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Management Institute

KAZAKHSTAN'S WATER SECURITY:

Current Challenges and Future Alternatives

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KAZAKHSTAN'S WATER SECURITY: CURRENT CHALLENGES AND FUTURE ALTERNATIVES

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This analytical report was prepared by the Kazakhstan Institute for Strategic Studies under the President of the Republic of Kazakhstan with reviewed support from the International Water Management Institute (IWMI). The report presents an analysis of the current state of Kazakhstan's water security and examines the contemporary challenges facing the country in the water sector. Particular attention is paid to strategic directions for strengthening water sustainability, including improving the management system, modernising infrastructure, developing monitoring systems and adapting to climate change. The report's findings are of practical interest for the development of long-term solutions in the field of water policy and sustainable development.

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CONTENTS

SYMBOLS AND ABBREVIATIONS

BNS	Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan
UNDP	United Nations Development Programme
FAO	Food and Agriculture Organization of the United Nations
WB	World Bank
OECD	The Organisation for Economic Co-operation and Development
AIC	Agricultural sector
WHO	World Health Organization (WHO)
GIZ	German Society for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit) GmbH
UNDRR	United Nations Office for Disaster Risk Reduction
RK	Republic of Kazakhstan
MWRR RK	Ministry of Water Resources and Irrigation of the Republic of Kazakhstan
GDP	Gross Domestic Product
IWMI	International Water Management Institute (IWMI)
WRI	World Resources Institute

FOREWORD AND ACKNOWLEDGEMENTS

The report was prepared on the occasion of the Regional Environmental Summit held in Astana in April 2026 an international platform aimed at developing joint practical solutions to climate and environmental challenges, bringing together a wide range of countries, regions, and partners, and demonstrating, through the example of Central Asia, how interregional cooperation can enhance global efforts.

The report examines the key challenges facing Kazakhstan's water sector, including the growing water scarcity, climate change, transboundary risks, and the need to transition to sustainable water management models. In the current context, the water issue has become broader than mere scarcity; it lies in the instability of the system, where increasing uncertainty reduces governance capacity. The main conclusion is that ensuring Kazakhstan's water security under heightened uncertainty requires a systemic transformation of water resource management. At the same time, the state's strategic task is to establish a flexible system capable of functioning under elevated risks.

The material was prepared with reviewed support from the International Water Management Institute a leading international research organization specializing in sustainable water resources management.

The team of authors included staff from the Kazakh Institute for Strategic Studies under the President of the Republic of Kazakhstan – Asel Aben, Chief Expert of the Economic Policy Analysis Department at KazISS, and Zholdaskazy Zamira, Chief Expert of the Economic Policy Analysis Department at KazISS, as well as reviewers from The International Water Management Institute (IWMI).

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INTRODUCTION

Water security in the Republic of Kazakhstan is a systemic category of sustainable development and encompasses not only the physical availability of water resources, but also the reliability of water supply, water quality, the resilience of aquatic and coastal ecosystems, as well as the institutional predictability of management. According to the approach of the International Water Management Institute (IWMI), water security should be viewed through the prism of risks affecting economic growth, public welfare and environmental sustainability; the focus is on resilience to extreme hydrological events, equitable resource distribution and the capacity of institutions to ensure coordinated management under conditions of uncertainty.

Global trends are heightening the importance of the water agenda. According to forecasts, global water demand will increase by 20-25% by 2050, and the number of river basins facing high variability and reduced predictability of water supply will rise. According to the World Resources Institute (WRI), Kazakhstan is among the regions facing high levels of water stress over the next 15-20 years. International assessments also indicate that the absence of more effective water management strategies could lead to significant macroeconomic losses in a number of regions worldwide, including Central Asia, by 2050.

Against this backdrop, Kazakhstan's public policy is focused on improving the manageability of the water sector, reducing losses and strengthening resilience to the risks of water scarcity and extreme events. This report outlines the general contours of this policy, its key objectives, directions and strategic steps, which form the basis for the transition to a managed water system, taking into account internal constraints and external challenges.

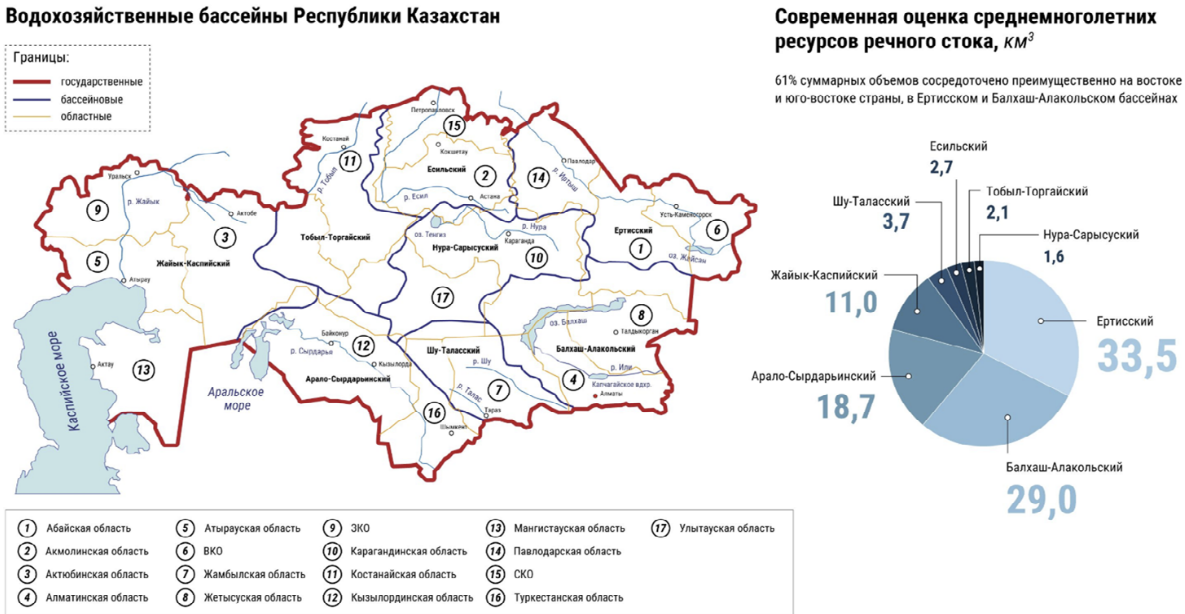
1. CURRENT CHALLENGES

1.1. NATIONAL CHALLENGES

GENERAL SITUATION

There are eight river basins in Kazakhstan: the Aral-Syr Darya, Balkhash-Alakol, Irtysh, Esil, Zhayik-Caspian, Nura-Sarysu, Tobol-Torgay and Shu-Talas (Figure 1). Total resources consist of local river waters formed within the country and transboundary river waters flowing in from neighboring countries.

