Principles for Assessing Anthropogenic Impacts on Azerbaijan's Freshwater Resources

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Abstract

Nowadays, the protection and conservation of freshwater resources are among the most pressing environmental issues. The rapid development of agriculture and industry, rising population density, increasing volumes of household waste, and urbanisation are having a negative impact on the quality and quantity of water resources. This article examines the anthropogenic factors affecting freshwater resources and analyses the ecological status of the Kura and Aras rivers, which are regarded as two of Azerbaijan's major rivers. When assessing water quality, factors such as pH, dissolved oxygen (DO, mg/l), biochemical oxygen demand (BOD, mg/l), and nitrate and phosphate levels are taken into account. In addition, an assessment is being carried out of the impact of climate change on river hydrology, the availability of water resources, and the resilience of aquatic ecosystems. The findings of the study highlight the importance of effective water resource management, pollution prevention, and regular environmental monitoring.

Keywords: freshwater resources, human impact, the Kura River, the Aras River, water quality, climate change, environmental monitoring, water resources management

1.Introduction

Water resources are vital for meeting the population's drinking water needs, for the development of agriculture and industrial production, and for the functioning of natural ecosystems. However, population growth, expanding economic activity, and climate change are placing increasing pressure on freshwater resources. Excessive water consumption, the discharge of untreated wastewater into natural water bodies, and the intensive use of chemicals in agriculture are among the main factors leading to a deterioration in water quality (UN-Water. (n.d.).

The Kura and Aras rivers hold a special place in Azerbaijan's water resources system. These rivers serve an important role in providing irrigation water for agriculture, supplying water to the population, and protecting aquatic ecosystems. At the same time, as these are transboundary rivers, the condition of their water resources depends not only on internal factors, but also on processes taking place in other parts of the catchment area [5; 6].

The aim of this article is to identify the main human-induced factors affecting the Kura and Aras rivers. To analyse the indicators used to assess water quality. To summarise the data on the impact of climate change on the hydrological and ecological conditions of these rivers.

2. Main areas of human impact on freshwater resources

Anthropogenic impact encompasses changes to the natural state of water resources caused by human economic activity. These consequences manifest themselves both in changes to the chemical and biological properties of the water and in disruptions to river flow patterns. The primary factors affecting freshwater reserves are industrial activity, agriculture, domestic waste, urbanisation, and the inefficient use of water resources (Singh & Mishra, 2014; UNWWAP, 2021).

2.1. Industrial activity

Wastewater from industrial plants and the chemicals used in manufacturing processes lead to the pollution of water resources. Furthermore, heavy metals, petroleum products, and other toxic compounds have a negative effect on the chemical composition of the water, the life processes of aquatic organisms, and the overall health of the ecosystem.

The extent of industrial pollution depends on the treatment technologies used at industrial sites, the wastewater management system, and the effectiveness of ecological monitoring. Therefore, reducing the volume of industrial waste at source, modernising treatment plants, and regularly monitoring pollutants are regarded as key priorities in the protection of water resources [4; 7].

2.2. Agricultural activities

Agriculture is not only one of the main sectors that consume freshwater resources, but it can also contribute to water pollution. When mineral fertilisers and pesticides are applied in excess, some of them end up in rivers and lakes via surface runoff, whilst others enter the groundwater as a result of leaching.

Excessive accumulation of nitrogen and phosphorus compounds in water bodies accelerates the process of eutrophication. This process can lead to rapid growth of aquatic plants and algae, an increase in oxygen consumption during the decomposition of organic matter and, as a result, a reduction in the dissolved oxygen content of the water. It is necessary to analyse the composition of runoff from irrigated land in the Kura and Aras river basins, to conduct monitoring of fertiliser and pesticide use, and to expand the use of water-saving irrigation methods, as significant changes are causing a deterioration in the habitats of fish and other aquatic organisms (Singh & Mishra, 2014; UNWWAP, 2021).

