TECHNOLOGICAL SOLUTIONS FOR WATER RESOURCES MANAGEMENT IN AZERBAIJAN TO ACHIEVE SUSTAINABLE DEVELOPMENT: MONITORING AND IMPROVEMENT OF MANAGEMENT AND FORECASTING

SOLUÇÕES TECNOLÓGICAS PARA GESTÃO DE RECURSOS HÍDRICOS NO AZERBAIJÃO PARA ATINGIR O DESENVOLVIMENTO SUSTENTÁVEL: MONITORAMENTO E MELHORIA DA GESTÃO E PREVISÕES

SOLUCIONES TECNOLÓGICAS PARA LA GESTIÓN DE RECURSOS HÍDRICOS EN AZERBAIYÁN PARA LOGRAR EL DESARROLLO SOSTENIBLE: SEGUIMIENTO Y MEJORA DE LA GESTIÓN Y PREVISIÓN

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ABSTRACT

The currently observed water deficit across the world is predicted to intensify further. A pronounced scarcity of water is experienced by the Republic of Azerbaijan, whose territory mainly occupies a transitional climatic zone and is poorly supplied with water resources. The goal of the study is to assess changes in water resources under natural and anthropogenic factors, which has become an especially acute issue in recent years. The study analyzes the use of water resources withdrawn from natural sources and consumed in two time intervals (1990– 2021 and 2000–2021). Throughout the first period spanning from 1990 to 2021, there is a negative dynamic in the use of water resources withdrawn from natural sources and consumed, whereas the second period between 2000 and 2021 shows a positive dynamic in water resource use. It is established that in both periods, only 70% of the water extracted from natural sources was consumed and 30% went to waste. Irrigation takes up 69-70% of the consumed water, production accounts for 26%, and household needs require 4-5%.

Keywords: anthropogenic impact, pollution, natural resources, water reserves.

RESUMO

Prevê-se que o déficit hídrico actualmente observado em todo o mundo se intensifique ainda mais. Uma pronunciada escassez de água é vivida pela República do Azerbaijão, cujo território ocupa principalmente uma zona climática de transição e é mal abastecido com recursos hídricos. O objetivo do estudo é avaliar as mudanças nos recursos hídricos sob fatores naturais e antropogênicos, o que se tornou uma questão especialmente aguda nos últimos anos. O estudo analisa o uso de recursos hídricos retirados de fontes naturais e consumidos em dois intervalos de tempo (1990–2021 e 2000–2021). Ao longo do primeiro período, que vai de 1990 a 2021, verifica-se uma dinâmica negativa na utilização dos recursos hídricos retirados de fontes naturais e consumidos, enquanto o segundo período, entre 2000 e 2021, apresenta uma dinâmica positiva na utilização dos recursos hídricos. Verifica-se que em ambos os períodos apenas 70% da água extraída de fontes naturais foi consumida e 30% foi desperdiçada. A irrigação ocupa 69-70% da água consumida, a produção representa 26% e as necessidades domésticas requerem 4-5%.

Palavras-chave: impacto antrópico, poluição, recursos naturais, reservas hídricas.

RESUMEN

Se prevé que el déficit de agua observado actualmente en todo el mundo se intensificará aún más. La República de Azerbaiyán, cuyo territorio ocupa principalmente una zona climática de transición y está mal abastecido de recursos hídricos, sufre una pronunciada escasez de agua. El objetivo del estudio es evaluar los cambios en los recursos hídricos bajo factores naturales y antropogénicos, lo que se ha convertido en un problema especialmente grave en los últimos años. El estudio analiza el uso de los recursos hídricos extraídos de fuentes naturales y consumidos en dos intervalos de tiempo (1990-2021 y 2000-2021). A lo largo del primer período que abarca de 1990 a 2021, existe una dinámica negativa en el uso de los recursos hídricos extraídos de fuentes naturales y consumidos, mientras que el segundo período entre 2000 y 2021 muestra una dinámica positiva en el uso de los recursos hídricos. Se establece que en ambos periodos sólo el 70% del agua extraída de fuentes naturales se consumió y el 30% se desperdició. El riego consume entre el 69% y el 70% del agua consumida, la producción representa el 26% y las necesidades domésticas requieren entre el 4% y el 5%.

Palabras clave: impacto antropogénico, contaminación, recursos naturales, reservas de agua.

