mean diameter and root area, although responses vary among plant functional groups and with drought duration. Kalra et al. (2024) and Gusain et al. (2024) likewise highlight root-system architecture, hydraulic conductance and hormone signalling as central to drought adaptation. These findings show that the commonly described strategy of "deeper roots under drought" is not universal; root responses depend on species, developmental stage and stress severity.

At leaf level, the source project focuses strongly on photosynthesis. This is supported by Qiao et al. (2024), who review evidence that drought can limit photosynthesis through stomatal closure, reduced carbon dioxide supply, pigment and photosystem damage, and disruption of electron transport. Earlier sunflower research also showed that water stress imposed at budding or flowering reduced leaf area index, water status, crop growth and yield (Hussain et al., 2009). Kiani et al. (2007) further demonstrated substantial genetic variation in sunflower water status and gas exchange under dehydration and rehydration, reinforcing the source project's attention to variation among plants and varieties.

The salinity component is equally important for irrigated landscapes. Salinity creates an initial osmotic effect that restricts water uptake and, with continued exposure, may produce ion toxicity and nutrient imbalance. Han et al. (2024) used Landsat-based salinity assessment and modelling in the Kur-Araz lowland and showed that climate and water management jointly shape soil salinity trajectories. Their findings provide a contemporary regional context for the student project's discussion of irrigation, groundwater and salt accumulation.

The wider Kura–Caspian environmental literature also suggests that agricultural stress should be considered within an integrated landscape framework. Arifzade (2026) identifies hydroecological pressure signals in Mingachevir Reservoir; Mammadov et al. (2026) document microplastic and anthropogenic pressure in the Caspian Sea basin; Qadimli and Mammadov (2026a, 2026b) connect ecosystem sustainability and restoration priorities with green finance; and Qadimli et al. (2026) link blue-green landscape assets to sustainable development in Central Aran. Although these studies do not measure plant drought physiology directly, they support the broader interpretation that water, soil, ecosystem condition and economic resilience are interconnected.

MATERIALS AND METHODS

This study is a structured narrative review developed from an 11-page student manuscript entitled "Ecological problems and their solutions." The original work was prepared by Mehdi Allahverdiyev and focused primarily on the physiological effects of water stress on higher plants, followed by a section on salt stress and salinized soils. The source manuscript contains four visual materials: a global water-stress map, an illustration of root morphology under moist and dry soil conditions, a global map of salt-affected soils and a photograph of salinized agricultural land. All four are retained in the present article as part of the student's original research record.

The original text was coded into six thematic categories: (1) plant growth and development under water deficit; (2) morphological adaptation; (3) photosynthesis and stomatal regulation; (4) respiration and metabolic adjustment; (5) mineral nutrition and productivity; and (6) salinity and land degradation. Statements with clear citations in the source project were retained and standardized where the underlying reference could be identified. Quantitative claims for which the source file did not provide a traceable dataset or reference were not repeated as established facts.

The source material was then compared with peer-reviewed literature on drought physiology, root responses, crop photosynthesis and soil salinity, including recent regional evidence from the Kur-Araz lowland. The analysis is qualitative and interpretive; no new plant experiment, soil sampling, physiological measurement or statistical meta-analysis was conducted. Consequently, the results describe mechanisms supported by the reviewed literature rather than new causal estimates generated by the present study.

RESULTS AND DISCUSSION

4.1. Water deficit as a multi-level plant stress

The source project identifies water deficit as a stress that begins with reduced water availability but rapidly becomes a whole-plant problem. Restricted soil water lowers the capacity of roots to supply the shoot, affects cell turgor and expansion, changes transpiration and can reduce biomass formation. This is consistent with plant physiological ecology: growth depends on coordinated water uptake, gas exchange, carbon assimilation and nutrient acquisition rather than on water content alone (Lambers et al., 1998).

The project also distinguishes atmospheric and soil drought. High temperature and low air humidity can increase evaporative demand even when some soil moisture remains, while prolonged precipitation deficits may reduce soil water availability directly. Modern water-risk frameworks similarly distinguish several dimensions of water stress rather than treating drought as a single uniform condition. The World Resources Institute's Aqueduct framework integrates supply, demand and variability indicators and is most appropriately used as a screening and prioritization tool rather than as a substitute for local measurement (Kuzma et al., 2023).

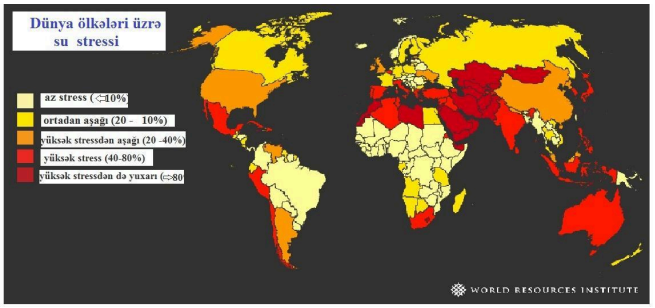


Figure 1. Global water-stress map retained from the original student project. The image attributes the map to the World Resources Institute; current Aqueduct indicators should be consulted for contemporary risk assessment.

4.2. Root and leaf morphological responses

A major theme of the original project is morphological adjustment. It describes deeper or more strongly developed roots as one pathway through which some plants may access water under dry conditions, while leaves may become smaller, fewer or more xeromorphic to reduce transpiring surface area. The project also discusses succulents, xerophytes and ephemeral plants as examples of contrasting strategies for coping with seasonal water shortage.

Recent synthesis adds an important qualification to this interpretation. Sun et al. (2024) show that root responses are not universally positive under drought: severe or extreme stress can reduce root length, area and diameter, and the direction of response varies among plant groups. Thus, adaptive root reconfiguration may improve access to water under moderate stress, but severe drought can

suppress root growth itself. This distinction strengthens the student project by separating adaptive plasticity from damage caused by stress intensity.

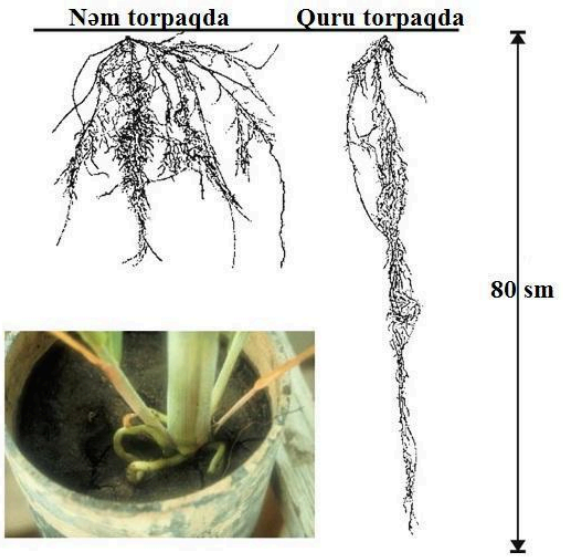


Figure 2. Root morphological differences under moist and dry soil conditions as presented in the original student project. The figure is retained as qualitative visual evidence of drought-related root adjustment.

4.3. Photosynthesis, stomatal regulation and respiration

The source project correctly places stomatal behaviour at the centre of the drought response. As soil and plant water status decline, ABA signalling can promote stomatal closure. This reduces transpiration and conserves water, but it also limits carbon dioxide diffusion into leaves. If stress continues, photosynthetic limitations may extend beyond stomata to chlorophyll, photosystems, electron transport and metabolic processes. Qiao et al. (2024) summarize these interacting mechanisms across major food crops.

The student manuscript further notes that drought can accelerate leaf senescence, reduce chlorophyll and decrease leaf area. The sunflower study of Hussain et al. (2009) provides direct experimental support for several of these patterns: water stress at critical growth stages reduced leaf area index, water relations, crop growth and yield. Kiani et al. (2007) also showed variation among sunflower genotypes in water status and gas exchange, indicating that crop responses cannot be generalized without considering genetic background and recovery after rehydration.

Respiration is another component of the carbon balance emphasized in the original work. Plants require respiratory energy for maintenance, ion transport and growth, yet drought can alter substrate supply and metabolic demand. The exact response of respiration varies with tissue, temperature, stress duration and acclimation, so the source project's general statement that respiration may decline under drought is best interpreted as a common response rather than a universal rule. What is clear is that photosynthesis and respiration must be considered together when evaluating biomass and productivity.

4.4. Mineral nutrition, osmotic adjustment and productivity

Water deficit also affects nutrient acquisition because ions move through soil and roots in a water-dependent system. Reduced soil moisture can limit diffusion and mass flow, while lower transpiration may reduce nutrient transport to the shoot. The original project notes changes in nitrogen distribution and soluble sugars under drought and links these changes to stress adjustment. Such osmotic compounds can contribute to cellular water retention, although their importance differs among species and stress conditions.

These physiological effects ultimately matter because they influence yield and resource productivity. A plant that closes stomata for long periods may survive but accumulate less carbon; a plant that invests strongly in roots may maintain water uptake but allocate less biomass to harvestable organs. Drought-resilient agriculture therefore requires a balance between survival traits and sustained productivity. This is the logic behind breeding and management approaches that evaluate yield under defined water-limited conditions rather than selecting for one physiological trait in isolation (Blum, 2011).

4.4.1. Integrated physiological pathway from stress exposure to productivity

Taken together, the student project and supporting literature describe a sequential but interacting pathway. Reduced soil water first changes the physical environment around the root. The plant responds through hydraulic signals and hormonal regulation, including ABA-mediated stomatal closure. Leaf expansion and transpiration may decline, while roots may alter their distribution in search of available moisture. These adjustments can conserve water in the short term, but they also reduce the exchange of carbon dioxide and may restrict the production of assimilates needed for growth.

As stress becomes stronger or more prolonged, the balance can shift from adaptation to damage. Photosynthetic pigments and electron-transport processes may be impaired, leaf senescence can accelerate and respiratory metabolism may be reorganized. At the same time, nutrient mobility in dry soil declines and the transport of mineral elements from roots to shoots becomes more difficult. The combined result is a reduction in canopy development, biomass accumulation and reproductive performance. This chain of effects explains why the source project repeatedly links water status with photosynthesis, respiration, mineral nutrition and final productivity rather than treating these processes separately.

The practical implication is that no single indicator is sufficient for diagnosing drought impact. A crop can show reduced leaf area before severe chlorophyll loss appears, while root changes may occur below ground before visible shoot symptoms become obvious. Likewise, a low-yield outcome does not reveal whether the dominant mechanism was poor water supply, salinity, nutrient limitation or a combination of stresses. Reliable assessment therefore benefits from a small set of complementary indicators covering soil conditions, plant water status, canopy development and final biomass.

4.5. Salinity as a compound stress in the Kura–Araz agricultural context

The latter part of the source project moves from drought to salinity, an important extension because water deficit and salt stress can occur together in irrigated drylands. Salinized soil reduces the ability of roots to extract water even when moisture is physically present, while high concentrations of particular ions can disturb nutrient balance and damage tissues. In this sense, salinity creates a form of physiological drought.

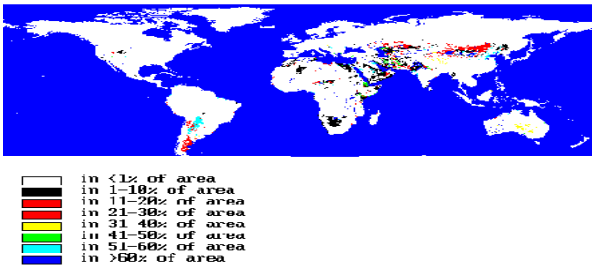


Figure 3. Global distribution of salt-affected soils as presented in the original student project. The underlying source was not specified in the submitted file; the image is retained as part of the original research record.

For Azerbaijan, the most relevant regional evidence comes from the Kur-Araz lowland. Han et al. (2024) reconstructed salinity dynamics for 1986–2021 using Landsat-derived indicators and modelling and showed that salinity is shaped by the interaction of climate and water management. Their analysis found historical improvement under combined rainfall and drainage effects but projected a risk of future re-salinization under changing climate conditions. This provides a more robust basis for the student project's concern about salinized agricultural soils than unverified percentage estimates.



Figure 4. Salinized agricultural land retained from the original student project as a visual example of soil degradation affecting crop production.

4.6. Management implications for resilient and green agriculture

The solutions proposed in the original project—better irrigation design, protection of freshwater resources, reduced pollution, prevention of desertification and selection of drought-resistant plants—remain relevant when reframed as an integrated resource-efficiency strategy. Irrigation modernization can reduce avoidable delivery losses, but it should be combined with drainage, salinity monitoring, crop-specific water scheduling and management of total abstraction so that efficiency gains do not simply encourage higher water consumption.

The ecosystem dimension is also important. Arifzade (2026) shows that water quality pressures in Mingachevir Reservoir must be assessed through multiple indicators, while Mammadov et al. (2026) demonstrate that anthropogenic pollution in the connected Caspian basin includes emerging contaminants such as microplastics. These pressures do not act through the same mechanism as drought or salinity, but together they reduce the environmental quality of water and landscapes that support agriculture and communities.

Nature-based restoration and green finance can complement farm-level adaptation. Qadimli and Mammadov (2026b) show how remote sensing can be used to prioritize nature-based solutions and restoration finance, while Qadimli and Mammadov (2026a) connect ecosystem sustainability with green-finance-based ecotourism. Qadimli et al. (2026) similarly demonstrate that blue-green assets are part of sustainable development planning in Central Aran. Applied to water-stressed agricultural landscapes, the same principle supports investment in riparian buffers, soil restoration, efficient irrigation, drainage and monitoring as forms of natural-capital protection.

The green-economy relevance is therefore direct. Water stress and salinity reduce the efficiency with which land, water, fertilizer and energy are converted into agricultural output. Preventive management can lower long-term degradation costs, protect productive soils and increase resilience to climatic variability. The student project's physiological focus helps explain why such investments matter at plant level: management decisions influence whether crops can maintain water status, photosynthesis, nutrient acquisition and yield under stress.

4.7. Indicators for plant-stress monitoring

The source project contains several physiological variables that can be developed into a practical monitoring framework. Leaf area, chlorophyll status, stomatal behaviour, root development, visible wilting and final biomass all respond to water stress at different stages. Their value lies in combining simple observations with more informative measurements. For example, leaf number and plant height can be recorded without specialized equipment, while chlorophyll meters, soil-moisture sensors or low-cost electrical-conductivity meters can add quantitative evidence where available.

A useful monitoring design should distinguish exposure from response. Soil moisture and electrical conductivity describe the stress environment, whereas leaf area, relative water content, chlorophyll, root traits and biomass describe the plant response. Recording both is important because similar visible symptoms can arise from different mechanisms. A plant growing in saline soil may wilt even when soil moisture is present because high salt concentrations reduce the osmotic potential of the soil solution. Conversely, a plant in non-saline soil may show comparable symptoms because actual water availability is low.

Timing also matters. The original project notes that flowering and reproductive stages can be particularly sensitive to water deficit. A monitoring programme should therefore record the developmental stage at which stress occurs rather than treating all observations as directly comparable. The experimental evidence of Hussain et al. (2009), which imposed water stress at budding and flowering in sunflower, illustrates why growth stage should be treated as a core variable when interpreting yield effects.

The same principle applies to recovery. Kiani et al. (2007) compared sunflower genotypes before and after rehydration and showed that stress response and recovery differ among genotypes. Future school- or farm-based studies could therefore include a rewatering phase and document whether leaf posture, chlorophyll condition, new growth and biomass accumulation recover after water supply is restored. This would convert the student project's descriptive discussion of drought tolerance into a repeatable experimental framework.

For a repeatable assessment, soil moisture can be treated as the primary exposure indicator, while electrical conductivity can be used to screen for salinity. Plant height, leaf number and leaf area provide simple measures of vegetative growth. If equipment is available, relative water content and chlorophyll indices can add information on tissue hydration and photosynthetic condition. Root length and architecture provide evidence on below-ground adjustment, and final dry biomass or yield integrates the cumulative effect of stress across the growing period.

These indicators should be interpreted together rather than as fixed thresholds. Lower soil moisture does not produce the same response in every species, and high electrical conductivity can affect plants differently depending on ion composition and crop tolerance. Similarly, a reduction in leaf area may represent an adaptive reduction in water loss under moderate stress but become a sign of growth suppression under severe stress. Repeated measurements through time are therefore more informative than a single observation.

A school-level experiment could use replicated pots with a well-watered control, a moderate water-deficit treatment and a stronger water-deficit treatment, while keeping soil type, light and temperature as similar as possible. Measurements could be taken at fixed intervals and followed by a rewatering period. Such a design would allow the student's original ideas about drought avoidance, root growth and recovery to be tested without claiming more than the measurements support.

4.8. Resource efficiency, green economy and optimization implications

Plant-level stress responses translate directly into resource-efficiency questions. If drought or salinity lowers photosynthesis and nutrient uptake, more irrigation water, fertilizer, energy and land may be required to obtain the same unit of agricultural output. Conversely, management that maintains root-zone conditions and crop physiological function can improve water productivity without relying solely on greater abstraction. This makes drought adaptation an optimization problem as well as a biological one: the objective is to allocate limited water and other inputs where they protect the greatest amount of productive plant function.

Several management variables can be optimized together. Irrigation timing can be matched to crop growth stages; drainage can be used to control salt accumulation; crop and variety selection can reflect drought and salinity tolerance; and soil-cover or organic-matter practices can help reduce evaporative loss and improve water retention. These measures should be evaluated not only by water applied per hectare but by crop output, soil condition, energy use and the maintenance of ecosystem services.

The wider green-economy literature used in this special issue reinforces this multi-objective approach. Qadimli and Mammadov (2026b) demonstrate the value of prioritizing restoration interventions spatially, while Qadimli and Mammadov (2026a) show how ecosystem condition can be linked with green-finance decisions. Qadimli et al. (2026) similarly connect blue-green assets with regional sustainable-development priorities. For agricultural landscapes, an equivalent approach would direct investment toward areas where irrigation modernization, drainage rehabilitation, soil restoration or vegetation buffers can deliver the largest combined gains in productivity, water security and environmental quality.

This perspective also clarifies why pollution control belongs within agricultural resilience planning. Hydroecological pressure in Mingachevir Reservoir (Arifzade, 2026) and microplastic and anthropogenic pressure in the Caspian basin (Mammadov et al., 2026) show that water resources can be constrained by quality as well as quantity. Green agricultural development therefore depends on both efficient use of water and the protection of the environmental quality of the water entering soils, canals, reservoirs and downstream ecosystems.

4.9. Limitations and future research

This article is based on a student literature project and therefore has clear limitations. It does not contain a controlled drought experiment, field soil measurements, crop-yield observations or a reproducible literature-search protocol. Several quantitative statements in the source manuscript could not be traced to a specific dataset and were therefore not treated as verified results. The four original figures are retained because they form part of the student's work, but where an underlying source was not stated this is explicitly noted in the caption.

A logical next stage would be a small empirical study comparing well-watered and water-stressed plants under controlled conditions. Measurements could include soil moisture, plant height, leaf number or area, relative water content, root length, chlorophyll index and final biomass. A parallel field component in the Kura–Araz lowland could combine soil electrical conductivity, irrigation-water quality and crop condition. Such data would allow the conceptual mechanisms identified in the present article to be tested quantitatively.

CONCLUSIONS

The original student project correctly identified water deficit as a multi-level ecological stress that affects plant growth, morphology, photosynthesis, respiration, mineral nutrition and productivity. Its strongest contribution is the integration of these processes with visible adaptations such as altered root systems, reduced leaf area and drought-avoidance strategies. Contemporary literature confirms these mechanisms while showing that responses depend strongly on stress intensity, duration, species and developmental stage. The project's extension to soil salinity is particularly relevant for Azerbaijan, where modern research in the Kur-Araz lowland demonstrates that climate and water management jointly shape salinity risk. Effective adaptation should therefore combine efficient irrigation, drainage and salinity control with drought-resilient crop selection, water-quality protection, monitoring and ecosystem restoration. These actions connect plant physiology to the green economy because they aim to maintain agricultural output while using water, soil, nutrients and financial resources more efficiently. Future experimental work should test the proposed mechanisms using measured plant and soil indicators under local conditions.