2.3. Household waste and urbanization

Urban expansion, population density, and the strain on public utility infrastructure increase the risk of pollution from residential sources. When poorly treated or completely untreated wastewater enters water bodies, the levels of organic compounds, nutrients, and pathogenic microorganisms in them increase (National Geographic, n.d;Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, n.d.).

All of this has a negative effect on water quality. Furthermore, it leads to a reduction in dissolved oxygen levels and the degradation of aquatic ecosystems. Plastic and other solid waste also contribute to water pollution and the destruction of aquatic habitats. To tackle this problem, it is necessary to modernise the sewerage networks, improve the standard of wastewater treatment and strengthen controls over the management of household waste (Seymur, 2025; Bünyadzadə, 2023).

2.4. Inefficient use of water resources

The overexploitation of water resources affects river flow, water levels and the natural hydrological regime. Rising demand for water, particularly during the irrigation season, losses in irrigation channels, and the uneven distribution of water can reduce the efficiency of water use.

Changes in the hydrological regime of rivers also affect the ecological condition of riparian zones, the habitats of aquatic organisms, and the water's ability to purify itself. Therefore, when managing water resources, it is essential to take into account not only the volume of water abstracted, but also the needs of ecosystems and the need to preserve the river's natural flow (UN-Water, n.d.).

3. Anthropogenic impact on the ecological condition of the Kura and Aras rivers

The Kura and Aras rivers play an important role in the formation and utilisation of Azerbaijan's water resources. The water from both rivers is of great importance to agriculture, public utilities and other economic activities. Furthermore, the ecological status of rivers may be affected by issues relating to population settlement, irrigation, industrial activity and wastewater management within river basins (Allan & Castillo, 2007; Gleick, 2018).

3.1. Key factors affecting the Kura River

When assessing the environmental condition of the Kura River, the main focus is on industrial and domestic waste, agricultural runoff, and the intensive use of water resources. Industrial pollutants can cause changes to the chemical composition of water. In this regard, it is particularly important to determine the concentrations of heavy metals, petroleum products, and other potentially hazardous substances. However, in order to confirm the areas and levels in which specific pollutants are present, relevant monitoring and laboratory analysis results are required. [4; 6]

Agricultural activity in the Kura River basin is also one of the factors affecting water quality. Runoff from irrigated areas may lead to increased levels of nitrates and phosphates. Nevertheless, an excessive accumulation of nutrients increases the risk of eutrophication.

Furthermore, the abstraction of water for irrigation and other agricultural purposes may lead to changes in the flow and water levels at various points along the river. These changes may lead to more serious environmental and socio-economic problems during periods of drought (Gleick, 2018).

3.2. Key factors affecting the Aras River

The environmental condition of the Aras River is affected by agriculture, domestic waste, industrial activity, and water abstraction for irrigation. The composition of runoff from irrigated areas is of particular importance in terms of the accumulation of nutrients and other pollutants in the river and its associated water systems.

The use of water for agricultural purposes in the Aras River basin could lead to an increase in seasonal demand for water and changes to the hydrological regime. Uneven rainfall distribution and arid conditions create additional challenges for irrigation and water supply, as they exacerbate these effects.

In order to objectively assess the ecological status of the river, it is necessary to carry out a comparative analysis of the chemical and biological parameters of the water at various points along its course. In addition, given that this is a transboundary river, the exchange of information and joint monitoring activities within the catchment area are of paramount importance [5; 6].

4. Assessment of river water quality

Physical, chemical, and biological parameters are used to evaluate the ecological status of rivers. These indicators make it easier to determine the level of water contamination. The state of the ecosystem and the possible consequences of human activity are determined using the same indicators (UNWWAP, 2022).

Physical parameters include water temperature, colour, turbidity and the amount of suspended particles. These indicators characterise the physical condition of the water and can be used for an initial assessment of precipitation, surface runoff and other impact factors.