1. INTRODUCTION

The world community has been experiencing water shortage since late the 20th century. Preliminary projections suggest that water scarcity will continue until the middle of the 21st century. The World Resource Institute (WRI) predicts that one-fifth of the world's countries will be affected by water shortage by 2040. Climate change, which disrupts rainfall distribution and population growth, exacerbates the water demand. Unfortunately, one of the countries expected by the Institute to face the threat of drought is Azerbaijan. To be exact, among the 33 countries listed, Azerbaijan is in 18th place. The Republic's water resources, comprised mainly by river flow, average at 30.9 km3. Of these, 20.3 km3 are transit flows from other countries (predominantly the Kura and Aras rivers), and 10.6 km3 are generated within the country (Rustamov et al., 1989). Given that two-thirds of total water resources (30.9 km3) are transit flows, most pollution occurs in these rivers (Mamedov et al., 2018). Given the country's great water resources, the fact of Azerbaijan holding 18th place in the list can be explained by rather large amounts of wastewater, widespread use of flood irrigation, and the fact that 70-73% existing irrigation network consists of earthen canals. The World Health Organization (WHO) has established the norm of 450 l of drinking and household water a day per person. Given international norms, the population of Azerbaijan needs to be supplied with 1.6 billion m3 of drinking and household water each year. Across 32 years (1990–2021), the average water supply for the population was 367 million m3, which is 4.4 times less than the prescribed norm. This translates into a consumption rate of 100 l per person per day, 4.5 times lower than the international norm.

Due to the expansion of irrigated agricultural land in the countries of the South Caucasus, the need for water has risen in recent years. This increase reaches 2 billion m3 in Georgia, 1.2 billion m3 in Azerbaijan, and 1 billion m3 in Armenia. As a result, the region requires an additional 4.2 billion m3 of water. Natural water abstraction is projected to increase by 13.99 km3 in 2040 and 14.86 km3 in 2050 (Ismailov, 2023). As a result of global climate change, a 1.1 degree increase in air temperature over the past 20 years has hampered rain-fed agriculture (Makhmudov, 2022). Providing irrigation water to the more cultivated areas has thus become an important factor. However, because of outdated irrigation systems, the country's water resources are being used inefficiently and the expansion of irrigated areas is scaling up water losses. The main canals on the balance of the "Melioratsiia i vodnoe khoziaistvo" OJSC were constructed back in Soviet times. Specifically, the Upper Karabakh and Upper Shirvan canals were commissioned in 1958, the Samur-Absheron Canal – in 1940, the Bash-Mughan Canal – in 1960, and the Bash Mil Canal – in 1976.

At present, the importance of accounting for the hydrological role of indirect influences in water management calculations is recognized. Up until the middle of the 20th century, many scholars did not consider the position of the basin, following the climatic concept of the formation of streams, believing that only meteorological changes determine the size and water regime of the river. On the other hand, the nature of agricultural activities can sometimes affect water resources even kilometers away from water bodies. In the second half of the 19th century, V.V. Dokuchaev, A.A. Izmail, and N.A. Kostychev and the American researcher G. Marsh linked the deterioration of the water regime of rivers (increased flooding, shallowing) with massive land clearing and deforestation. Replacement of wet land with arable land resulted in the deterioration of soil infiltration properties, thus increasing surface run-off and causing flooding.

In the late 1920s and 1930s, a new hydrological phenomenon occurred: the former spring plowing for spring crops was increasingly replaced by autumn plowing. With autumn plowing, the soil has better infiltration properties at the beginning of the spring snow subsidence than unpaved areas. In the 1960s and 1980s, autumn plowing and other agro-technical measures that contributed to the retention of surface water spread across 40-60% of the entire territory of the former USSR. By this time, the hydrological role of autumn plowing and other agricultural activities had been reported by water balance stations. Studies by A.M. Green (1965) confirmed the conclusion of V.V. Dokuchaev and other soil researchers on the direction of hydrological consequences of plowing wet soils.

The situation is also unfavorable with underground drainage, which is stable in time and does not require regulation. The country's groundwater resources are estimated at 4.38 km3 (Aliev, 2000). In most of Azerbaijan's rivers, 60-70% of annual flow comes from relatively short spring floods, whereas the greatest water demand occurs in the summer and autumn periods when rivers are fed mainly by groundwater flow. In addition, most of the total river flow belongs to mountainous areas, where the population is relatively sparse, and the well-developed industries have lower water demand.

Of utmost importance are the rational means of influencing rivers to prevent or minimize the risk of negative socio-economic consequences, changes in the amount and quality of existing water resources due to both climate change and anthropogenic factors having direct or indirect influence (through relief, soil, or biota) and the detection and accurate estimation of the speed of changes. Improving water supply requires not only reduced and frugal water use but also optimization of water resource management (Imanov et al., 2017).