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Ecological pressures on the Kura River and sustainable pathways for pollution control, water conservation and biodiversity protection

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Keywords
Kura River, water quality, water security, biodiversity, green economy

ABSTRACT

The Kura River is a transboundary freshwater system linking upstream, middle-basin and downstream communities, agriculture, infrastructure and ecosystems across the South Caucasus. This study restructures and extends an original educational research project on the ecological problems of the Kura River while preserving its central themes, visual materials, tables and ten-question survey instrument. The source project identified three interrelated pressure groups: water-quality deterioration and transboundary pollution, declining water availability and hydrological alteration, and biodiversity loss associated with habitat change, river regulation and riparian degradation. The present article evaluates these themes through a structured narrative review supported by recent monitoring, biodiversity, water-security and green-economy literature. The analysis confirms that water quantity and water quality should be assessed separately but jointly, because usable water can decline through both reduced availability and deteriorating chemical or ecological condition. Recent Kura monitoring shows longitudinal changes in major-ion composition, while regional studies identify anthropogenic pressure, altered hydrology and riparian degradation as important ecosystem concerns. The original project's proposed solutions—water conservation, efficient irrigation, wastewater treatment, rainwater harvesting, reuse, riverbank clean-up, ecological education and transboundary monitoring—are reframed as elements of integrated and circular water management. The article concludes that Kura River protection requires coordinated monitoring, pollution prevention, resource-efficient water use, nature-based restoration and biodiversity-sensitive river management, with future research based on traceable datasets and repeatable field measurements.

INTRODUCTION

The Kura River is the principal river corridor of the South Caucasus and an important shared resource for settlements, irrigated agriculture, industry, energy systems and freshwater ecosystems. Its transboundary character means that water quantity, water quality and ecological condition are influenced by processes occurring at multiple locations along the basin. The original research project prepared by the "Kürün səsi" group recognized this connectivity and organized the river's environmental problems around pollution, declining water availability and biodiversity loss.

The source project also had a strong solutions-oriented character. It proposed joint monitoring, water conservation, modernization of irrigation, tree planting, riverbank clean-up campaigns, local water-quality laboratories, rainwater harvesting and the filtration and reuse of wastewater. These proposals are important because they move beyond problem description toward resource efficiency and public participation. In a journal context, however, some of the numerical graphics in the source file require cautious interpretation because the submitted project does not provide the underlying monitoring datasets used to generate them.

Recent evidence supports the need for an integrated assessment. Aliyev and Abduyev (2025) analysed water samples from 14 locations along the Kura in Azerbaijan during 2020–2022 and documented systematic downstream changes in mineralization and major-ion composition. Arifzade (2026) further synthesizes nutrient, microbial and major-ion evidence for Mingachevir Reservoir, illustrating that hydroecological pressure is multidimensional. Upstream, Baytaşoğlu (2023) used physicochemical parameters and benthic macroinvertebrate indices at 30 stations in the Kura–Aras basin of Türkiye, demonstrating the value of biological as well as chemical monitoring.

This article preserves the student group's core structure, tables, survey instrument and visual materials, while separating source-project observations from externally verified evidence. It asks: (1) what ecological pressure pathways are most important in the source project; (2) how should the project's pollution, hydrological and biodiversity concerns be interpreted against recent literature; and (3) how can the proposed solutions be reframed through integrated water management, green-economy and nature-based restoration principles?

LITERATURE REVIEW

Water-quality deterioration in a transboundary river may arise from municipal wastewater, industrial discharge, agricultural runoff, solid waste and changes in hydrological conditions. These pressures can interact with natural hydrochemistry, making source attribution difficult without coordinated monitoring. Aliyev and Abduyev (2025) show that the Kura's downstream chemical pattern reflects contributions from tributaries, groundwater, agricultural runoff and other anthropogenic influences, while Baytaşoğlu (2023) shows that

biological indices can reveal ecological condition that is not captured by chemistry alone.

Hydrological stress is equally complex. Lower river levels can result from climatic variability, prolonged drought, water withdrawals, reservoir operation and seasonal demand. The World Bank Group (2024) identifies water security, irrigation performance, water-supply systems and institutional coordination as major priorities for Azerbaijan. The National Strategy on the Efficient Use of Water Resources for 2024–2040 similarly emphasizes integrated management, water-use efficiency, improved irrigation supply, water quality and water security (President of the Republic of Azerbaijan, 2024).

Biodiversity responses depend on habitat quality, flow regime and riparian condition. Gurbanov et al. (2026) document high diversity and complex vegetation structure in Azerbaijan's Tugai forests and identify grazing, deforestation and hydrological alteration as important degradation drivers. These riparian systems stabilize banks, support habitat connectivity and contribute to soil and microclimate regulation. Their loss therefore represents not only a biodiversity problem but also a decline in natural infrastructure.

The green-economy perspective broadens the interpretation of river protection. Qadimli and Mammadov (2026a) link ecosystem sustainability to green-finance-based nature tourism, while Qadimli and Mammadov (2026b) demonstrate how remote sensing can guide nature-based solution priorities and restoration finance. Qadimli et al. (2026) connect blue-green landscape assets with sustainable development in Central Aran. These studies suggest that river restoration, riparian vegetation, water quality and recreation should be evaluated as components of natural capital rather than as separate environmental topics.

Pollution also extends beyond conventional contaminants. Mammadov et al. (2026) synthesize evidence of microplastic pollution and coastal anthropogenic pressure in the Caspian Sea basin. Because the Kura ultimately discharges to the Caspian, prevention of plastic leakage and improved solid-waste management in the river basin can contribute to downstream coastal protection. This creates a basin-to-sea logic for pollution prevention.

MATERIALS AND METHODS

The study used a structured narrative-review design based on a 15-page educational research project titled "Kür çayının ekoloji problemləri və onların həlləri." The source file identifies B. Asya, Ə. Mahirə and M. Sədaqət as the project editors, the group name as "Kürün səsi," the location as Baku and İ. Aytac as supervisor. The original project combines desk research, explanatory text, tables, graphs, photographs, an infographic, a riverbank clean-up example, a rainwater-harvesting scheme and a ten-question survey instrument.

The content was coded into five analytical categories: (1) transboundary and local pollution; (2) declining water availability and hydrological change; (3) biodiversity and riparian ecosystem pressure; (4) water use and economic exposure; and (5) proposed management solutions. The original survey questions were retained as a research instrument, but no completed questionnaires, sample size or response dataset were supplied. Accordingly, no survey statistics are reported in this article.

The project's three time-series graphics were also handled cautiously. They present annual values for pollution severity, water-level decline and selected fish-abundance indices from 2020 to 2025, but the submitted file does not identify an underlying monitoring dataset or sampling method. The graphics are therefore preserved as source-project visualizations and are discussed as illustrative indices rather than official empirical time series. Photographs and other visual materials are likewise retained; where the original image source or licence was not stated, this is noted in the captions.

To strengthen academic interpretation, the project was compared with recent peer-reviewed studies, institutional reports and national strategy documents relevant to Kura water quality, biodiversity, water security and restoration. The study does not claim to be a systematic review, and it does not generate new water-quality, discharge, biodiversity or economic measurements.

Table 1. Kura River background indicators as reported in the original project

Indicator	Project-reported value
Source	Qızılgədik Mountain, 2740 m
Mouth	Caspian Sea, −25.8 m
Basin area	188 thousand km²
Reported feeding shares	Snow 52%; groundwater 30%; rainfall 18%

Note. Values are retained from the original project for continuity and are not independently re-estimated in this study.

RESULTS AND DISCUSSION

4.1. Water-quality and pollution pressures

The source project treats pollution as the first major ecological pressure and emphasizes the transboundary nature of the river. It discusses industrial and municipal wastewater, mining-related contaminants, heavy metals, petroleum products and solid waste. The academic evidence supports the broader concern that pollution sources are spatially distributed along the basin, but it also shows why individual-source attribution requires measured loads and consistent monitoring rather than general assumptions about upstream origin.

Aliyev and Abduyev (2025) provide direct contemporary evidence from Azerbaijan. Their 2020–2022 monitoring shows systematic changes in major ions and mineralization along the river, including a downstream shift toward sodium-sulfate water in lower reaches. These changes reflect combined hydrochemical and anthropogenic influences rather than a single source. Arifzade (2026) similarly shows that hydroecological condition in Mingachevir Reservoir should be interpreted through multiple indicators, including nutrient, microbial and major-ion evidence.

The source project's concern with plastics and visible riverbank waste is also important. Mammadov et al. (2026) show that microplastic pollution is part of the wider anthropogenic pressure affecting the connected Caspian basin. Riverbank litter prevention, improved waste collection and wastewater control can therefore produce benefits beyond the immediate river reach by reducing the transfer of contaminants toward downstream reservoirs, the delta and the Caspian Sea.

Complementary evidence from a Kura tributary also illustrates the value of repeated field monitoring. Aliyev, Farzali, and Dürrani (2023) measured nutrients, metals/metalloids, oxygen-demand indicators and macrozoobenthos in the Turyanchay River basin and reported substantial temporal variation across months. Their design demonstrates how chemical and biological measurements can be combined to establish a baseline and to distinguish seasonal variability from persistent degradation.

4.2. Hydrological stress and declining usable water

The second major theme in the source project is declining water availability. It links lower river levels to climate change, changing precipitation, higher temperatures, reservoirs and intensive water use. These mechanisms are plausible, but their individual contributions vary by location and season. A reliable attribution would require discharge records, precipitation and temperature series, withdrawal data and reservoir-operation information for the same time periods.

This distinction between water quantity and usable water is essential. Water quality can reduce the suitability of water even when discharge remains substantial, while a physical decline in discharge can intensify competition among drinking-water, agricultural and ecological uses. The World Bank Group (2024) therefore frames Azerbaijan's water challenge around both institutional efficiency and investment priorities, while the 2024–2040 National Strategy emphasizes integrated management and efficient use (President of the Republic of Azerbaijan, 2024).

The source project also raises the issue of salinity in the lower river and the possibility of seawater influence near the mouth during low-flow conditions. This concern should be investigated with simultaneous measurements of river discharge, electrical conductivity, chloride and water level along the lower Kura. Such measurements would allow a future study to distinguish marine influence from other sources of mineralization and groundwater interaction.

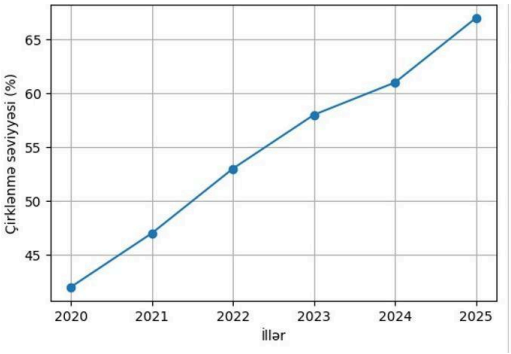


Figure 1. Original project trend graphics for pollution severity, water-level decline and selected fish-abundance indices, 2020–2025. The submitted project does not provide the raw datasets or sampling design; the graphics are therefore retained as illustrative source-project indices rather than verified monitoring time series.

4.3. Biodiversity, fish migration and riparian ecosystems

Biodiversity is the third core theme of the source project. The authors emphasize fish, wetlands, Tugai forests and the ecological consequences of water-level change and dams. Flow regulation can alter migration routes, seasonal habitats and sediment processes, while lower or more variable water levels can affect floodplain vegetation and wetlands. The significance of these mechanisms depends on the ecological requirements of particular species and river reaches.

Recent research on Tugai forests provides strong regional support for the project's emphasis on riparian vegetation. Gurbanov et al. (2026) describe diverse Populus-, Salix-, Ulmus-, Alnus- and Tamarix-dominated communities and show that hydrological alteration, deforestation and grazing can degrade these ecosystems. Healthy riparian vegetation functions as natural infrastructure by stabilizing riverbanks, supporting habitat connectivity and contributing to soil and local microclimate regulation.

Field research from the Agjabadi section of the Kura further supports a restoration-oriented approach. Gurbanov and Ahmadova (2024) describe riparian vegetation communities and emphasize that conservation requires attention to the ecological condition of the riverbank environment rather than tree planting alone. This reinforces the student project's proposal to expand vegetation and protect river margins as part of a broader ecosystem-management strategy.

This ecosystem-service interpretation creates a direct connection with green economic resilience. Biodiversity protection can support fisheries, landscape quality, recreation and nature-based tourism, while riparian restoration can reduce erosion and strengthen natural capital. Qadimli and Mammadov (2026a) and Qadimli et al. (2026) provide examples of how ecosystem condition and blue-green assets can be linked with sustainable development and tourism opportunities.



(a) Riverbank photograph retained from the source project



(b) Kura River landscape retained from the source project



(c) River view retained from the source project

Figure 2. River and riverbank photographs retained from the original project. The submitted file did not identify the photographer or publication licence for these images; source and permission should be confirmed before final external publication.

4.4. Water use, resource efficiency and economic exposure

The source project includes a sectoral table in which agriculture is presented as the dominant water-use category, followed by drinking-water supply and energy/industry. Because no statistical source is attached to the percentages, the shares should be interpreted as project-reported estimates rather than official national statistics. Nevertheless, the management logic is sound: inefficient irrigation increases the volume that must be withdrawn and delivered to obtain a given agricultural outcome, while water-quality deterioration can increase treatment requirements for domestic or industrial use.

Table 2. Water-use structure and management issues retained from the original project

Sector	Project-reported share	Main management issue identified in the project
Agriculture	~75%	Traditional or ageing irrigation systems, leakage, evaporation and inefficient delivery
Drinking-water supply	~10–12%	Need for treatment and protection of water quality before distribution
Energy and industry	~13–15%	Need to reduce avoidable losses and improve recirculation/reuse where feasible

The green-economy implication is that water losses, pollution and ecosystem degradation all reduce resource productivity. Water must be

abstracted, conveyed, treated and sometimes pumped with energy. If part of that water is lost or rendered unsuitable by pollution, the same social or economic service requires greater physical and financial input. Preventive pollution control and efficient water delivery can therefore reduce environmental pressure while improving economic efficiency.

4.5. From project solutions to circular and nature-based water management

One of the strongest aspects of the original project is its practical solutions section. It proposes water-saving behaviour, modernization of irrigation, small water-quality laboratories in river districts, rainwater collection for non-potable uses, treatment and recirculation of wastewater, riverbank clean-up campaigns and environmental education. These ideas can be organized within a circular water-management framework in which water is conserved, treated, reused where appropriate and prevented from becoming waste.

Rainwater harvesting is particularly relevant as a decentralized supplementary measure. Collected rainwater can reduce demand for treated freshwater in garden irrigation, cleaning and other non-potable uses where local regulations and water-quality requirements are satisfied. Wastewater reuse has greater technical requirements but can similarly reduce pressure on freshwater abstraction when treatment is appropriate for the intended use.

Nature-based solutions add an ecosystem dimension to this circular approach. Riparian buffers, wetland restoration and Tugai rehabilitation can complement engineered treatment by stabilizing banks, trapping sediments, improving habitat and maintaining ecological connectivity. Qadimli and Mammadov (2026b) show how nature-based solution priorities can be mapped and linked to green-finance needs. The same investment logic is applicable to river corridors where restoration benefits water security, biodiversity and local economic resilience.

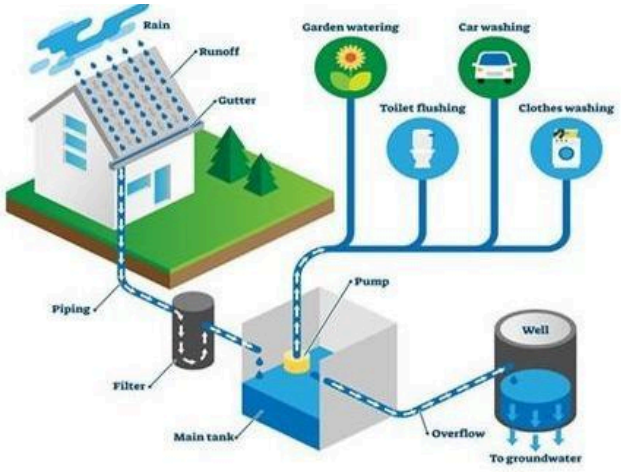


Figure 3. A rainwater-harvesting system. Original external image sources or licences were not specified in the submitted file and should be confirmed before final publication.

4.6. Transboundary monitoring and shared evidence

The source project calls for stronger transboundary cooperation and common monitoring. This is consistent with UNECE-supported work aimed at strengthening cooperation between Azerbaijan and Georgia in the Kura basin and with the broader principle that shared water systems require data exchange and comparable monitoring protocols (United Nations Economic Commission for Europe [UNECE], n.d.). A scientifically useful monitoring system should include discharge, major ions, nutrients, selected metals, microbial indicators and biological measures, together with transparent information on sampling location, date and analytical method.

The upstream dimension also deserves attention without reducing the basin to country-by-country blame. Baytaşoğlu (2023) demonstrates that Kura–Aras water quality in Türkiye can be assessed using both physicochemical data and benthic macroinvertebrate indices. Comparable methods across the basin would make it easier to distinguish local pressures from cumulative downstream change and to identify where restoration or pollution-control investment can have the greatest effect.

4.7. Preservation of the original survey instrument and future empirical design

The original project prepared a ten-question survey covering perceived pollution causes, health effects, control of municipal and industrial waste, impacts on fish, individual responsibility, agricultural damage, riverbank litter infrastructure, environmental education, water filtration and future risk. This shows an effort to connect ecological science with public perception. Because no completed survey responses were provided, the present article does not infer public opinion from the instrument.

Table 3. Themes in the original ten-question survey instrument

Ques.	Theme
1–2	Main pollution causes and perceived human-health effects
3–4	Wastewater prevention and perceived impacts on fish and aquatic life
5–7	Individual responsibility, agriculture and riverbank litter infrastructure
8–9	Environmental education and views on water-filtration technology
10	Perceived long-term risk of severe degradation or unusable water

Note. The source project provides the questions but no respondent sample, completed forms or response dataset.

A future empirical version of the project could combine three data streams: repeated water-quality measurements at defined Kura locations, georeferenced observations of riverbank litter and riparian condition, and a documented perception survey with a defined sample. Linking these datasets would allow the authors to test whether public concerns correspond to measured environmental patterns and would transform the present diagnostic review into a reproducible mixed-method study.

4.8. Implementation priorities and monitoring indicators

A practical management sequence can begin by mapping pressure–pathway–receptor relationships along selected Kura River reaches. For each reach, potential pressure sources such as wastewater outfalls, agricultural drainage, solid-waste accumulation, riverbank modification and flow regulation should be recorded together with the ecological receptors most likely to be affected. This type of spatial screening would help convert the broad concerns identified in the original project into location-specific priorities for monitoring and intervention.

A minimum monitoring package should combine hydrological, chemical, biological and visual indicators. River level or discharge, temperature, electrical conductivity, dissolved oxygen, nutrients, selected major ions and microbial indicators can be complemented by macroinvertebrate or habitat assessments where feasible. Repeated riverbank observations can document litter density, vegetation condition and erosion. The value of this approach is that it avoids relying on a single indicator: a chemically acceptable sample may still occur in a degraded habitat, while visible pollution may not reveal dissolved contaminants.

Management options should then be evaluated in terms of both environmental effectiveness and resource efficiency. Wastewater treatment, irrigation rehabilitation, rainwater harvesting, riparian restoration and clean-up programmes differ in cost, scale and expected benefit. A simple decision framework could compare each option by pollution reduction, water saved or reused, biodiversity benefit, implementation cost, maintenance requirement and community participation. Such multi-criteria assessment would align closely with the optimization focus of JGEOR and with the green-finance and nature-based solution perspectives developed by Qadimli and Mammadov (2026a, 2026b).

