

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

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Keywords

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

ABSTRACT

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

INTRODUCTION

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

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

Recent scientific evidence supports the ecological mechanisms identified in both source studies. Gurbanov et al. (2026) describe Azerbaijani Tugai forests as biodiversity-rich riparian systems

dependent on river hydrology, shallow groundwater and alluvial conditions, while identifying deforestation, grazing, river regulation, irrigation abstraction and climate change as major degradation pressures. Ahmadova (2026) further argues that restoration requires recovery of river–floodplain–groundwater processes rather than simple tree planting.

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

LITERATURE REVIEW

Human activities affect river ecosystems through both direct pollution and physical alteration. Industrial and municipal wastewater can change chemical and biological water quality, while agricultural runoff can transport fertilizers and pesticides into surface waters. Solid waste creates additional habitat and landscape pressures. Flow regulation and dam construction can modify sediment transport, seasonal

discharge and fish migration. Rustamli's source research organizes these mechanisms into a practical pressure framework and links them to biodiversity decline and ecosystem imbalance.

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

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

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

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

MATERIALS AND METHODS

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

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

Quantitative graphics from the source documents were used cautiously. Percentage shares shown in Hamidov's illustrative pressure chart were not treated as measured statistics because no sampling design or underlying dataset was provided.

Likewise, internally inconsistent area figures presented in a

conservation infographic were not used for numerical inference. The analysis therefore preserves the authors' qualitative findings while avoiding unsupported quantitative claims. Recent peer-reviewed literature was used to verify ecological mechanisms and strengthen interpretation.

RESULTS AND DISCUSSION

Human pressure pathways affecting the Kura River ecosystem

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

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

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

Tugai forests as biodiversity refuges and natural infrastructure

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

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

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

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

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

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

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

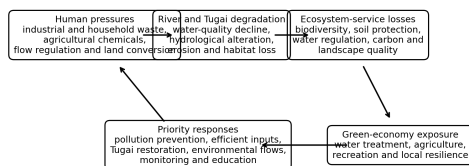


Figure 1. Integrated pathway from human pressures to Tugai ecosystem-service loss and green-economy responses

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

Conservation and restoration priorities

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

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

Green economic resilience and local development

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

Monitoring, restoration and evidence needs

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

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

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

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

CONCLUSIONS

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

align biodiversity protection with water security, resource efficiency and green economic resilience in Azerbaijan.

AUTHOR CONTRIBUTIONS

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

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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This research received no external funding.

DATA AVAILABILITY

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

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