Anthropogenic impacts on water resources have long attracted the attention of hydrologists, water managers, environmentalists, and other scientists. However, much of the research has been focused on anthropogenic impacts on water quantity rather than quality, although water pollution poses the greatest threat.

The purpose of the present study is to assess the degree of anthropogenic impact on water quality and treatment measures.

2. METHODOLOGY

The primary material used to assess anthropogenic changes in water resources, primarily river flow and water quality, is data from hydrological stations on water consumption and water pollution and archive, stock, and literary materials of Goskomstat. Regrettably, the amount of information on the hydrometeorological condition of Azerbaijan's territory has reduced in recent decades, especially due to the closure of occupied stations in Karabakh and East

Zangezur. Much effort is now being made to install automatic stations transmitting data at a distance. Furthermore, there are significant shortcomings in the quality of hydrometeorological data received from other areas.

There are many methods to determine anthropogenic impact on water resources (flow differentiation under the same hydrometeorological conditions but different nature and level of economic activity, comparison of water quality indicators, mathematical modeling, etc.). Due to the influence of climatic and anthropogenic factors, the volume of water resources varies both year by year and season by season, so evaluating the influence of these factors is one of the main tasks. Since the factors are closely interconnected, the assessment will be relative in any case.

The direct impact of different economic activities, for example on water use, was determined based on water statistics. Indirect effects were established by quality and other hydrological observations at hydrometeorological stations. Methodological approaches to determining anthropogenic impact on water resources have been described by many researchers (Georgiadi et al., 2014; Koronkevich, 1990; Koronkevich et al., 2017; Fatullaev, 2002; Shiklomanov, 1979).

3. RESULTS AND DISCUSSION

Impact on water quality

The greatest threat to water resources in most countries, including Azerbaijan, is pollution. This issue is addressed in numerous studies, particularly concerning pollution due to wastewater discharge into rivers and canals. The danger is posed not only by polluted and insufficiently treated wastewater but also by so-called conditionally clean waters because they carry harmful substances even after the most advanced biological treatment. Additionally, wastewater is often heated, which poses a threat to aquatic ecosystems. The mixing of wastewater with clean water and the processes of water bodies' self-purification are often not viable due to excessive amounts of wastewater. Many water bodies have lost their ability to self-purify, especially from diffuse (area dispersed) pollution products. Pollutants, and particularly biogenic substances that serve as a source of eutrophication of natural water bodies and reservoirs, are brought by surface and groundwater runoff from agricultural and urbanized areas. One of the main suppliers of organic and nutritious substances to water bodies are organic and mineral fertilizers. Depending on the type of soil, the amount and type of fertilizers, the technique of their application, and atmospheric and other conditions, 1 ha of fertilized land can contain 14.5-25% of nitrogen and 1.0-1.5% of phosphorus (up to 7% in crude form in soils) (Laskorin et al., 1975).About 10% of organic and mineral fertilizers applied to the soil are carried into water bodies (Topachevskii et al., 1975). Currently, Azerbaijan uses 350-400 thousand t of fertilizers annually. Although under natural conditions biogens, which are waste products of the biota, are also transported from water bodies to rivers and streams, anthropogenic input significantly augments these flows.

Indirect impact on the amount and regime of water resources

Investigation of the indirect effects of relief, soils, and biota on river flow is quite topical. By the end of the 20th century, almost three-fourths of Earth's land area (except Antarctica) were seeing changes in natural landscapes caused by various forms of economic activity. These changes affected 85% of land area in Europe, over 55% in Asia, and in some countries – up to 90%. In Germany and the Netherlands, the area occupied by buildings and roads approached 15% (Kotliakov et al., 1998; Hannah et al., 1994). At present, these numbers are even higher. Compared to the early 20th century, the area of disturbed land across the world increased by more than three times. For this reason, in many places around the world, as well as in Azerbaijan, water balance and flow have long been unnatural. It would be more appropriate to call them conditionally natural for the time the ongoing changes are evaluated.

M.I. Lvovich (1963), having examined experimental observations, concluded that autumn plowing reduces surface runoff by 1.5 times in the forest zone, and by 3-5 times in the steppe, which inevitably causes an increase in surface and annual runoff (especially of small rivers) by tens of percent. Nevertheless, the impact of autumn plowing on the 1 million ha of land in Azerbaijan is not unavoidable.