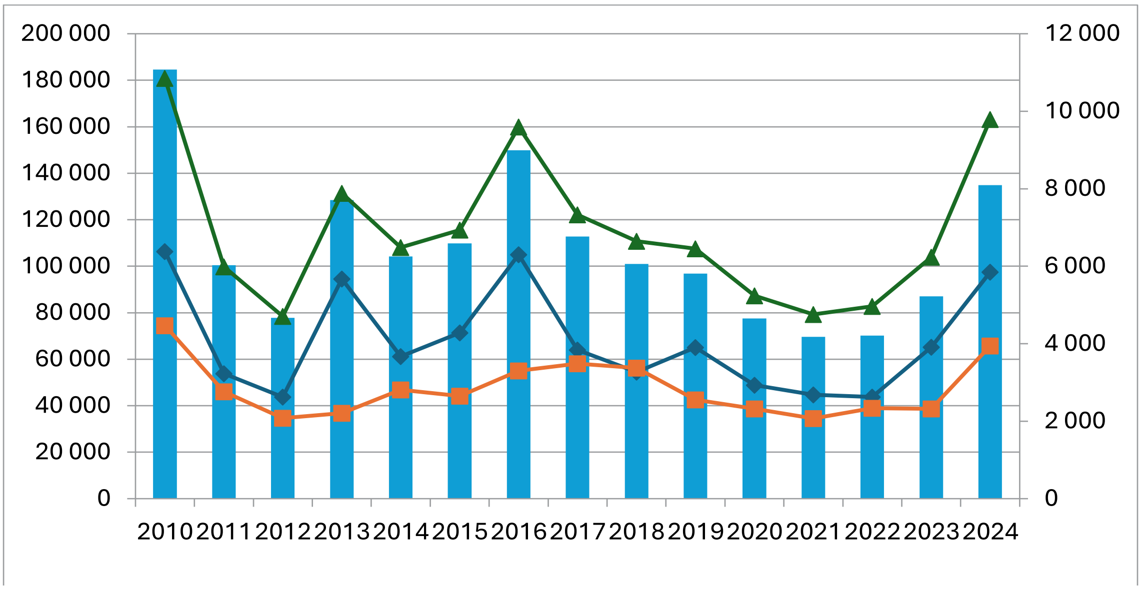
Figure 1. Water management and administrative zoning of the territory of the Republic of Kazakhstan



Source: Institute of Geography and Water Security of the Ministry of Science and Education of the RK

Kazakhstani water resources experts predict a further reduction in river flow from neighbouring countries [1]. The Concept for the Development of the Water Resources Management System of the Republic of Kazakhstan for 2024-2030 notes that, according to preliminary forecasts, the water balance up to 2030 is expected to see a reduction in domestic river flow resources from 106 km³to 104 km³³)due to a reduction in inflow from neighbouring countries from 50.8 km³to 46.4 km³. At the same time, an increase in locally generated resources is anticipated. This increase in local resources is due to the accelerated rate of glacier melt. However, as the area of glaciers shrinks, this flow will decrease [2]. Figure 2 below presents data illustrating the dynamics of renewable freshwater resources in the country over the last 15 years.

Figure 2. Renewable freshwater resources (annual river flow resources) by year, million m³(left axis), renewable freshwater resources per capita in m³(right axis).



Source: National Statistics Bureau of the Republic of Kazakhstan // https://stat.gov.kz/ru/climate-change/impact/

According to the graph, between 2010 and 2024, Kazakhstan's renewable freshwater resources fluctuated extremely unevenly. The highest values were observed in 2010, 2016 and 2024, whilst the lowest were in 2012 and during the period 2020-2022. The main factor driving inter-annual variability was domestic inflow, whilst external inflow from neighbouring countries played an important but less volatile role. Overall, the trends demonstrate a greater dependence of the country's water supply on the hydro-climatic conditions of a specific year and point to the need to manage the water system with a view to adapting to fluctuations, rather than merely to average values.

WATER SECURITY ISSUES

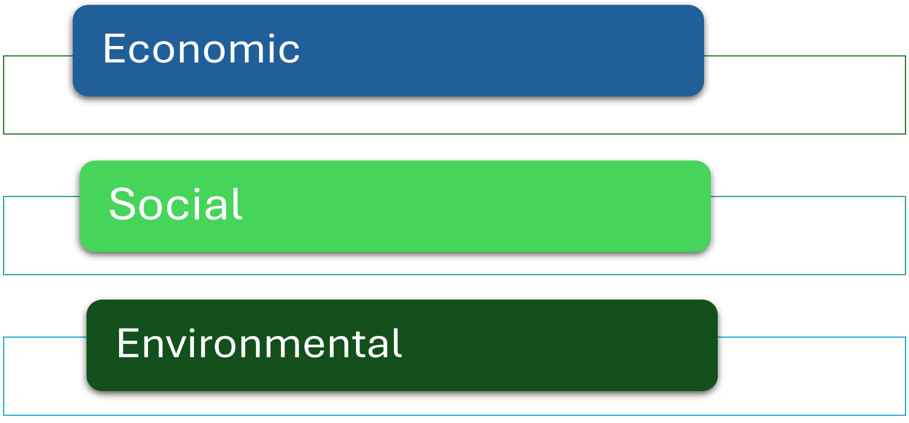
Ensuring water security is one of the fundamental components of a country's national security and the foundation of its economic stability. Water security concerns not only the availability of sufficient water, but also encompasses all other water-related issues.

According to the provisions of the new Water Code of the Republic of Kazakhstan, adopted in 2025, ensuring water security is defined as a priority state task. This concept is interpreted as the state of protection of the population and the national economy from threats caused by a shortage of resources, their inadequate quality, and the harmful effects of water [3]. In practice, the country's water security framework is based on three key elements:

- the availability of the necessary volume of water;
- maintaining its quality standards;
- engineering protection of territories against natural disasters.

Together, these form **the three dimensions** of water security: economic, social and environmental (Figure 3).

Figure 3. The three dimensions of Kazakhstan's water security



Source: compiled by the authors based on the Water Code of the RK, 2025.

Failure to maintain a balance between these elements leads to measurable risks that directly affect the sustainability of national development, public welfare and the conservation of natural ecosystems. This stems from the contemporary paradigm of water security, supported by international institutions such as UN-Water, the OECD and IWMI, which is based on a triad of objectives: ensuring sustainable economic growth, supporting the social well-being of the population and preserving the ecological integrity of natural systems.

ECONOMIC RISKS

Water scarcity imposes long-term constraints on a country's economic growth, investment attractiveness and sustainable development. Water is a factor of production and an infrastructural resource on which the functioning of all economic activity depends. In the face of shortages and high inter-annual variability in water flow, economic losses arise both through a direct reduction in output and through increased costs for water supply, technological adaptation and mitigation of social impacts. According to World Bank estimates, due to low water use efficiency (6-8 times below global standards), the country is already losing around **1.5% of GDP annually.** By 2030, this gap will become critical for industrial zones due to infrastructure deterioration [4].

The agro-industrial sector is the largest consumer of water (60-70%) and is most sensitive to seasonal restrictions and shortages during the growing season. A lack of irrigation water during the growing season directly leads to **lower crop yields**. In recent years, grain production has remained below average due to alternating droughts and excessive rainfall [5].

In southern Kazakhstan, according to government data, the projected inflow for the 2026 growing season is estimated at just 1-1.5 billion cubic metres. This creates a risk of an irrigation water deficit of up to 1 billion cubic metres [6]. At the macro level, this exacerbates the volatility of food supply and pressure on food prices, and increases the need for support measures for farmers and compensation mechanisms during drought years. In the long term, water constraints necessitate a review of crop patterns, accelerated modernization of irrigation, and a shift towards water-saving technologies.

According to a World Bank report, water resources, including groundwater, in the Atyrau and Mangistau regions are under significant or severe stress [7]. This suggests that water scarcity and water stress can exacerbate water security risks and act as one of the factors holding back further industrial development in the regions. In water-scarce basins, water availability becomes a constraint on the launch of new facilities, the expansion of existing production, and the implementation of investment projects. When water supply is insufficiently predictable, investment risk increases and the competitiveness of water-intensive industries declines.

The accumulation of infrastructure debt leads to an increase in the accident rate, higher repair costs and a decline in service quality. The modernization of networks and treatment facilities requires significant capital investment and necessitates the coordination of tariff policy and budgetary contributions. It is estimated that the economic consequences of inadequate water supply and sanitation cost the country US $750 million per year. These costs exceed the investment required to address gaps in water supply, sanitation and hygiene by approximately US $500 million [7].

The uneven distribution of water resources across Kazakhstan exacerbates **inter-regional disparities** in economic growth potential. Water availability is becoming a key indicator of regional competitiveness, influencing the location of industries, the development of urban agglomerations and the cost of infrastructure projects. Increasing droughts in the southern regions and the drying up of rural areas will lead to a flow of human capital to 'water-rich' regions. Crop failures and migration from rural areas to cities may exacerbate economic instability.