The public-engagement component of the source project should also be retained in future implementation. Riverbank clean-up campaigns and school-based environmental education cannot replace wastewater infrastructure or basin-scale water management, but they can reduce visible waste leakage, improve stewardship and generate local observations. The original ten-question survey could be administered before and after awareness activities to test whether knowledge and behavioural intentions change, provided that sampling, consent and data handling are documented.

Finally, monitoring should be designed to support comparison through time. The illustrative 2020–2025 charts in the source project demonstrate the authors' interest in trend analysis, but future versions should use dated measurements from the same locations and the same methods. Consistent metadata would allow the group to distinguish short-term fluctuations from persistent trends and would make later updates scientifically comparable.

4.9. Limitations

The main limitation is that the underlying work is an educational research project rather than a standardized field investigation. Several numerical claims and graphics are not accompanied by raw data or traceable methodological documentation. They are preserved because they represent substantive student effort, but they are not used as official monitoring evidence. The study also does not independently verify the provenance or publication permissions of every image in the source file. Final journal production should therefore confirm image rights, complete the authors' full names and institutional affiliation, and replace or source any visual whose licence cannot be documented.

CONCLUSIONS

The original "Kürün səsi" project identifies a coherent set of ecological challenges for the Kura River: pollution, declining usable water, hydrological alteration, biodiversity pressure and inefficient resource use. Recent scientific evidence supports the importance of these themes while also showing the need for more precise attribution and measurement. Contemporary monitoring demonstrates spatial changes in Kura water chemistry, biodiversity research highlights the ecological value of Tugai forests, and current water-security planning emphasizes integrated management and efficiency. The project's solutions are particularly valuable when interpreted through circular and green-economy principles. Efficient irrigation, wastewater treatment and reuse, rainwater harvesting, solid-waste prevention, riverbank restoration, ecological education and transboundary monitoring can reduce pressure on both water quantity and quality. Nature-based restoration can complement engineered infrastructure by protecting riparian habitat and natural capital. The next stage should move from illustrative charts and unsampled survey questions to traceable field measurements, documented datasets and reproducible survey methods. In this form, the student project provides a useful foundation for a broader evidence-based framework for Kura River protection and sustainable water management.

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The Kura River: Our history, nature, and future

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Kura River, cultural landscape, ecosystem services, water security, green economy

ABSTRACT

The Kura River is simultaneously a historical corridor, ecological system and economic resource whose condition has direct implications for water security and sustainable development in Azerbaijan and the wider South Caucasus. This article develops an original student research project on the Kura River into a structured interdisciplinary review organized around three questions: how the river has shaped human settlement and cultural memory, how its natural systems support biodiversity and ecosystem services, and what environmental pressures must be addressed to protect its future. The source project emphasized the river's role in agriculture, hydropower, water supply, fisheries, riparian habitats and public well-being, while also highlighting pollution prevention and careful water use. These ideas are expanded with recent historical, hydrochemical and green-economy literature. The review shows that the Kura has long functioned as both a connector and a resource base in the Caucasus, including through the Early Bronze Age Kura-Araxes cultural landscape. In the present day, the river supports irrigation, energy production, settlements and ecosystems, but downstream water quality, habitat condition and competing water demands require stronger monitoring and integrated management. Recent evidence from the Middle Kura and lower basin further shows that mineralization and other hydroecological pressures vary spatially. The study concludes that the Kura's future depends on combining water-use efficiency, pollution control, ecosystem restoration, transboundary cooperation and green investment, while maintaining public and youth engagement in river stewardship.

INTRODUCTION

The Kura River is one of the defining natural features of the South Caucasus. Rising in northeastern Türkiye, flowing through Georgia and Azerbaijan, and ultimately reaching the Caspian Sea, the river connects mountain landscapes, cities, reservoirs, agricultural plains and coastal environments within a single hydrological system. Encyclopaedia Iranica describes the Kura as the largest river of the Transcaucasus and records its importance both as a historical landmark and as a source of fertile land and connectivity across the region (Wordsworth, 2021). The original student project that forms the basis of this article approached the river from a similarly integrated perspective: the Kura was presented not only as a source of water, but as a resource supporting agriculture, energy production, biodiversity and everyday life.

This broad framing is important because the river cannot be understood through a single discipline. Hydrology explains the movement and seasonal availability of water; ecology examines habitats, fish, birds and riparian vegetation; history and archaeology reveal the long relationship between people and the river corridor; and economics considers how water, land, electricity, agriculture and ecosystem services contribute to development. These dimensions are interdependent. A reduction in water quality can raise treatment needs, changes in river flow can affect agriculture and habitats, and degradation of riparian ecosystems can weaken natural protection against erosion and reduce recreational or cultural value.

The student source emphasized six practical themes: the Kura's regional geography, its importance for farming and communities, the role of Mingachevir Reservoir, the presence of plants and animals, the need to test and treat drinking water, and the importance of pollution prevention and water saving. The present article preserves those themes and develops them into an interdisciplinary review organized around the idea of "history, nature, and future." The historical dimension examines the Kura as a corridor of settlement and cultural development; the natural dimension considers biodiversity and ecosystem services; and the future dimension evaluates how monitoring, efficient water use, restoration and green investment can strengthen resilience.

Accordingly, the article asks three questions. First, how has the Kura contributed to the historical and cultural development of the South Caucasus? Second, which ecological and economic functions make the river valuable today? Third, which environmental pressures and management priorities are most important for protecting the river for future generations? The analysis is based on a structured narrative review rather than new field sampling, so measured evidence and broader interpretation are distinguished throughout.

LITERATURE REVIEW

2.1. The Kura as a historical and cultural corridor

The river's historical importance extends far beyond modern water management. Wordsworth (2021) notes that archaeological sites have been documented along the Kura corridor from the Neolithic onward and that the river functioned as both a landmark and an artery linking settlements and agricultural landscapes. Its historical names—Cyrus in Greek and Latin sources and Mtkvari in Georgia—also reflect the river's long presence in the cultural geography of the region.

The best-known archaeological expression of this history is the Kura-Araxes cultural tradition. Recent radiocarbon-based research places the Kura-Araxes phenomenon within the Early Bronze Age of the South Caucasus and emphasizes its wide regional distribution and chronological complexity (Passerini et al., 2026). The tradition is named after the Kura and Araxes rivers that frame its core region. This does not mean that the river alone created the culture, but it illustrates how major river basins can become enduring geographical reference points for settlement, agriculture, mobility and cultural interaction.

2.2. Natural capital and ecosystem services

From an ecological perspective, the Kura is a network of connected habitats rather than only a channel of flowing water. River water, floodplains, reeds, riparian woodland, fish, birds and associated wetlands form a system in which biological and physical processes interact. The student source correctly emphasized that plants along the banks provide food and shelter for wildlife and that maintaining clean water is necessary for protecting these habitats. Such functions can be interpreted as ecosystem services: water provision, habitat support, bank stabilization, nutrient cycling, recreation and cultural value.

Recent JGEOR research provides a useful green-economy context for this interpretation. Qadimli and Mammadov (2026a) connect ecosystem sustainability with green-finance-based ecotourism, while Qadimli and Mammadov (2026b) show how remote sensing can support the spatial prioritization of nature-based solutions and restoration finance. Qadimli et al. (2026) extend this logic to Central Aran by linking blue-green assets with tourism potential and sustainable development priorities. These studies do not measure the Kura's historical value directly, but they demonstrate why rivers, wetlands and riparian landscapes can be treated as productive natural capital within regional planning.

2.3. Water quality, hydrological pressure and the connected Kura-Caspian system

The future of the Kura also depends on the quality and usability of its water. Aliyev and Abduyev (2025) analysed samples from 14 points along the Azerbaijani section of the river during 2020–2022 and documented a downstream increase in mineralization and substantial spatial changes in major-ion composition. Their results show why a river can remain physically present while the quality and suitability of its water change between locations. The source project's statement that river water should be tested and treated before drinking is therefore consistent with direct monitoring evidence.

Hydroecological synthesis from Mingachevir Reservoir similarly indicates that nutrient, microbial and major-ion evidence should be interpreted together when evaluating the condition of the Middle Kura cascade (Arifzade, 2026). Downstream, the Kura also contributes to the broader Caspian basin, where Mammadov et al. (2026) review microplastic pollution and coastal anthropogenic pressure. These studies reinforce the idea that river management should connect freshwater quantity, water quality, ecosystem condition and downstream environmental consequences.

MATERIALS AND METHODS

This article used a structured narrative review built from an original student project entitled "The Kura River in Azerbaijan," which was later developed under the publication title "The Kura River: Our History, Nature, and Future." The source document contains short thematic sections on the river's geography, importance for agriculture and communities, Mingachevir Reservoir, plants and animals, drinking-water quality, river protection and a final conservation message. No experimental sampling, survey dataset, laboratory analysis or statistical model was provided in the original source.

The source text was first coded into six analytical categories: geography and connectivity; historical and cultural significance; water and economic use; biodiversity and habitats; water quality and pollution; and conservation actions. Each source claim was then classified as either a general educational statement requiring contextual support or a point suitable for comparison with peer-reviewed evidence. The analysis deliberately avoids creating new measurements from descriptive statements. For example, the source project correctly notes that water quality varies along the river, but it does not quantify that variation; quantitative hydrochemical evidence is therefore drawn from Aliyev and Abduyev (2025) rather than inferred from the student text.

The external literature was selected to strengthen three dimensions that were brief or absent in the source: historical context, recent hydroecological evidence and green-economy interpretation. Historical evidence was drawn from Encyclopaedia Iranica and recent Kura-Araxes archaeological research. Environmental evidence was taken from recent peer-reviewed studies of the Kura and Mingachevir Reservoir. The five JGEOR and Caspian references requested for the KuraWatch 2 series were integrated where they contribute relevant perspectives on ecosystem sustainability, restoration, blue-green development and basin pollution. The review is qualitative and does not claim the completeness of a systematic review or meta-analysis.

RESULTS AND DISCUSSION

4.1. Geography as the foundation of the Kura's historical and ecological role

The first result of the synthesis is that geography explains much of the river's long-term significance. The Kura rises in the uplands of northeastern Türkiye, crosses Georgia and Azerbaijan, receives the Araxes near Sabirabad and reaches the Caspian Sea (Wordsworth, 2021). Its approximately 1,515 km length and large basin create continuity between mountainous headwaters, urban centres, reservoirs, agricultural plains and the coastal zone. This continuity makes the river useful for settlement and economic activity, but it also transmits pressures between upstream and downstream sections.

The source project framed the Kura primarily from the perspective of Azerbaijan, where it supports farming, water supply, fisheries and energy. This national importance should be understood within the river's transboundary structure. UNECE records long-running efforts to strengthen cooperation between Azerbaijan and Georgia on monitoring, pollution prevention, biodiversity protection and sustainable use of shared Kura waters. The existence of such cooperation mechanisms demonstrates that the river's future cannot be managed only at isolated local sites; information and actions need to be coordinated across connected sections of the basin.

4.2. Historical continuity from river corridor to cultural landscape

The historical dimension expands the student project's central idea that the Kura is part of people's everyday life. Long before modern reservoirs or irrigation canals, the river corridor provided water, fertile land and routes of movement. Wordsworth (2021) describes the Kura as a long-standing landmark and artery of the Caucasus, while archaeological research identifies the wider Kura-Araxes zone as a major Early Bronze Age cultural landscape.

Recent work by Passerini et al. (2026) demonstrates that the Kura-Araxes phenomenon was temporally and regionally complex rather than a single uniform culture. This is an important caution for environmental history: a river can structure human geography without producing identical social systems along its whole course. The Kura's historical value therefore lies in continuity of interaction—settlement, farming, mobility, fishing and cultural memory—rather than in a simple narrative of one civilization directly determined by the river.

4.3. Nature, biodiversity and ecosystem services

The source project identifies fish, birds, grasses, trees and other riverside vegetation as visible components of the Kura ecosystem. These observations are simple, but they capture an important ecological principle: river biodiversity is distributed across water, banks and floodplain habitats. Fish depend on aquatic conditions, birds use shoreline and wetland habitats, and riparian vegetation provides shelter, food and physical stabilization of river margins.

Treating these functions as ecosystem services clarifies their economic significance. Bank stabilization can reduce erosion-related damage, vegetated corridors support biodiversity and recreation, and functioning floodplain habitats can contribute to landscape resilience.

Qadimli and Mammadov (2026b) show in another Azerbaijani landscape how restoration priorities can be identified spatially and linked to green-finance needs. Applied to the Kura, an equivalent approach would prioritize degraded riparian sections where restoration could jointly improve habitat, bank stability, landscape quality and ecological connectivity.

Table 1. The Kura River as a linked historical, ecological and green-economy system

Dimension	Core value	Future priority
Historical-cultural	Settlement corridor, Kura-Araxes heritage, cultural memory	Protect cultural landscapes and strengthen environmental education
Water and agriculture	Irrigation, community supply and productive land	Increase water-use efficiency and monitor abstraction
Energy and regulation	Reservoir storage and hydropower	Balance operational benefits with ecological flow and water-quality needs
Biodiversity	Fish, birds, riparian vegetation and floodplain habitats	Protect and restore riparian and aquatic habitats
Water quality	Usable water for households, agriculture and ecosystems	Expand monitoring, wastewater treatment and pollution prevention
Green economy	Natural capital, recreation, resilience and regional development	Target restoration and blue-green investment where benefits overlap

4.4. Water, agriculture, hydropower and resource efficiency

The original project strongly emphasizes practical economic uses of the Kura. Farmers rely on river water to support crops, communities depend on the river system for water supply, and Mingachevir Reservoir contributes to hydropower generation and irrigation. These functions explain why the Kura should be treated as economic infrastructure as well as an ecosystem. However, the value of the river is not proportional simply to the volume of water withdrawn. If irrigation systems lose water, if pollution raises treatment needs or if riverbank degradation reduces ecosystem services, the same level of economic activity requires more inputs and generates higher costs.

This is where the green-economy perspective becomes useful. Resource efficiency means producing agricultural, energy and social benefits while reducing avoidable losses and environmental damage. Qadimli et al. (2026) show that blue-green assets can be integrated into regional development priorities in Central Aran, a region directly shaped by Kura-related water systems. The implication for the present study is that river management should evaluate irrigation, energy, ecosystems and recreation together rather than as separate sectors competing for the same water.

4.5. Water quality and the limits of a simple "clean or polluted" classification

The student source makes a careful and scientifically responsible point: there is no single percentage that can describe how much of the Kura River is "safe to drink" at every location and time. Water quality is spatially variable and must be tested before use. This distinction is strongly supported by direct monitoring. Aliyev and Abduyev (2025) found substantial downstream changes in major ions and mineralization along the Azerbaijani section of the Kura, including sharp increases after the confluence with the Araxes and in the lower river.

The correct interpretation is not that every downstream site is unsafe for every use, but that water suitability depends on location, treatment requirements and the purpose of use. Arifzade (2026) reaches a compatible conclusion for Mingachevir Reservoir by synthesizing nutrient, microbial and major-ion evidence: hydroecological assessment requires multiple indicators rather than one simplified label. This supports the source project's emphasis on regular testing, treatment and pollution prevention.

The Kura-Caspian connection adds a further downstream perspective. Mammadov et al. (2026) review microplastic pollution and coastal anthropogenic pressure in the Caspian basin. Although their study concerns a broader receiving environment rather than the Kura alone, it shows why solid-waste and wastewater management within river basins matter beyond the immediate riverbank: materials transported through connected waters can contribute to cumulative coastal pressure.

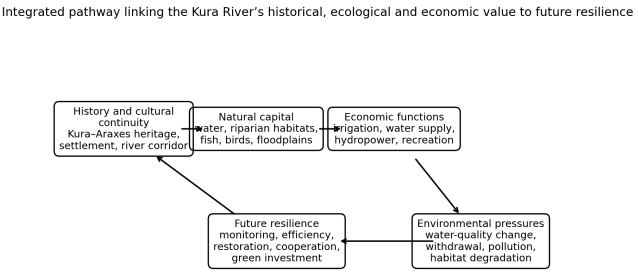


Figure 1. Integrated pathway linking the Kura River's historical, ecological and economic value to future resilience.

4.6. Mingachevir Reservoir as a multifunctional Middle Kura node

Mingachevir Reservoir deserves separate attention because it sits at the intersection of several themes in the source project. It is a water-storage and hydropower facility, an important element of irrigation supply, a large aquatic ecosystem and a hydrological control point within the Middle Kura cascade. This multifunctional role means that the reservoir cannot be evaluated only through electricity generation or stored water volume. Its ecological condition also affects downstream water quality, fisheries, recreation and the reliability of water delivered to other users.

Arifzade (2026) synthesizes nutrient, microbial and major-ion evidence for Mingachevir and shows why a multi-indicator approach is necessary. A reservoir may appear physically full while still experiencing ecological pressures that influence the quality of water released downstream. Conversely, an isolated water-quality measurement cannot explain the full hydrological condition of the system. The key analytical lesson is that quantity, quality and ecological status are related but distinct dimensions.

This distinction also improves interpretation of the student project. The original work correctly identifies Mingachevir as a major national water resource, but its role is broader than storage. It connects upstream inflow, reservoir processes and downstream river conditions. Management therefore benefits from coordinated monitoring of inflow, outflow, water quality, seasonal storage changes and ecosystem indicators rather than from any single measure considered in isolation.

4.7. Monitoring and decision framework for the future Kura

A practical future-oriented framework can be built around four evidence groups. Hydrological indicators describe how much water is available and when; water-quality indicators describe whether that water is suitable for particular uses; ecological indicators describe habitat and biodiversity condition; and socioeconomic indicators

show how river changes affect agriculture, water supply, energy, recreation and treatment costs. These groups should be interpreted together because improvement in one dimension does not automatically mean improvement in the others.

Hydrological monitoring should include seasonal discharge, reservoir storage and water-withdrawal information where available. Water-quality monitoring can track mineralization, major ions, nutrients, microbial indicators and selected pollutants. Ecological assessment can combine field observations of riparian vegetation and habitats with remote sensing of land cover, wetlands or erosion-prone areas. Qadimli and Mammadov (2026b) demonstrate how spatial evidence can support prioritization of restoration investment, which is directly relevant to identifying degraded river sections where interventions may produce multiple benefits.

Socioeconomic monitoring should then connect environmental change to practical consequences. Useful indicators include irrigation reliability, water-treatment requirements, recreational use, restoration expenditure and the condition of productive land close to the river. Such indicators do not require that every ecosystem service be given a monetary value. Their purpose is to make trade-offs visible so that decisions about infrastructure, pollution control or restoration can consider both ecological and economic outcomes.

The green-finance perspective adds a further decision layer. Qadimli and Mammadov (2026a) show how ecological condition can be connected with financing and ecotourism opportunities, while Qadimli et al. (2026) demonstrate the value of spatially explicit blue-green development priorities. For the Kura, this suggests that restoration funding should target locations where water security, biodiversity, public access and local economic value can improve together, provided that tourism or recreation is managed within ecological limits.

Table 2. Suggested evidence groups for integrated Kura River monitoring

Evidence group	Example indicators	Decision use
Hydrology	Seasonal discharge, reservoir storage, withdrawals	Identify low-flow periods and allocation pressure
Water quality	Mineralization, major ions, nutrients, microbial indicators	Assess treatment needs and suitability for different uses
Ecology	Riparian cover, habitat condition, erosion, biodiversity observations	Prioritize habitat protection and restoration
Socioeconomics	Irrigation reliability, treatment needs, recreation, restoration costs	Compare environmental and development trade-offs
Spatial planning	Remote sensing of land cover, wetlands and degraded riverbanks	Target blue-green and nature-based investments

4.8. Future pathways for a resilient Kura River

The future-oriented recommendations in the source project are direct and practical: keep rubbish away from the river, treat wastewater before discharge, use agricultural water carefully, limit harmful chemical runoff, save water in households and strengthen monitoring. These actions remain valid, but an integrated management framework helps explain how they fit together. Pollution prevention protects water quality; efficient irrigation reduces pressure on limited supplies; riparian restoration supports habitats and bank stability; and transparent monitoring provides evidence for management decisions.