Forestry

Although the water-regulating role of forests is broadly recognized, the impact of logging and reforestation on annual runoff remains a controversial issue. In this area, the method proposed by O.I. Krestovskii is considered the most reliable (Krestovskii, 1986). Deforestation increases runoff, especially surface runoff. Then, as the forest regenerates and becomes more productive, evapotranspiration increases, and runoff is reduced. Peak evaporation and, accordingly, the lowest runoff are observed in mid-aged forests, which show the greatest biological productivity. Mature forests are characterized by low evaporation and maximum runoff. Studies conducted using O.I. Krestovskii's method revealed that reforestation in the Volga basin reduced runoff by about 2% (Kashutina et al., 2013). In the 18th and 19th centuries, 35% of the present territory of Azerbaijan was covered with forest. Presently, only 11.8% of the current territory of Azerbaijan is forested. Young trees make up 11.2% of the forest, middle-aged trees – 63.3%, mature trees – 13.4%, and mature and old trees – 12.1%. Only with a change in the structure of forest soils can the expected transformation of the water balance (in the middle and late 21st century) be even more significant. The process of reforestation takes place in many parts of the world, but the way it is associated with decreasing runoff due to higher biological productivity of forests and the increase of this productivity due to clearing and replacing agricultural land can be defined as the process of reforestation.

Anthropogenic load on river basins

Generalization of the obtained data and literary materials enabled us to identify general regularities in the influence of the anthropogenic load of river basins on the flow (Lvovich et al., 1983). A study conducted at the beginning of the 21st century showed an almost 10% increase in the annual river flow compared to the norm, reaching up to a 27% increment in the summer-autumn period as a result of anthropogenic load in the Moskva River basin (Koronkevich et al., 2015). It is established that a 1% anthropogenic load on the river basin (urbanization, expansion of the territory of rural settlements, increase in the density of the transport network, etc.) causes approximately the same increase in flow, and a 1% load in impermeable zones causes an increase of 2-3%.

Our previous studies (Abduev, 2007; Abduev, 2010). have found that among Azerbaijan's river basins, 2% are subjected to a low level of anthropogenic load, 25% experience a moderate load, and 73% are affected severely. The hydrological effect of the anthropogenic load is more pronounced in warmer seasons when flow coefficients of natural and disturbed landscapes differ the most, which creates prerequisites for intensified summer floods. Ultimately, despite increasing water resources, this process results in the pollution of rivers and reservoirs.

Direct influence on water resources

Flow regulation by hydraulic structures, especially the creation of reservoirs, is of great importance for Azerbaijan. However, it produces significant negative ecological consequences. Sometimes lands are flooded, water is consumed to fill the dead volume of the reservoir, and additional evaporation from the surface of reservoirs and flooded areas increases. Several researchers believe that the creation of reservoirs ultimately worsens water quality. However, this idea is often disputed (Edelshtein, 1998).

Water abstraction and use

In the early 1970s, M.I. Lvovich assessed current and prospective water consumption in the former USSR and globally (Lvovich, 1974). The researcher argued that a depletion of water resources quality is to be expected, since the treatment applied in compliance with the principles of water protection and wastewater discharge into rivers and reservoirs is not exhaustive. Therefore, M.I. Lvovich proposed a preventive principle of water protection, which consists in comprehensive prevention of wastewater discharge into rivers and reservoirs. Statistics on water abstracted from natural sources and its consumption and losses according to Goskomstat are presented in Table

Table 1.

Water taken, consumed, and lost from natural sources (in millions of m3)

Water abstraction and consumption	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2021**	**mean**
Water from natural sources	16,176	13,971	11,110	12,050	11,566	12,285	13,743	12,689
Per capita water, m^3	2,293	1,847	1,397	1,438	1,295	1,289	1,372	1,512
Water consumed – total	12,477	10,223	6,588	8,607	7,715	8,567	10,526	8,879
for drinking and household purposes	402	327	449	521	405	323	321	367
for production purposes	3,418	2,173	2,316	2,360	1,742	2,117	2,566	2,307
including: drinking	317	111	82	61	54	46	52	86
for irrigation and supply of agriculture	8,627	7,720	3,819	5,710	5,497	6,057	7,575	6,170

Volume of water consumed periodically and continuously	1,628	1,696	1,875	2,224	1,787	2,441	2,795	1,966
towards total production water consumption, in %	32	44	45	49	51	54	52	46
Loss of water during transportation	4,206	3,747	3,053	3,443	3,851	3,718	3,217	3,661
In %	26	27	27	28	33	30	23	28
wastewater income	5,026	4,247	4,106	4,878	6,037	5,575	5,237	4,850
including: untreated	303	134	171	161	164	305	229	216

Source: data provided by Goskomstat

Our analysis of water use in Azerbaijan covers the period from 1990 to 2021. This period is characterized by two different stages. The first stage is marked by a decrease in water abstraction from natural sources in 1990-2000, while the second stage is distinguished by an increase in water abstraction from natural sources in the period from 2000 to 2021. Apart from gradual water abstraction, other indicators of water use are synchronous (Figure 1).

