

## EVALUATING PRIORITIES FOR ENHANCING WATER SECURITY AND SUSTAINABILITY IN AZERBAIJAN IN THE CONTEXT OF CLIMATE CHANGE RESILIENCE

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**Abstract:** The article outlines key priorities for ensuring water security in Azerbaijan, emphasizing a fair, balanced approach to managing water, land, and related resources. The main goal of the study is to identify and evaluate key priorities for enhancing water security in Azerbaijan, particularly in the face of increasing climate change impacts. The objective is to promote a sustainable, ecosystem-conscious water management approach that ensures reliable access to clean water for current and future generations while preserving river basin ecosystems. Integrated Water Resources Management (IWRM) in Azerbaijan focuses on the coordinated use of water, land, and related resources to ensure sustainable development and environmental protection. It emphasizes cross-sectoral integration and stakeholder participation, particularly in managing transboundary water resources. The article applies the principles of Integrated Water Resources Management (IWRM) as the central framework for analysis. This involves evaluating water usage trends, resource availability, and environmental impacts through a coordinated, multisectoral lens. Key areas of focus include the effects of climate change on water sources, particularly surface water reductions and the growing dependence on groundwater. The study also reviews adaptation strategies, such as improving infrastructure, modernizing irrigation systems, promoting alternative water sources (treated wastewater and harvesting rainwater), and reducing inefficiencies through technology and governance reforms. The study identifies significant climate-induced risks to Azerbaijan’s water security, including declining surface water availability caused by altered precipitation patterns, reduced snowmelt, and prolonged droughts. These changes have led to increased reliance on groundwater, raising concerns about aquifer depletion, water quality degradation, and ecosystem harm. The analysis underscores the urgent need for sustainable groundwater management. It also reveals that current water infrastructure and usage practices are inefficient and poorly adapted to emerging climate challenges. By emphasizing IWRM, the article recommends actionable priorities such as strengthening institutional coordination, implementing climate-resilient infrastructure projects, and promoting the use of alternative water sources. Modernizing irrigation and expanding water-saving technologies are highlighted as practical steps to reduce water loss and enhance resilience. The findings point to the necessity of integrating environmental protection with long-term strategic planning to ensure water availability and ecological sustainability. Ultimately, the study concludes that Azerbaijan can secure its water future by adopting adaptive, integrated policies that align with environmental and climate resilience goals.

**Keywords:** irrigation, drinking water supply, water scarcity, sustainable development

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### INTRODUCTION

Azerbaijan faces four major water resource problems. First, water scarcity is a critical issue due to limited internal sources and increasing demand from agriculture, industry, and population growth. Second, transboundary water challenges arise because over 70% of Azerbaijan’s surface water originates in neighboring countries, making the country vulnerable to upstream pollution, reduced flows, and lack of coordinated management. Third, water pollution from industrial discharge, agricultural runoff, and untreated wastewater degrades water quality and poses risks to health and ecosystems. Fourth, inefficient infrastructure and institutional fragmentation lead to water losses and hinder the effective implementation of integrated water management policies. Azerbaijan has made progress toward adopting Integrated Water Resources Management (IWRM), but opportunities remain to strengthen implementation. Enhancing institutional coordination can further unify water governance efforts across sectors. Improving data systems and increasing stakeholder participation will support more informed and inclusive decision-making. Investing in infrastructure and capacity-building can accelerate sustainable water use and resilience. This research aims to build on existing achievements by offering policy solutions that support the full realization of IWRM principles in Azerbaijan. As a country facing increasing water stress due to climate

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change, transboundary river dependency, and growing demand, Azerbaijan provides a critical context for evaluating how IWRM can be applied effectively. The country's evolving institutional frameworks and development priorities offer a unique opportunity to explore the integration of sustainable water practices into national policy.

By studying Azerbaijan, we can gain insights into how to navigate institutional complexity, align water management with development goals, and promote stakeholder inclusion. These lessons can inform IWRM strategies in other countries with similar environmental and governance challenges. In Azerbaijan, the adoption of Integrated Water Resources Management (IWRM) presents a valuable opportunity to enhance sustainable water use and address key challenges. The country is gradually strengthening its policy and legal frameworks, aiming to improve coordination among water management institutions. There is growing recognition of the importance of involving diverse stakeholders, including transboundary partners, to foster collaboration and shared water governance. With increasing investments in management tools, improved financing mechanisms, and rising public awareness, Azerbaijan is well-positioned to overcome environmental and societal challenges and advance effective IWRM implementation. Climate change poses serious threats to Azerbaijan's water security, as new challenges arise in the management of water resources. Azerbaijan is highly vulnerable to climate variability due to its semi-arid and mountainous geography, dependence on glacial and snowmelt-fed rivers, and high evapotranspiration rates (Guliyev et al., 2016; Hansen et al., 1996). Studies such as those by Huseynov et al. (2024a); Safarov et al. (2024); Safarov et al. (2025) emphasize that shifts in precipitation patterns and glacial retreat in the Caucasus significantly affect seasonal water availability, altering hydrological regimes and increasing drought frequency. The impacts of climate change on water cycles are well-documented globally (Szilagyi et al., 2024), and similar concerns have been reflected in the Kura-Aras basin, where surface water flow shows marked seasonal and interannual variability (Rustamov, 1960; UNDP/GEF, 2013). The reduction in river flow directly affects Azerbaijan's agriculture, energy, and drinking water sectors, which are heavily reliant on this transboundary river system (Abbasov & Flores, 2023; UNDP/GEF, 2007).

Institutional fragmentation and overlapping water management authorities continue to hinder progress toward Integrated Water Resources Management (IWRM) in Azerbaijan (Ahmadov, 2020; Aliyev, 2008). Despite policy frameworks aligned with EU Water Framework Directive principles (Directive 2000/60 EC), the implementation of adaptive water governance remains weak. The Global Water Partnership (2000) and Biswas (2004) argue that successful IWRM in developing regions requires not only legal and technical reforms but also political commitment and inclusive decision-making.