Nature-based solutions and green finance can strengthen this framework. Qadimli and Mammadov (2026b) emphasize the value of prioritizing restoration spatially, while Qadimli and Mammadov (2026a) link ecosystem sustainability with finance and ecotourism opportunities. For the Kura, this suggests that restoration investment should be directed toward places where ecological and economic benefits overlap—for example, riverfronts where improved habitat quality can also support recreation, environmental education or local tourism without increasing ecological pressure.

Transboundary cooperation is equally important. UNECE documents sustained efforts to strengthen data sharing, monitoring and cooperation between Azerbaijan and Georgia on the Kura basin. Such cooperation does not replace national or local action, but it helps countries interpret upstream and downstream changes using comparable information. A river shared across borders benefits from shared evidence, especially when pollution, drought or altered flows may affect more than one jurisdiction.

4.9. Environmental education, youth research and stewardship

The source project is itself evidence of an important future pathway: environmental education. A student investigation that asks why a river matters, why water must be tested and how pollution can be prevented may not replace professional monitoring, but it can strengthen environmental literacy. Young researchers can contribute through supervised observation, litter audits, mapping, photographic documentation and interpretation of published datasets, provided that observations are clearly distinguished from scientific measurements.

This educational dimension also connects history with future stewardship. Understanding that the Kura has supported communities for thousands of years can make present-day conservation more meaningful. Historical continuity does not guarantee future security; rather, it creates responsibility to maintain the ecological conditions that allow the river to continue supporting water supply, agriculture, biodiversity, culture and local economies.

A second research direction concerns historical-environmental change. Archaeological and historical sources can show how the river corridor has supported settlement over long periods, while modern geospatial datasets can document changes in reservoirs, riparian vegetation, settlement expansion and agricultural land. Combining these time scales would help distinguish cultural continuity from modern environmental transformation and would give the title's "history" dimension a measurable spatial basis.

A third direction is participatory monitoring. Schools and local communities can contribute repeatable observations of litter, riverbank condition, visible erosion, vegetation change and public use. These observations should not be presented as substitutes for laboratory or hydrological data, but they can identify locations that deserve professional investigation and can strengthen public understanding of why river protection depends on both individual behaviour and institutional monitoring.

4.10. Drinking-water security, public health and treatment implications

The source project makes an important distinction between a river as a water source and river water as finished drinking water. The Kura contributes to water-supply systems, but raw river water must be monitored and treated before household consumption. This distinction is especially relevant in a long river with multiple tributaries, reservoirs, settlements and agricultural areas because the

physical and chemical character of water can change substantially along the course. A single statement about whether "the river is clean" is therefore scientifically inadequate.

Aliyev and Abduyev (2025) provide direct evidence for this spatial variability by showing marked downstream changes in mineralization and major-ion composition. Their monitoring does not imply that all downstream water is unusable, but it demonstrates that treatment requirements and suitability can vary by location. The practical consequence is that public-health protection depends on reliable monitoring networks, appropriate treatment technologies and rapid identification of pollution events rather than on assumptions based on the visual appearance of the river.

The same principle applies to reservoir water. Arifzade (2026) shows that hydroecological assessment of Mingachevir requires consideration of nutrient, microbial and major-ion evidence together. A treatment system designed only around one parameter may not capture the full range of pressures affecting raw-water quality. For future Kura management, monitoring programmes should therefore connect source-water protection with treatment planning so that pollution prevention upstream can reduce treatment burdens downstream.

This approach has an economic dimension as well. Preventing wastewater, solid waste and agricultural pollutants from entering the river can lower the need for repeated remediation and treatment, while protecting water quality for irrigation, ecosystems and recreation. In green-economy terms, pollution prevention is not simply an environmental expense; it is a form of preventive investment that helps maintain the productivity and reliability of a natural asset.

4.11. Agriculture, riverfront landscapes and green economic development

Agriculture is one of the clearest examples of how the Kura links nature with economic development. The source project notes the importance of river water for crops and farming communities. This relationship is strongest when water supply is reliable and efficient, but it becomes vulnerable when conveyance losses, drought, salinity or poor water quality increase. Sustainable agricultural use therefore requires more than simply increasing withdrawals. It requires irrigation scheduling, maintenance of canals and distribution systems, protection of soil condition and monitoring of the quality of water reaching fields.

The Central Aran study by Qadimli et al. (2026) is relevant because it demonstrates that blue-green assets can support broader regional development objectives. River corridors, reservoirs and associated landscapes can contribute to recreation, tourism and local identity alongside agriculture. These uses are compatible only when ecological condition is protected. A polluted or degraded riverfront has lower recreational value, while uncontrolled tourism can itself create new waste and habitat pressure. Green development therefore depends on managing economic use within ecological capacity.

Qadimli and Mammadov (2026a) provide a related example by linking ecosystem sustainability and green finance with ecotourism opportunities. Their work suggests a useful financing principle for the Kura: projects that restore natural systems can be evaluated not only for conservation benefits but also for the economic services they protect or create. Riparian restoration, cleaner public riverfronts, wetland protection and low-impact visitor infrastructure can strengthen landscape quality and local economic opportunities when planned with ecological safeguards.

Qadimli and Mammadov (2026b) further show how remote sensing can support the prioritization of nature-based solutions. Along the Kura, satellite and GIS analysis could help identify areas of vegetation loss, bank erosion, wetland change or rapid land-use transformation. Such spatial information would allow restoration budgets to be directed toward sites where ecological risk is high and where improved river condition can also support agriculture, settlements or public access.

The future economic value of the river therefore depends on maintaining several forms of capital at the same time: built infrastructure such as reservoirs and irrigation networks; human capital in monitoring and water management; and natural capital in the form of functioning river, floodplain and riparian ecosystems. Investment that strengthens only one of these components while allowing the others to deteriorate may deliver short-term benefits but weaken long-term resilience.

Finally, the connection to the Caspian Sea means that local river management contributes to a larger downstream system. Mammadov et al. (2026) show that microplastic and other anthropogenic pressures affect the Caspian basin. Measures that reduce plastic leakage, improve wastewater management and prevent solid waste from entering the Kura can therefore generate benefits beyond the immediate river reach. This basin-to-coast perspective reinforces the student project's conservation message: protecting the Kura is simultaneously a local, national and regional environmental responsibility.

4.12. Limitations and future research

The main limitation of this study is that the original student project is a concise educational review rather than a field-based research dataset. It contains no original discharge records, water samples, biodiversity census or economic valuation. The present article therefore expands the interpretation through external literature but does not convert descriptive observations into quantitative findings. Historical and archaeological material is also selective and is included only to explain the title's "history" dimension, not to provide a comprehensive history of the Kura basin.

Future research could combine three evidence streams. First, long-term hydrological and water-quality monitoring can track quantity and usability of water. Second, remote sensing and field surveys can assess riparian vegetation, wetland condition and riverbank change. Third, economic and social research can estimate the value of irrigation reliability, treatment costs, recreation, ecological restoration and cultural landscapes. Integrating these datasets would allow the Kura to be evaluated as one socio-ecological system rather than as separate environmental and economic sectors.

CONCLUSIONS

The Kura River can be understood through three connected perspectives: history, nature and future. Historically, the river has functioned as a corridor of settlement, agriculture, mobility and cultural development, with the Kura-Araxes tradition providing a prominent archaeological reference to the wider river region. Ecologically, the Kura supports water, fish, birds, riparian vegetation and floodplain habitats that generate ecosystem services as well as biodiversity value. Economically, it supports irrigation, water supply, hydropower and regional development. These functions are interdependent. Water-quality deterioration, inefficient use or habitat degradation can weaken both ecological condition and economic resilience. Protecting the Kura therefore requires regular monitoring, pollution control, efficient irrigation, riparian restoration, transboundary cooperation and investment in blue-green natural capital. The student source's central message remains valid: protecting the Kura today is part of protecting Azerbaijan's future. A stronger evidence base can turn that message into measurable priorities for

water security, ecosystem sustainability and green economic development.

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Mother Kura - comprehensive information about the Kura River

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Keywords
Kura River, natural capital, water security, ecosystem services, sustainable river management

ABSTRACT

The Kura River is a transboundary river system that links geography, biodiversity, settlement, agriculture, water supply, hydropower, cultural history and environmental management across the South Caucasus. This article develops the submitted "Mother Kura" educational research document into a structured interdisciplinary review while preserving its original organization around geographical location, tributaries, natural features, economic importance, historical significance and conservation. The analysis uses secondary-source synthesis to examine the river from its headwaters in Türkiye through Georgia and Azerbaijan to the Caspian Sea, with particular attention to the Azerbaijani section and the Mingachevir water management system. The review shows that the river's value extends beyond direct water extraction. Riparian habitats, fish and waterbirds, irrigation, hydropower, drinking-water supply, settlement and landscape identity form an interconnected socio-ecological system. Environmental pressures include untreated wastewater, agricultural runoff, solid waste, excessive withdrawal, hydrological alteration, drought and habitat degradation. These pressures can reduce both ecological integrity and economic resilience by weakening ecosystem services and increasing water-management costs. The paper interprets the Kura as natural capital within a green-economy framework and identifies efficient irrigation, water-quality monitoring, wastewater treatment, riparian restoration, data sharing and environmental education as complementary responses. The study concludes that long-term protection of the Kura requires integrated basin management that connects historical and cultural value with present-day water security, ecosystem sustainability and future-oriented economic development.

INTRODUCTION

Rivers are not only channels that move water from uplands to the sea. They are landscape-forming systems, ecological corridors, sources of water and energy, transport and settlement axes, and carriers of cultural memory. The submitted "Mother Kura" document adopts this broad perspective by presenting the Kura River through its geography, tributaries, natural features, economic importance, history and environmental challenges. This structure provides a strong basis for an interdisciplinary article because the river's ecological and economic functions are closely connected.

The Kura rises in northeastern Türkiye, flows through Georgia and Azerbaijan and reaches the Caspian Sea. Its course links mountain landscapes, urban areas, reservoirs, the Kura–Araz lowland and coastal environments. The source document emphasizes that these spatial differences shape the river's flow, channel form, vegetation, wildlife and patterns of human use. The river's transboundary character also means that water quantity and quality cannot be interpreted only at a local scale.

The purpose of the present article is to preserve the educational document's comprehensive "Mother Kura" framing while strengthening it with current academic and institutional literature. Four questions guide the synthesis: how geography structures the river system; how the Kura supports ecosystems and economic activity; how historical and cultural value adds to its significance; and which environmental-management pathways can protect these benefits in the future.

LITERATURE REVIEW

2.1. Geography, historical continuity and the Kura corridor

Historical and archaeological research demonstrates that the Kura has long been more than a physical boundary. Encyclopaedia Iranica describes the river as an important corridor and landmark that supported fertile agricultural land and settlements across the Caucasus. The name Kura-Araxes is also used for a major Early Bronze Age cultural tradition whose material remains spread far beyond the immediate river basin. Archaeological scholarship places this tradition in the wider history of the South Caucasus and neighbouring regions (Kohl, 2009; Ismayilova, 2024).

This historical perspective supports the source document's argument that the river influenced settlement, movement and economic life over long periods. It also explains why the expression "Mother Kura" carries a meaning that is broader than hydrology. The river is simultaneously a physical resource and part of the cultural landscape.

2.2. Ecosystem services and natural capital

Freshwater systems create economic value through ecosystem services as well as through direct extraction. Flores and Abbasov (2015) assessed freshwater ecosystem services in the Kura–Aras basin in relation to hydropower and considered links with irrigated agriculture, drinking-water supply, nature-based tourism and natural-hazard

regulation. This provides a useful framework for interpreting the source document's separate sections on wildlife, agriculture, water supply and energy as components of one natural-capital system.

Recent JGEOR studies reinforce this interpretation. Qadimli and Mammadov (2026a) connect ecosystem sustainability with green-finance-based ecotourism opportunities, while Qadimli and Mammadov (2026b) show how remote sensing can prioritize nature-based solutions and restoration finance. Qadimli et al. (2026) further demonstrate that blue-green assets can be incorporated into regional sustainable-development planning in Central Aran. These studies do not measure the Kura as a single economic asset, but they support the principle that ecological condition influences development opportunities.

2.3. Water quality and connected downstream pressures

Water availability is only one dimension of river security; water quality determines whether water is suitable for particular uses. Aliyev and Abduyev (2025) documented major-ion variation along the Azerbaijani reach of the Kura and showed that hydrochemical conditions change downstream. Arifzade (2026) similarly synthesized nutrient, microbial and major-ion evidence for Mingachevir Reservoir, emphasizing the value of multi-indicator assessment rather than simple "clean versus polluted" classifications.

The river-to-sea connection is also important. Mammadov et al. (2026) review microplastic pollution and coastal anthropogenic pressure in the Caspian Sea basin. Although their study focuses on the Caspian rather than the Kura itself, it demonstrates why downstream environmental quality should be considered within a connected basin perspective.

MATERIALS AND METHODS

This article is a structured narrative review developed from the submitted five-page "Mother Kura" educational document. The source text is organized into geographical location and source, course and tributaries, natural features, importance for Azerbaijan, historical and cultural significance, environmental problems, conservation measures and conclusion. No author name, school or supervisor information was included in the submitted source file, and no such metadata was invented in the present manuscript.

The source content was coded into five analytical themes: (1) geographical structure and hydrology; (2) biodiversity and riparian ecosystems; (3) economic functions; (4) historical and cultural significance; and (5) environmental pressures and conservation. The document contains no original field dataset, laboratory measurements, survey results, figures or tables. Accordingly, the present article does not claim new empirical findings. Its contribution is an academically structured synthesis that preserves the source document's organization and extends it through peer-reviewed and institutional literature.

External sources were selected to verify the river's historical context, ecosystem-service importance, hydroecological pressures and transboundary-management relevance. Recent Kura-focused and Azerbaijan-focused publications were given priority where possible. The review distinguishes descriptive source material from independently documented scientific evidence and avoids using unsupported percentages or unverified claims.

RESULTS AND DISCUSSION

4.1. Geographical structure and river connectivity

The first major finding is that the Kura must be understood as a connected longitudinal system. Mountain headwaters, tributaries, reservoirs, lowland channels and the river mouth perform different functions but remain hydrologically linked. The source document correctly emphasizes that the upper river passes through mountainous terrain, whereas the middle and lower reaches occupy broader valleys and plains. These differences affect flow velocity, sediment movement, floodplain processes and human use.

The Araz is the Kura's largest tributary and substantially increases the scale and complexity of the downstream system. Other tributaries contribute water, sediment and pollutants according to seasonal and local conditions. Reservoirs, irrigation canals and abstraction modify this natural connectivity. Consequently, changes in one part of the basin may influence water quantity, quality or habitat conditions elsewhere.

4.2. Natural features, biodiversity and riparian habitats

The source document identifies fish, waterbirds, aquatic plants and riverside vegetation as characteristic biological components of the Kura system. It also notes that vegetation and wildlife vary along the river because climate, topography and hydrology change from mountains to semi-arid lowlands. This is an important ecological observation: biodiversity is structured by habitat heterogeneity rather than distributed uniformly along the river.

Riparian vegetation has significance beyond species presence. Riverbank trees, shrubs and wetland vegetation can stabilize soils, provide shade and habitat, contribute organic material and support ecological connectivity. These functions make riparian zones a form of natural infrastructure. Their degradation can therefore create both ecological losses and economic costs through erosion, habitat decline and reduced landscape quality.

4.3. Agriculture, water supply, hydropower and settlement

The source document gives particular attention to irrigation and agriculture in the Kura–Araz lowland. This emphasis is well founded because river water and associated canals support crop production across dry lowland environments. However, the economic value of irrigation depends on how efficiently water is delivered and used. High conveyance losses, poorly timed irrigation or salinity problems can reduce the productivity gained from each unit of water.

Mingachevir Reservoir represents another major node in the river system because it combines water storage, hydropower and irrigation functions. The source document presents these benefits clearly. At the same time, reservoir management must be understood as a balancing problem: storage and release decisions influence energy production, downstream water supply and ecological conditions. Arifzade (2026) adds a water-quality perspective by showing that reservoir condition should be assessed through several hydroecological indicators.

Drinking-water supply creates an additional requirement. The source document correctly states that river water is not automatically safe to drink and must be monitored and treated. Water quality varies spatially and temporally, so no single percentage can represent the safety of the entire river. This cautious formulation is scientifically appropriate and is consistent with the evidence of downstream hydrochemical variation reported by Aliyev and Abduyev (2025).

4.3.1. River functions as an integrated resource system

The source document presents irrigation, water supply, hydropower, fisheries, navigation, settlement and biodiversity as separate themes, but their value is best understood together. Irrigation converts river water into agricultural production; reservoirs store water and generate electricity; riparian habitats sustain biodiversity; and settlements depend on both water availability and water quality. These functions can compete for the same water at different times of year, which makes allocation and reservoir operation central management questions.

This integrated perspective also shows why efficiency must be defined broadly. A technically efficient irrigation system is beneficial only if basin-scale withdrawals remain compatible with downstream needs. Hydropower production is valuable, but reservoir operation should also consider ecological and water-supply requirements. Water treatment can protect public health, but preventing pollution at source may be less costly than repeatedly treating degraded raw water. In each case, the objective is not to maximize one use in isolation but to maintain the river's capacity to support several uses over time.

4.4. Historical and cultural significance

The historical section of the source document is one of its distinctive features. It links the river to settlement, movement, agriculture and the Kura–Araxes cultural tradition. Archaeological research confirms that the Kura–Araxes label is associated with a major Early Bronze Age cultural horizon whose material culture spread across a large part of the South Caucasus and beyond (Kohl, 2009; Ismayilova, 2024). This does not mean that the river alone created the culture, but it demonstrates the long historical importance of the basin as a geographic and cultural space.

The expression "Mother Kura" therefore has analytical value as well as emotional meaning. It captures the idea that the river links generations through water, food production, settlement and landscape memory. Environmental degradation may therefore affect not only ecosystem services but also cultural relationships with place.

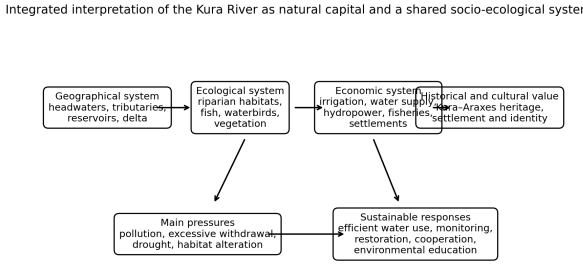


Figure 1. Integrated interpretation of the Kura River as natural capital and a shared socio-ecological system.

4.5. Environmental pressures and cumulative risk

The source document groups the main pressures into untreated domestic and industrial wastewater, agricultural fertilizers and pesticides, plastic and other solid waste, excessive water withdrawal, drought and climate change. These pressures act through different mechanisms. Pollution can reduce water quality and harm aquatic organisms; excessive abstraction can reduce available flow; drought can intensify scarcity; and habitat alteration can weaken ecological resilience.

These pressures can also reinforce one another. Lower flows may reduce dilution capacity, while degraded riparian zones can increase erosion and reduce habitat quality. Pollution may increase the cost of treatment and reduce the range of safe uses, meaning that water-quality degradation can create an economic scarcity even when water remains physically present. This distinction is central to an integrated understanding of water security.

4.6. Green economy and natural-capital interpretation

A green-economy perspective reframes Kura protection as investment in natural capital rather than as an environmental cost separate from development. Healthy river and riparian systems support agricultural productivity, water treatment functions, biodiversity, recreation and hydropower reliability. Flores and Abbasov (2015) provide a direct Kura–Aras example by connecting freshwater ecosystem services with hydropower and other sectors.