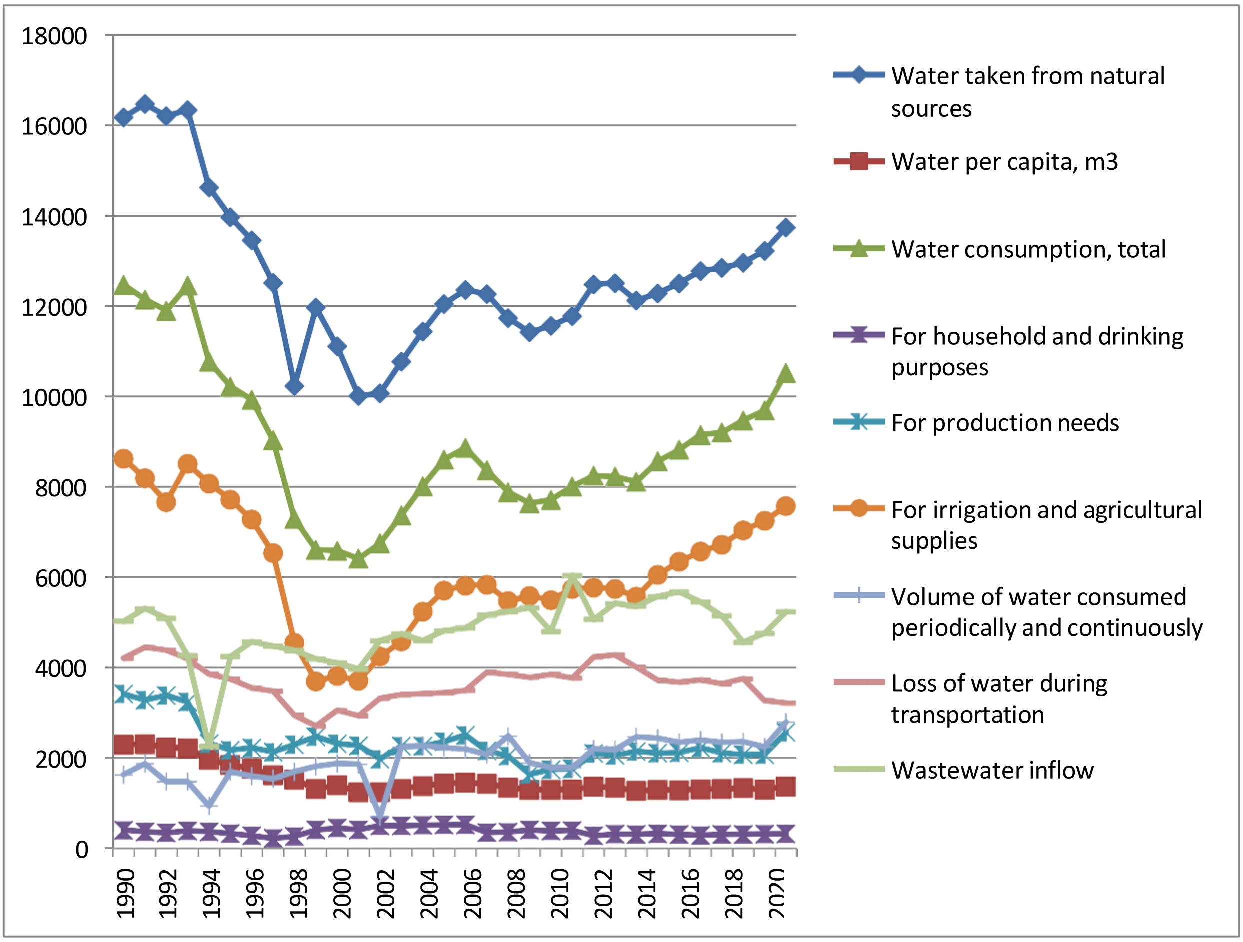

Figure 1. Dynamics of water resource use in 1990–2021
Source: compiled by authors.

Except for graphs showing the dynamics of wastewater discharged and the volume of water used periodically and continuously, the other graphs reveal a negative trend. This can be explained by the economic crisis following the collapse of the USSR against the backdrop of dwindling water resources and the restructuring of the economy towards less water-intensive industries. A positive trend can be traced in graphs showing the dynamics of the volume of wastewater and intermittently consumed water.

Analyzing the available statistics, we observe that in the 32 years between 1990 and 2021, the average abstraction of water from natural sources reached 12,689 million m^3, the highest level recorded in 1991 at 16,474 million m^3 and the lowest – in 2001 at 10,012 million m^3. Although 71% of the abstracted water was consumed, 29% was lost (Figure 2).