Several authors point to a lack of reliable hydrometeorological data, insufficient groundwater monitoring, and weak enforcement mechanisms as major limitations (Imanov & Alakbarov, 2017; Alakbarov, 2014; Farda et al., 2015). Additionally, the over-extraction of groundwater and degradation of aquifer quality in regions such as Absheron present further challenges (Alakperov, 2000; Alakperov et al., 2006; Alakbarov et al., 2010).

Resilience-building strategies in water management require both structural (infrastructure) and non-structural (policy, education, ecosystem-based) approaches. Molden et al. (2010) and Ahouissoussi et al. (2014) stress the importance of improving water productivity in agriculture, where irrigation inefficiencies remain high. In Azerbaijan, where irrigation consumes over 70% of freshwater, the modernization of irrigation systems is considered a top priority (Pasha et al., 2023; Guliyev et al., 2024). Ecosystem-based adaptation also plays a growing role in improving resilience. Studies such as Abbasov & Flores (2023) evaluate the value of freshwater ecosystem services in the Kura-Aras Basin, suggesting that maintaining wetland and riparian ecosystems contributes to both biodiversity and water regulation functions. From a transboundary perspective, cooperation on shared waters is critical. Alakbarov & Imanov (2010), UNDP/GEF (2013) and Pasha et al. (2025) highlight the strategic need for integrated regional water agreements among South Caucasus states.

While research has advanced in hydrogeology (Geology of Azerbaijan, 2008; Geology of Azerbaijan, 2015), climate impact assessments (İsmayılov & Suleymanov, 2024), and policy analysis (OECD, 2020; Kadi & Arriens, 2012), significant gaps remain. These include the spatial modeling of water risk hotspots, the role of community-based governance in rural areas, and the integration of indigenous water knowledge, such as the qanat systems in Karabakh (Guliyev et al., 2024). Pahl-Wostl (2007) calls for adaptive management practices that can respond dynamically to uncertainty, a concept that is still underutilized in Azerbaijan's centralized water governance structures. In this regard, promoting stakeholder participation, decentralized planning, and climate-informed budgeting could serve as transformative tools. The literature consistently recognizes that enhancing water security in Azerbaijan under climate change requires an integrated, multi-scalar, and adaptive approach. Priority areas include modernization of infrastructure, ecosystem restoration, improved data systems, institutional reform, and regional cooperation. With the mounting pressures of climate variability and socio-economic development, the strategic alignment of national water policies with resilience frameworks is essential for ensuring long-term water security in Azerbaijan. The primary objective of this study is to comprehensively evaluate and identify strategic priorities for strengthening water security in Azerbaijan, with particular emphasis on enhancing the country's resilience to the adverse impacts of climate change. This evaluation aims to inform policy development and guide effective resource management to ensure sustainable water availability and safeguard socio-economic development under evolving climatic conditions. The study focuses on assessing water resource vulnerabilities and addressing institutional and policy challenges to improve water governance. It evaluates resilience strategies and identifies gaps in data and monitoring systems while considering traditional knowledge for sustainable management. The research aims to enhance transboundary cooperation and support the development of a climate-resilient, adaptive water management framework for Azerbaijan.

### **Study Area**

Azerbaijan is a transcontinental country located at the crossroads of Eastern Europe and Western Asia, bordered by the Caspian Sea to the east, Russia to the north, Georgia to the northwest, Armenia to the west, and Iran to the south. Covering

an area 86,600 square kilometers, Azerbaijan presents a diverse landscape ranging from the flat, arid plains of the Kur-Araz Lowland to the rugged peaks of the Greater and Lesser Caucasus Mountains (Geology of Azerbaijan, 1961). The country's elevation ranges from -28 meters at the Caspian Sea shoreline to over 4,000 meters in the Greater Caucasus, resulting in varied climatic and ecological zones. Azerbaijan is a country located in the southern part of the Caucasus region. The Caucasus Mountains are located in the northern and western parts of the country (Alizadeh et al., 2016). The Greater Caucasus and Lesser Caucasus Mountains form natural borders between Georgia, Armenia, and Azerbaijan. Along the Caspian Sea coast, vast lowlands are widespread (Figure 1).

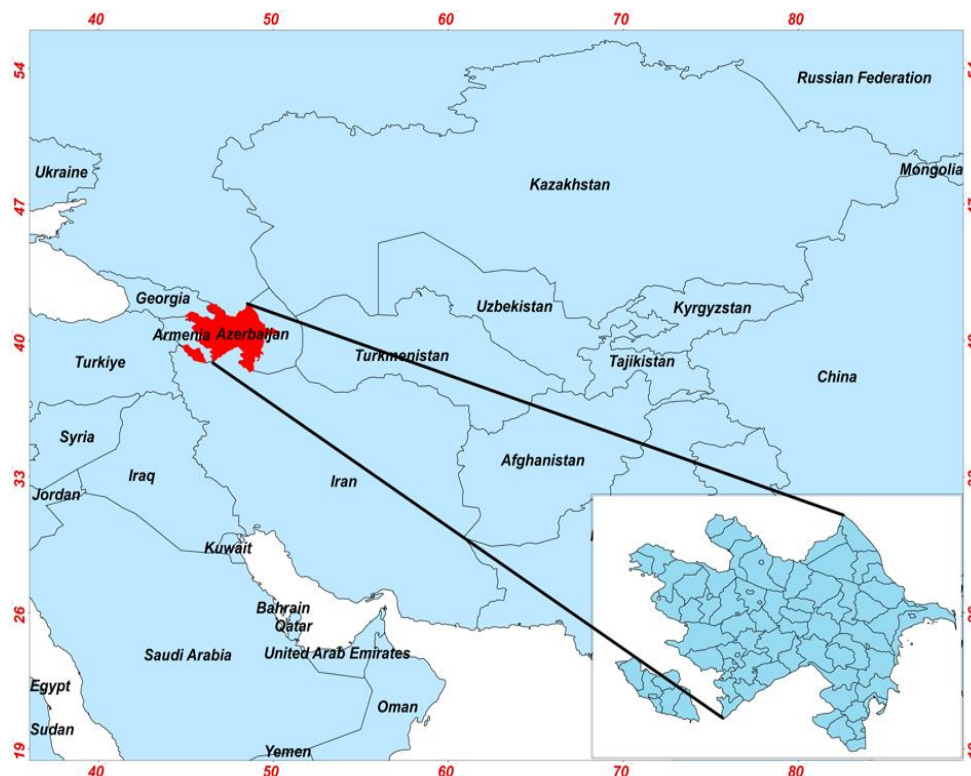


Figure 1. Location of the Republic of Azerbaijan

Due to the geographical diversity of the land, Azerbaijan's climate varies significantly: harsh winters prevail in the mountainous regions, while the plains experience a milder climate. The country is rich in flora and fauna, hosting numerous endemic plant and animal species (Abbasov & Flores, 2023). Overall, Azerbaijan's geographical position holds significant importance both in terms of tourism and economic development (Alakbarov, 2010; Islamzade & Mukhtarov, 2024.).