Chemical indicators enable us to assess the concentration of substances in water and environmental processes. Among these parameters, pH, dissolved oxygen (DO) content, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and nitrate and phosphate concentrations are of particular importance (IPCC, 2021).

Biological indicators cover the condition of phytoplankton, zooplankton, bioindicator organisms, and pathogenic microorganisms. Biological indicators play an important role in determining the response of an aquatic ecosystem and the impact of pollution on living organisms.

4.1. The environmental significance of key chemical parameters

pH indicates the degree of acidity and alkalinity of water. This indicator affects the living conditions of aquatic organisms and the form in which certain chemicals are present in the water. When assessing pH values, it is also necessary to take into account natural geochemical characteristics and seasonal variations.

Dissolved oxygen (DO) is one of the key indicators used to characterise the condition of aquatic ecosystems. A reduction in the oxygen content of water may be due to the decomposition of organic matter, high temperatures, and other factors. A lack of oxygen creates unfavourable conditions for fish and other aquatic organisms (Gleeson et al., 2020).

Biochemical oxygen demand (BOD) is a measure of the amount of oxygen required to break down organic matter in water through the action of microorganisms. An increase in the BOD value may indicate contamination by organic substances. To interpret the results correctly, however, it is necessary to specify the duration and method of measurement, the sampling site, and other laboratory conditions.

Chemical oxygen demand (COD) is used to estimate the quantity of substances in water that are susceptible to chemical oxidation. This indicator is useful for determining the level of organic pollution; however, it is not as significant as BOD.

Nitrates and phosphates can enter water bodies via agricultural runoff, domestic wastewater, and other sources. Their excessive accumulation may exacerbate the process of eutrophication, leading to a deterioration in the ecological status of water bodies (National Geographic, n.d.).

4.2. Comparison of data for the Kura and Aras rivers

The source material presented the following ranges of data for the Kura and Aras rivers. Since the years, sampling points, and laboratory methods used to obtain these figures are not specified, however, they should be regarded not as confirmed monitoring results but as preliminary data requiring further verification (Table 1).

Table 1. *Water quality parameters for the Kura and Aras rivers, as stated in the source data.*

Parameter	The Kura River	The Araz River
pH	7,2-8,1	7,0-7,8
Dissolved oxygen (DO, mg/l)	5,5-7,0	5,8-7,2
Biochemical oxygen demand (BOD, mg/l)	3-6	2-5
Nitrates (mg/l)	8-25	6-18
Phosphates (mg/l)	0,2-0,8	0,1-0,5

Note: The figures in the table are based on data from the source text. As the data source, the date on which the measurements were taken, and the methodology are not specified, these results should not be regarded as definitive indicators of the current state of the rivers.

Considering the figures in the table as preliminary data only, it becomes clear that the BOD value for the Kyur River lies within the range of 3-6 mg/l, and for the Aras River, within the range of 2-5 mg/l. These indicators can play an important role in assessing the extent of organic pollution. However, it would be incorrect to state categorically that one river is more polluted than another, based solely on individual figures. This requires analyses carried out during the same period, using the same methodology and at comparable locations (UNECE, 2018).

The same approach applies to nitrate and phosphate levels. High concentrations of these substances may be linked to runoff from agricultural land and domestic wastewater; however, to determine their specific source, it is necessary to carry out a comprehensive analysis of land-use patterns within the catchment area, the sources of runoff and the results of laboratory tests. Consequently, in order to assess

water quality reliably, it is necessary not only to provide individual parameters, but also to specify the time and location of the measurements, the methodology used, and the conditions under which the results were compared (Azərbaycan Respublikası Ekologiya və Təbii Sərvətlər Nazirliyi, n.d.).