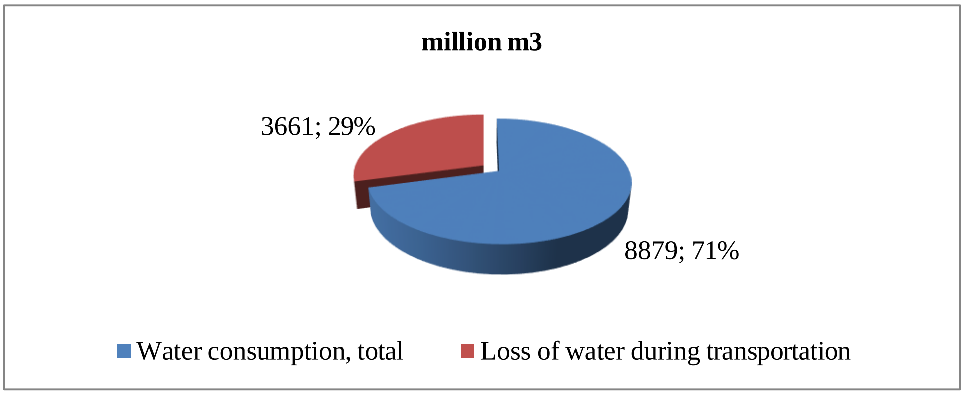

Figure 2. Distribution of water abstracted from natural sources in 1990–2021
Source: compiled by authors

Loss of water in transportation averages at 3,661 million m^3, peaking in 1991 at 4,449 million m^3 and hitting the lowest point in 1999 at 2,704 million m^3. Among CIS countries, water loss amounts to 20% in Armenia, 13% in Kazakhstan, 12% in Ukraine, 10% in Russia, 7% in Moldova, and 5% in Belarus, while first place belongs to Azerbaijan with 29-30%.

Average water consumption in the considered period amounts to 8,879 million m^3, with the highest value of 12,477 thousand m^3 recorded in 1990 and the lowest – 6,414 thousand m^3 – in 2001. Average water use for irrigation and supply of agriculture is 6,170 million m^3, the highest level observed in 1990 – 8,627 million m^3, and the lowest in 1999 – 3,697 million m^3. Overall, 70% of the consumed water was directed towards irrigation and agriculture. The average use of water for production purposes reaches 2,307 million m^3 with the greatest volume in 1990 – 3,418 million m^3, and the lowest in 2010 – 1,742 million m^3. In total, production accounts for 26% of consumed water, while household and drinking water takes up only 4% (Figure 3).

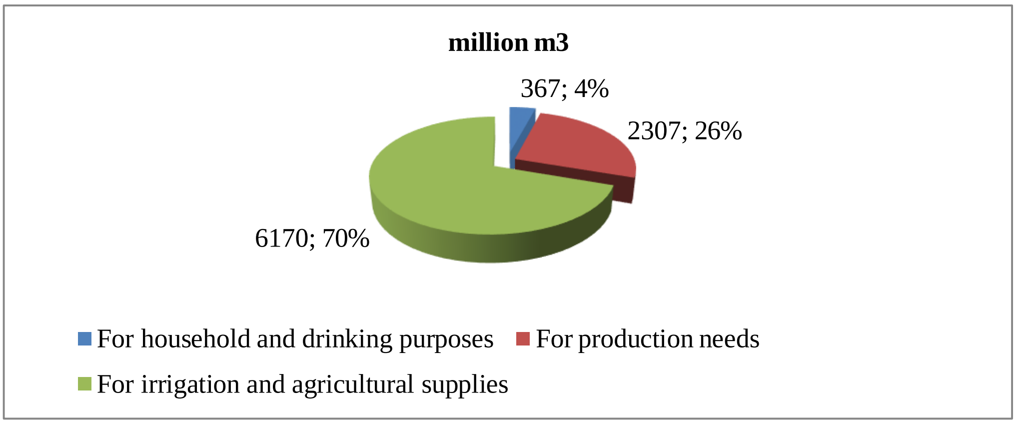

Figure 3. Distribution of water resource use by economic sectors in 1990–2021
Source: compiled by authors

The volume of collected wastewater amounted to 6,037 million m^3 in 2010 and 2,255 million m^3 in 2010, the average being 4,850 million m^3. Per capita water consumption in this period was around 1,512 million m^3, the highest value recorded in 1991 – 2,304 million m^3, and the lowest being 1,242 million m^3. This fact owes to the introduction of modern technology of water use, payment for its use, and changes in the structure of water use, including the closure of many water-intensive industries and the reduction of irrigated areas.