There are several common challenges in ensuring Azerbaijan's water security. Due to climate change, the reduction of water resources and the increasing frequency of droughts are leading to the depletion of water sources (Alakbarov & Imanov, 2010). The pollution of the Kura and Araz rivers is deteriorating water quality. Outdated irrigation systems and water wastage result in inefficient use of water in the agricultural sector. The technical condition of water reservoirs and dams complicates the proper management of water. Conflicts over transboundary water resources hinder the fair distribution of water. Droughts and floods lead to an unequal distribution of water reserves. Existing gaps in water valuation and regulation make effective governance difficult. Shortcomings in public awareness and education hinder the efficient use of water. All these issues pose significant threats to Azerbaijan's water security and require urgent action.

### Assessment of Azerbaijan's Water Security: Materials and Methodology

A comprehensive and multidisciplinary approach was adopted to assess Azerbaijan's water security in the context of climate change and socio-economic pressures. The assessment synthesizes a wide range of scientific studies, official data sets, policy analyses, and advanced modeling techniques to build a holistic understanding of the current status and future prospects of the country's water resources. At the foundation of this assessment lies an extensive review of peer-reviewed scientific literature and analytical reports that examine climate-induced hydrological changes in the Caucasus region. Studies such as those by Ahouissoussi et al. (2014), Guliyev et al. (2016), and the most recent work of Ismayilov & Suleymanov (2024) provided key insights into the long-term risks associated with climate variability, glacial retreat, and changing precipitation patterns. These sources enabled the identification of specific vulnerabilities in Azerbaijan's water system, including seasonal fluctuations in river flows and increased drought frequency.

To quantify and analyze these vulnerabilities, the study employed official hydrometeorological and statistical data from national agencies and international institutions. These datasets include long-term records of river discharge, precipitation levels, snowpack accumulation, and temperature variations, which are essential for detecting trends and anomalies in water availability (Farda et al., 2015; Rustamov, 1960; Huseynov et al., 2024a). The integration of historical and contemporary

data facilitated a spatially differentiated analysis across Azerbaijan's diverse climatic zones—from semi-arid lowlands to mountainous regions—allowing for detailed assessments of water quantity and quality at local and regional scales.

Agricultural water use represents a dominant demand sector in Azerbaijan, consuming over 70% of the available freshwater. To address this critical component, research on irrigation efficiency and water productivity was incorporated. Key references such as Molden et al. (2010), Ahmadov (2020), and Pasha et al. (2023) informed the evaluation of current irrigation practices and identified opportunities for modernization and water conservation. These studies highlighted the potential for substantial improvements through infrastructure upgrades, adoption of efficient technologies, and policy incentives aimed at reducing water losses and enhancing crop water productivity. In parallel, environmental and ecological impact assessments were conducted to evaluate how water management practices affect ecosystem health and biodiversity. This involved examining freshwater ecosystem services in the Kura-Aras Basin, wetlands conservation, and riparian buffer functions (Abbasov & Flores, 2023; Guliyev et al., 2024; Kreamer et al., 2015). These assessments emphasized the importance of maintaining ecosystem integrity not only for biodiversity conservation but also for natural water regulation processes, which are crucial under changing climatic conditions. International frameworks and best practices played a significant role in shaping the methodological approach. The EU Water Framework Directive (Directive 2000/60/EC) served as a benchmark for evaluating Azerbaijan's water governance and management policies. Reports by UNDP/GEF (2007, 2013) provided diagnostic insights into institutional capacities, transboundary water cooperation, and integrated water resource management (IWRM) challenges. These international documents were used to align the national assessment with global water security standards and to identify gaps in legal and institutional frameworks (Aliyev, 2008; Imanov & Alakbarov, 2017).

Risk assessment methodologies were systematically applied to identify climate-related and anthropogenic threats to water security. Drawing on hydrological and climatic models from Guliyev et al. (2016) and Safarov et al. (2024), the study projected future scenarios of water availability under varying emission trajectories and socio-economic development paths. These models incorporated key drivers such as glacial melt rates, changes in precipitation intensity and frequency, and increasing water demand pressures. Geographic Information Systems (GIS) technologies were employed to spatially map these risks and visualize hotspots of water stress and vulnerability across Azerbaijan (Alizadeh et al., 2016; Islamzade & Mukhtarov, 2024). The use of GIS facilitated the integration of diverse datasets, including hydrological parameters, land use patterns, and socio-economic indicators, enabling a robust spatial analysis of water security challenges.

Hydrometeorological assessments also incorporated critical parameters such as streamflow variability, snowpack dynamics, and evapotranspiration rates, as detailed in recent works by Huseynov et al. (2024a) and the Geology of Azerbaijan reports (2008). These measurements provide a scientific basis for understanding seasonal water availability fluctuations and inform water allocation planning in agriculture, energy production, and domestic use sectors.

In recognition of the socio-ecological dimensions of water security, environmental and social impact assessments were integrated into the methodology. These assessments considered the implications of water management on ecosystem resilience, rural livelihoods, and community wellbeing (Ahmadov, 2020; Gleick, 2000; Kadi & Arriens, 2012). Stakeholder engagement and participatory approaches, although limited in the national context, were reviewed through existing studies to understand the scope for enhancing community-based governance mechanisms.