Declining water availability and increasing climate uncertainty heighten the frequency of supply shocks in agriculture, raise costs for industry and the energy sector, and increase the need for government investment in infrastructure. Without transparent accounting and a managed water balance, there is an increased risk of inefficient resource allocation, underfunding of critical infrastructure and the accumulation of hidden liabilities.

SOCIAL RISKS

Water directly affects the population's quality of life, health, social stability and the country's territorial connectivity. Insufficient or unstable water supply, poor drinking water quality and an increase in the frequency of extreme hydrological events create social risks, which manifest themselves through a deterioration in the sanitary and epidemiological situation, increased vulnerability of households and growing inequality between regions and types of settlements.

Guaranteed access to safe drinking water is a key social indicator of water security. According to data from the Ministry of Industry and Construction of the Republic of Kazakhstan, 99.3% of the urban population and 97.5% of the rural population have access to water supply services [8]. At the same time, access specifically to the centralised water supply remains significantly more uneven: according to World Bank estimates, 94% of the urban population and 63% of the rural population have access to piped water, indicating a persistent infrastructure gap between urban and rural areas [7]. Under these conditions, some rural settlements continue to rely on decentralised forms of water supply. The issue of achieving 100% coverage of the population with drinking water remains relevant due to population growth and the annual wear and tear of water supply networks [9].

Despite the high level of coverage by centralised water supply in towns, rural settlements remain more vulnerable to disruptions, poor water quality and a lack of infrastructure. To bridge this gap, significant government investment is required in rural water supply networks, local treatment systems and sanitary monitoring. According to data from the Ministry of Industry and Construction, as part of the National Project for the Modernization of the Energy and Utilities Sectors, 1.9 trillion tenge in investment is planned for water supply and sanitation systems [10].

Sanitation lags behind, and the majority of the population (97.9%) has access only to basic sanitation facilities, whilst only 37% of the population is connected to sewerage systems. Sanitation is particularly underdeveloped in rural areas, where less than 2% of the population is connected to sewerage systems, and less than 2% of wastewater is treated.

Water quality affects the pattern of disease incidence and the burden on the healthcare system. According to data from the National Centre for Public Health of the Ministry of Health of the Republic of Kazakhstan, high levels of mineralization (up to 1.5-2.0 g/l) and the presence of heavy metals in the transboundary basins of the Urals and Syr Darya correlate with an increase in the incidence of digestive and kidney diseases among the population in the lower reaches. The social cost of poor water quality is higher in regions with limited access to healthcare services and among vulnerable population groups.

Inadequate treatment and monitoring increase the risk of microbiological contamination, excessive mineralization and elevated levels of certain chemical components, resulting in direct and indirect losses. By the end of 2025, the Ili, Irtysh, Ilek, Saryozen and other rivers were classified as third-class polluted. The Tobol, the tributaries of the Ishim and the Ilek were classified as Class 4 (polluted rivers). The Tobol and Ubagan were classified as having a high level of pollution. The Emel River, which flows from China, was recognised as the most polluted [11].

Droughts and floods result in direct social losses. Droughts lead to a reduction in rural household incomes, the loss of livestock , a deterioration in living conditions in rural areas, and an increased need for targeted support. Floods cause evacuations, damage to housing and infrastructure, and disruptions to access to water, electricity and social services. The increasing frequency of extreme events places greater demands on the preparedness of local authorities and on the resilience of early warning and response systems.

ENVIRONMENTAL RISKS

The environmental component of water security determines the state of aquatic ecosystems, the quality of natural resources and the long-term capacity of river basins to support the population and the economy. Deterioration of the hydrological regime, degradation of water quality and disruption of ecological flows lead to a decline in biodiversity, degradation of floodplain and delta ecosystems, increased desertification and a deterioration of natural conditions in vulnerable regions. The environmental consequences of water scarcity exacerbate economic and social risks.

A key environmental risk is linked to the reduction in available flow and the transformation of the hydrological regime of transboundary rivers. In conditions of water scarcity, the likelihood of a deterioration in the ecological condition of river and delta ecosystems increases, as reduced flow limits their ability to sustain the functioning of floodplains and wetlands. For the Zhayik (Ural) river basin, which feeds the ecosystems of the north-eastern Caspian Sea, this problem is of particular significance. One of the factors driving this process is the regulation of flow by reservoirs in the upper and middle reaches of the river within the territory of the Russian Federation. Combined with anthropogenic pressure and climate change, this poses serious risks to hydro-ecological security and the sustainable development of the natural-economic system of Western Kazakhstan [12].

For Kazakhstan, processes of salinization and land degradation linked to the water regime and inefficient irrigation and drainage practices are of significant importance. Excessive or irrational water use, high mineralization in certain basins and inadequate drainage infrastructure lead to salt accumulation, reduced soil fertility and decreased land productivity. Diffuse inputs of fertilisers and pesticides exacerbate the pollution of surface and groundwater and increase the risk of long-term deterioration in resource quality.

Reduced inflow and changes in water use patterns lead to the degradation of delta systems, a reduction in the area of wetlands and a decline in biodiversity. The deterioration of such ecosystems reduces their natural functions of regulating the water regime, filtering pollutants and maintaining the microclimate, which increases the vulnerability of these areas to droughts and floods.

Environmental degradation affects large tracts of irrigated land prone to salinization, which reduces agricultural productivity and necessitates a review of water management regimes. Around 75% of Kazakhstan's territory is subject to desertification and degradation to a greater or lesser extent. According to data on land quality in the Republic of Kazakhstan, there are over 90 million hectares of eroded and erosion-prone land, of which 29.9 million hectares are actually eroded [13]. Bringing abandoned irrigated land back into use under the EDB experts' moderate scenario will require around $75-150 million in investment per year, and for the period up to 2030 this will amount to $900 million, or approximately $128 million per year [14].

The condition of hydraulic structures and treatment infrastructure directly affects the environmental parameters of water security. Insufficient capacity and wear and tear of treatment facilities increase the discharge of pollutants. Inefficient drainage systems exacerbate salinization and water pollution. A lack of monitoring of evaporation, water quality and the condition of water bodies reduces the ability to identify environmental threats in a timely manner and adjust water use regimes.

Biodiversity loss affects all river basins, having a widespread impact on riparian areas. Increasing anthropogenic pressure and declining biodiversity in river basins lead to a deterioration in the quality of water resources and a reduction in their actual availability, increasing the costs of water treatment for the economy and heightening risks to public health.

Environmental aspects are still insufficiently addressed. In most studies of the relationship between water resources and the environment, environmental issues are either not taken into account or are considered with insufficient precision. Future research should prioritize environmental aspects and examine soil health issues within the context of the relationship between water resources and the environment [14,15].

1.2. OUTLINES OF EXTERNAL CHALLENGES

THE ARAL SEA BASIN

The water crisis extends beyond the scope of national policy. Kazakhstan's future development depends on the policies of neighbouring states with which the waters of the transboundary **Syr Darya and Amu Darya rivers** are shared in the southern part (Figure 4). According to EDB estimates, the Central Asian region will face a water deficit of 5-12 million m^3annually from 2028-2029 [14]. Central Asian states are expressing serious concern about the impending shortage, as this has profound implications for socio-economic development both within the states themselves and across the region as a whole.

Central Asia's water supply depends to a large extent on the flows of two major rivers, which are fed by the glaciers of the Pamir and Tien Shan ranges. Glaciologists have noted a significant reduction in glacier cover, resulting in a less predictable hydrological regime for the rivers, which increases the long-term risks of water scarcity. Over the past 50-60 years, the region has lost 14-30% of its glaciers, and the period 2022-2024 has seen the largest three-year loss of glacial mass in recorded history [16]. Glacier retreat increases short-term risks, damages the economy and ecosystems, and threatens long-term water security.

