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CHANGES IN THE ANNUAL FLOW OF THE KURA RIVER

ZMIANY ROCZNEGO PRZEPŁYWU KURY

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Abstract
The article presents the analysis of changes in the annual flow of the Kura River and its large transboundary tributaries, resulting from climate change and anthropogenic factors, mainly irrigated agriculture. It is shown that a significant change in the flow regime of the Kura River began after the construction of the multi-purpose Mingachevir reservoir in 1953. Morevoer, climate change observed in the river basin since the mid 1990s manifests itself by an increase in air temperature and a decrease in precipitation, which has led to a further decrease in the river's flow. During the lengthy drought period that began in 2011 and is still in progress, the decrease in the river flow in the downstream section of the Kura River has reached critical levels, causing serious problems regarding not only the irrigation of drylands, but also the supply of drinking water to settlements. The second part of the article describes also other social and economic, as well as environmental consequences of a decrease in the flow of the Kura River.

Keywords: Kura River, transboundary rivers, water reservoirs, annual flow, natural flow, water intake, irrigated area, climate change.

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Streszczenie
W artykule przedstawiono analizę zmian rocznego odpływu rzeki Kury i jej większych transgranicznych dopływów, uwarunkowanych zmianami klimatycznymi oraz czynnikami antropogenicznymi, głównie nawadnianiem stosowanym w rolnictwie. Wykazano, że istotna zmiana reżimu przepływu rzeki Kury rozpoczęła się po wybudowaniu w 1953 r. wielofunkcyjnego zbiornika Mingaczewir. Ponadto od połowy lat 90. XX w. w basenie Kury obserwowane są zmiany klimatyczne przejawiające się wzrostem temperatury powietrza oraz spadek opadów, co doprowadza do dalszego zmniejszenia przepływu rzeki. W warunkach długotrwałej suszy, która rozpoczęła się w 2011 r. i trwa nadal, spadek przepływu rzeki w dolnym odcinku osiągnął poziomy krytyczne, powodując poważne problemy nie tylko dla nawadniania terenów suchych, ale także dla zaopatrzenia w wodę pitną osiedli. W drugiej części artykułu opisano także inne społeczne i gospodarcze oraz środowiskowe konsekwencje zmniejszenia przepływu.

Słowa kluczowe: rzeka Kura, rzeki transgraniczne, zbiorniki wodne, przepływ roczny, przepływ naturalny, ujęcie wody, obszar nawadniany, zmiany klimatu.

INTRODUCTION

One of the actual global challenges of the 21st century is ensuring sufficient water supply for the population and various sectors of the economy. In line with population growth and economic development, the use of water resources is increasing rapidly all over the world, while at the same time in many countries and regions water supply is sharply deteriorating. At the same time, as a result of global warming, available water resources are observed to decline. The aggravation of the water problem has a direct impact on the food supply and ecological security of the population in many regions. Currently, water has become one of the decisive factors for the sustainable development of a country. As a result, research and practical actions should be accelerated towards the reduction of water use and the implementation of technologies enabling efficient water consumption.

Currently, river water is used more often for various purposes, and the majority of big rivers are to be included among transboundary rivers. There are 263 such rivers in the world, and their catchment areas together make up 45% of the land area, housing about 40% of the world's population (Shiklomanov, Rodda, 2003). Also, 19 river basins cover the territory of five countries and more. For example, there are 17 countries in the Danube basin, while the Congo, Niger, Nile, Rhine and Zambezi rivers flow each through 9–11 countries. In total, there are 145 countries wholly or partly located in international river basins. In many countries, most of their water resources originate from transboundary rivers: 97% in Egypt, 94% in Botswana, 89% in the Netherlands, and so on. In Azerbaijan, this figure is 67%. About half of the world's surface water resources (19,000 km^3) accumulate in the 25 largest rivers, of which 20 have a status as an international river (United Nations, 1978; Kojakov, Sarsembekov, 2006).

In transboundary river basins, the protection of water resources from pollution and depletion, as well as the balanced use of water and the development of a country's economy depend on the level and effectiveness of regional cooperation among the river's riparian states. The mutual interests of these states should be based on international legal documents on the joint use of transboundary river waters and a coordinated regional water policy (Gavardashvili, 2014).

The article analyses the natural and anthropogenic transformation of the annual flow of the transboundary Kura River, in relation to the social, economic and environmental causes of the flow reduction.