Mathematical statistical modeling and predictive analytics were employed to simulate water demand and supply trajectories under different climate and policy scenarios. Concepts from adaptive management literature, including the framework by Pahl-Wostl (2007), informed the evaluation of governance adaptability and the potential for dynamic responses to uncertainty and variability. This enabled the assessment of policy options such as climate-informed budgeting and decentralized water planning. Finally, a thorough legal and institutional review was conducted, analyzing national water legislation, enforcement practices, and institutional coordination mechanisms (Alakbarov, 2014; Imanov & Alakbarov, 2017; UNDP/GEF, 2013). This component was essential for identifying systemic weaknesses in water governance, particularly fragmentation among agencies, enforcement gaps, and challenges in transboundary water cooperation. The findings underscored the need for integrated and coherent policy frameworks supported by robust institutional capacities. In summary, this multidisciplinary methodology integrates diverse data sources, modeling tools, and policy analyses to deliver a comprehensive assessment of Azerbaijan's water security. The approach not only diagnoses existing vulnerabilities but also supports the formulation of adaptive management strategies, evidence-based policymaking, and long-term resilience planning tailored to Azerbaijan's unique environmental and socio-political context.

## RESULTS

In Azerbaijan, population growth and economic development are driving increased demand for water resources. This demand is intensified by limited water reserves, climate change, and reduced water inflows from neighboring countries (Ait Kadi & Arriens, 2012; Imanov & Alakbarov, 2017). Expanding agriculture, irrigation, and drinking water supply networks further raise water consumption, highlighting the need for strategic water security measures (Shiklomanov et al., 2003; Shekinski & Alekperov, 1995; İsmayilov, 2019; Guliyev et al., 2024). To address these challenges, a State Commission was established by Presidential Decree on April 15, 2020, to improve water management and implement modern technologies. The Commission, comprising leaders of key state bodies, coordinates efforts to enhance water use efficiency and irrigation systems. Additionally, the "Action Plan for Ensuring Efficient Use of Water Resources for 2020–2022," approved by Presidential Decree on July 27, 2020, focuses on boosting water reserves, reducing losses, upgrading infrastructure, and raising public awareness. These initiatives aim to secure water resources and support sustainable development.

The National Strategy for the Efficient Use of Water Resources, approved by Presidential Decree on October 10, 2024, presents a long-term framework for the protection, efficient use, and sustainable management of Azerbaijan's water resources.

The National Strategy for the Efficient Use of Water Resources (2024) is complemented by a series of legal and governmental documents, including the Water Code of the Republic of Azerbaijan, the Law on Environmental Protection, and relevant presidential decrees and cabinet decisions. Together, these documents establish the institutional and legal basis for integrated water resource management, water quality control, and infrastructure development. A comparative analysis reveals gaps in enforcement mechanisms, limited stakeholder coordination, and the need for updated data systems to support evidence-based decision-making. Aligning these legal instruments with the 2024 Strategy will require harmonization of policies, institutional strengthening, and targeted investment in digital monitoring and cross-sectoral planning tools.

The strategy addresses ongoing challenges related to climate change, water scarcity, and increasing demand. The strategy spans from 2024 to 2040 and is structured in three distinct phases:

1. Phase I (2024–2027): Focus on modernization of water infrastructure, reassessment of national water reserves, and the implementation of integrated water resource management in the Karabakh and Eastern Zangazur economic regions;

2. Phase II (2028–2030): Establishment of key conditions for sustainable water governance, with an emphasis on alignment with the United Nations Sustainable Development Goals (SDGs);

3. Phase III (2031–2040): Addressing hydro-ecological challenges through innovative technologies, expanding the use of alternative water sources, and ensuring reliable access to clean water for all sectors.

The principal measures, implementation timelines, and related Sustainable Development Goals (SDGs) under the National Water Strategy are presented in Table 1.

Table 1. Key Measures Implemented Under the National Water Strategy (2024–2040)

Measure	Description	Timeline	Related SDGs
Infrastructure Modernization	Rehabilitation and upgrading of irrigation and water supply systems	2024–2027	SDG 6, SDG 9
Integrated Water Resource Management (IWRM)	Implementation in Karabakh and Eastern Zangazur regions	2024–2027	SDG 6, SDG 15
Expansion of Alternative Water Sources	Use of rainwater harvesting, greywater recycling, and desalination technologies	2031–2040	SDG 6, SDG 13
Development of Water Monitoring and Information Systems	Nationwide data collection and real-time monitoring of water resources	2024–2030	SDG 6
Public Awareness and Education Programs	Campaigns and training to promote water-saving behaviors	Ongoing	SDG 6, SDG 12
Legal and Institutional Reforms	Strengthening of water governance frameworks	2024–2030	SDG 6, SDG 16

The strategy's primary objective is to ensure water security through improved resource assessment, modernization of irrigation systems, and the development of climate-resilient infrastructure. Monitoring mechanisms will be established to track progress throughout all phases. Water scarcity and inadequate water supply and sanitation services negatively affect food security and public health globally. Droughts continue to contribute to hunger and declining living standards, particularly in low-income countries. Notably, six out of the seventeen UN Sustainable Development Goals are directly tied to water resources, particularly Goal 6: Clean Water and Sanitation. According to global forecasts, by 2050, one in four people may experience chronic or recurring freshwater shortages (UN-Water, 2023).

In this context, Azerbaijan's strategic approach to water security is crucial for adapting to climate change, ensuring sustainable development, and enhancing national resilience (Ait Kadi & Arriens, 2012; Imanov & Alakbarov, 2017; İsmayilov, 2019; Kreamer et al., 2015; Kreamer et al., 2024). Azerbaijan faces an average annual water scarcity of 3.7 km<sup>3</sup>, which increases to 4.75 km<sup>3</sup> during low-water years. When factoring in mandatory water releases for ecological, energy, and other purposes, water scarcity levels rise significantly. Of the water withdrawn, 60–70% is used for irrigation and agriculture, 20–25% for industrial needs, and the remainder for domestic and drinking water supply. Both surface and groundwater sources are utilized for these purposes. Key figures on water resources and their use are summarized in Table 2.