The same logic is reflected in recent Azerbaijan-focused green-economy research. Qadimli and Mammadov (2026a) link ecosystem sustainability with green-finance-based ecotourism, while Qadimli and Mammadov (2026b) demonstrate spatial prioritization of restoration and green-finance needs. Qadimli et al. (2026) show how blue-green assets can support regional development priorities. Together, these studies suggest that river restoration, efficient water systems and riparian protection can be evaluated as productive investments that reduce future ecological and economic risk.

4.7. Conservation measures and integrated management

The conservation measures proposed in the source document are practical and mutually reinforcing: treat wastewater before discharge, prevent illegal dumping, modernize irrigation, reduce water loss, use fertilizers and pesticides responsibly, monitor water quality, protect riverside vegetation, strengthen data sharing and expand environmental education. The scientific value of these recommendations increases when they are linked to clear indicators and responsible institutions.

Transboundary cooperation is particularly important because the Kura crosses national borders. UNECE documents long-running efforts to strengthen cooperation and information exchange between Azerbaijan and Georgia on shared water resources in the Kura basin. The practical lesson for research is that comparable monitoring methods and accessible data are essential for distinguishing upstream and downstream pressures and for evaluating management outcomes.

Environmental education is another important component. The source document was itself prepared for educational purposes, showing how river geography, ecology and conservation can be communicated in an integrated way. School-based research can support stewardship through supervised observation, litter audits, mapping and water-saving projects, provided that student observations are clearly distinguished from formal scientific measurements.

4.7.1. Pressure-response pathways and priority actions

The main pressure-response relationships identified in the source document can be summarized as follows. Untreated wastewater primarily creates chemical and microbial water-quality risks and therefore requires treatment, monitoring and enforcement. Agricultural runoff can introduce nutrients and pesticides and is better addressed through more efficient input use, riparian buffers and improved irrigation management. Solid waste degrades habitat and landscape quality and requires collection, prevention, recycling and community stewardship.

Water withdrawal and drought operate differently because they affect the quantity and timing of flow. Their management requires water accounting, demand reduction, reservoir planning and attention to ecological requirements. Riparian degradation adds a habitat and erosion dimension, making vegetation protection and nature-based restoration important. These categories should not be treated as independent: lower flow can make pollution more damaging, and habitat loss can reduce the ecosystem's ability to absorb disturbance.

4.8. Monitoring framework for the future

The comprehensive character of "Mother Kura" can be translated into a practical monitoring framework. Hydrological indicators should include discharge, seasonal low flows, reservoir storage and withdrawals. Water-quality monitoring should track chemical, microbial and physical parameters appropriate to intended uses. Ecological indicators should cover riparian vegetation, habitat condition and selected aquatic biota. Socioeconomic indicators

should examine irrigation reliability, treatment needs, hydropower production, recreation and the costs of restoration.

This multi-indicator approach avoids a common problem in river discussions: treating one variable as a complete measure of river health. A river can have adequate flow but poor water quality, or acceptable water chemistry but degraded habitat. Similarly, a reservoir can provide energy and irrigation benefits while still requiring ecological monitoring. Integrated management therefore depends on combining physical, chemical, biological and economic evidence.

4.9. Spatial differentiation from headwaters to the Caspian Sea

A basin-wide interpretation also requires spatial differentiation. In the upper basin, steep terrain, snowmelt and mountain tributaries are important to runoff generation. Through Georgia, the river passes major urban and industrial areas before entering Azerbaijan. In the Azerbaijani section, large reservoirs, irrigation systems, lowland agriculture and the confluence with the Araz reshape the river's hydrological and economic role. Near the mouth, river flow interacts with coastal and delta environments before entering the Caspian Sea. These zones should not be managed as if they were ecologically identical.

Spatial differentiation is also important for interpreting environmental evidence. A water-quality sample from one station represents local conditions at a particular time, not the entire river. Likewise, a biodiversity observation in a riparian forest cannot be generalized automatically to reservoir or delta habitats. This is why the source document's broad geographical structure is useful: it encourages readers to think of the Kura as a sequence of linked but different environments.

4.10. The water-food-energy-ecosystem nexus

The Kura can also be interpreted through a water-food-energy-ecosystem nexus. Water stored in reservoirs can support hydropower and irrigation, while the same flow regime influences downstream habitats and water quality. Agricultural production depends on reliable water, but excessive abstraction or inefficient delivery can weaken downstream security. Hydropower is a low-carbon energy source, yet dam and reservoir operation can modify river connectivity. Ecosystem services, in turn, can protect soils, regulate erosion and sustain natural processes that support infrastructure and productive sectors.

UNECE has used nexus approaches in parts of the wider Kura basin, including shared sub-basins between Azerbaijan and Georgia. The relevance for this study is methodological rather than political: management choices should be evaluated across sectors because a decision that benefits one use can create costs or constraints for another. This is especially important under climate variability, when water allocation becomes more difficult and the value of efficient use rises.

4.11. Economic risks of degradation and the case for green investment

Environmental degradation creates several categories of economic risk. Poorer raw-water quality can increase treatment requirements. Lower or less reliable irrigation supply can reduce agricultural output or increase pumping and storage needs. Erosion and riparian degradation can create maintenance costs and reduce habitat quality. Loss of attractive riverfront landscapes can weaken recreation and tourism potential. These are not identical or easily combined into one monetary value, but together they show that ecological decline can impose material costs on households, enterprises and public infrastructure.

Green investment aims to reduce these risks by directing finance toward resource efficiency and ecosystem condition. The studies by Qadimli and Mammadov (2026a, 2026b) are useful examples because they connect ecosystem sustainability, nature-based solutions and green finance. Applied to the Kura, comparable investments could include wastewater treatment, irrigation modernization, riparian restoration, monitoring infrastructure and riverfront planning that protects ecological functions rather than replacing them.

The Central Aran analysis of Qadimli et al. (2026) adds a regional-development perspective by treating blue-green assets as part of tourism and sustainability planning. The implication for the Kura is that environmental quality can support economic diversification. Clean and accessible riverfront areas can contribute to recreation and nature-based tourism, while degraded or polluted environments reduce these opportunities. The green-economy value of the river is therefore partly preventive: maintaining ecosystem quality can preserve future options that are lost when degradation becomes severe.

4.12. Environmental education and the "Mother Kura" concept

The educational framing of the source document is itself important. "Mother Kura" presents the river not only as a technical water-management problem but as a shared natural system with historical, cultural and moral significance. This framing can help environmental education connect everyday water-saving behaviour with larger basin processes. Students may understand pollution more clearly when they can relate household waste or agricultural runoff to fish, drinking-water treatment and downstream ecosystems.

However, environmental education should also teach evidence standards. Observations, photographs and maps are valuable for learning, but they should be distinguished from measured water-quality data, hydrological records or biodiversity surveys. Future school-based projects could use simple but repeatable methods such as litter counts, fixed-point photography, mapped riverbank observations or publicly available monitoring datasets. This would preserve the accessible character of the original project while increasing scientific reproducibility.

4.13. Research priorities for an integrated Kura assessment

A comprehensive future assessment could combine four evidence streams. First, hydrological records should track discharge, low-flow frequency, reservoir levels and withdrawals. Second, water-quality data should include major ions, nutrients, microbial indicators and relevant pollutants. Third, ecological monitoring should map riparian vegetation, wetlands and selected aquatic communities. Fourth, economic analysis should measure treatment requirements, irrigation reliability, restoration costs, recreation use and other ecosystem-service outcomes.

Integrating these streams would make it possible to evaluate trade-offs more transparently. For example, a restoration project could be assessed not only by the area planted but by changes in bank stability, habitat condition and avoided maintenance costs. An irrigation intervention could be evaluated by both field-level efficiency and basin-level water savings. Such analysis would move beyond descriptive river profiles toward decision-oriented evidence while remaining consistent with the comprehensive perspective introduced by the source document.

4.14. Limitations and future research

The principal limitation of this study is that the source document is an educational overview rather than an empirical research dataset. It contains no original sampling protocol, time series, biodiversity census, water-quality laboratory results or economic valuation. The present article therefore does not infer trends or causal relationships

that the source cannot support. Geographical figures in the source are retained only in general form because published values can differ according to definitions and measurement methods.

Future research could build on the source document by integrating georeferenced water-quality observations, reservoir and river-discharge data, riparian vegetation mapping, biodiversity surveys and economic indicators. Historical and cultural research could also be combined with environmental mapping to examine how settlement, land use and river functions have changed over time. Such work would turn a comprehensive educational profile into a reproducible interdisciplinary river-basin assessment.

CONCLUSIONS

The "Mother Kura" research document presents the Kura as a river of geography, nature, economy, history and responsibility. Its central strength is this integrated perspective. The Kura supports irrigation, water supply, hydropower, fisheries, settlement, riparian biodiversity and cultural identity, while its transboundary course connects environmental conditions across national borders. Pollution, excessive withdrawal, drought, hydrological alteration and habitat degradation can weaken these functions simultaneously. A green-economy interpretation shows that protecting the river also protects natural capital and reduces long-term development risks. Efficient irrigation, wastewater treatment, water-quality monitoring, riparian restoration, transparent data exchange and environmental education should therefore be treated as complementary parts of one management strategy. Future research should add measured hydrological, ecological and economic indicators, but the source document's underlying message remains valid: caring for the Kura means caring for the ecological and economic systems that depend on it and for the cultural landscape inherited by future generations.

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The main causes of decreasing water levels in the Kura River

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Kura River, water levels, climate change, water use, water security

ABSTRACT

Declining water levels are a growing concern in many river basins because they affect water security, agriculture, ecosystems and economic activity. This article develops an original student research project on the main causes of decreasing water levels and applies its causal framework to the Kura River. The source project identified climate change, drought, reduced rainfall, rising temperatures, excessive water use, population growth, pollution and poor water management as the principal drivers of water shortage. The present study preserves those themes and strengthens them through a structured narrative review of hydrological, water-quality and management literature relevant to the Kura Basin. The evidence shows that declining water availability cannot be explained by one factor alone. Climatic variability and warming can change runoff timing and increase evaporative demand; irrigation and other withdrawals can intensify low-flow stress; reservoirs redistribute water across seasons; and infrastructure losses can increase the volume that must be abstracted to meet demand. Water-quality deterioration does not necessarily reduce physical discharge, but it can reduce the amount of water suitable for particular uses and therefore worsen effective scarcity. The article links these pressures to agricultural productivity, ecosystem resilience and green-economic performance. It concludes that improving Kura River water security requires integrated monitoring, efficient irrigation, abstraction control, wastewater treatment, reservoir coordination, ecosystem restoration and public water-conservation awareness. Future research should combine long-term discharge records with climate, withdrawal, storage and water-quality data so that the relative contribution of each pressure can be quantified more reliably.

INTRODUCTION

Water-level decline is a visible expression of a broader water-security problem. Rivers, lakes and reservoirs support domestic supply, agriculture, industry, hydropower and ecosystems, but their levels and flows respond to both natural variability and human demand. The original student research by Ilham Abdullayev framed the problem through a simple but useful question: why are water levels decreasing, how do human activities contribute, and what can be done to protect water supplies? The source project identified climate change, drought, reduced rainfall, high temperatures, excessive water consumption, population growth, pollution and poor water management as the main causes.

The present article preserves that causal framework but applies it specifically to the Kura River, one of the major transboundary river systems of the South Caucasus. This is an important refinement because a river basin differs from a generic water body. River level and discharge are influenced by precipitation, snowmelt, tributaries, reservoir storage and release, abstraction, return flows and seasonal demand. As a result, the causes of low water levels can vary substantially between upstream and downstream sections and between wet and dry years.

Water scarcity should also be distinguished from water-quality degradation. A river can retain substantial flow while pollution or high mineralisation reduces the amount of water suitable for drinking, irrigation or ecological use. Conversely, low flow can increase vulnerability to pollution by reducing dilution. This distinction is especially relevant to the Kura because recent research documents both hydrological variability and downstream changes in hydrochemistry (Aliyev & Abduyev, 2025; Arifzade, 2026).

The article therefore has three objectives. First, it evaluates the main natural and human drivers identified in the source project against Kura-specific scientific literature. Second, it explains how those pressures interact to affect effective water availability, agriculture and ecosystems. Third, it develops management priorities that connect water conservation with resource efficiency, ecosystem restoration and green economic resilience.

LITERATURE REVIEW

2.1. Climate variability, warming and runoff

The Kura is naturally variable because its flow depends on precipitation, temperature, snow accumulation and snowmelt across a large and topographically diverse basin. Long-term variability is therefore a necessary starting point for any interpretation of declining water levels. Bakhtiyorov et al. (2024) reconstructed July-August streamflow in western Transcaucasia using tree-ring chronologies extending from 1720 to 2021 and identified extended wet and dry phases. Their results show that low-flow periods are not exclusively a modern phenomenon, although future model scenarios in the study indicate additional hydrological stress under continued climatic change.

Rising temperature can influence water availability through several pathways. Higher evaporative demand increases losses from soils, vegetation, reservoirs and open water; warmer conditions can change the timing of snowmelt; and prolonged heat can increase irrigation demand at the same time that natural supply is reduced. The original

student project correctly emphasized this interaction between high temperature, drought and declining water levels. However, climate attribution requires long-term records rather than a comparison of only a few dry years.

Historical flow analysis from Azerbaijan also demonstrates the importance of trend context. Imanov and Verdiev (2016) reported that annual Kura flow at Salyan during 1991-2010 was substantially below the long-term average used in their analysis. The result is important as a historical indicator but should not be repeated as a present-day percentage decline. More recent work by Imanov et al. (2023) connects changes in annual flow with the combined influence of climate, reservoirs and water use, supporting a multi-causal rather than single-cause interpretation.

2.2. Human water demand and irrigation pressure

The source project lists increasing water consumption and population growth among the main causes of water-level decline. In a river basin, population growth does not reduce flow automatically; the effect occurs through higher municipal, industrial and food-production demand. Agriculture is especially important because irrigation withdrawals can be large during hot and dry periods, precisely when river inflow is already under stress.

Irrigation efficiency is therefore central to Kura River water security. Water can be lost from canals and distribution systems through leakage, seepage and evaporation, while poorly timed application may deliver more water than crops require. Yet efficiency should be interpreted carefully. Water diverted from a canal is not necessarily lost from the basin if part of it returns to groundwater or surface flow. True basin savings depend on consumptive use, return flows and whether efficiency improvements lead to expansion of irrigated land. Effective management therefore requires both technical modernization and monitoring of total abstraction.

2.3. Reservoirs, flow regulation and seasonal availability

Reservoirs complicate the relationship between river level and water scarcity. Storage can reduce downstream flow while a reservoir is filling, but later releases can increase dry-season availability. Reservoirs also support hydropower, irrigation and water supply, creating benefits that must be balanced with downstream ecological requirements. Mingachevir Reservoir is particularly important within the middle Kura cascade and illustrates why river-management studies should distinguish annual discharge from seasonal timing and local water level.

Arifzade (2026) adds a complementary hydroecological perspective by synthesizing nutrient, microbial and major-ion evidence for Mingachevir Reservoir. This work does not directly quantify water-level decline, but it shows why reservoir management must consider both quantity and quality. Water stored for later use is only fully valuable when its ecological and chemical condition remains suitable for intended purposes.

2.4. Water quality and effective scarcity

Pollution appears in the original student project as one of the causes of reduced water availability. Scientifically, pollution should be described as a driver of effective or usable-water scarcity rather than a direct cause of lower river discharge. Aliyev and Abduyev (2025) analysed major-ion concentrations at multiple locations along the Kura in Azerbaijan and documented downstream changes in mineralisation. Such patterns affect the suitability and treatment requirements of water even if the physical volume of water is unchanged.

The downstream connection to the Caspian Sea further broadens the pollution context. Mammadov et al. (2026) review microplastic pollution and coastal anthropogenic pressure in the Caspian Sea basin. Their findings do not measure Kura River water levels, but they demonstrate how material pollution can move through connected water systems and reduce environmental quality. This is relevant to water security because water quantity and water quality jointly determine the practical value of a water resource.

2.5. Ecosystem condition, restoration and green-economy relevance

Declining water availability can affect riparian vegetation, wetlands and aquatic habitats, while degraded ecosystems may in turn reduce resilience to drought and erosion. Recent Azerbaijan-focused studies provide useful examples of how ecosystem protection can be linked to development decisions. Qadimli and Mammadov (2026a) assess ecosystem sustainability and green-finance-based ecotourism opportunities, while Qadimli and Mammadov (2026b) use remote sensing to prioritize nature-based solutions and restoration finance. Qadimli et al. (2026) similarly identify blue-green assets as part of regional sustainable-development planning in Central Aran.

These studies do not directly explain Kura water-level change, and they are not used here as hydrological evidence. Their relevance is instead managerial: they demonstrate how restoration, ecosystem condition and green finance can be incorporated into decisions about landscapes that depend on water. For the Kura Basin, that logic supports investment in riparian restoration, efficient irrigation, monitoring and water-reuse systems as measures that can protect natural capital while reducing economic exposure to water scarcity.

MATERIALS AND METHODS

This study is a structured narrative review developed from a two-page student research project prepared by Ilham Abdullayev in 2026. The original project investigated decreasing water levels in rivers, lakes and reservoirs and used online articles, educational websites, reports and geography resources. It did not include field measurements, original hydrological data, laboratory analysis, figures or tables. The present article preserves the source project's research questions, causal categories and recommendations while applying them to Kura River evidence.

The source content was coded into six driver groups: (1) climate change and higher temperatures; (2) drought and reduced rainfall; (3) excessive water use in agriculture and industry; (4) population growth and increasing demand; (5) pollution; and (6) poor water management. These categories were compared with peer-reviewed Kura Basin studies and recent Azerbaijan-focused research. A seventh category, river regulation and infrastructure, was added because it is necessary for interpreting seasonal flow and water availability in a regulated basin.

Evidence was classified according to what it can support. Hydrological measurements and reconstructions were used to discuss flow variability; water-quality monitoring was used to discuss effective usability rather than physical discharge; and ecosystem or green-finance studies were used only for management implications. No attempt was made to assign a percentage contribution to each driver because the available studies cover different locations, periods, variables and methods. This avoids presenting incomparable evidence as if it were a single quantitative model.

RESULTS AND DISCUSSION

4.1. The source project correctly identifies a multi-causal problem

The main finding is that the student project's causal framework is broadly consistent with the scientific literature, but several terms

require more precise interpretation. Climate change, drought and high temperature influence natural supply; irrigation, industry and municipal demand influence withdrawals; reservoirs influence timing and storage; infrastructure efficiency influences the amount that must be abstracted; and pollution influences the usability of the resource. These mechanisms can operate simultaneously.

This distinction matters because "decreasing water levels" can refer to different observations. It may mean lower river stage at a particular station, lower discharge, lower reservoir storage, lower groundwater level or a smaller volume of water that is safe and economically usable. Future monitoring should state clearly which indicator is being measured. A river-stage observation alone cannot establish the cause of change without corresponding discharge, storage, withdrawal and climate data.

Table 1. Driver framework derived from the student project and refined for the Kura River

4.2. Climatic pressure changes both supply and demand

The original project describes climate change as one of the most significant factors because it affects rainfall and evaporation. This is a reasonable conceptual conclusion, but the literature does not support a single basin-wide percentage contribution. Bakhtiyorov et al. (2024) demonstrate strong historical variability in Kura-related streamflow, while Imanov et al. (2023) show that observed flow change is connected to both natural and human influences. A dry period may therefore reflect climatic variability, long-term warming, water use, reservoir operation or several of these at once.

Climate also affects demand. Higher temperature can increase crop water requirements and household consumption, creating a double pressure in which natural inflow is lower while irrigation demand is higher. This interaction is especially important in summer. Management systems designed around average annual water volumes may therefore perform poorly if they do not account for seasonal coincidence between low flow and high demand.

4.3. Agricultural withdrawals and efficiency are central management variables

The source project recommends improving irrigation efficiency, and the Kura literature supports this as a practical priority. Efficient delivery can reduce avoidable conveyance losses and improve the reliability of supply to farms. However, technical efficiency should be combined with abstraction control and crop-sensitive scheduling. If water savings simply allow additional land to be irrigated, total basin consumption may remain unchanged or increase.