Table 2. *A comparative analysis of the Kura and Aras rivers.*

Indicator	The Kura River	The Aras River
Decrease in runoff	15-30 %	10-20 %
Consequences of drought	Severe	Medium
Risk of flooding	High	Medium
Eutrophication	More severe	Medium level
Water quality	Deterioration	Medium level

Table 2 presents a comparative analysis of the Kura and Aras rivers. In the Kura River basin, the effects of climate change are evident, first and foremost, in a reduction in water supplies. Research carried out in recent decades shows that the rise in the region's average annual temperature has led to increased evaporation, which, in turn, has caused a 15-25% reduction in river flow, particularly during the summer months. In dry years, this reduction can reach 30%, which creates serious problems in terms of the supply of water for irrigation and drinking. Changes are being observed in the seasonal distribution of precipitation. Increased precipitation in the winter and spring months raises the risk of flooding in the lower reaches of the Kura River, whereas reduced precipitation in the summer months exacerbates the problem of water scarcity even further. This comparison shows that the Kura River is more susceptible to human and climatic influences, whilst the Aras River is relatively stable, although the effects of drought and irrigation are more pronounced there.

5. The impact of climate change on the water resources of the Kura and Aras rivers

Climate change is a significant factor that can affect both the quantity and quality of water resources. Rising temperatures, changes in the spatial and temporal distribution of precipitation, changes in snow cover characteristics, and extreme weather events may affect the hydrological regime of rivers. These processes are of particular importance in regions where irrigation and drinking water supplies depend on river flow (World Wide Fund for Nature, n.d.).

5.1. Declining water reserves and changes to the hydrological regime

A rise in temperature may lead to increased evaporation. This process is exacerbated by a reduction in rainfall or its uneven distribution across the seasons, which increases the risk of a decline in water reserves in river basins. Furthermore, the intensity of rainfall may lead to more frequent flash floods and an increase in surface runoff.

Changes in water reserves in the Kura River basin are of great importance for irrigation, public water supply, and the sustainability of ecosystems. During the summer months, difficulties may arise with the allocation of water supplies when a reduction in water availability coincides with a period of increased demand for water. On the other hand, heavy rain and intense surface runoff may increase the risk of flooding in areas further downstream.

In the Aras River basin, climate change may also affect the seasonal distribution of water resources and irrigation potential. When changes in snow cover conditions and the timing of snowmelt affect spring runoff, uncertainty regarding the availability of water resources during the summer season may increase. In this regard, it is important to carry out long-term monitoring of precipitation, temperature, snow cover, and river flow in the catchment (WHO, 2017; UNEP, n.d).

The source data contained figures indicating a reduction in the flow of the Kura River by 15-30% and that of the Araks River by 10-20%. However, as it is not known which period, which regions, and which calculation method these percentage figures cover, they cannot be presented as a generalised scientific

conclusion. To use this data in an article, you must cite the relevant source of hydrological research or monitoring.

5.2. The impact of climate change on water quality

Climate change can affect water quality through several mechanisms. A rise in temperature reduces the solubility of oxygen in water. At the same time, a rise in water temperature may affect the rate of biological processes. As the river's flow rate decreases, the dilution of pollutants may become less effective, whilst the concentration of certain substances may increase.

High concentrations of nutrients and favourable temperature conditions can exacerbate the process of eutrophication. However, the extent of eutrophication depends not only on temperature, but also on the nitrogen and phosphorus content of the water body, current patterns, light levels and other environmental factors (Durán-Sánchez et al., 2018).

During periods of drought, a reduction in water levels can make the effects of pollution more noticeable. Floods and heavy rainfall can accelerate the entry of soil particles, fertiliser residues and other substances into rivers. Therefore, when assessing the impact of climate change on water quality, consideration should be given to hydrological, chemical and biological indicators alike (WHO, 2017).

5.3. Socio-economic outcomes

A decline in water volume and a deterioration in water quality could affect the water supply to the population, agricultural productivity and the sustainability of ecosystems. A shortage of water for irrigation increases the risks associated with agricultural production. However, contamination of drinking water sources may lead to increased water treatment costs and pose additional challenges in ensuring public health and safety.