Table 2. Water Resources of the Republic of Azerbaijan and Their Use (Imanov & Alakbarov, 2017; <https://www.stat.gov.az/source/environment>)

Types of Water Resources	Water Resources, km <sup>3</sup>	Volume of Water Withdrawn from Natural Sources, in km <sup>3</sup>
Surface Water	Local	10.2
	Transboundary	
Groundwater	4.38	1.50
Total	35.3	11.7

Azerbaijan's river water resources average 10.6 km<sup>3</sup>, while annual usage has reached 11.7 km<sup>3</sup>. Approximately 70% of the river water (20.3 km<sup>3</sup>) comes from neighboring countries through transboundary rivers, often arriving in a polluted state.

The country faces limited water resources, with 3,253 m<sup>3</sup> of water per capita annually. However, local water resources account for only 1,051 m<sup>3</sup> per person. By 2025, Azerbaijan is expected to have just 972 m<sup>3</sup> of local water per capita, making it one of the most water-scarce nations. Climate change, with projected temperature rises of 2–3°C, could lead to a 15% reduction in surface and groundwater resources over the next 50 years (İsmayilov & Suleymanov, 2024).

Climate change is driven by anthropogenic activities such as fossil fuel use, deforestation, and industrial growth, which contribute to the greenhouse effect and disruptions in local meteorological conditions (Hansen et al., 1996; Molina, 2012; Osman Yıldız, 2007; Pahl-Wostl, 2007; Ahouissoussi et al., 2014). Deforestation in the Caucasus, along with glacier and snow cover reduction, exacerbates these effects (Safarov et al., 2024). The impact of regional climate change has become an increasingly evident phenomenon in the country over the years. The rise in air temperature, particularly from the mid-1980s onward, has been observed at a rapid pace, leading to climate changes affecting all aspects of the region. The

analysis of CMIP9 model data provides a more detailed view of how this increase has developed over historical stages. Between 1901 and 1930, the average air temperature in Azerbaijan was 11.9°C. This increased slightly to 12.0°C from 1931 to 1960. However, the temperature rise became more significant between 1961 and 1990, reaching 12.2°C, marking a period when the effects of climate change were more noticeable. From the mid-1980s onwards, temperature increases accelerated. By 2024, the average air temperature had risen to 13.0°C, indicating a substantial intensification of regional warming.

Comparing the baseline period of 1961–1990 to 1991–2024, the air temperature increased by approximately 0.8°C, reflecting the heightened impacts of climate change. These changes have particularly affected agriculture, water resources, and biodiversity. Recent studies using the CMIP9 model show that while climate change has been gradual, the rate of temperature increase in recent years has been much higher. Between 2011 and 2024, the average temperature rose by 0.9°C compared to the 1981–2010 period, confirming the intensifying effects of climate change across the country.

These findings emphasize the need for proactive measures to mitigate future impacts. Changes in atmospheric precipitation have also been observed, with notable alterations in both the total amount and regional variations compared to previous periods. The uneven distribution of precipitation across different regions highlights the varying impacts on agriculture and other sectors throughout the country (Figure 2). These shifts in precipitation patterns further exacerbate the challenges posed by climate change, affecting water availability and crop yields in certain areas. The increase in temperature and uncertainties in precipitation patterns highlight the deepening effects of climate change in Azerbaijan. The rise in temperature, particularly during the summer months, amplifies the risk of drought, potentially reducing water resources and agricultural productivity. The changes in atmospheric precipitation underscore the need for updated approaches to water resource management. Climate change in Azerbaijan involves not only rising temperatures but also shifts in atmospheric conditions and the distribution of natural resources. It is crucial to implement measures to prevent or mitigate these changes.

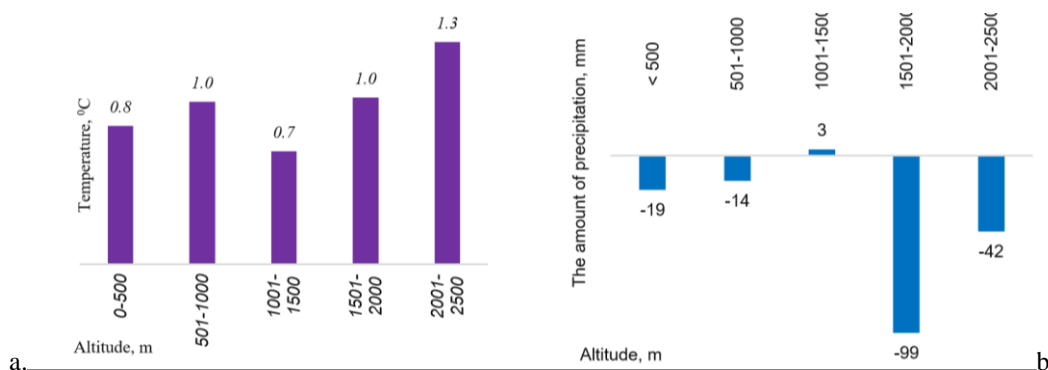


Figure 2. Temperature Anomaly (a) and Precipitation Amount Anomaly (b) by Elevation developed by the authors using statistical data from the State Statistical Committee of the Republic of Azerbaijan (<https://www.stat.gov.az/source/environment/?lang=en>)

In areas between 1501 and 2500 meters in elevation, where significant temperature increases were observed, there was a decrease in precipitation. Conversely, lower elevations experienced a slight increase in rainfall. This reveals a trend of decreasing precipitation with rising temperatures. Regional warming, increased evaporation, and reduced rainfall are contributing to an expanding drought risk. Between 2011 and 2024, the most significant temperature increases were recorded in the summer months of 2011–2022. Climate change is increasingly impacting Azerbaijan’s water resources. Reduced rainfall and its uneven distribution are lowering river levels, while the early melting of snow cover disrupts seasonal water patterns. As temperatures rise, water evaporation accelerates, increasing irrigation needs and depleting groundwater resources. These changes heighten pollution risks and complicate agricultural and drinking water supply, emphasizing the need for modern, sustainable water management solutions (Molden et al., 2010; Abbasov & Flores, 2023).

The analysis of water extraction from natural sources between 2000 and 2024, based on state water usage accounting, shows that the volume ranged from 9.91 to 13.03 km<sup>3</sup>. The highest volume of water extracted occurred in 2022, while the lowest was recorded in 2002 (Figure 3). On average, 11.7 km<sup>3</sup> of water was extracted annually over the past 24 years. This period saw an increase of 2.1 km<sup>3</sup> (19.8%) in the volume of water extracted from natural water sources.