STUDIED AREA

The Kura River is the largest transboundary river in the Caucasus and its main course flows into the Caspian Sea through Turkey, Georgia and Azerbaijan (Fig. 1).

Fig. 1. Map of the Kura River basin

Source: unmodified from https://commons.wikimedia.org/wiki/File:Kurabasinmap.png, author: Shannon1.

The source of the Kura River is a group of springs located at an altitude of 2,720 MASL on the north-eastern slope of Gizil-Gadik Mountain in Turkey. The total length of the main Kura River is 1,515 km, the area of the basin covers 86,000 km^2 or 188,000 km^2 if the Aras River basin, the largest triburaty is included (Table 1) (Fatullaev, 2002).

Table 1. Length of the Kura River by country and catchment area

No	Country	Length of river [km]	Catchment area [km^2]	
			excluding Aras River basin	together with Aras River basin
1	Turkey	174	5,590	27,548
2	Georgia	522	34,740	34,740
3	Azerbaijan	819	37,960	56,700
4	Armenia	–	7,710	29,800
5	Iran	–	–	39,212
	Total	1,515	86,000	188,800

Source: own elaboration based on literature (Water resources of Trans-Caucasus, 1988; Rustamov, Gashgai, 1989).

The total water resources of the Kura River basin are 25.9 km^3, of which 16.8 km^3 are formed directly in the Kura River basin (excluding the Aras River basin), and 9.1 km^3 in the Aras River basin. In the Kura River basin, 9.39 km^3 of water resources are formed in Georgia, 4.6 km^3 in Azerbaijan and 1.54 km^3 in Armenia (Water resources..., 1988). 3.5 km^3 are formed in the Turkish part of the Kura basin, of which 0.9 km^3 falls on the Kura and 2.6 km^3 on the Aras basin (Yıldız et al., 2007; Öziş, Özdemir, 2009).

Along its course, main tributaries contribute to the Kura River, and their water resources are widely used for various purposes in all three countries. As a result, the annual flow of the Kura River is undergoing a natural and anthropogenic transformation along its course.

Owing to the arid climate of the Kura basin plains, irrigated agriculture has been developed here since ancient times. For this reason, even before instrumental observations were made on the river's water flow, its natural flow was subjected to anthropogenic transformation. At the beginning of the 20th century, the actual annual flow in the near-mouth part of the river was 31% less than the natural flow (Rustamov, 1960).

The territory of the Republic of Azerbaijan, one of the three countries in the South Caucasus region, is mostly located in the downstream section of the transboundary Kura River basin. Azerbaijan borders the Republic of Dagestan of the Russian Federation to the north, the Republic of Georgia to the northwest, the Republic of Armenia and Turkey to the west, and the Islamic Republic of Iran to the south (Fig. 1). The total area of the Republic of Azerbaijan is 86,600 km^2, 58% of which is mountainous, while 42% consists of plain areas (Museibov, 1998). Arid climate is typical of nearly half of the country, which is reflected in the country's water balance: the average annual atmospheric precipitation is 427 mm, the evaporation 308 mm, and river flow 119 mm (Rustamov, Gashgai, 1978).

The main part of Azerbaijan's surface water resources (65%) form in the Kura River basin, and Azerbaijan is the country that uses most water in this river basin. Agriculture is the largest water consumer in the country, its share of total water use comprising 69.8%, followed by industry (25.0%) and other economic sectors. At the same time, agriculture has the highest index of loss of non-renewable resources by water users and systems. The analysis of information recorded in the state accounting system of water use shows that the long-term average annual volume of water withdrawn from natural surface water sources between 1990 and 2018 was 11.1–16.2 km^3, augmented with an additional 1.54–0.51 km^3 from underground water resources. At the same time, water losses in the Azerbaijan section of the Kura River basin are large, equal to 32.4% of the annual flow of the Kura River (National..., 2019). In total, 142 reservoirs of various sizes were built in Azerbaijan to strengthen the efficient use of water resources (Khalilov, 2003; Ahmadzade, Hashimov, 2016).

MATERIALS AND METHODS

To analyse changes in river runoff, data for 1938–2018 were used. All information was provided by the National Hydrometeorological Service of the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. Additionally, generalised data on the annual runoff of hydrological stations located on the territory of neighbouring countries were used. Methods of geographical comparison and statistical analysis were applied.