After 2000, there was an increase in the volume of water consumed by spheres other than domestic and drinking and production purposes (Figure 4).

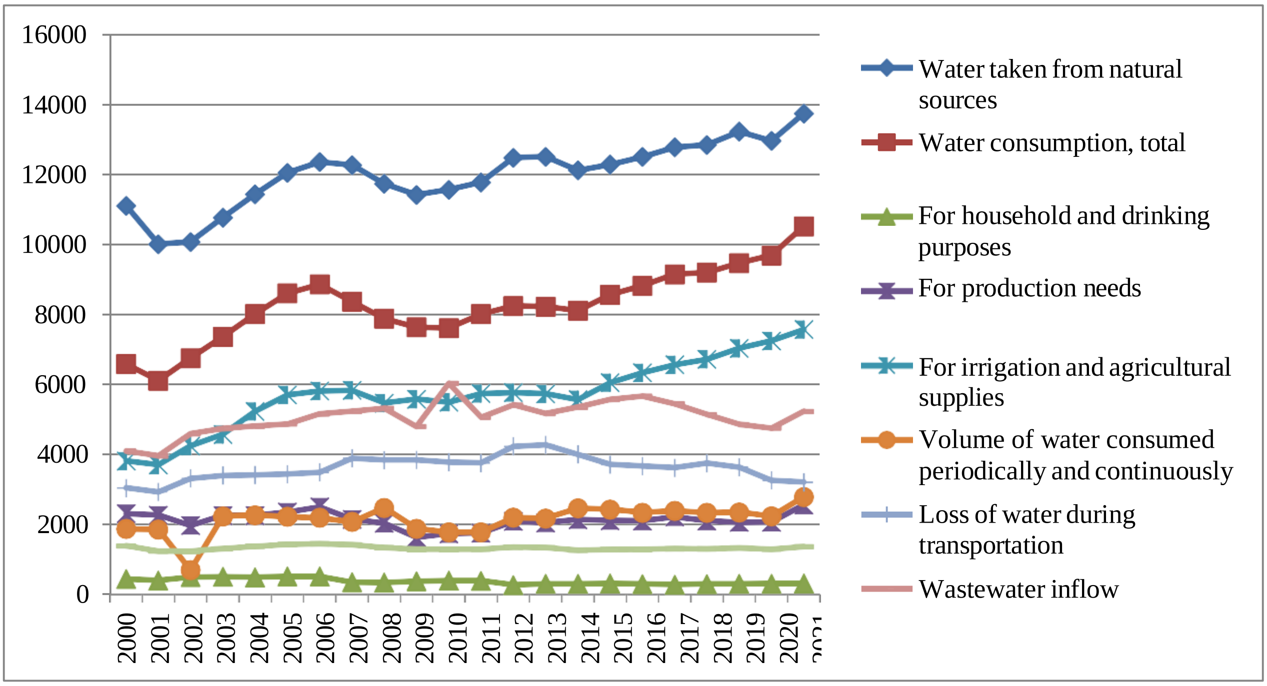

Figure 4. Dynamics of water resources use in 2000–2021
Source: compiled by authors

However, in 1990–2021, the volume of water abstraction from natural sources averages at 12,689 million m^3, while virtually the same amount of water (12,003 million m^3) was abstracted in 2000–2021. The same applies to the amount of consumed water lost during transportation, used for irrigation and production purposes, and consumed as drinking and household water. Thus, average prices for the volume of used water in 1990-2021 and 2000-2021 are not much different. Compared to the years 1990-2021, there was a slight decrease in per capita water consumption and an increase in wastewater discharge in 2000-2021.

In the 22 years from 2000 to 2021, 70% (8,285 million m^3) of the 12,003 million m^3 of water taken from natural sources were consumed, and 30% (3,621 thousand m^3) were lost (Figure 5).

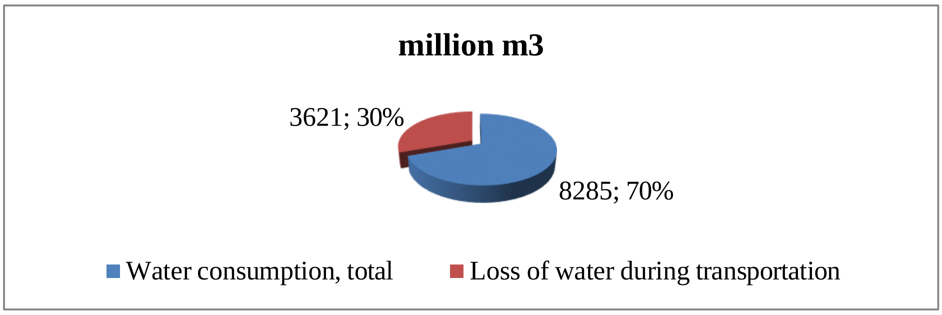

Figure 5. Distribution of water abstracted from natural sources in 2000–2021
Source: compiled by authors

Although the average amount of water taken from natural sources was higher in 1990–2021 (12,689 thousand m^3), its losses were lower (29%) and the share used for consumption was higher (71%).