Figure 3. Changes in the volume of water withdrawn from natural water sources (in km<sup>3</sup>), 2000–2024. (X-axis: Years (2000–2024); Y-axis: volume of water withdrawn (km<sup>3</sup>) developed by the authors using statistical data from the State Statistical Committee of the Republic of Azerbaijan (<https://www.stat.gov.az/source/environment/?lang=en>)

If the volume of water extracted from water sources continues at this rate, it is projected that by 2030, the volume will reach 12.35 km<sup>3</sup>, by 2040 it will be 12.82 km<sup>3</sup>, and by 2050 it will be 12.81 km<sup>3</sup> (Figure 4).

The analysis of water extraction from both surface water and groundwater sources reveals a noticeable trend over the multi-year period. Specifically, there has been a decrease in the amount of water extracted from surface water sources (Figure 5). Over this period, the volume of water withdrawn from surface water sources decreased by 0.08 km<sup>3</sup>, or 0.79%.

The same analysis was conducted for the volume of water withdrawn from groundwater sources. During the analysis, an increase in the amount of water withdrawn from groundwater sources over the multi-year period was observed (Figure 6). Over the average multi-year period, the volume of water withdrawn from groundwater sources increased by 2.03 km<sup>3</sup>.

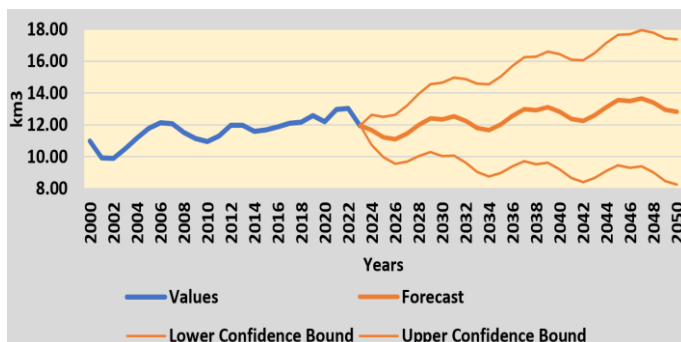


Figure 4. Projected changes in the volume of water withdrawn from natural water sources. (X-axis: years (2024–2050); Y-axis: projected volume of water withdrawal (km<sup>3</sup>)) developed by the authors using statistical data from the State Statistical Committee of the Republic of Azerbaijan (<https://www.stat.gov.az/source/environment/?lang=en>)

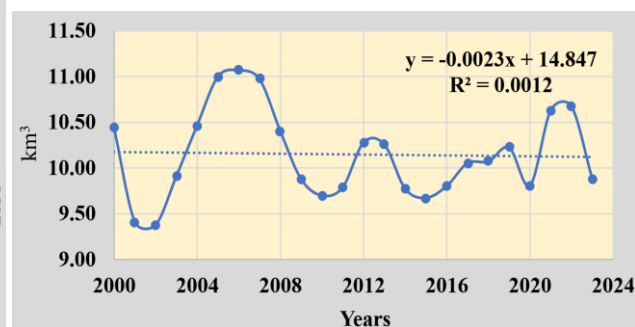


Figure 5. Changes in the volume of water withdrawn from surface water sources (2000–2024). (X-axis: Year; Y-axis: volume of water withdrawn (km<sup>3</sup>)) developed by the authors using statistical data from the State Statistical Committee of the Republic of Azerbaijan (<https://www.stat.gov.az/source/environment/?lang=en>)

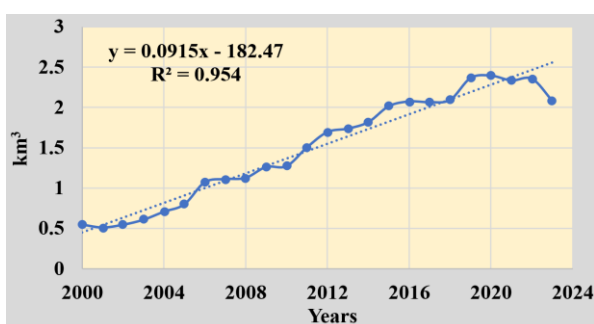


Figure 6. Changes in the volume of water withdrawn from groundwater sources (2000–2024). (X-axis: year; Y-axis: Volume of water withdrawn (km<sup>3</sup>)) developed by the authors using statistical data from the State Statistical Committee of the Republic of Azerbaijan (<https://www.stat.gov.az/source/environment/?lang=en>)

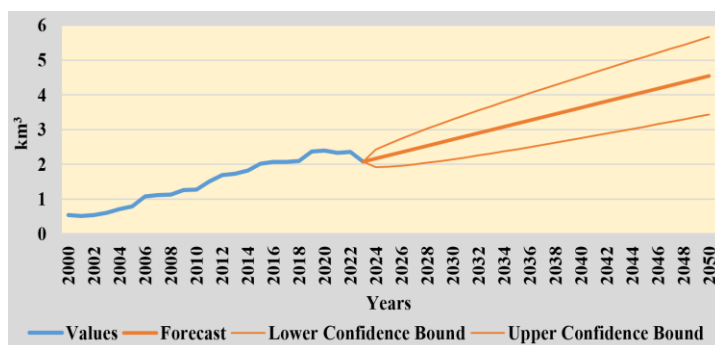


Figure 7. Forecast of changes in the volume of water withdrawn from groundwater sources (2000–2024). (X-axis: Year; Y-axis: projected volume of groundwater withdrawal (km<sup>3</sup>)) developed by the authors using statistical data from the State Statistical Committee of the Republic of Azerbaijan (<https://www.stat.gov.az/source/environment/?lang=en>)

The analysis of water extractions by sources indicates that the increase in the use of groundwater sources may lead to significant problems in the region's ecosystem in the future. As is well known, Azerbaijan's confirmed groundwater reserves amount to 4.38 km<sup>3</sup>. A forecast has been made regarding the changes in the volume of water extracted from groundwater sources (Figure 7). If groundwater extraction continues at the current rate, it is projected to reach 2.72 km<sup>3</sup> by 2030, 3.64 km<sup>3</sup> by 2040, and 4.55 km<sup>3</sup> by 2050. Overuse of groundwater could lead to ecological disasters, making it essential to prioritize surface water sources. Climate change is a major driver of global water resource depletion, with rising temperatures, altered precipitation patterns, and extreme weather events affecting the quality and quantity of freshwater sources. Projections for Azerbaijan suggest a 22.5% decrease in water resources by 2050 and 20.7% by 2100, primarily due to increased evaporation, reduced snow accumulation, and erratic rainfall (Douglas et al., 2000; UNDP/GEF, 2007; UNDP/GEF, 2013; Farda et al., 2015; Kreamer et al., 2015).