However, the problem stems not only from a decline in the resource base against the backdrop of climate change, but also from low water-use efficiency. Experts at the New Lines Institute, an international analytical center, note that over the past 40 years, per capita freshwater availability in Central Asia has fallen by more than threefold – from 8,400 to 2,500 m^3 per year. According to their assessment, this elevates the water deficit to the category of direct risks to the region's economy. The reduction in available resources against a backdrop of rising water consumption exacerbates water stress, particularly in agriculture and the energy sector, and requires prompt, comprehensive measures [17].

According to World Bank estimates, more than 37 million people (49% of the population) in Central Asia live in areas with acute water scarcity. By 2050, 75 million people will be living in areas with high levels of water scarcity, linked primarily to population dynamics, as well as to water consumption and water availability [18]. According to estimates by international institutions, the water and energy sectors of Central Asia require additional investment of US$90 billion for infrastructure development between 2021 and 2030 [19].

Figure 4. The Aral Sea basin.

Source: https://ecifas.kz/drugie-resursy/basseyn-aralskogo-morya

Currently, the economies of Central Asian countries are demonstrating high resilience and upward momentum. By the end of 2025, the region's GDP growth averaged 6.2-6.6%, with the figures for each country distributed as follows: Kyrgyzstan – 11.1% (regional leader), Tajikistan – 8.4%, Uzbekistan – 7.7%, Kazakhstan – 6.5% and Turkmenistan – 6.3%. According to World Bank estimates, the forecast for 2026 is expected to be 5.0% for the region, with a subsequent decline to 4.6% in 2027.

At the same time, existing power generation capacity in Central Asia does not yet fully meet the growing demands associated with economic growth, and simultaneously requires modernization to meet CO_2 emission reduction targets. All this is taking place against the backdrop of an impending water shortage. According to World Bank estimates, by 2050 the water shortage could trigger a 6-11% decline in regional GDP.

Currently, some Central Asian states face yet another challenge originating from Afghanistan due to the construction of the Kosh-Tepa Canal. The situation is described as 'transboundary impacts without a transboundary mechanism'. Experts warn that the canal could reduce water supplies; the canal is capable of diverting up to 15-20% (depending on the season – up to 30%) of the river's flow, which will create a water shortage for Uzbekistan and Turkmenistan. This, in turn, will force neighboring countries to review water allocation limits on the Syr Darya, which will directly affect Kazakhstan's interests [20].

As scientists note, the rapid construction and Afghanistan's unwillingness to negotiate the project with its neighbors threaten to disrupt the fragile balance of water security in the region. This intervention risks triggering a cascade of political, environmental and socio-economic problems, with potential consequences as serious as the Aral Sea crisis [21].

At the same time, cross-border cooperation faces significant obstacles. The current system of cross-border water uses in Central Asia, which relies on the mechanisms of the Interstate Water Coordination Commission (IWCC), faces a number of systemic challenges in the current context. Despite the existence of basic agreements, the current model requires adaptation to changing climatic and economic realities. In the absence of flexible and legally sound regulations that take into account glacial retreat and population growth, current water-sharing mechanisms may become less effective in the long term, posing risks to the region's long-term water security. In these circumstances, it becomes critically important to transition to the full application of the norms of international water law, which can transform existing agreements into legally binding regulations.

It is worth noting that Kazakhstan, Uzbekistan and Turkmenistan are parties to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Helsinki, 17 March 1992). Kyrgyzstan and Tajikistan have not yet acceded to the Convention on Transboundary Waters. In 2024, Kazakhstan also acceded to the UN Convention on the Law of Non-navigational Uses of International Watercourses, which sets out measures for the construction of hydraulic structures.

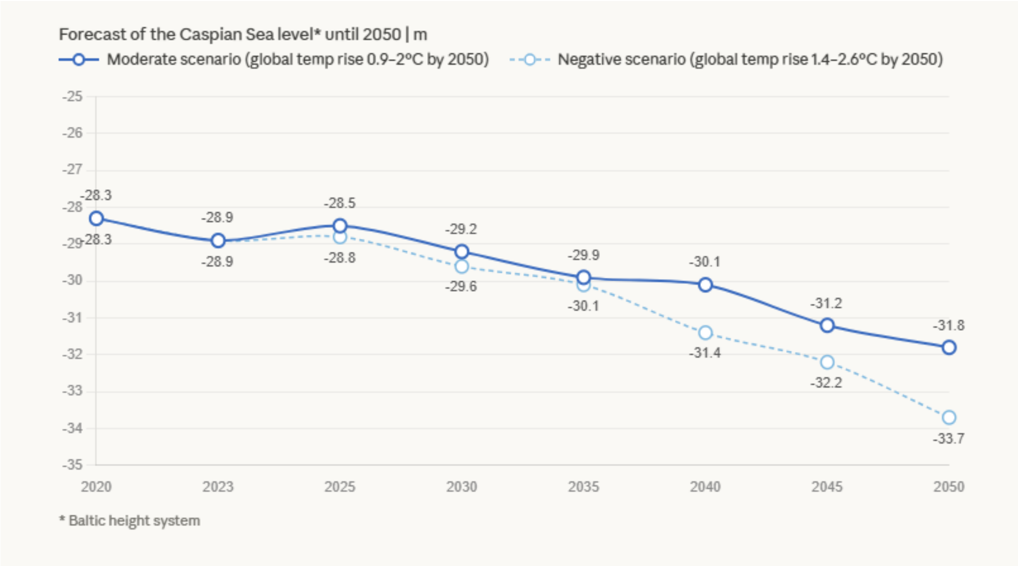
THE CASPIAN SEA

In western Kazakhstan, the Caspian Sea is a strategic asset of national importance, serving simultaneously as a key energy reservoir, a vital logistics hub and a unique ecosystem. The Caspian Sea, rich in natural resources such as oil and gas, is vulnerable to climate change and fluctuations in water levels. As the country's sole access to international sea routes, the Caspian Sea ensures the functioning of the Trans-Caspian route (Middle Corridor) and serves as the foundation for strengthening Kazakhstan's economic sovereignty and diversifying its export flows.

According to observations, the average level of the Caspian Sea in 2025 was approximately minus 29.35 m on the Baltic height system, confirming the continuing decline in sea level. According to estimates released by the Ministry of Ecology and Natural Resources of the Republic of Kazakhstan, under an optimistic climate scenario, the sea level could fall to – 29.8 m by 2030 and to – 32.4 m by 2050, and under a pessimistic scenario, to – 30 m and – 34 m respectively (Figure 5) [22].

The process of the Caspian Sea's shallowing is transforming from an environmental challenge into a critical barrier to the development of an international transport route. Forecasts of a drop in water levels by the end of the century pose strategic risks to the implementation of Kazakhstan's trade initiatives, as the current shallowing already limits the loading of vessels at the port of Aktau to 75% of their design capacity. A sustained decline in the Caspian Sea level creates a range of environmental and economic consequences for the country.

Figure 5. Forecast of the Caspian Sea level up to 2050, m.



Source: Ministry of Water Resources and Irrigation of the RK, adapted from https://energyprom.kz/

Climate change issues also center on the security of oil and gas infrastructure. Security risks are assessed as low to medium in the short to medium term. Long-term climate change and security risks remain uncertain due to the lack of reliable models and knowledge regarding fluctuations in the Caspian Sea level in the context of global climate change.

For Kazakhstan, this trend poses a complex threat requiring constant capital investment in dredging works and the adaptation of port infrastructure to a changing coastline. Thus, a sustained decline in the Caspian Sea level by 2050 is directly linked to the region's long-term investment attractiveness and its effectiveness as a key logistics hub between East and West.