This issue has direct green-economic significance. Water shortages can reduce crop yields, increase pumping or storage costs and raise competition among users. Conversely, well-designed irrigation modernization can improve water productivity, meaning more agricultural value per unit of water consumed. That outcome aligns with resource-efficiency goals because it seeks to maintain production while reducing unnecessary pressure on the river.

4.4. Reservoirs redistribute rather than simply remove water

The effect of reservoirs should not be simplified as "dams cause lower water levels." Reservoirs alter the timing and location of water. During filling, downstream flow may decline; during release, the opposite can occur. Evaporation, water withdrawals from storage and operating rules also affect the balance. The scientific question is therefore how storage and release interact with inflow and demand over time.

Mingachevir illustrates this multi-purpose management challenge. It supports hydropower and water regulation while forming part of the agricultural supply system. Arifzade (2026) shows that hydroecological condition should also be considered. A management strategy that focuses only on storage volume may miss nutrient, microbial or major-ion pressures that influence the effective value of stored water.

4.5. Pollution reduces usable water but should not be confused with flow decline

The student project lists pollution among the causes of decreasing water levels. This idea is best refined by separating physical water quantity from effective availability. Pollution generally does not make water disappear, but it can make a larger share of existing water unsuitable or more expensive to use. In practical terms, users may experience greater scarcity even when river flow has not changed.

Aliyev and Abduyev (2025) provide direct evidence of spatial hydrochemical variation along the Azerbaijani Kura. Mammadov et al. (2026) extend the environmental-quality discussion to microplastic and coastal anthropogenic pressure in the connected Caspian basin. These studies support stronger treatment, monitoring and pollution prevention, but they should not be used as substitutes for discharge data when the research question concerns water-level decline.

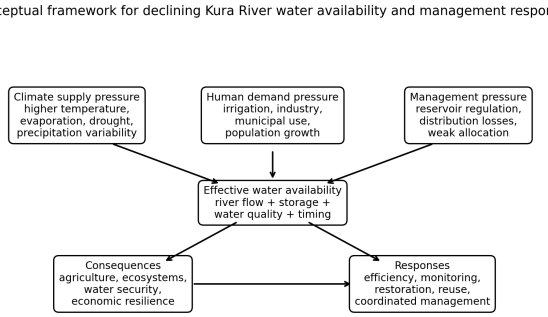


Figure 1. Conceptual framework linking climatic supply, human demand, management and water quality to effective Kura River water availability.

4.6. Population growth is an indirect driver

Population growth appears in the source project as a major factor because more people require water for homes, food and economic activity. This relationship is real but indirect. Population becomes hydrologically important through changes in per-capita consumption, irrigated food production, industrial demand, wastewater generation and land use. Two regions with similar population growth may therefore create very different pressures if their water-use efficiency, infrastructure and economic structure differ.

For this reason, future Kura studies should avoid using population alone as a proxy for water stress. More useful indicators include municipal withdrawals per person, irrigation abstraction per hectare, losses from distribution systems, industrial water intensity and the proportion of treated wastewater that can be safely reused. Such indicators connect demographic change to measurable water demand.

4.7. Green-economy and ecosystem implications

Declining water availability creates economic exposure because water is an input to agriculture, energy, settlements and ecosystems. A low-flow period that coincides with peak irrigation demand can reduce agricultural reliability. Degraded riparian habitats can lose biodiversity and erosion-control functions. Poor water quality can raise treatment requirements. These impacts represent different pathways, but all reduce the value generated by the basin's natural capital.

The restoration and green-finance literature required for this special issue provides a useful decision framework. Qadimli and Mammadov (2026a) link ecosystem sustainability with green-finance-based ecotourism, while Qadimli and Mammadov (2026b) show how

nature-based solutions can be prioritized using spatial evidence. Qadimli et al. (2026) identify blue-green assets as part of sustainable development in Central Aran. Applied to the Kura, the same logic supports financing for riparian buffers, irrigation modernization, wastewater treatment, wetland protection and monitoring where combined ecological and economic benefits are greatest.

This perspective also strengthens the source project's recommendation to plant trees and protect forests. Tree planting is not a universal solution to water scarcity, because vegetation also consumes water, but well-designed riparian restoration can stabilize banks, improve habitat and contribute to landscape resilience. The appropriate intervention depends on location, native vegetation, water balance and restoration objectives.

4.8. Management priorities derived from the student recommendations

The source project proposes six broad responses: reduce water waste, improve irrigation efficiency, protect rivers and wetlands, increase public awareness, plant trees and protect forests, and improve water-management policies. These recommendations remain useful when translated into measurable actions. Water-waste reduction should include leak detection and repair; irrigation efficiency should include scheduling and abstraction monitoring; ecosystem protection should prioritize riparian and wetland functions; and public-awareness programmes should connect everyday conservation with actual water-use data.

Water reuse is another relevant option. Treated wastewater can substitute for freshwater in selected agricultural, industrial or landscape applications where health and environmental standards are met. Reuse does not create new water, but it can reduce demand for high-quality freshwater. Similarly, reservoir management can improve seasonal reliability when storage rules, ecological needs and forecast information are considered together.

The strongest strategy is therefore integrated rather than single-sectoral. Climate adaptation without demand management may leave high withdrawals unchanged; irrigation modernization without abstraction control may not produce basin savings; pollution control without quantity management cannot solve low flows; and restoration without hydrological planning may fail if water availability is insufficient. Effective water security depends on coordinating these interventions.

4.9. Monitoring and research priorities

The main limitation of the original source project is that it identifies causes conceptually but provides no measured dataset for ranking their relative importance. This is appropriate for an educational review but insufficient for hydrological attribution. A future evidence-based study should combine long-term discharge data with precipitation, temperature, drought indices, reservoir storage and release, irrigation withdrawals, municipal demand and water-quality observations.

Monitoring should also distinguish concentration from pollutant load, withdrawals from consumptive use, and reservoir level from downstream discharge. These distinctions prevent common analytical errors. A low reservoir level can reflect low inflow, high releases, evaporation or withdrawals; high pollutant concentration can reflect increased loading, reduced dilution or both. Only synchronized datasets can separate these mechanisms.

A practical student-research extension could compare publicly available monthly water-level or discharge data with temperature and precipitation for the same period, then map major withdrawals and reservoirs. Even a simple analysis would be stronger if the variables were aligned in time and location. Where official data are unavailable, the limitation should be reported rather than replaced with unsupported percentages.

4.10. Interaction between drought, demand and seasonal low-flow risk

The most serious water shortages often occur when several pressures coincide. A hydrologically dry year can reduce tributary inflow and reservoir recharge, while high summer temperatures increase crop water requirements and open-water evaporation. If irrigation demand peaks during the same period, river levels and storage may decline faster than would be expected from climate alone. This interaction explains why the same meteorological drought can produce very different social and ecological outcomes under different water-management conditions.

Seasonality is therefore critical. Annual flow totals may conceal short periods of severe low flow that matter greatly for agriculture, municipal supply and aquatic habitats. A basin may receive near-normal annual precipitation but still experience operational scarcity if water arrives in seasons when demand is low or if storage and conveyance systems cannot transfer it efficiently to periods of peak demand. For the Kura, research should therefore report monthly or seasonal discharge and storage in addition to annual averages.

The student project also emphasizes public water use and population growth. These pressures become most important during low-flow periods because the margin between available supply and demand narrows. Demand-management measures can reduce this vulnerability. Metering, leak repair, efficient appliances, industrial reuse and conservation campaigns can lower withdrawals without reducing essential services. Their success should be evaluated through measured reductions in water delivered or consumed rather than through awareness indicators alone.

4.11. Optimization of water allocation and infrastructure performance

A water-security strategy for the Kura should treat allocation as an optimization problem involving several objectives: reliable drinking-water supply, agricultural production, hydropower, ecosystem needs and resilience to drought. These objectives cannot always be maximized simultaneously. During a dry season, storing more water for future irrigation may reduce immediate downstream flow, while releasing more water for ecosystems or municipal use may reduce reservoir storage. Transparent operating rules and scenario analysis can help make such trade-offs explicit.

Infrastructure performance is equally important. Distribution losses mean that a larger volume must be withdrawn from the river or reservoir to deliver a smaller useful amount to the final user. Repairing canals and pipelines can therefore reduce pressure on source water. However, the basin-level effect should be checked carefully because seepage from unlined canals may recharge groundwater and return to the river elsewhere. The most useful performance indicators are not only engineering efficiency but also net consumptive use, return flow, energy requirements and the amount of water saved at basin scale.

Digital monitoring can improve this optimization. Flow meters, reservoir-level sensors, remote sensing of irrigated land, soil-moisture information and seasonal climate forecasts can be combined to estimate demand and identify abnormal losses. Such systems can also improve transparency by showing whether water-saving investments actually reduce withdrawals. The same principle is consistent with spatial prioritization approaches used by Qadimli and Mammadov (2026b), although their work focuses on ecosystem restoration rather than river-allocation modelling.

4.12. Ecosystem restoration, environmental education and long-term resilience

Protecting rivers, lakes and wetlands is one of the original project's recommendations. For the Kura, this can include maintaining riparian vegetation, protecting floodplain habitats where feasible and avoiding unnecessary disturbance of riverbanks. These measures do not replace water allocation or drought planning, but they can improve habitat continuity, reduce erosion and strengthen ecological resilience. Restoration should be designed around hydrological conditions so that planted or protected vegetation is compatible with the available water regime.

Environmental education also has a practical role. The student project demonstrates that complex water issues can be organized around understandable categories such as climate, drought, water use, pollution and management. School research can build on this by using repeatable observations: recording household water-saving actions, mapping litter along riverbanks, comparing public water-level datasets or tracking seasonal photographs from fixed locations. Such activities can strengthen environmental literacy without presenting informal observations as formal hydrological measurements.

The green-economy connection is strongest when restoration and education are linked with measurable resource outcomes. Riparian restoration can be assessed through erosion, habitat or vegetation indicators; irrigation modernization can be evaluated through water productivity; wastewater treatment can be assessed through reuse volumes and water-quality improvement; and awareness programmes can be evaluated through actual reductions in consumption. This results-oriented approach helps direct limited financial resources toward interventions that provide the greatest combined environmental and economic benefit.

4.13. Scenario planning and investment priorities under uncertainty

Because the relative importance of climate, withdrawals and reservoir operations changes from year to year, water management should be tested under several plausible scenarios rather than one average forecast. A baseline scenario can represent typical inflow and demand; a drought scenario can combine lower inflow with higher irrigation needs; and a compound-risk scenario can add water-quality deterioration or infrastructure failure. Comparing these cases can reveal which interventions remain useful across a wide range of conditions.

Scenario analysis also helps prioritize investment. Some measures mainly improve reliability, such as reservoir coordination and emergency storage; others reduce demand, such as leak repair and irrigation scheduling; and others protect effective water quality, such as wastewater treatment and runoff control. Nature-based measures can protect riparian habitat and erosion-control functions. A robust portfolio should combine these categories so that the system is not dependent on one intervention performing perfectly.

Green-finance principles can be used to direct funding toward interventions with measurable environmental and economic returns. Qadimli and Mammadov (2026a, 2026b) illustrate how ecosystem sustainability and restoration priorities can be linked to finance, while Qadimli et al. (2026) demonstrate the regional-development relevance of blue-green assets. In a Kura water-security context, comparable criteria could include cubic metres of verified water savings, reduction in distribution losses, hectares of restored riparian habitat, wastewater safely reused, improvement in water-quality indicators and avoided treatment or drought-response costs.

The World Bank (2024) also emphasizes the institutional and infrastructure dimensions of Azerbaijan's water-security challenge. This reinforces a key lesson from the student project: water conservation is not only an individual behavioural issue. Household awareness matters, but durable savings depend on infrastructure condition, agricultural practices, pricing and allocation incentives, monitoring systems and the capacity to coordinate decisions across sectors. The strongest strategy therefore combines individual conservation with institutional and technological change.

Finally, uncertainty should be reported openly. Forecasts of future river conditions depend on climate scenarios, model structure, assumptions about water demand and the quality of monitoring data. Management decisions should not wait for perfect certainty, but they should distinguish measured observations from projections and should be revised as new evidence becomes available. Adaptive management is especially appropriate for the Kura because both natural variability and human use can change the relationship between inflow, storage, demand and downstream ecological needs.

4.14. Limitations

This article remains a narrative review and does not present new field measurements, reservoir records or statistical attribution. The external studies cited use different spatial scales and methods, so their findings cannot be combined into one numerical ranking of causes. The five required Azerbaijan-focused publications are used according to their actual relevance: Arifzade (2026) for hydroecological condition, Mammadov et al. (2026) for anthropogenic pollution in the connected Caspian basin, and Qadimli and Mammadov (2026a, 2026b) and Qadimli et al. (2026) for ecosystem-restoration, green-finance and blue-green development implications rather than as direct measurements of Kura River water-level change.

CONCLUSIONS

The original student research correctly identified decreasing water levels as a problem produced by both natural and human pressures. When applied to the Kura River, the strongest conclusion is that water availability is shaped by interacting climatic, demand and management processes rather than by a single cause. Climate variability and warming influence runoff and evaporation; drought reduces natural supply; irrigation and other withdrawals intensify pressure during low-flow periods; reservoirs redistribute water through time; and infrastructure efficiency affects how much water must be abstracted. Pollution generally does not reduce physical river flow, but it can reduce the amount of water that is safe or economically suitable for use and therefore intensify effective scarcity. The management response should combine efficient irrigation, abstraction monitoring, reservoir coordination, water-quality protection, treated-water reuse, ecosystem restoration and public conservation awareness. From a green-economy perspective, these measures protect natural capital and reduce risks to agriculture, ecosystems and water-dependent development. Future research should use synchronized hydrological, climatic, storage, withdrawal and water-quality records to quantify the relative importance of each pressure and to evaluate whether management interventions are producing real basin-level water savings.

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Riparian flora and fauna diversity along the Kura River and key conservation pressures

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Keywords
Kura River, riparian biodiversity, flora and fauna, Tugai forests, ecosystem conservation

ABSTRACT

Riparian zones along the Kura River support a mosaic of aquatic, riverbank and nearby terrestrial habitats that are important for plants, fish, birds, mammals, amphibians and reptiles. This article develops an original student research project on flora and fauna diversity around the Kura River into a structured academic review while preserving its central species examples, research questions, methodological approach and original river photograph. The source project identified poplar, willow, plane trees, tamarisk, reeds and herbaceous plants as characteristic vegetation and listed carp, kutum, catfish, waterbirds, small mammals, reptiles and amphibians among the fauna associated with the river corridor. The present study reorganizes these observations into habitat groups and compares them with recent literature on Azerbaijani Tugai forests, water quality, ecosystem services and restoration. Results indicate that riparian biodiversity depends on the interaction of water regime, floodplain connectivity, vegetation structure, water quality and human disturbance. Pollution, waste discharge, tree cutting, overfishing, hydrological alteration and climate-related stress can affect several trophic and habitat levels simultaneously. Riparian vegetation is especially important because it stabilizes banks, provides shade and nesting or refuge habitat, and contributes to ecological connectivity. Interpreted through a green-economy perspective, protecting the Kura's flora and fauna also protects natural capital supporting water security, agriculture, recreation and local landscape value. Priority actions include pollution control, riparian restoration, biodiversity monitoring, sustainable fishing, efficient water use and environmental education.

INTRODUCTION

The Kura River is one of the principal freshwater systems of the South Caucasus and forms an ecological corridor that links aquatic habitats with riverbanks, floodplains, riparian woodland and nearby terrestrial environments. The original student research prepared by Firuzə Mustafazadə focused on a simple but ecologically important question: which plants and animals are associated with the Kura River and how can this biological diversity be protected? The source project approached the topic through books, encyclopedias, online materials, maps and photographs and organized its findings around flora, fauna, human uses of the river and environmental threats.

A major strength of the source project is that it does not treat plants and animals as isolated lists. It connects riverbank vegetation with erosion control, shade and shelter; reeds and tamarisk with nesting and refuge habitat; fish and waterbirds with the aquatic system; and mammals, reptiles and amphibians with the wider river corridor. It also identifies pollution, household and industrial waste, tree cutting, overfishing and climate change as pressures that can reduce biodiversity. These observations provide a useful basis for a riparian-ecosystem interpretation.

Recent scientific work in Azerbaijan reinforces the importance of this perspective. Gurbanov et al. (2026) describe Tugai forests of the Kura basin as structurally diverse riparian ecosystems whose composition depends on hydrological regime, groundwater and soil conditions. Ahmadova (2026) similarly argues that restoration of Tugai forests requires attention to river–floodplain–groundwater processes rather than simple tree planting. Water quality also matters because chemical and microbial pressures can affect aquatic habitat and the suitability of water for ecological and human uses (Aliyev & Abduyev, 2025; Arifzade, 2026).

The objective of this article is therefore to preserve and academically develop the student's original work by: (1) organizing the reported flora and fauna into habitat-based groups; (2) explaining the ecological functions of riparian vegetation and animal communities; (3) assessing the major conservation pressures identified in the source project; and (4) interpreting biodiversity protection through ecosystem-services and green-economy perspectives.

LITERATURE REVIEW

2.1. Riparian ecosystems and Tugai vegetation

Riparian ecosystems occupy the transition between river channels and surrounding terrestrial landscapes. Because they are influenced by flooding, groundwater, alluvial soils and lateral water movement, they often support vegetation and fauna that differ from drier surrounding areas. In Azerbaijan, Tugai forests are among the most characteristic riparian ecosystems of the Kura and Araz corridors. Gurbanov et al. (2026) documented high floristic diversity and layered vegetation structure in these forests and identified hydrological alteration, water

abstraction, agricultural expansion, deforestation, grazing, invasive species and climate change as important degradation pressures.

The source project's plant list—poplar, willow, plane tree, tamarisk, reeds and herbaceous vegetation—fits this broader riparian logic. Not every listed plant should be interpreted as occurring uniformly along the full river, and the student project did not conduct a taxonomic inventory. Nevertheless, the list correctly captures the coexistence of woody riparian vegetation, shrub-like salt- and drought-tolerant plants, emergent wetland vegetation and grasses. Ahmadova (2026) emphasizes that the long-term persistence of such communities depends on hydrological connectivity, groundwater conditions and adaptive monitoring.

2.2. Aquatic and terrestrial fauna

The student project identifies fish, waterbirds, small mammals, reptiles and amphibians as major fauna groups connected with the Kura corridor. Its fish examples include carp, kutum, a locally named "çəki" fish and catfish; the project also lists ducks, storks, pelicans and gulls among the birds, and foxes, hares, hedgehogs and jackals among terrestrial mammals. Because the source document is a literature-based school project rather than a field survey, these examples should be treated as reported species groups rather than verified observations at a defined sampling site.

This distinction is scientifically important. River biodiversity varies spatially with water depth, flow velocity, channel form, vegetation, season and water quality. Tributaries and floodplains can also provide different habitats from the main channel. Research on the Turyanchay, a tributary of the Kura, has shown how biological communities and environmental conditions can vary through time and space, illustrating the need for site-specific monitoring rather than basin-wide generalization.

2.3. Ecosystem services and green-economy relevance

Biodiversity has economic relevance because riparian and aquatic ecosystems provide services that support people and productive sectors. Vegetation can stabilize banks and reduce erosion, wetlands and riparian zones can contribute to water regulation, and healthy fish and bird communities can support cultural, recreational and educational value. Freshwater ecosystem-service assessment in the Kura–Aras basin has also linked river condition with hydropower, irrigated agriculture, drinking-water supply and nature-based tourism.