The water sector includes stages like collection, storage, delivery, and wastewater treatment (Ait Kadi, 2010; Ahmadov, 2020). Efficient water use, water-saving technologies, and reduced water losses are crucial for sustainable supply (Aliyev, 2008). Integrated water resource management (IWRM), involving policymakers, experts, and organizations, is essential for ensuring water security (Guliyev et al., 2016). Before 2023, water management in Azerbaijan was fragmented, leading to inefficiencies, outdated infrastructure, and high technical losses (Guliyev et al., 2024).

IWRM was endorsed at the 1992 UN Conference on Environment and Development and further emphasized at international conferences in Dublin and Rio de Janeiro (Smith & Brown, 2020). In response, the Global Water Partnership (GWP) was established in 1996 to support IWRM (GWP, 2000). The Azerbaijan State Water Resources Agency, established

in 2023, centralizes water management, improves resource evaluation, and coordinates infrastructure modernization. It also promotes fair water distribution, enhances transparency, and supports international cooperation on transboundary waters.

To effectively manage water resources, IWRM based on the basin principle is crucial, particularly given climate change (Gleick, 2000; Farda et al., 2015). This approach ensures unified management, reduces water losses, and supports sustainable water supplies for agriculture and drinking. The basin principle strengthens intersectoral coordination and community involvement, forming the foundation for sustainable water policy (Pasha et al., 2023; İsmayılov & Suleymanov, 2024). The hydrological zoning model proposed by Rustamov (1960) is based on river basins, utilizing the 10 basins shown in Figure 8, which allows for the individual analysis of each basin's hydrological characteristics and an overall distribution.

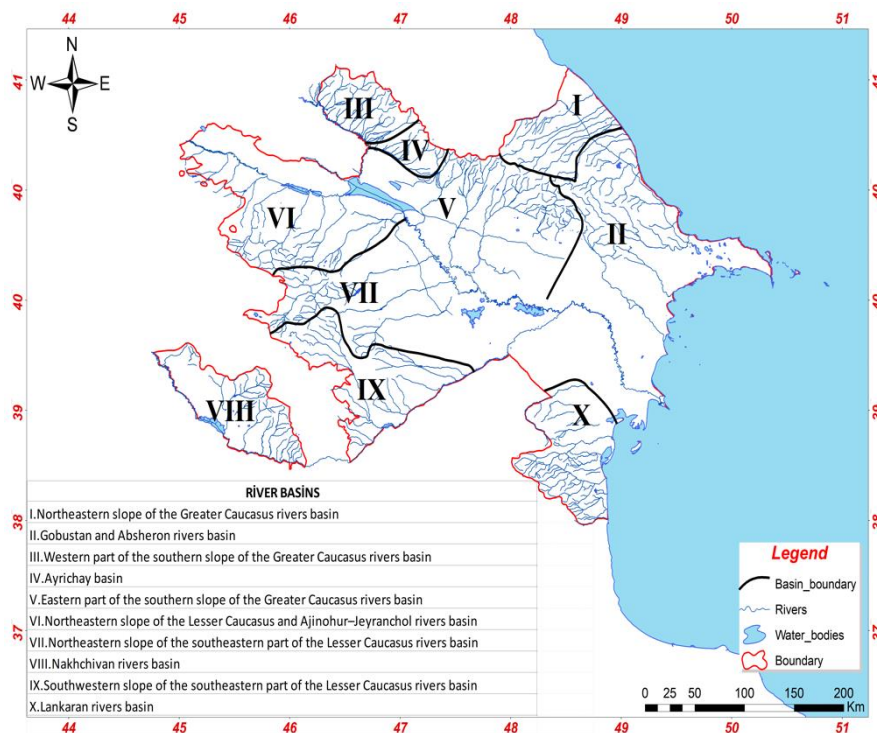


Figure 8. Proposed River basins for integrated water resource management. (Adapted from Rustamov, 1960)

Ensuring water security in Azerbaijan requires unified management of river basins through integrated water resource management (IWRM), which monitors all water sources and involves stakeholders in decision-making. IWRM aims to balance water use with ecosystem sustainability, enhancing economic and social welfare. It focuses on coordinating water, land, and resource management for efficient use. Key challenges include transboundary water issues and managing resources in newly liberated territories. Azerbaijan aligns with the Helsinki Convention for basin-wide planning and ecosystem protection, though cooperation with Georgia and Iran on the Kura and Araz basins is hindered by political barriers. Integrated transboundary management could improve water quality, reduce drought and flood impacts, support ecosystems, and reduce Caspian Sea pollution (Neafie et al., 2025).

## DISCUSSION

The findings of this study highlight the complex and diverse challenges related to water security in Azerbaijan. Various factors contribute to these difficulties, making the issue multifaceted. Addressing water security in the country requires a comprehensive and integrated approach. These challenges are becoming increasingly complex and intertwined, driven primarily by the compounded impacts of climate change, rapid population growth, and long-standing unsustainable water use practices. The analysis clearly demonstrates that Azerbaijan's water resources are under severe and growing pressure. Notably, the country is already experiencing significant water scarcity, with annual shortages averaging 3.7 km<sup>3</sup> in typical years and escalating up to 4.75 km<sup>3</sup> during dry periods. This level of scarcity is alarming, considering the critical role that water plays not only in human consumption but also in agriculture, industry, and ecosystem services.