As can be seen from Figure 5, average water consumption in 2000–2021 was 8,285 million m^3. Irrigation and supply of agriculture took up 69% of the water consumed (5,735 million m^3). Production used an average of 2 130 million m^3 of water, which makes up 26% for both the period of 1990–2021 and 2000–2021. The volume of water used for household and drinking purposes (381 million m^3) increased by 5% compared to 1990–2021 (see Figure 6).

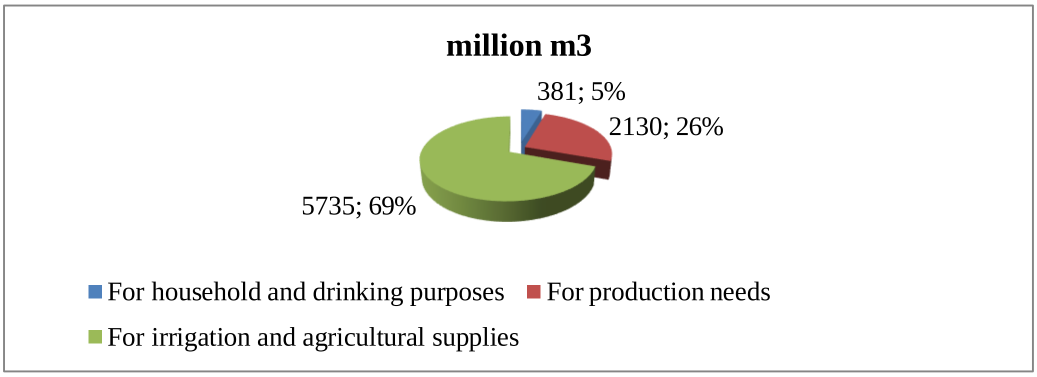

Figure 6. Distribution of consumed water by sectors
Source: compiled by authors

Compared with the period between 1990 and 2021, there is a minor increase in the amount of wastewater, the average being 5,064 million m^3. Per capita water consumption in this period decreased by 1.13 times, reaching an average of 1,333 million m^3. this fact can be attributed to population growth

4. CONCLUSION

The conducted study has limitations due to the availability of hydrometeorological data. In recent decades, the amount of information on the hydrometeorological condition of Azerbaijan has been significantly reduced, especially due to the closure of the occupied stations in Karabakh and East Zangezur. This may affect the accuracy and completeness of the analysis, since the inaccessibility of data on some regions may create gaps in our understanding of hydrometeorological conditions. In addition, there are significant shortcomings in the quality of hydrometeorological data obtained from other areas, which may also hamper the extrapolation of the results across the region. For more reliable conclusions and forecasts, these limitations need to be considered and the available data carefully analyzed.

Given the threat of water quality depletion, measures to prevent and address this risk should be among the priorities. It is crucial to improve wastewater treatment, yet it is equally important to prevent even treated wastewater from entering rivers and water bodies. The primary means of achieving this goal are integrated water conservation, anhydrous technologies, and closed-loop water use, the feasibility of which was proven back in the 1980s.

Measures to reduce water pollution and surface run-off (alternation of forest and field lands, water-conserving agrotechnologies, etc.) can also reduce erosion in the basin. Thus, the issue of improving the water supply of agricultural land will also be addressed.

The success of many technological solutions to water problems depends on monitoring and the improvement of management and forecasting, including prediction of the long-term condition of water resources under climatic and anthropogenic factors. Water management using reservoirs and, in some cases, transfer of water are still relevant. In mountainous and foothill regions of the Republic, these measures can be integrated into a regional network to ensure efficient use of water resources by creating water bodies, ponds, and artificial lakes to collect rainwater and river and groundwater. These waters will satisfy the drinking and irrigation water needs of the people living in these territories, and excess water can be transported to regions in need.

To make efficient use of the available water resources and reduce water losses to infiltration and evaporation, water taken from natural sources should be transferred by pipes.

To improve the efficiency of irrigation water use, it is advisable to transfer water to a large-scale drip irrigation system.

The increase in water resources can be achieved by such measures as expanding greenery, especially forests, and improving grass cover.

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