The criterion of significance of the sample correlation coefficient (R) for the dependences Q_{annual}= f(t) was used to assess linear trends in the series of annual water discharge. The hypothesis of the absence of a trend was not refuted if the term was given by

$$|R| < t_{2\alpha}\sigma_R \quad (1)$$

- t_α – theoretical value of t-student's statistic at significance level α = 5%;
- σ_R – standard error of the correlation coefficient, calculated by the formula:

$$\sigma_R = \sqrt{\frac{1 - R^2}{n - 2}} \quad (2)$$

DISCUSSION

The strongest impact of anthropogenic factors on the runoff regime of the Kura River began with the construction of the Varvara and Mingachevir water reservoirs between 1950 and 1953. Later, the Shamkir (1982) and Yenikend (2000) water reservoirs were built, as well as the Sarsang reservoir (1976) on the Terter River, in addition to other water reservoirs on the tributaries of the Kura River (Imanov, Aliyeva, 2019). Currently, river water resources are widely used in all basin countries (UNDP/GEF, 2013).

Anthropogenic factors refer primarily to water withdrawal from the Kura River for irrigation. The quantity of runoff transmitted downstream of the Mingachevir reservoir depends on the operating regime of the Mingachevir Hydropower Station, as well as on the amount of water diverted into the Upper Shirvan irrigation canal (capacity of 78 m^3s^{-1}) and the Upper Karabakh irrigation canal (capacity of 113 m^3s^{-1}), the headwater intake structures of which are located at the Mingachevir dam. In the lowlands of the Kura, the Aras basin in Azerbaijan, an extensive irrigation infrastructure network was developed (Imanov, Verdiyev, 2016).

Monitoring results show that between 1991 and 2017 the average annual discharge in the downstream section of the Kura River decreased by 425 m^3s^{-1}, or 49.8% of the natural long-term average discharge. The dynamics of the annual flow decrease in the mouth of the Kura River during the instrumental observation is shown in Figure 2.

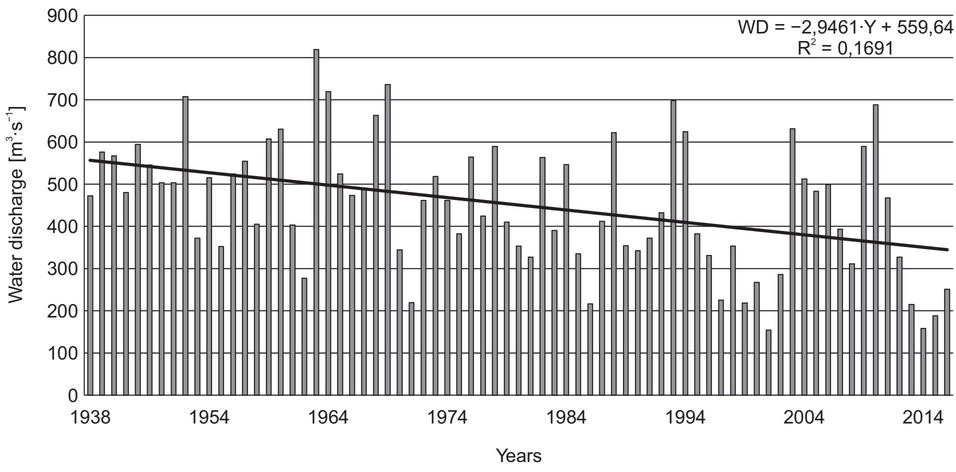

Fig. 2. Dynamics of average annual discharge (WD) of the Kura River at the Salyan monitoring station
Source: own elaboration.

According to monitoring data, until 2011 there was no significant change in the annual flow of the Kura River in Turkey (Akkiraz station), and in Georgia the decrease in flow was 8–12% (Tbilisi station). The annual flow at the Kura River closing station (Salyan) decreased by 425 m^3s^{-1}, or 49.8%. A decrease of 325 m^3s^{-1} was recorded directly in the Kura basin, and a decrease of 100 m^3s^{-1} was recorded in the basin of the Aras River, its main tributary (Imanov, 2016). However, in the period 2011–2021, the flow of the Kura River, coming from the territory of Georgia to Azerbaijan, significantly decreased (27–31%).

Changes in the flow of transboundary tributaries of the Kura River

Below are estimates of the decrease in annual runoff in the downstream sections of the three main transboundary tributaries of the Kura River (Aras River, Ganikh (Alazani) River and Gabyrry (Iori) River (Table 2).