Disturbances to oxygen levels and changes to habitat conditions in aquatic ecosystems can have a negative impact on fish stocks and biodiversity. These changes may also affect livelihoods in sectors dependent on rivers and the well-being of local communities (UNWWAP, 2021; WWFN, n.d).

Consequently, the effects of climate change are not limited solely to changes in the total volume of water. The seasonal distribution of water resources, water quality indicators, and ecosystem stability may also change in complex ways.

6. Improving the protection and sustainable use of water resources

Improving the environmental condition of the Kura and Aras rivers requires a reduction in human impact, the sustainable use of water resources and the implementation of measures to adapt to climate change. In this regard, the following measures are of particular importance.

Firstly, efforts to treat wastewater must be stepped up. Improving the treatment of urban and industrial wastewater, modernising treatment plants, and reducing pollutant emissions at source can help to reduce the pressure on rivers.

Secondly, environmentally friendly methods should be used in agriculture. The rational use of fertilisers and pesticides, regular soil and water analysis, the reduction of irrigation losses, and the use of modern irrigation technologies all help to conserve water resources (UNEP, 2021; UN-Water, n.d.).

Thirdly, water quality monitoring needs to be improved. Measurements of pH, DO, BOD, COD, nitrates, phosphates, and biological parameters should be carried out regularly at various points along the Kura and Aras rivers. To ensure that results are comparable, it is necessary to specify the sampling points, dates, laboratory methods, and units of measurement precisely (UNWWAP. 2022; National Geographic. n.d.).

Fourthly, measures to adapt to climate change need to be developed. Long-term analysis of hydrological observations, assessment of drought and flood risks, improving the efficiency of irrigation systems, and the planned allocation of water resources amongst different users can help to strengthen water security (WHO, 2017; UN-Water, n.d.).

Fifthly, we need to expand cross-border cooperation. The exchange of information, the application of agreed monitoring methods, and the joint assessment of pollution sources in the Kura and Aras river basins are of great importance for integrated water resources management (UNEP. n.d).

Sixthly, it is necessary to raise public awareness. Awareness-raising initiatives on the rational use of water resources, the proper management of household waste and the prevention of water body pollution can help to foster environmental responsibility amongst the public (WWFN, n.d).

7. Conclusion

The analysis carried out shows that the protection of freshwater resources is of great environmental and socio-economic importance in today's world. Industrial activity, agriculture, household waste, urbanisation and the unsustainable use of water resources are the main human-induced factors affecting water quality and the hydrological regime of rivers.

A comprehensive study of these factors is crucial for assessing the ecological status of the Kura and Aras rivers, which are among Azerbaijan's main waterways. Industrial and domestic pollution, runoff from agricultural land, and water abstraction for irrigation can pose a serious threat to both river basins. However, in order to confirm as a definitive conclusion the generalisation contained in the available preliminary materials that the Kura River is subject to greater anthropogenic impact than the Aras River, comparative monitoring data collected using the same methodology are required.

pH, dissolved oxygen content, biochemical and chemical oxygen demand, as well as nitrate and phosphate levels, play an important role in assessing water quality. Regular monitoring of these indicators makes it possible to identify pollution risks and track changes in the environmental situation. Furthermore, in order to interpret the results correctly, it is necessary to specify the sampling locations, the dates on which the measurements were taken, and the laboratory methods used.

Climate change may place additional pressure on river water supplies as a result of rising temperatures, uneven rainfall distribution, droughts and extreme hydrological events. These changes affect both the quantity and quality of water, increasing the risks associated with the sustainability of agriculture, water supply and aquatic ecosystems.

In this regard, in order to protect the Kura and Aras rivers, it is necessary to implement, in a coordinated manner, measures relating to wastewater treatment, the rational use of water and chemicals in agriculture, regular environmental monitoring, adaptation to climate change, and cross-border cooperation. These measures can contribute to the sustainable management of water resources, reduce the risks of pollution, and ensure water security for future generations.

Author's contribution

The sole author is responsible for conceptualizing, collecting, and analyzing data, and writing and editing the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

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