The Zhayik River (Ural) is another important transboundary river, representing a vital source of water for industrial purposes. Cooperation with Russia is conducted under the 2010 Agreement on the Joint Use and Protection of Transboundary Water Bodies. However, both countries currently face certain challenges. Firstly, changes in hydrological conditions require a review of the monthly water supply volumes set out in the document. Secondly, the increase in anthropogenic pressure on the river, including industrial discharges and agricultural runoff, threatens water quality. In 2024, the nitrate content in the Zhayyk River in the Atyrau region exceeded the standard by 0.03 milligrams per litre, requiring additional treatment measures [23]. The joint efforts of the two countries in the areas of monitoring, infrastructure modernization and the introduction of new technologies demonstrate the potential for further strengthening cooperation in ensuring water security.

THE BALKHASH LAKE BASIN

In south-eastern Kazakhstan, the Ili-Balkhash Basin plays a significant role; it is a sensitive area for Kazakhstan's water security, as a substantial portion of the inflow into Lake Balkhash originates outside the country. Under these conditions, water supply parameters in the south-eastern regions depend on water use regimes and flow regulation in the upper reaches. The management challenge lies in the need to improve the predictability of inflow through coordinated approaches to monitoring, data exchange and the establishment of sustainable water allocation regimes in the transboundary section with China.

Figure 6. The basin of Lake Balkhash.

Source: adapted from https://ru.wikipedia.org

The main watercourse feeding Lake Balkhash is the Ili River (Figure 6). According to a study by Kazakhstani and German scientists published in the journal Applied Sciences, an acute problem in the Ili River basin has become the deterioration of water quality and, consequently, the state of the aquatic ecosystem under the influence of economic activity and transboundary impacts [24]. As the authors of the article note, the pollution of transboundary waters flowing from China via the Ili River with various toxic and biogenic compounds has been addressed in a number of scientific publications over many years.

Kazakhstan's water relations with China are governed by the Agreement on Cooperation in the Use and Protection of Transboundary Rivers, signed on 12 September 2001 in Astana. Under this Agreement, a Kazakhstan-China Joint Commission and a Working Group of Experts have been established to coordinate the use and protection of rivers along the border. Negotiations on a water-sharing agreement have been ongoing between the countries since 2015, but so far only documents on data exchange and water quality protection have been signed. Legally binding quotas (specifying exactly how many cubic meters of water each country is entitled to withdraw) have not yet been formalized.

THE IRTYSH RIVER BASIN

In the north-east, the Irtysh basin is of multi-sectoral importance to Kazakhstan, including water supply, industry, agriculture and energy, and at the same time constitutes a multilateral transboundary system. In Kazakhstan, the water resources of the Irtysh and its tributaries sustain the livelihoods of almost 30% of the population. Around 45% of the country's agricultural output is produced within the basin. The Irtysh cascade of hydroelectric power stations accounts for 10% of the country's total electricity generation (80% of hydroelectric power) [25].

Water resources planning in the Kazakhstani part of the Irtysh basin depends on changes in water abstraction upstream (China), as well as on commitments to ensure flow for downstream users (Russia). A key institutional challenge relates to ensuring data comparability, consistency of management regimes and the predictability of transboundary inflow within the China-Kazakhstan-Russia trilateral water cycle.

Taking into account all existing challenges, and with the aim of minimizing risks, Kazakhstan has moved from a declarative model of integrated water resources management (IWRM) to a practical mechanism enshrined in the new Water Code. This mechanism includes strengthening water diplomacy, building up domestic reserves and technological modernization, which will reduce the economy's dependence on transboundary inflows and ensure national stability.

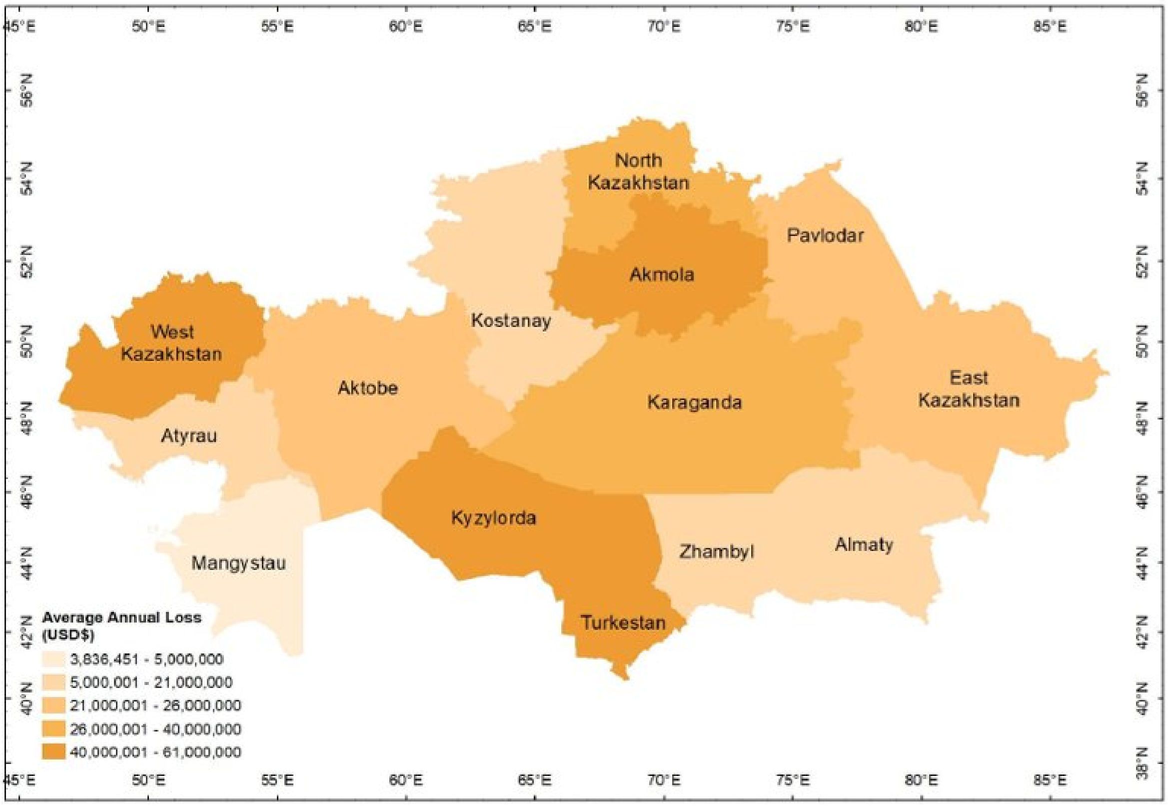
1.3. CLIMATE CHALLENGES КЛИМАТИЧЕСКИЕ ВЫЗОВЫ

Kazakhstan's climate is generally hot and humid in summer and cold and dry in winter (December to February), with precipitation amounting to less than 60% of the annual average (World Bank, 2023).

Climate risks are often divided into two categories: (i) transition risks associated with the transition to a low-carbon economy, and (ii) physical risks arising from the direct physical impacts of climate change, such as extreme weather events (acute risks) and long-term climate changes (chronic risks), which can cause damage to people, infrastructure, the economy, ecosystems and species [26].

Despite its arid climate, Kazakhstan frequently faces the risk of flooding. Floods on rivers such as the Syr Darya, Shu, Talas, Zhaik, Tobyl, Nura, Esil, Uba (a tributary of the Irtysh), Bukhtarma and Irtysh have caused significant economic and environmental damage in various years (Figure 7). Floods in Kazakhstan are not only natural in nature but also have a pronounced transboundary character. According to World Bank estimates, around 70% of floods in the country are linked to spring snowmelt; however, transboundary flows also play a significant role, including the consequences of the operation of hydraulic structures in neighboring countries. In particular, the Syr Darya basin has already seen recurring downstream flooding in Kazakhstan linked to water management decisions in the upper reaches. Average annual losses amount to US$419 million, equivalent to 1.4% of GDP – seven times greater than the damage caused by earthquakes [7,27].

Figure 7. Average annual losses (in US dollars) associated with floods in Kazakhstan. .



Source: CAREC (2022).