Table 2. Main transboundary tributaries of the Kura River

No	Rivers	Riparian countries	Catchment area [km^2]	Natural annual flow [m^3s^{-1}]
			total	total
1	Aras	Turkey, Iran, Armenia, Azerbaijan	102,000	290.0
2	Ganikh (Alazani)	Georgia, Azerbaijan	12,080	125.0
3	Gabyrry (Iori)	Georgia, Azerbaijan	4,840	15.9

Source: own elaboration based on literature (Water resources of Trans-Caucasus, 1988; Rustamov, Gashgai, 1989).

Aras River

The largest tributary of the Kura River and originates in Turkey. The development of irrigation infrastructure and the construction of reservoirs are the main anthropogenic factors in the basin. Currently, a total of 300,000 hectares are under irrigation in both the Azerbaijan and Armenian parts of the Aras River basin, in addition to 100,000 hectares in Turkey and 270,000 hectares in Iran. Overall, 49 water reservoirs were built in Iran, 30 in Armenia and 44 in Azerbaijan.

In Azerbaijan, a significant changes of the natural regime of the Aras River began with the construction of the Bahramtapa water intake station in 1959, with several canals withdrawing water from the Aras River for irrigation. In 1970 the Aras reservoir was built, with a volume of 1.35 km^3.

Monitoring shows that in the downstream section of the Aras River at the Novruzlu station, the annual flow decreased by 160 m^3s^{-1}, or 55.2% (Table 4). The dynamics of the annual flow decrease in the mouth of the Aras River during the

Table 3. The catchment area of the Aras River by countries and the average long-term annual flow (1930–1980)

No	Country	Catchment area [km^2]	Average annual flow [m^{3}s^{-1}]	Average annual flow [%]
1	Turkey	25,784	74.3	24
2	Armenia	17,919	132.0	43
3	Azerbaijan	16,457	50.4	16
4	Iran	41,840	53.4	17
	Total	102,000	310.0	100

Source: own elaboration based on literature (Water resources of Trans-Caucasus, 1988; Rustamov, Gashgai, 1989).

instrumental observation is shown in Figure 3. Considering that at present Iran is building the Khudafarin reservoir on the Aras River, with a total design capacity of 1.6 km^3, it is expected that the decline in river flow will continue in the near future.

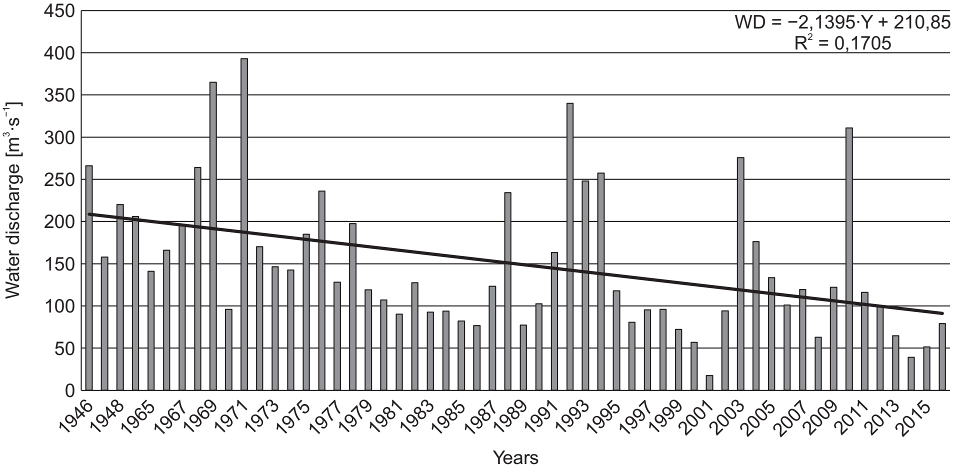

Fig. 3. Dynamics of the average annual water discharge (WD) for the Aras River at the Novruzlu monitoring station
Source: own elaboration.

The Ganykh River (Alazani in Georgia)

Left tributary of the Kura River, originating in Georgia. Currently, it flows into the Mingechevir reservoir in Azerbaijan. Irrigation water withdrawal for irrigated agriculture is the main impact factor on water resources in the river basin, primarily due to the climatic conditions in this part of the basin, where in low-lying areas the amount of annual precipitation is about 400 mm, of which only 20% is available during the summer period, when evaporation is high, and the need for irrigation water is large (Mammadov, Fatullaev, 1997). Irrigated infrastructure in the river basin is installed at about 140,000 hectares. About 42.3 m^3s^{-1} of water is taken by canals and the unused part of the water is discharged back into the river (Rustamov, Gashkai, 1989). Monitoring shows that in the downstream section of the Ganykh River, the annual flow decreased by 20 m^3s^{-1}, or 16% (Table 4).