A key dimension of Azerbaijan's water security predicament is its high dependence on transboundary rivers, which contribute over 70% of the surface water resources. This dependency introduces a complex geopolitical layer to water management, as the quality and quantity of water flowing into Azerbaijan are often influenced by upstream activities in neighboring countries. The study highlights that the water quality upon entry is already degraded, which not only reduces the usable water volume but also increases treatment costs and health risks for downstream users. This situation necessitates robust diplomatic engagement and cooperative water governance frameworks at the regional level to ensure equitable and sustainable management of these shared resources. Without such cooperation, Azerbaijan remains vulnerable to upstream pollution, water diversion, and unilateral resource exploitation, all of which could exacerbate domestic water insecurity. Climate change acts as a multiplier of existing stresses on water resources. The study's projections and

observations reveal that increasing temperatures and changing precipitation patterns are intensifying water stress by accelerating evaporation rates and disrupting the timing and quantity of seasonal snowmelt, which traditionally replenishes river flows. These climatic shifts not only reduce the volume of water available during critical periods but also increase variability and unpredictability, complicating water planning and management efforts. In particular, the highland regions, which serve as natural water towers, are experiencing pronounced anomalies in temperature and precipitation, thus demanding region-specific adaptation strategies. These shifts threaten agricultural productivity, energy generation from hydropower, and the livelihoods of communities dependent on stable water supplies. Groundwater resources have historically acted as an important buffer during surface water shortages, especially in arid and semi-arid areas of Azerbaijan. However, the study highlights a concerning trend: projected groundwater extraction is likely to surpass confirmed reserves by 2050 if current consumption trajectories continue unchecked. This overexploitation risks severe ecological consequences, including aquifer depletion, land subsidence, and deterioration of water quality due to increased salinization and contamination.

Sustainable groundwater governance, therefore, becomes critical—not only to preserve these reserves for future generations but also to maintain ecosystem health and prevent irreversible damage. Policies need to balance groundwater use with recharge rates, while incorporating technological solutions such as artificial recharge and improved irrigation efficiency.

The institutional response to these challenges, as reflected by the recent establishment of the Azerbaijan State Water Resources Agency in 2023 and the adoption of the "National Strategy for the Efficient Use of Water Resources (2024–2040)," represents significant progress. These developments indicate a move toward more centralized and integrated water management approaches, which are crucial given the fragmented nature of water governance historically. Nonetheless, the success of these initiatives hinges on consistent political commitment, effective coordination across various sectors—including agriculture, energy, environment, and urban planning—and substantial investment in modern water-saving technologies and infrastructure. Moreover, transparency and public participation are essential to foster trust and ensure that policies are responsive to local needs. This study further emphasizes the indispensable role of Integrated Water Resource Management (IWRM), particularly under the basin principle, in ensuring sustainable water security in Azerbaijan.

Implementing IWRM involves a holistic reassessment of water resources within the context of evolving climate scenarios, improved monitoring through modern data collection technologies, and active stakeholder engagement at multiple levels—from local communities to transboundary water commissions. Such an approach facilitates adaptive management that can respond to emerging challenges dynamically rather than relying on static policies. The spatial and temporal irregularities in temperature and precipitation patterns, especially in mountainous and upland areas, call for tailored regional interventions that consider the unique hydrological and socio-economic contexts. Beyond infrastructural and technical measures, the study highlights the critical importance of raising public awareness and education on water conservation and climate resilience. Engaging society at large helps build a culture of responsible water use and supports behavioral changes necessary for sustainability. Furthermore, fostering strong international cooperation remains vital, particularly given Azerbaijan's reliance on transboundary water bodies. Multilateral agreements, joint monitoring programs, and conflict resolution mechanisms will be crucial for ensuring that water resources are managed equitably and sustainably in the face of increasing climate variability. In summary, Azerbaijan's future water security rests on a multifaceted and balanced approach that integrates ecological sustainability, technological innovation, institutional reform, and societal engagement. Addressing the complex and interconnected water challenges requires not only robust policies and investments but also a commitment to cooperative governance at both national and regional scales. Only through such comprehensive strategies can Azerbaijan build resilience against the mounting pressures of climate change, population growth, and economic development, securing water for its people and ecosystems for decades to come.

## CONCLUSIONS

Climate change presents increasingly complex and serious challenges for Azerbaijan's water security. Rising temperatures, altered precipitation patterns, increased evaporation, and the retreat of glaciers are contributing to a measurable decline in water availability across the country. These pressures are exacerbated by Azerbaijan's dependence on transboundary water sources—over 70% of which originate outside the country—many of which enter in a polluted state, reducing usable water volumes and increasing treatment burdens. Combined with outdated infrastructure, growing demand, and inefficient water use, the country faces mounting stress on both surface and groundwater resources.

To ensure Azerbaijan's water security, the following measures are essential:

- **Re-evaluation of Water Resources:** Given that over 30 years have passed since the last comprehensive assessment, it is crucial to reassess Azerbaijan's water resources, taking into account their distribution by river basins, regional availability, and assurance years. This reassessment is critical for supporting sustainable and sector-specific water management.
- **Protection of Water Sources and Pollution Reduction:** Water pollution poses a major threat to environmental and public health. Enhancing wastewater treatment, implementing effective pollution control measures, and improving the protection of water basins are key to preserving water quality.
- **Promotion of Efficient and Sustainable Water Use:** Reducing water losses, adopting rational water use models, and expanding the application of water-saving technologies are essential for long-term sustainability and intergenerational equity.
- **Strengthening National and International Cooperation:** Building strong partnerships with international organizations and fostering regional cooperation, especially for shared transboundary water resources, will be vital in mitigating water conflicts and managing climate-driven challenges.
- **Raising Public Awareness:** Promoting water conservation through education and public engagement is critical. Integrating water sustainability topics into school curricula and community programs can help build a culture of responsible water use.

In conclusion, ensuring water security in Azerbaijan requires a comprehensive, scientifically grounded, and adaptive approach. It must integrate technical innovation, institutional reform, cross-border diplomacy, and active public participation. Only through coordinated and sustained efforts can the country effectively manage its water resources, safeguard public and environmental health, and build resilience against the long-term impacts of climate change.

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