Recent Azerbaijan-focused studies extend this connection to green finance and spatial planning. Qadimli and Mammadov (2026a) connect ecosystem sustainability with green-finance-based ecotourism, while Qadimli and Mammadov (2026b) identify restoration priorities using remote sensing and a nature-based-solutions framework. Qadimli et al. (2026) likewise show that blue-green landscape assets can be integrated into regional sustainable-development planning. These studies support treating riparian biodiversity as natural capital rather than as an environmental feature separate from economic development.

The wider basin context is also relevant. Mammadov et al. (2026) review microplastic pollution and anthropogenic pressure in the Caspian Sea basin, demonstrating that river and coastal ecosystems are connected by material flows and human activity. Pressures originating inland can therefore contribute to downstream environmental risks, while degradation at river margins can reduce habitat quality before water reaches the Caspian.

MATERIALS AND METHODS

The present study was developed from a nine-page student research document entitled "Çay ətrafı ərazilərdə fauna və flora müxtəlifliyi" ("Fauna and flora diversity in areas around the river"), prepared by Firuzə Mustafazadə in 2026. The original project used online research, geography and biology books, maps and photographs. It did not report field transects, specimen collection, laboratory analysis, GPS points or a quantitative biodiversity survey. Accordingly, the present article preserves the project as a literature-based synthesis and does not present the listed organisms as newly observed field records.

The source material was organized into four analytical categories: (1) riparian flora; (2) aquatic and terrestrial fauna; (3) ecosystem functions; and (4) conservation pressures. The original research questions were retained conceptually: which flora and fauna are associated with the Kura River, how environmental problems can affect these organisms, and which measures can support conservation. The species examples, ecological interpretations and original river photograph were retained.

The student's source list was reviewed and strengthened with peer-reviewed and institutional literature. Educational sources such as AZERTAC and the original geography materials were retained where they supported general background, while stronger scientific evidence was added for Tugai ecology, water quality, ecosystem services and restoration. No unsupported abundance figures or species-population trends were introduced.

RESULTS AND DISCUSSION

4.1. Flora reported in the source project

The source project identifies poplar, willow, plane tree, tamarisk, reeds and different herbaceous plants as characteristic vegetation around the Kura. These forms represent several ecological layers. Trees and tall shrubs can create shade, nesting sites and structural complexity; reeds and other emergent vegetation occupy wetter margins; herbaceous plants cover exposed or seasonally moist ground. Together, these components create a habitat gradient from open water to dry land.

The student's explanation of vegetation functions is also ecologically sound in general terms. Roots can help stabilize soil and riverbanks, plant cover can reduce direct erosion, foliage provides shelter and microclimate effects, and dense riverbank vegetation can support breeding or refuge habitat for birds, amphibians, insects and small mammals. Gurbanov et al. (2026) provide contemporary field evidence that Azerbaijani Tugai forests possess complex, multi-layered vegetation and high ecological value, while Ahmadova (2026) highlights the importance of floodplain and groundwater processes for their restoration.

4.2. Fauna groups and habitat dependence

The student project groups the fauna into fish, birds, mammals, reptiles and amphibians. This is useful because each group depends on the river in a different way. Fish depend directly on water quality, flow and aquatic habitat. Waterbirds use open water, reeds, mudflats, islands and riparian vegetation for feeding or resting. Amphibians require moist habitats and are particularly sensitive to changes in water availability and contamination. Reptiles and mammals may use the riparian corridor for feeding, movement, cover or access to water.

The listed species should not be interpreted as a formal census of the whole Kura basin. The original study did not report where, when or how individual animals were observed. Its value lies instead in demonstrating habitat diversity and the ecological relationships

among vegetation, water and fauna. A future field study could test these relationships through fixed observation points, seasonal bird counts, vegetation plots, fishery records or camera traps.

Table 1. Flora and fauna groups retained from the original student project and their main ecological roles4.3. The original river image and habitat interpretation

Group	Examples reported in source project	Main ecological role
Woody flora	Poplar, willow, plane tree, tamarisk	Bank stability, shade, structural habitat and ecological connectivity
Wetland and herbaceous flora	Reeds and different grasses/herbs	Cover, nesting/refuge habitat and transition between water and land
Fish	Carp, kutum, "çaki", catfish	Aquatic food-web functions and fishery value
Birds	Duck, stork, pelican, gull; cormorant also discussed in the abstract	Feeding, migration, predation and nutrient transfer
Mammals	Fox, hare, hedgehog, jackal	Use of river corridor for food, water and shelter
Reptiles and amphibians	Snakes, lizards, frogs	Predator–prey interactions and sensitivity to habitat and moisture conditions

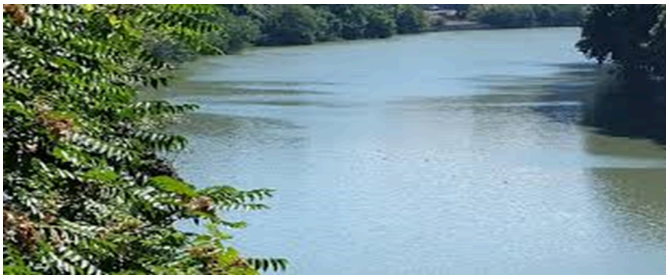


Figure 1. Kura River

The photograph included in the source project is important because it visually reinforces the student's focus on the boundary between water and vegetated riverbank. Even without a documented sampling location, the image illustrates the type of riparian interface where aquatic and terrestrial processes meet. Such margins can provide shade, organic inputs, shelter and movement corridors, but they are also sensitive to bank clearing, trampling, waste accumulation and changes in water level.

4.4. Pollution and water-quality pressure

Pollution is one of the principal threats identified in the original research. The student specifically refers to household and industrial waste reaching the river. These pressures can affect fauna directly through toxicity or poor water quality and indirectly through changes in food resources, oxygen conditions and habitat. Aliyev and Abduyev (2025) demonstrate that major-ion composition and mineralization vary along the Azerbaijani section of the Kura, while Arifzade (2026) emphasizes the need to consider nutrient, microbial and major-ion evidence together when evaluating Mingachevir Reservoir.

Water-quality deterioration should not automatically be equated with biodiversity decline at every site because ecological response depends on pollutant type, concentration, exposure duration and species sensitivity. However, maintaining good water quality is a necessary condition for protecting aquatic organisms and many riparian species. The Caspian-focused review by Mammadov et al. (2026) adds a downstream perspective by showing that emerging pollutants such as microplastics also form part of the wider anthropogenic pressure affecting the connected basin.

4.5. Vegetation loss, hydrological alteration and climate stress

The source project also identifies tree cutting and climate change as conservation problems. Vegetation removal can simplify habitat structure, expose banks to erosion and break ecological connectivity. Hydrological alteration can be equally important because riparian plants depend on the timing and availability of river water and groundwater. Gurbanov et al. (2026) report that reservoir construction, river regulation and intensive water abstraction have contributed to Tugai degradation, while Ahmadova (2026) argues that successful restoration requires re-establishing hydrological processes rather than planting trees alone.

Climate stress may intensify these pressures by changing drought frequency, temperature, evaporation and water demand. The effects are likely to vary along the Kura because mountain, reservoir, lowland and delta habitats have different hydrological conditions. Conservation planning should therefore be site-specific and should combine vegetation monitoring with flow, groundwater and water-quality information.

4.6. Overfishing and aquatic biodiversity

Overfishing is another pressure highlighted by the student. Fishing can be sustainable when harvest remains within the reproductive capacity of populations, but excessive or illegal harvest can reduce abundance and alter age structure. Dams, pollution and habitat degradation can compound fishing pressure by reducing spawning or nursery habitat. Caspian fisheries research shows that migratory fish conservation is particularly difficult where river connectivity and spawning habitat are affected by infrastructure and other human activities.

Because the source project did not provide catch records or population data, the present article does not quantify fishing impacts on any Kura species. A future study could use official fishery statistics, interviews with fishers, seasonal catch data or scientific monitoring to test whether particular populations are declining and why.

4.7. Ecosystem services, natural capital and green economy

The student's conclusion that the Kura is important for both nature and people can be developed through the concept of ecosystem services. Riparian vegetation contributes to erosion control and habitat provision; aquatic biodiversity supports ecological food webs and can contribute to fisheries; attractive river landscapes support recreation and environmental education; and healthy ecosystems can complement engineered water-management infrastructure. These functions are forms of natural capital.

This interpretation is consistent with green-economy research in Azerbaijan. Qadimli and Mammadov (2026a) show how ecosystem quality can support controlled ecotourism and green-finance opportunities, while Qadimli and Mammadov (2026b) use remote sensing to identify restoration and nature-based-solution priorities. Qadimli et al. (2026) similarly connect water-adjacent blue-green assets with sustainable regional development. For the Kura corridor, investment in riparian restoration, waste prevention, monitoring and low-impact recreation can therefore serve ecological and economic objectives simultaneously.

4.8. Conservation priorities and monitoring

The source project proposes keeping the river clean, protecting vegetation, conserving rare animals and improving environmental awareness. These recommendations can be translated into a more operational framework. Pollution control should prioritize wastewater treatment, solid-waste prevention and agricultural-runoff management. Riparian conservation should protect existing native vegetation and restore degraded sections where hydrological conditions remain suitable. Fishing management should rely on monitoring and enforceable rules rather than general prohibition.

Biodiversity monitoring should distinguish between habitat indicators and species indicators. Habitat measures can include riparian vegetation width, continuity, tree and shrub cover, reed-bed condition, exposed banks and visible waste. Species-based monitoring can include bird counts, amphibian observations, fish data and records of invasive species. Repeatable monitoring at fixed locations would allow future student or professional research to detect real change rather than relying on one-time lists.

Environmental education is especially relevant because the source project itself demonstrates how biodiversity can be introduced through accessible examples. School projects can contribute through supervised litter surveys, fixed-point photography, simple vegetation classification and citizen-science observations. The key scientific requirement is to separate observed data from information taken from books or online sources.

4.9. Spatial differentiation of biodiversity along the river corridor

The Kura corridor should not be treated as one uniform habitat. The upper basin is influenced by mountain hydrology and relatively steep valleys, whereas the middle river contains major reservoirs and regulated sections. The lower river crosses drier lowlands where floodplain vegetation, agricultural land and settlement become increasingly important. The delta and mouth connect the river to the Caspian Sea. Each zone offers different combinations of water depth, flow, sediment, vegetation and human pressure, so the composition of flora and fauna can change substantially between them.

This spatial variation helps explain why the student's species list is best interpreted as a general educational inventory rather than a site-specific census. Poplar and willow may be associated with well-watered riparian sites, while tamarisk is better adapted to more saline or arid conditions. Reeds can form dense marginal stands in shallow or slow-flowing water. Fish communities also vary with channel morphology, water temperature, connectivity and migration opportunities. The same is true for birds: some species use open water, others depend on reed beds or exposed banks, and migratory species may use the river only during particular seasons.

A practical consequence is that conservation targets should be matched to river section. Protecting a wooded floodplain requires different actions from restoring a degraded urban bank or monitoring a reservoir shoreline. Site-specific planning can therefore reduce the risk of applying one generic intervention everywhere. This is consistent with the restoration logic of Ahmadova (2026), which links ecological interventions to hydrology, floodplain connectivity and measurable indicators.

4.10. Reframing the student research questions as a monitoring programme

The three original research questions can be converted into a repeatable monitoring framework. The first question—what flora and fauna occur around the Kura—requires a defined study area and consistent observation method. A school-level vegetation survey could record trees, shrubs, reeds and herbaceous plants within fixed riverbank plots, while bird observations could be made for a fixed period at the same points during different seasons. Photographs taken from the same location can provide a visual record of vegetation cover, bank condition and visible waste.

The second question—how environmental problems affect living organisms—requires linking biological observations with pressure indicators. Simple habitat variables such as visible litter, bank disturbance, vegetation removal, water colour or odour can be recorded, but these are not substitutes for laboratory water-quality data. Where public monitoring information is available, student observations could be compared with official measurements of major ions, nutrients, microbial indicators or other relevant parameters. The work of Aliyev and Abduyev (2025) and Arifzade (2026) demonstrates the type of measured evidence needed to move beyond general descriptions of pollution.

The third question—what can be done to protect the Kura and its surroundings—can then be evaluated through before-and-after indicators. A riverbank clean-up can be assessed through the number or mass of collected waste; a planting activity through survival and growth of native vegetation; and an awareness campaign through participation or knowledge surveys. This turns environmental education into a small but transparent evidence cycle: identify a pressure, apply a response and measure whether the targeted condition changes.

Such a design would also preserve the educational value of the original project. The student's initial work already combines geography, biology and conservation. Adding coordinates, dates, fixed observation points and repeat measurements would strengthen the scientific quality without changing the central research idea. It would also make future student projects more comparable across schools and river sections.

4.11. Biodiversity conservation as a local green-development pathway

The green-economy implications of riparian biodiversity extend beyond conservation areas. Riverbanks near settlements can support walking, environmental education, birdwatching, photography and other low-impact activities when access is planned without damaging sensitive habitat. Healthy riparian vegetation can also reduce erosion and improve landscape quality, creating benefits that would otherwise require engineered solutions or repeated maintenance. These services do not mean that every riverbank should be developed for tourism; sensitive habitats may require restricted access and stronger protection.

The work of Qadimli and Mammadov (2026a) is relevant because it shows how biodiversity observations and visitor planning can be combined with green-finance thinking in protected landscapes. Qadimli and Mammadov (2026b) similarly demonstrate that restoration priorities can be identified spatially rather than distributing investment evenly. Applied to the Kura corridor, this suggests a hierarchy of interventions: protect intact riparian habitat first, restore degraded areas where ecological processes can recover, and concentrate visitor infrastructure in places with lower sensitivity and adequate management capacity.

Central Aran is particularly relevant to this logic because the Kura and associated water bodies are among the region's key blue-green landscape features. Qadimli et al. (2026) show that water proximity,

land cover and development priorities can be evaluated together when considering blue-green tourism. Biodiversity data could strengthen this type of planning by identifying locations where recreational potential overlaps with sensitive habitat, allowing decision-makers to distinguish suitable visitor areas from conservation-priority zones.

The economic value of biodiversity should nevertheless be interpreted carefully. The present study does not calculate monetary values for erosion control, fish resources, recreation or habitat. Instead, it identifies plausible pathways through which ecological condition can influence local welfare and development. Future valuation could compare restoration costs with avoided bank erosion, improved recreational use, fishery benefits or other measurable outcomes. Such work would make the concept of natural capital more operational while avoiding unsupported claims about economic returns.

A final dimension is resilience. Diverse and structurally complex riparian ecosystems may provide more ecological functions than simplified banks dominated by bare soil or fragmented vegetation. Protecting native vegetation, maintaining water quality and reducing direct disturbance can therefore be viewed as risk-management measures. They help preserve options for future agriculture, recreation, education and ecosystem restoration under uncertain climate and hydrological conditions.

4.12. Conservation indicators, ecosystem services and management priorities

A conservation programme for the Kura should link biodiversity observations to indicators that can be repeated and compared through time. For riparian vegetation, useful indicators include the width and continuity of native vegetation, the proportion of bare or eroding bank, visible regeneration of trees and shrubs, reed-bed condition and evidence of cutting or grazing. For fauna, indicators can include standardized bird counts, amphibian observations, fishery records and evidence of breeding or nesting habitat. These measures are more informative than a single species list because they allow researchers to detect direction of change.

Water condition should be monitored in parallel because habitat quality and water quality are closely connected. At a simple level, field teams can record temperature, turbidity, conductivity and visible pollution where appropriate equipment and supervision are available. More advanced assessment should use laboratory or official monitoring data for nutrients, major ions, microbial indicators and priority pollutants. Arifzade (2026) illustrates the value of combining several hydroecological indicators in the Middle Kura cascade, while Aliyev and Abduyev (2025) show how major-ion chemistry varies along the river. These studies demonstrate why biodiversity monitoring benefits from being paired with physical and chemical evidence.

Management priorities can then be matched to the dominant pressure. Where waste and untreated discharges are visible, pollution prevention and wastewater control should come first. Where riverbank vegetation has been removed, restoration may be appropriate, but only if hydrological and groundwater conditions can sustain the planted or naturally regenerating vegetation. Where recreational use is high, designated access points, waste collection and environmental information can reduce trampling and litter. Where fishing pressure is a concern, monitoring and enforcement should focus on species, season and catch rather than rely on broad assumptions.

This pressure-specific approach also supports more efficient use of conservation finance. Green investment is most effective when the intervention is chosen because it addresses an identified ecological driver. Qadimli and Mammadov (2026b) demonstrate this logic by linking restoration priorities to spatial evidence, while Ahmadova (2026) argues for driver-based Tugai restoration. Applied to the Kura, the same principle means that planting, monitoring, wastewater treatment, visitor infrastructure and fishery management should be targeted according to local ecological need instead of implemented uniformly.

The potential co-benefits are important. Restored vegetation may improve habitat while also stabilizing banks and increasing landscape quality. Better water quality benefits aquatic organisms while reducing risks for recreation and water use. Carefully managed riverfront access can support environmental education and low-impact recreation without sacrificing sensitive areas. In this way, biodiversity conservation can contribute simultaneously to ecological resilience, public awareness and local green-development opportunities.

Monitoring should also include a feedback stage. If vegetation restoration shows low survival, investigators should examine whether the problem is inappropriate species selection, insufficient water, soil salinity, grazing or repeated disturbance. If litter returns after a clean-up, the response may require better collection infrastructure or community engagement rather than repeated one-day campaigns. Adaptive management turns conservation from a one-time action into a learning process in which results influence the next intervention.

4.13. Limitations and future research

The principal limitation of this study is inherited from the original project: it is a literature-based educational synthesis rather than a standardized biodiversity survey. No coordinates, sampling dates, transects, quadrats, abundance counts or laboratory measurements were provided. The animal and plant examples therefore cannot be used to estimate species richness, population size or distribution across the entire Kura basin.

Future research could select two or three clearly defined riverbank sites and repeat observations in different seasons. Vegetation could be recorded using small plots, birds through fixed-time counts, visible litter through transects, and water condition through basic field parameters where safe and supervised. Photographs could be geotagged and compared over time. Such a design would preserve the student's original interest in flora and fauna while producing more reproducible ecological data.

CONCLUSIONS

Firuza Mustafazade's original project identifies the Kura River corridor as a biologically rich environment in which riparian plants, fish, waterbirds, mammals, reptiles and amphibians are linked by shared dependence on water and habitat. The project's main ecological insight is that vegetation is not merely scenery: trees, reeds, tamarisk and herbaceous plants contribute to bank stability, shelter, nesting conditions and ecological connectivity. Its main conservation concerns—pollution, waste discharge, tree cutting, overfishing and climate change—are supported in general form by current research, although their local effects require site-specific measurement. Recent work on Azerbaijani Tugai forests shows that hydrological regime, groundwater and human disturbance are central to riparian ecosystem condition. Protecting biodiversity along the Kura therefore requires pollution prevention, hydrologically informed restoration, sustainable fishing, monitoring and environmental education. From a green-economy perspective, these measures protect natural capital that supports water security, landscape quality, recreation and resilient local development. Future field-based student research

can build on this foundation by using repeatable sampling methods and clearly distinguishing direct observations from secondary-source information.

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An investigation into the major causes of declining water availability in the Kura River Basin

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Kura River Basin, water availability, water security, climate variability, irrigation efficiency

ABSTRACT

Declining water availability in the Kura River Basin is a multidimensional water-security challenge shaped by climatic variability, human withdrawals, irrigation inefficiency, river regulation, water quality and transboundary management. This article develops an original student research review into a structured synthesis of hydrological, environmental and governance evidence while preserving its central research question, source figure and emphasis on evidence quality. Historical studies indicate substantial variation in Kura flow and document periods of reduced discharge, while recent tree-ring reconstruction demonstrates that wet and dry phases have occurred over long timescales. Irrigation and other abstractions can intensify seasonal scarcity, particularly where conveyance losses increase the amount of water required to satisfy demand. Reservoirs alter the timing and distribution of flow rather than producing a uniform effect on annual discharge, and declining water quality can reduce the amount of water suitable for particular uses without necessarily reducing physical river volume. The review therefore distinguishes water quantity from water quality and measured observations from projections or secondary interpretations. It concludes that resilient management requires long-term hydrological monitoring, efficient irrigation, adaptive reservoir operation, pollution control, ecosystem restoration and coordinated data exchange. From a green-economy perspective, such measures protect agricultural productivity, water security and ecosystem services while reducing long-term environmental and economic risk.