The floods of spring 2024 occupy a special place in the recent history of water-related risks in Kazakhstan. According to UNDRR, this flood was described as the country's worst disaster in over 80 years; it affected almost a third of Kazakhstan's territory and led to the evacuation of over 120,000 people, including the flooding of vast areas and the city of Atyrau. This disaster demonstrated that even for a country traditionally associated primarily with water scarcity, a destructive excess of water remains one of the key climate and infrastructure risks. Furthermore, uncoordinated actions by neighboring states can also give rise to flood threats. An example is the accident at the Sardob Reservoir in Uzbekistan in 2020, the consequences of which also affected Kazakhstan [28].

2. FORECAST FRAMEWORK FOR THE FUTURE

In recent years, projections regarding Kazakhstan's future water security have been developed at the intersection of several research and applied traditions: scenario-based modelling of water availability and demand, probabilistic assessment of water-related and climate-related hazards, and national water resources planning for the medium term. This section attempts to present an overview of these assessments as key findings based on recent studies: an assessment of the Republic of Kazakhstan's water security using SSP/RCP scenario combinations and World Bank model calculations (2024), GIZ analytical materials on the probabilities of water and climate-related hazards and source databases (2025), the Concept for the Development of the Water Resources Management System of the Republic of Kazakhstan for 2024-2030 with a balance forecast (2024), as well as taking into account the OECD approach, which emphasizes the significance of interannual variability and extreme years for water risks (2021) [29].

It is, however, crucial to note that the reports and documents under consideration differ in terms of methodology, objectives and the scope of analysis. Consequently, our analysis does not replace the original models or reduce them to a single figure, but rather identifies consistent trends and points of divergence.

The scenario-based logic underpinning most contemporary projections assumes that the 'future of water' is determined simultaneously by climate trajectories and socio-economic development. Three combinations are used in the assessment of Kazakhstan's water security: optimistic (SSP1 + RCP2.6), medium (SSP3 + RCP7.0; SSP2 + RCP4.5 is applied for part of the flood risk) and pessimistic (SSP5 + RCP8.5) (WB, 2024). The GIZ materials use comparable global scenarios (SSP1-2.6, SSP2-4.5, SSP5-8.5), which allow for the assessment of changes in the probabilities of droughts and floods depending on the intensity of climate change (GIZ, 2025). The general thrust of the scenario-based approach in the water sector is that it is not only the level of average resource values that becomes key, but also the nature of variability and the frequency of extreme events. The OECD specifically emphasizes that inter-annual variability in renewable water resources can significantly undermine water security even with a relatively stable average annual supply, as management must be designed to cope with low-flow years and periods of scarcity (OECD, 2021).

With regard ***to the resource base***, projections paint a picture in which 'average' changes do not rule out an increase in risks. The World Bank's assessment of water security indicates that water availability could increase by an average of approximately 10% by 2050 compared to the historical baseline (WB, 2024). However, such a formulation does not in principle imply an automatic improvement in water security: with high fluctuations in flow and an increase in extremes, *resilience is determined by how the system copes with unfavorable seasons and years.* The national planning horizon provides additional practical guidance for interpretation. The Water Resources Management Concept for 2024-2030 sets out a forecast of the water balance, according to which total river flow resources will decrease from 106 to 104 km³ by 2030, with the key factor being a reduction in inflow from neighboring states from 50.8 to 46.4

km³ (Concept, 2024). This assessment is significant in that it highlights a structural constraint: *even with possible changes in precipitation and internal water resources, the transboundary component remains a significant variable of uncertainty for the country's basin balance.*

The most sensitive component of the forecast is water demand and its sectoral dynamics. The water security assessment shows that under medium and pessimistic scenarios, domestic and industrial demand increases, whereas under the optimistic scenario, a slight decrease is projected by 2050 (WB, 2024). However, the report contains a key methodological caveat: the demand forecast is conservative, as the area under irrigation is fixed at the 2000 level and any potential expansion of irrigated areas is not included in the calculations (WB, 2024). This means *that the uncertainty surrounding demand may be comparable in significance to the uncertainty of the resource base, particularly in circumstances where irrigation accounts for the bulk of water abstraction.* It is telling that even under such cautious assumptions, the water security assessment identifies the possibility of a sharp increase in water stress in certain extreme years – up to a twofold increase compared to historical experience (WB, 2024). Consequently, *the key challenge for the future lies not only in 'average' water security, but in the system's ability to prevent and manage shortages during peak demand periods.*

Climate hazards add to this picture, pointing to a potential 'double burden': the simultaneous intensification of drought and flood risks under adverse scenarios. GIZ's findings provide probabilistic assessments of meteorological droughts across three hazard levels; in the high-emission scenario SSP5-8.5, the probability of droughts increases across all categories, reaching approximately 50% (low), 31% (medium) and 15% (high) by (GIZ, 2025). For river floods, GIZ shows that under SSP5-8.5, the probability of low- and medium-intensity events increases significantly by the end of the century (whilst the probability of rare high-intensity events remains lower), which implies an increase in the regular strain on infrastructure and warning systems (GIZ, 2025). The authors emphasize the limitations of the source data and differences in the resolution and formats of the datasets used for the calculations, which require caution in interpreting absolute values, but do not negate the direction of the trends (GIZ, 2025). For strategic analysis, this implies the following: under high-impact scenarios, *the system faces not a single dominant threat, but a combination of water shortages during dry periods and flood damage, which increases the demands on the adaptability of management.*

At the national policy level, the forecast framework is 'grounded' in a medium-term management horizon, where benchmarks for improving efficiency are established. The 2024-2030 Concept sets out target parameters for irrigation water savings, water reuse and the reduction of losses in water conveyance channels in agriculture, as well as expected outcomes regarding the minimization of the negative consequences of hazardous hydrological phenomena (floods, inundations, droughts) and the restoration of water bodies to an ecologically sound condition. Taken together, this shows that *national planning is already based on the need to manage not only the resource itself, but also the risks associated with its variability.*

A comparison of the data allows us to formulate a general forecast.

Firstly, Kazakhstan's future water security will increasingly depend on the frequency of extreme years and interannual variability, which is consistent with the OECD framework that considers variability as an independent risk factor (OECD, 2021).

Secondly, uncertainty regarding demand and its structure is a critical source of risk: even under conservative assumptions, years of sharply increased water stress are possible (WB, 2024).

Thirdly, the transboundary component of the resource base remains a structural constraint, which is explicitly noted in the national forecast up to 2030 through a reduction in inflows from neighboring states (Concept, 2024).

Finally, ***fourthly,*** probabilistic assessments of climate hazards indicate that, under adverse scenarios, the intensification of droughts and floods places a double burden on the economy and infrastructure, increasing the cost of management errors and delayed decisions (GIZ, 2025).