Table 4. Observed changes in the annual flow of main transboundary rivers between 1991 and 2017

No	River and station	Natural annual flow [m^3s^{-1}]	Average annual flow 1991–2017 [m^3s^{-1}]	Decrease in annual flow	
				[m^3s^{-1}]	[%]
1	Aras – Novruzlu	290.0	130.0	160.0	55.2
2	Ganikh – Below mouth of Ayrichay River	125.0	105.0	20.0	16.0
3	Gabyrry (Iori) – Keseman	15.9	8.2	7.7	48.7

Source: own elaboration.

The Gabyrry River (Iori in Georgia)

Also a left tributary of the Kura Riveroriginating in Georgia and also flows into the Mingechevir Reservoir. The Sioni water reservoir was built on the river, with a total volume of 325 million m^3. From the Iori River and the Sion reservoir, 14 irrigation canals divert water for agriculture, the largest being the Upper Samgori canal (capacity of 11.5 m^3s^{-1}) and the Lower Samgori canal (capacity of 35.0 m^3s^{-1}). The total design area under irrigation in the Gabyrry River is about 60,000 hectares. Calculations show that for the 1991–2017 period the annual flow of the Gabyrry (Iori) River decreased by 7.74 m^3s^{-1} (48.7%) compared to the natural flow.

Impact of climate change on river flow

Climate indicators have been changing in Azerbaijan since the 1990s (MoENR, 2010). Compared to 1961–1990, the average annual air temperature increased by 0.7°C in 1991–2015, and annual precipitation decreased by 9.9% (MoENR, 2010; UNDP/GEF, 2013; ENVSEC, 2016). In neighbouring Georgia and Armenia temperatures are also rising (0.5–1.03°C) and precipitation is decreasing (8–10%) in the Kura River Basin (IPCC, 2014). At present, the contribution of the impact of climate change to reducing the annual flow of rivers in the Azerbaijani part of the Kura Basin is 5–15% (Taghiyeva, Verdiyev, 2020).

According to calculations made with the MAGICC/SCENGEN and PRECIS models, the air temperature in all three South Caucasus countries (Azerbaijan, Georgia and Armenia) will increase by 1–2°C in the period 2030–2050 compared to 1980–1999. For the period 2050–2100, this increase will be 3–5°C and precipitation in Azerbaijan will decrease by 5–23% (UNDP/GEF, 2011). The UN report *Water and Climate Change* also predicts a decrease in precipitation in the South Caucasus region, citing the IPCC for drinking water, irrigation, hydropower, etc. It is emphasised that the water problem will be made worse in the sectors (UNESCO, UN-Water, 2020).

The analysis also shows that the annual and maximum flow of the Kura River in the territory of Azerbaijan decreases mainly, while the minimum winter flow increases (Mahmudov, 2018). This is in line with the patterns observed in the rivers of other countries of the Caspian Basin, and is explained by the melting of snow cover in winter as a result of rising temperatures, and a decrease in precipitation in spring, summer and autumn.

A sharp manifestation of water scarcity in the Kura basin in recent years (2011–2021) is the significant reduction in atmospheric precipitation, primarily in the form of snow, in the context of climate change. One of the driest years of recent times was 2014. In the summer of that year, in all regions of the Kura River basin, some of the natural springs with medium and large flow rates dried up, which had never happened before.

Transboundary water policy

There are 30 transboundary rivers in Azerbaijan. As such, the protection of water resources of the transboundary river basins from contamination and overexploitation while promoting the sustainable use of water resources and development of the country's economy depends on the level and effectiveness of regional cooperation among the riparian countries. The mutual interests of the basin states should be based on international legal documents on the joint use of transboundary river waters and coordinated regional water policy. One of the most important documents is the UN Helsinki Convention on the *Protection and Use of Transboundary Watercourses and International Lakes* (The Convention…, 1992). Azerbaijan ratified the Convention in 2000 and joined its Protocol on Water and Health in 2002. Under the Convention, more than 20 projects have been implemented in the Kura-Aras basin and Azerbaijan with the support of the international organisations (UNDP/GEF, European Union, OSCE, etc.). Unfortunately, to date Azerbaijan is the only riparian state of the Kura-Aras basin which has joined the Helsinki Convention.