INTRODUCTION

Water security depends on more than the amount of water physically present in a river. Reliability, seasonal timing, water quality, infrastructure, allocation rules and ecosystem requirements all influence whether a water resource can support people, agriculture and nature. The original research by Narmin Mammadli, developed with academic supervision by Aynur Mammadova, approaches declining water availability in the Kura River Basin from this integrated perspective. Its central argument is that no single pressure adequately explains the basin's water challenge.

The Kura is a transboundary river whose flow is influenced by precipitation, temperature, snowmelt, tributary inflow, reservoirs, withdrawals and return flows. In Azerbaijan, the river is closely connected to irrigated agriculture, drinking-water supply, hydropower, reservoir management and downstream ecosystems. Historical analysis has reported substantial reductions in annual flow during particular periods, while more recent work demonstrates long-term hydroclimatic variability and the importance of separating historical observations from present-day conditions (Imanov & Verdiev, 2016; Bakhtiyorov et al., 2024).

The original study also makes an important methodological distinction between water quantity and water quality. Pollution or increasing mineralization may reduce the volume of water suitable for a specific use without directly proving that river discharge has declined. Conversely, lower flow can intensify some water-quality problems, but demonstrating such a relationship requires paired discharge and concentration data. This article preserves that distinction and expands it through a structured review of climate, withdrawals, regulation, pollution, governance and green-economy implications.

The objective is to identify the major mechanisms associated with declining water availability in the Kura River Basin, evaluate the type and strength of evidence supporting each mechanism, and outline management priorities that improve both water security and ecosystem resilience. The study does not assign a single percentage contribution to individual causes because the reviewed evidence is heterogeneous in location, period and method.

LITERATURE REVIEW

2.1. Climate variability and long-term streamflow change

Kura River flow is influenced by precipitation, temperature, snow accumulation and melt, evapotranspiration and seasonal climate variability. Bakhtiyorov et al. (2024) reconstructed July-August streamflow in western Transcaucasia using tree-ring chronologies spanning 1720-2021 and identified extended wet and dry phases. The study demonstrates that substantial variability existed before the modern instrumental period and that drought risk may increase under

the scenarios they examined. These results are regionally important, but they should not be converted into a single basin-wide percentage decline for Azerbaijan.

Imanov and Verdiev (2016), analysing flow to the Caspian Sea from Azerbaijan, reported that annual Kura flow at Salyan during 1991-2010 was substantially below the long-term average used in their study. Imanov et al. (2023) subsequently examined changes in annual Kura flow in relation to reservoirs, climate and water use. Together these studies support a multi-causal interpretation in which natural supply and human management interact.

2.2. Irrigation demand, withdrawals and efficiency

Agriculture is a major water user in the basin, making irrigation central to any analysis of water availability. Where canals or networks lose water through leakage, seepage or inefficient delivery, more water may need to be withdrawn to satisfy the same farm demand. Yet withdrawal is not identical to net consumptive loss: some water may return to rivers or aquifers, while some is consumed through evapotranspiration. The original research correctly treats these distinctions as reasons to avoid simplistic accounting.

Technical efficiency alone is therefore not sufficient. Repaired networks, improved irrigation scheduling and soil-moisture monitoring may reduce avoidable losses, but basin-scale savings depend on total abstraction and how any saved water is subsequently used. The water-security paper by Mammadova et al. (2026) and the climate-anthropogenic synthesis by Jafarova et al. (2026) both identify water-use efficiency as a management priority, while the original study cautions that local review evidence should be interpreted alongside hydrological records.

2.3. Reservoir regulation and environmental flow

Reservoirs provide storage, hydropower, irrigation supply and flood-management functions, but they also alter the timing of downstream flow. Storage may reduce flow during filling and increase it during later releases, meaning that annual totals, seasonal low flows and supply reliability should be examined separately. Abbasov and Smakhtin (2009) proposed environmental thresholds for mountain streams in the Kura basin and showed why water withdrawals should be evaluated relative to minimum ecological flow requirements.

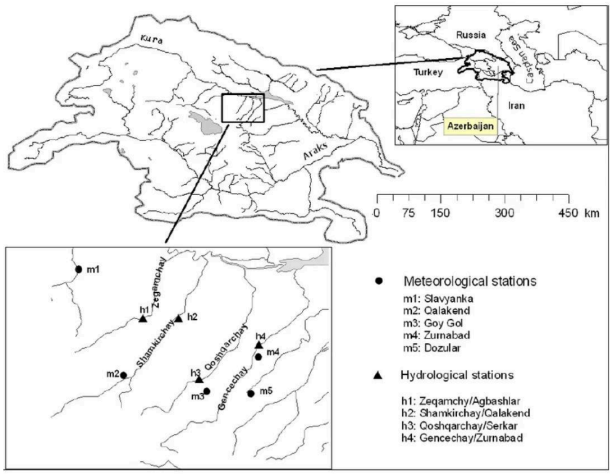


Figure 1. Map of the Kura River basin and the study area with meteorological and hydrological stations, retained from the original research source. Source: Abbasov and Smakhtin (2009).

2.4. Water quality and effective water availability

Water quality is a separate but connected dimension of water security. Aliyev and Abduyev (2025), using samples from multiple sites along the Kura in Azerbaijan, documented spatial variation in major-ion concentrations and mineralization. Arifzade (2026) synthesizes nutrient, microbial and major-ion evidence for Mingachevir Reservoir and similarly shows the value of multi-indicator assessment. Such evidence can demonstrate changes in water chemistry, but it does not by itself establish the magnitude of a decline in river discharge.

The broader basin connection is illustrated by Mammadov et al. (2026), who examine microplastic pollution and coastal anthropogenic pressure in the Caspian Sea basin. Their study concerns downstream coastal conditions rather than Kura discharge, but it reinforces the need to assess river management within a connected river-reservoir-sea system.

2.5. Governance, ecosystem restoration and green-economy context

Because the Kura is transboundary, water availability is influenced by institutional as well as hydrological conditions. Suleymanov (2025) examines the institutionalization of the Kura-Aras Basin and emphasizes cooperation, transparency and trust. Shared monitoring protocols and data exchange are especially important during drought because upstream and downstream pressures may intensify simultaneously.

A green-economy interpretation extends water security beyond supply infrastructure. Qadimli and Mammadov (2026a) link ecosystem sustainability with green-finance-based ecotourism; Qadimli and Mammadov (2026b) use remote sensing to prioritize nature-based solutions and restoration finance; and Qadimli et al. (2026) integrate blue-green assets into sustainable-development planning in Central Aran. These studies do not quantify Kura flow decline, but they are relevant to the economic value of ecosystem restoration and natural-capital protection.

MATERIALS AND METHODS

This study uses a structured narrative-review approach based on the original research manuscript entitled "An Investigation into the Major Causes of Declining Water Availability in the Kura River Basin." The source work synthesizes hydrological and climate research, water-use and infrastructure studies, water-quality monitoring, governance literature and locally focused KuraWatch publications. No new river samples, field measurements or discharge estimates were generated.

Evidence was organized into five analytical groups: climate variability and climate change; agricultural demand and irrigation efficiency; reservoir regulation; water quality; and transboundary governance. Each source was interpreted according to its method. Measured monitoring data, historical reconstructions, model projections, expert interviews and local desk-based reviews were not treated as equivalent forms of evidence.

The review also applied an evidence-quality rule used in the student manuscript: a numerical estimate was retained only when its origin and time period were clear. Historical values were labelled as historical rather than presented as current measurements. Survey or review-based claims were not converted into basin-wide hydrological estimates. The source figure from Abbasov and Smakhtin (2009) was preserved because it formed part of the original research presentation.

RESULTS AND DISCUSSION

4.1. Climate is a major pressure but not a stand-alone explanation

The literature supports the conclusion that climate affects both the quantity and timing of water entering the Kura system. Higher temperature can increase evaporative demand, while changes in precipitation and snowmelt alter runoff. However, the basin contains large reservoirs, tributaries and withdrawals that can modify how

upper-basin climatic signals appear downstream. A dry sequence therefore cannot be attributed to climate alone without comparison against long-term discharge and water-use data.

The long tree-ring reconstruction of Bakhtiyorov et al. (2024) is valuable because it places recent conditions within centuries of natural variability. At the same time, future projections depend on climate scenarios and model assumptions. The strongest conclusion is therefore not a precise future decline percentage but an increase in uncertainty and potential drought risk that should be incorporated into planning.

4.2. Withdrawals and irrigation can amplify low-flow stress

Human withdrawals matter most when demand is high and natural supply is low. Irrigation systems with conveyance losses may require greater gross abstraction to deliver the same volume to farms, intensifying pressure on the river during dry periods. Yet the size of the basin-wide effect cannot be inferred from the existence of inefficient canals alone. Reliable attribution requires records of withdrawals, return flows, crop demand and river discharge during comparable periods.

This is also where optimization becomes important. Water-management performance should be judged not only by the efficiency of equipment but by the amount of agricultural output and ecosystem protection achieved per unit of water consumed. Repairing distribution systems, scheduling irrigation according to crop requirements and monitoring total abstraction are therefore complementary measures rather than substitutes.

4.3. Reservoirs alter seasonal availability and ecological conditions

Reservoirs complicate trend analysis because they redistribute water through time. A downstream station may experience lower flow during storage and higher flow during release even if annual inflow is unchanged. Reservoir evaporation and connected withdrawals add further complexity. Evaluating their role requires records above and below major structures together with storage and release data.

Environmental-flow concepts provide a useful management bridge. Abbasov and Smakhtin (2009) demonstrate that withdrawal limits can be linked to ecological thresholds in Kura basin streams. Such approaches are valuable because they recognize that maintaining river function requires a minimum quantity and timing of flow for aquatic ecosystems as well as for human users.

4.4. Water quality affects usable supply but should not substitute for flow evidence

The review confirms that water quality is critical to water security. Mineralization, microbial contamination or other pollutants can make water more difficult or expensive to use. Gojali et al. (2026) identify wastewater, solid waste, agricultural runoff and transboundary pollutant pathways as recurring concerns, while Aliyev and Abduyev (2025) provide direct monitoring evidence of spatial hydrochemical variation.

However, concentration and discharge are different measurements. A higher concentration may result from lower dilution, greater pollutant input, groundwater interactions or other processes. Establishing causation requires simultaneous information on pollutant loads and flow. This distinction is one of the strongest methodological features of the original student research because it prevents water-quality evidence from being misused as proof of hydrological decline.

4.5. Governance and information gaps shape management risk

The literature also reveals an information problem. Flow records, water withdrawals, reservoir operations and water-quality monitoring are often produced for different purposes and periods. In a transboundary basin, inconsistent measurement and limited data exchange make it harder to distinguish climatic effects from management effects. Suleymanov (2025) therefore complements the hydrological evidence by showing that institutional cooperation and trust influence the ability to manage shared water resources.

Azerbaijan's National Strategy on Efficient Use of Water Resources for 2024-2040 provides a policy framework for water efficiency and management improvement. The research implication is that implementation should be evaluated through measurable indicators such as total withdrawals, network losses, irrigation reliability, treated-wastewater reuse, seasonal discharge and monitoring coverage rather than through general statements of progress.

Table 1. Main pressures identified in the literature and the evidence required for attribution

Pressure	What the literature supports	Evidence still needed
Climate variability and change	Long-term wet/dry variability and plausible future drought risk	Consistent local discharge-climate comparisons
Irrigation and abstraction	Potential intensification of low-flow stress and avoidable conveyance losses	Withdrawal, return-flow and crop-demand records
Reservoir regulation	Redistribution of water between seasons and locations	Storage, release and upstream/downstream discharge data
Water-quality deterioration	Reduced suitability of water for some uses	Paired concentration, pollutant-load and discharge data
Governance and coordination	Need for shared monitoring, transparency and allocation mechanisms	Comparable basin-wide datasets and implementation indicators

4.6. Green-economy and ecosystem-resilience implications

Declining water availability creates economic risk through lower agricultural reliability, higher treatment requirements, competition among users and stress on ecosystems. A green-economy response therefore seeks to reduce water intensity while maintaining ecological functions. Efficient irrigation, pollution prevention and restoration can be viewed as investments in natural capital and resource productivity rather than as environmental costs disconnected from economic development.

The restoration and blue-green planning studies of Qadimli and Mammadov (2026a, 2026b) and Qadimli et al. (2026) are relevant because they show how environmental condition can be integrated into finance and spatial development. For the Kura Basin, analogous priorities include riparian restoration, efficient irrigation infrastructure, water-quality monitoring and riverfront management that preserves ecosystem services. Arifzade (2026) and Mammadov et al. (2026) further demonstrate that water security should be understood within a wider reservoir-to-Caspian environmental system.

4.7. Monitoring and research priorities

Future research should prioritize long-term discharge analysis at consistent stations, comparison of flow records with precipitation and temperature, improved accounting of withdrawals and reservoir operations, and joint analysis of water quality with discharge and pollutant loads. These datasets would make it possible to estimate the relative contribution of climatic and human factors more reliably and to test whether management interventions are improving water security.

Monitoring should also distinguish annual averages from seasonal low-flow risk. Agriculture, ecosystems and communities can

experience serious shortages during critical months even when annual totals appear less extreme. Environmental-flow thresholds, drought indicators and seasonal demand data can therefore provide more useful management information than annual statistics alone.

Locally focused student and citizen-science research can complement formal monitoring through supervised observation, mapping and public awareness, but it should clearly identify sample sizes, methods and uncertainty. The original manuscript already follows this principle by distinguishing exploratory local evidence from hydrological measurements.

4.8. Interaction between climatic stress and management decisions

A central conclusion of the original research is that climatic and human pressures should not be separated too sharply. Reduced precipitation or higher evaporative demand can lower natural supply, but the severity of the resulting shortage depends on how water is stored, allocated and delivered. During a dry summer, for example, irrigation demand may rise at the same time that tributary inflow falls. If distribution networks lose substantial water or abstraction is weakly coordinated, management can amplify a climatic shortfall even when it did not create the initial drought.

The reverse interaction is also possible. Better infrastructure and allocation rules cannot create rainfall, but they can increase the reliability of a limited supply and reduce unnecessary withdrawals. This is why attribution and adaptation are related but different questions. Researchers may not be able to assign an exact percentage of observed scarcity to each cause, yet managers can still act on avoidable losses, inefficient timing, pollution and weak monitoring while climate uncertainty is being studied.

This distinction has practical value for the Kura Basin because climate adaptation should not be framed only as large new infrastructure. Demand management, drought planning, canal rehabilitation, improved monitoring and ecosystem protection can all reduce vulnerability. The most resilient strategy is therefore a portfolio of measures rather than dependence on one intervention.

4.9. Water-food-energy-ecosystem trade-offs

The Kura supports agriculture, reservoirs, hydropower, settlements and aquatic ecosystems, so water-management decisions create trade-offs across sectors. Water stored for later irrigation may temporarily reduce downstream flow; releases for energy production may not coincide with ecological or agricultural demand; and increasing abstraction for crops can reduce the water available for other users during low-flow periods. These interactions make seasonal timing as important as annual volume.

A water-food-energy-ecosystem perspective is therefore useful. Agricultural productivity should be assessed together with total water consumption and soil condition; hydropower benefits should be considered alongside ecological flow; and drinking-water security should include raw-water quality and treatment needs. This integrated view is consistent with the green-economy studies cited above, which treat ecosystems and blue-green assets as components of development rather than as separate environmental concerns.

For optimization, the management objective should be to maximize social and economic benefit from a finite water resource while maintaining ecological function. That requires indicators that can compare sectors rather than optimizing one use at the expense of the entire basin. Water productivity in agriculture, storage reliability, environmental-flow compliance, water-treatment requirements and ecosystem condition are examples of variables that can be monitored together.

4.10. Attribution framework for future Kura research

A stronger future attribution study could combine several datasets at the same temporal scale. First, monthly or daily river discharge should be analysed at consistent stations. Second, precipitation, temperature, snow and drought indices should be matched to those records. Third, reservoir storage and release data should be added to identify regulation effects. Fourth, irrigation, municipal and industrial withdrawals should be recorded with return-flow estimates where possible. Finally, water-quality concentrations should be paired with discharge so that pollutant loads can be calculated.

With these datasets, statistical models could test whether changes in discharge are more strongly associated with climate variables, abstraction, storage changes or combinations of factors at particular locations and seasons. Such models would still require careful interpretation because drivers can be correlated. However, they would provide a substantially firmer basis for attribution than comparing isolated statistics from different years and sources.

Spatial scale is equally important. Conditions in western Georgia, the Middle Kura around Mingachevir, the Kura-Araz lowland and the lower river near the Caspian should not be assumed to respond identically. Basin-wide conclusions should therefore be constructed from comparable local analyses rather than from one monitoring point extrapolated to the whole river.

4.11. Limitations

This review synthesizes studies with different geographical coverage, time periods and methods. A tree-ring reconstruction, a monitoring study, an expert-interview governance analysis and a desk-based student review cannot be combined into a single numerical estimate of the causes of water scarcity. Several sources describe historical or scenario-based conditions rather than current basin-wide measurements. Accordingly, the article identifies mechanisms and evidence gaps rather than claiming a definitive attribution model.

CONCLUSIONS

Improve water-use efficiency. Repair and maintain distribution infrastructure, monitor abstraction and encourage irrigation scheduling based on crop requirements and local soil-water conditions. Evaluate whether technical efficiency translates into real basin-level savings rather than assuming that more efficient equipment automatically reduces total consumption.

Strengthen climate adaptation. Integrate seasonal forecasts, drought indicators and long-term climate projections into allocation and reservoir planning. Drought plans should identify priority uses, ecological requirements and contingency measures before scarcity becomes acute.

Protect water quality. Expand effective wastewater treatment, reduce agricultural runoff and prevent solid waste from entering tributaries and the main river. Monitoring should report both concentrations and, where possible, pollutant loads so that changes can be interpreted relative to river discharge.

Develop shared monitoring and transparent data systems. Comparable hydrological methods, public reporting and coordinated information exchange can help distinguish upstream and downstream pressures. In a transboundary basin, better data are a prerequisite for credible attribution and cooperative drought response.

Restore riverine ecosystems. Protect riparian vegetation and floodplain habitats where feasible and assess restoration through measurable indicators such as bank stability, vegetation condition, habitat continuity and ecological flow. The restoration-finance approaches discussed by Qadimli and Mammadov (2026b) provide a useful

conceptual model for prioritizing interventions according to need and expected benefit.

Support evidence-based environmental education. School and youth research programmes can contribute through supervised mapping, litter audits and analysis of public monitoring data. Such projects should report sample sizes and methods clearly and should distinguish observations from formal hydrological measurements, as the original student study attempts to do.

Declining water availability in the Kura River Basin is best understood as the outcome of interacting climatic, hydrological, infrastructural and institutional pressures. Long-term evidence confirms substantial flow variability and historical periods of reduced discharge, while recent research indicates future drought risk under some climate scenarios. Irrigation withdrawals and inefficient delivery can intensify scarcity during low-flow periods, reservoirs alter seasonal availability, and water-quality deterioration can reduce the effective usability of water without directly proving a decline in physical discharge. Stronger attribution therefore requires integrated records of flow, climate, withdrawals, reservoir operations and pollutant loads. Sustainable management should combine efficient irrigation, adaptive reservoir operation, wastewater treatment, ecosystem restoration and transboundary data cooperation. From a green-economy perspective, these measures protect agricultural productivity, water security and ecosystem services while reducing long-term environmental and economic risk. The original research's most important contribution is methodological: it treats local concerns seriously while maintaining a clear distinction between measured evidence, projections and interpretations.

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