TThus, the forecasting frameworks presented in the aforementioned materials, despite their methodological heterogeneity, converge on a key thesis: the future of Kazakhstan's water security is determined not by a single factor, but by the interplay of climate variability, transboundary uncertainty and demand dynamics, subject to infrastructure and governance constraints. This conclusion is significant in that it shifts the water issue from a narrowly sectoral context into the realm of systemic sustainability: *water security becomes a function of the state's and the economy's ability to operate under conditions of uncertainty, maintaining manageability during extreme years and preventing the accumulation of deficits, which are shaped not only by nature but also by governance parameters.*

3. NEW PERSPECTIVES

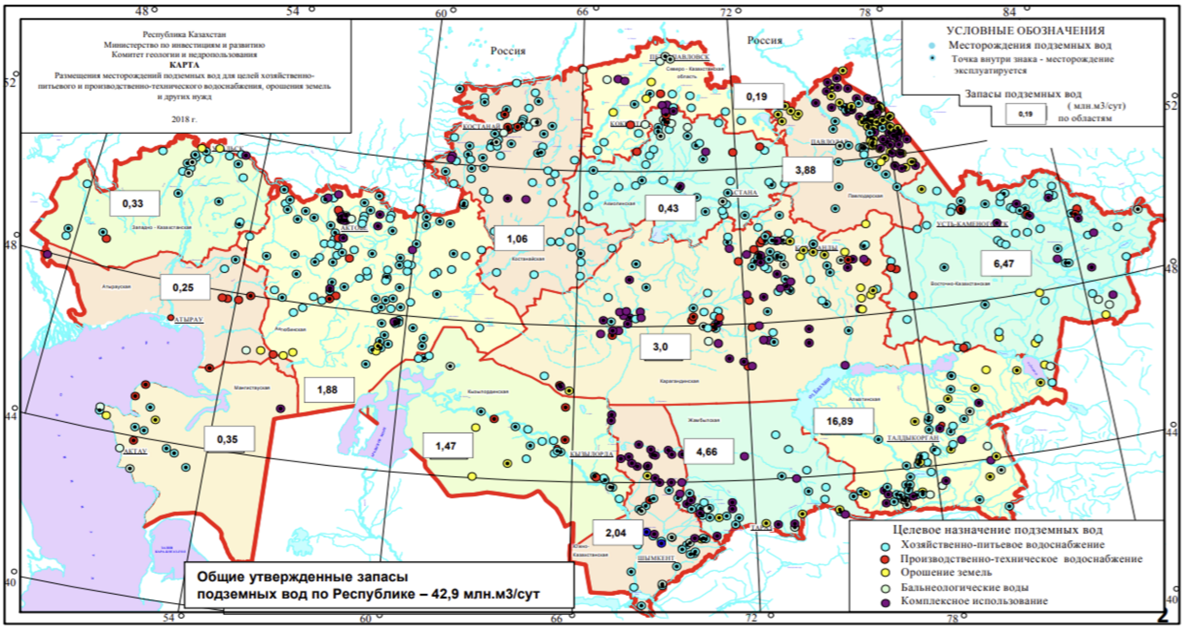
3.1. GROUNDWATER AS A STRATEGIC RESOURCE

RESOURCE BASE

According to the International Atomic Energy Agency (IAEA), groundwater accounts for approximately 30% of the world's freshwater resources [30]. Demand for groundwater is steadily increasing amid population growth, expansion of agricultural land, and rising water consumption in extractive industries, manufacturing, and livestock production. According to the United Nations World Water Development Report, agriculture accounts for around 70% of global water withdrawals, with this share being significantly higher in arid and semi-arid regions. Groundwater supports irrigation for approximately 38% of all land suitable for agricultural use and is directly involved in the production of food, cash crops, livestock products, and fiber. The development of groundwater resources may become a key factor in enhancing agricultural productivity and driving economic growth through the expansion of irrigated areas. Projections indicate that by 2050, food production will need to increase by 50% to meet the growing needs of the population [31].

Kazakhstan possesses significant groundwater reserves, of which 3.6% is utilized daily. According to data from the Ministry of Water Resources and Irrigation of the Republic of Kazakhstan, exploitable reserves amount to 43.2 million m³ per day, whilst current consumption stands at 1.5 million m³/day (Figure 8).

Figure 8. Map of Groundwater Deposits in the Republic of Kazakhstan

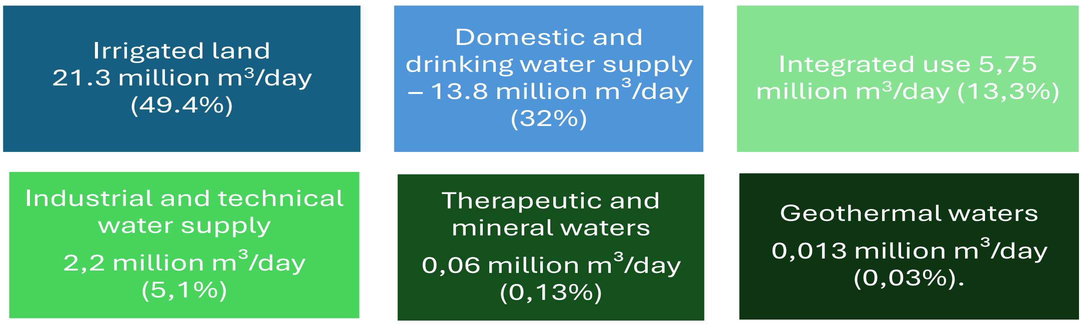


Source: https://unece.org/

According to the Ministry, there are 4,416 explored groundwater deposits in the country for drinking and industrial water supply, irrigation and other purposes. At the same time, in addition to its use in water supply and agriculture, the composition of groundwater contains industrial concentrations of beneficial elements – lithium, strontium, bromine and other minerals.

Around 68% of fresh groundwater (with a salinity of less than 1 g/l) is concentrated in the southern regions of Almaty, Zhambyl, Turkestan and Kyzylorda. In the western regions, their share does not exceed 15%, whilst the central, northern and eastern regions account for around 25% of total resources. The most limited reserves are found in the Atyrau, Mangistau and North Kazakhstan regions. By intended use, exploitable groundwater reserves are distributed as follows:

Figure 9. Exploitable groundwater reserves of the Republic of Kazakhstan.



Source: Data from the National Hydrogeological Service of the RK 'Kazhydrogeology'

POTENTIAL FOR AGRICULTURE

According to forecasts in the Concept for the Development of the Water Resources Management System for 2024–2030, the use of groundwater for irrigation could save over 2.1 km³ of water per year and increase crop yields by 1.5–2 times [32].

In January 2026, the installation of the **Water Base** system was completed; this will enable monitoring of groundwater conditions, maintenance of a water resources register, cartographic visualization, analytical processing and real-time data retrieval from remote sensors at the National Hydrogeological Service center [33].

MINERAL POTENTIAL

The economic potential of mineralized groundwater deserves special attention. According to a study published in the Journal of Hydrology (2025) [34], deep artesian brines in the Shu-Sarysu basin contain commercial concentrations of lithium, strontium, bromine and iodine. The study confirmed the economic viability of extracting these elements from formation waters during oil and gas production.

This is particularly relevant in the context of the global energy transition and growing demand for critical mineral resources. Kazakhstan is already one of the key suppliers: the country accounts for 38% of global uranium production (2024), ranks among the top ten producers of copper and zinc, and supplies 19 of the 34 raw materials critical to the EU economy. Including mineralized groundwater within the scope of economic planning will enable the diversification of revenue streams from the use of natural resources.

INDUSTRIAL APPLICATIONS

According to the National Hydrogeological Service "Kazhydrogeology," four prospective provinces of industrial groundwater have been identified in the territory of Kazakhstan: the Pre-Caspian, Mangistau-Ustyurt, Shu-Sarysu, and South Torgay provinces. The mineral resource potential of underground brines has been assessed across 37 promising areas, with proven reserves, estimated resources and estimated recoverable reserves determined. The mineral resource potential has been assessed for lithium, strontium, iodine and bromine. The total natural mineral resource potential of Kazakhstan's industrial brines is as follows: **lithium** – 241,260 tones, **strontium** – 17,995,710 tones, **iodine** – 391,540 tones, **bromine** – 12,868,620 tones. Lithium resources are concentrated mainly in the Shu-Sarysu (50.1%) and Caspian (41.2%) provinces, strontium – in the Mangistau-Ustyurt (72.9%) iodine and bromine – also in the Mangistau-Ustyurt (62.0% and 53.6% respectively).

Industrial waters have been identified mainly during exploration work for hydrocarbon resources. There are three promising areas of development. The first involves the exploitation of associated formation brines from active and decommissioned oil and gas fields, which allows for increased return on investment in oil and gas field development through the production of additional commercial products.

The second is the drilling of hydrogeological wells to assess the hydro-mineral potential of previously tested structures, primarily the lithium-bearing brines of the Shu-Sarysu Province, associated with Upper Devonian sandstones at depths of up to 1,700 m (lithium content up to 130 mg/l, rubidium up to 9.6 mg/l, caesium up to 5.65 mg/l).