Azerbaijan builds its relations with the neighbouring countries on the basis of bilateral contracts in line with international judicial principles, and all issues are settled respecting such principles accordingly. On 27 July 1963, an agreement was signed between the now-former Soviet Union and Iran *On Economic* *and Technical Cooperation*, regulating the exploitation and management of the Aras and Mil-Mugan reservoirs, put into operation in 1971 and 1972 respectively. Currently, there is an active Iran-Azerbaijan commission on the joint use of water and energy resources of the transboundary Aras River. The water resources of the transboundary Samur River used to be divided between Azerbaijan and Dagestan (Russia) according to a signed Protocol dating October 7, 1967. In 2010, this Protocol was replaced by a new agreement signed between the presidents of both countries, based on the principles of the Helsinki Convention.

The use of water resources of the transboundary rivers shared between Azerbaijan and Georgia is regulated on the basis of bilateral agreements signed and negotiations held between government agencies in charge of this issue. A number of international organisations, such as UNDP, UNECE, OSCE, ENVSEC, NATO, USAID, SIDA and others, have, by means of regional projects, contributed to the collaboration between these two countries in water governance.

Currently, the drafting of a new bilateral agreement between Azerbaijan and Georgia on the use and protection of water resources of transboundary rivers is being concluded with the support of the UN, the UN European Economic Commission for Europe and the Organization for Security and Co-operation in Europe (OSCE). The UNDP/GEF Kura II Project: Advancing Integrated Water Resource Management (IWRM) across the Kura River basin through implementation of the transboundary agreed actions and national plans, implemented in Azerbaijan and Georgia between 2017–2021, supported this agreement (UNDP/GEF, 2020).

Overall, 11 rivers enter Azerbaijan from Armenia, their total water resources amounting to 2.54 km^3 (Rustamov, Gashkai, 1989). However, nowadays there is no transboundary cooperation between Azerbaijan and Armenia.

Social, economic and environmental consequences of flow reduction

With the development of various sectors of the economy, especially agriculture and the rapid population growth in the Kura basin, the amount of water taken from natural water sources, including rivers, is increasing year by year. The depletion of water resources as a result of water use and climate change is a direct threat to food, water and energy security. Currently, a shortage of water to irrigate crops is observed each year. Owing to the lack of irrigation water that would conform to the norms, the productivity of agricultural crops decreases. Productivity is also declining in areas where rainfed agriculture is developed due to the decrease in rainfall. All this reduces the income of the rural population and has a negative impact on the living standards (Hannan et al., 2013).

A decrease in river water resources resulting from natural and anthropogenic factors is accompanied by deterioration of the water quality. All countries in the Kura basin are developing countries. Most cities and enterprises do not have wastewater treatment plants; at best only mechanical treatment of wastewater is carried out in the existing old facilities. All polluted and partially treated water is discharged into the Kura River and its tributaries, and eventually enters the Caspian Sea. The use of poor quality water has a negative impact on human health, leading to the emergence and spread of various diseases. At the same time, transboundary ecosystems are degraded, the number of plant and animal species in the river basin is declining, forests are thinning, and soil fertility is decreasing (UNDP/GEF, 2013). These adverse effects are more typical of the downstream of the Kura River. In the South Caucasus countries located in the Kura basin, little attention is paid to ensuring the amount of ecological flow when using surface water. What is neglected is the fact that water bodies, along with socio-economic and water management functions, have also ecological, geospheric, landscape and recreational-aesthetic purposes (2000/60/EC; Ecological…, 2015; Imanov et al., 2021).

Owing to the growing demand for water in agriculture resulting from climate change and population growth, the use of water in the basin will also increase. Thus, there is a need to minimise water stress, use water resources more efficiently and develop cross-border cooperation.

CONCLUSION

The research results show that over the past three decades the water resources of the Kura River and its main transboundary tributaries have decreased by 16.0–55.2%. This is because of the construction of new reservoirs and an increase in water withdrawals for irrigation, as well as the need to meet the requirements of other sectors of the economy in the countries located in the basin. The impact of climate change on the decrease in the river flow is approximately 5–15%. Owing to the lack of irrigation water that would conform to the norms, the productivity of agricultural crops decreases. All this reduces the income of the rural population. At the same time, transboundary ecosystems are degraded. Obviously, with the continued development of various types of economic activity in the basins of these rivers, a further reduction in the water resources of the rivers can be expected. Therefore, it is necessary to use water-saving technologies, primarily in agriculture, to use non-traditional water sources, and to strengthen transboundary cooperation.

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