Thirdly – the identification and assessment of the hydro-mineral potential of near-surface brines in saline lakes of the arid zone, in particular the saline lakes of the Shu-Sarysu Basin, where, according to sampling data from 2022–2023, the lithium content is 18.0–99.3 mg/l with a salinity of 365–400 g/l. The salt-bearing strata of the dried-up part of the Aral Sea are currently under study.

The development of industrial groundwater resources will strengthen Kazakhstan's position in the global market for critical mineral raw materials and enhance the efficiency of subsoil use through the comprehensive extraction of valuable components.

INVESTMENT ATTRACTIVENESS

Kazakhstan's groundwater resources are of interest not only as a tool of state water policy, but also as a promising target for private, institutional and international investment. The global water sector requires large-scale funding, yet state resources are insufficient to address all challenges, opening up opportunities for private capital.

Kazakhstan possesses some of the world's largest proven groundwater reserves, at 43.2 million m^3 per day. With the current utilization rate standing at 3.6% of proven reserves, the country has significant potential to increase the water security of its economy, creating a stable investment niche.

The water sector is often viewed by investors as relatively defensive, as demand for basic water supply and sanitation services is less sensitive to the phases of the economic cycle. 'Blue bonds' are of particular interest as a rapidly growing financing instrument for water and other 'blue economy' projects. According to ICE, in 2024 'blue bonds' remained the only category of sustainable bonds to show continuous growth for the third consecutive year. According to the BlueInvest Investor Report 2024, investment in the blue economy between 2018 and 2023 exceeded €13 billion, and one in five investors is actively seeking or considering investments in 'blue' projects. A prime example is the largest blue bond in history, structured by IDB Invest, worth $1.35 billion, to expand the wastewater management system in Brazil [35].

Investments in groundwater fit seamlessly within ESG criteria, being directly linked to the Sustainable Development Goals: SDG 6 (clean water and sanitation) and SDG 13 (climate action). This is particularly relevant for Kazakhstan in light of the transition to a 'green' economy and the attraction of 'green' financing.

The global groundwater management market is entering a phase of active technological transformation, driven both by the objective challenges of water scarcity and the maturity of digital solutions. According to estimates by analytical agencies, the market volume, which is expected to reach US$33–35 billion in 2025–2026, will reach US$45.75 billion by 2030, with an average annual growth rate of 7% [36]. North America remains the largest region, but the Asia-Pacific region is becoming the most dynamically developing one, which, for Kazakhstan, situated at the crossroads of the Central Asian and Asia-Pacific markets, opens up the opportunity for integration into the emerging regional ecosystem of water technologies.

The key drivers of growth are digitalization and the development of regulatory approaches to sustainable water use. Groundwater monitoring systems based on artificial intelligence, the Internet of Things and cloud platforms are becoming increasingly widespread, enabling real-time data collection and analysis without manual intervention. A prime example is India, where an advanced AI monitoring platform was launched in Bangalore in 2024, bringing together government bodies, research institutes and technology companies. At the same time, investment is growing in managed aquifer recharge (MAR) technologies, which are becoming the foundation of climate-resilient water systems in countries ranging from Israel to Australia. These trends are reinforced by the scale of water scarcity: according to the World Meteorological Organization, 3.6 billion people are already facing water shortages, and by 2050 this figure will exceed 5 billion.

Changes in international trade and tariff policy are becoming an important geopolitical factor. The rising cost of imported sensor equipment, drilling rigs and water quality analysis instruments is creating additional incentives for the development of localized production and regional solutions. Kazakhstan, with its well-developed engineering and mining-metallurgical sector, has the potential to establish domestic production of core components for groundwater monitoring and management systems.

The institutional framework for the sector's development is already taking shape. The adoption of a new Water Code in 2024, the establishment of the specialized agency 'Kazhydrogeology' [37], and the approval of the Water Resources Management Concept for 2024–2030 demonstrate the state's consistent commitment to transitioning to modern standards of water use. The Coordination Council of Partners for Water Sector Development, established in September 2024 under the Ministry of Water Resources and Irrigation and the UNDP, brings together 35 partner organizations.

Today, Kazakhstan is in the early stages of establishing a national groundwater management system, which provides an opportunity to proactively implement cutting-edge digital and technological solutions, drawing on international experience and avoiding the consequences of excessive water abstraction faced by many countries. The most promising areas appear to be the creation of monitoring systems based on artificial intelligence and the Internet of Things, the launch of pilot projects on artificial recharge of aquifers in flood-prone and water-scarce regions, as well as the formation of public-private partnerships with leading international companies for technology transfer and the development of local expertise.

Harnessing the potential of groundwater will strengthen the country's water and climate security, providing an alternative to the large-scale construction of surface reservoirs. The transition to a model of managed strategic reserves is not merely a water management task, but also a tool for agricultural development, climate resilience and economic diversification. Harnessing this potential through investment projects and management decisions will enable Kazakhstan not only to ensure long-term water self-sufficiency, but also to establish itself as a regional center of expertise in Central Asia, capitalizing on the growing demand for water technologies in neighboring countries.

3.2. INFRASTRUCTURE AND TECHNOLOGICAL SOLUTIONS IN AGRICULTURE

Modern infrastructure and technological solutions in the water sector are aimed at overcoming resource shortages, minimizing losses and automating management. Key areas include the modernization of physical facilities, the implementation of digital monitoring systems and treatment technologies. The modern technological landscape of water infrastructure is characterized by rapid innovation and growing accessibility.

The agricultural sector is a prime example, as it is the most water-intensive sector and one of the largest polluters of water resources. Irrigation associations are adopting technologies focused on digital transformation to optimize water use (by 20% to 50%, according to the FAO), increase agricultural productivity (yield increases of up to 25%) and reduce costs (energy savings of up to 30%). In addition to these tangible benefits, modernization improves the future of agriculture through significant improvements in water resource management, which is essential in the context of growing migration to urban centers and ensuring food security [38].

Modern innovative solutions in agriculture include:

- Smart irrigation systems: technologies such as drip irrigation and Internet of Things (IoT)-based soil moisture sensors optimize water distribution, significantly reducing water loss. These solutions are widely used in Israel, Spain and California, where water use efficiency is crucial for maintaining high-yield agriculture.
- Desalination for agriculture: solar-powered desalination systems and hybrid systems are proving their effectiveness in ensuring a sustainable water supply for irrigation, particularly in arid regions.
- Wastewater reuse: Treated wastewater is increasingly being used for irrigation, reducing dependence on freshwater sources. Countries such as Singapore and Australia have successfully implemented large-scale programs for the reuse of wastewater in agriculture.
- Drought-tolerant crops: Advances in agricultural biotechnology are leading to the development of crops that require less water whilst maintaining high yields.

By adopting these technologies, farmers can boost productivity whilst conserving water resources for future generations.

KAZAKHSTAN'S POLICY

Changes to water legislation have laid the foundation for a transition to integrated resource management, a strengthened basin approach, and the introduction of tools to prevent water shortages. One of the key priorities of this reform has been to encourage rational water use through economic mechanisms and state support for the technological modernization of the agro-industrial complex. In agriculture, the use of modern irrigation systems and water-saving technologies (WST), including drip and sprinkler irrigation, is gradually expanding.

Between 2014 and 2023, the country has seen an increase in budgetary support for the introduction of WST. Under state subsidy programs, 2,117 projects were implemented, totaling 57.03 billion tenge. The volume of funding increased almost eightfold (from 2.6 billion to 18.4 billion tenge, adjusted for inflation), whilst the number of projects rose approximately threefold (from 82 to 240).

Since December 2023, updated rules on investment subsidies have been introduced, aimed at expanding support for the agricultural sector. A key focus of operational activities has been the implementation of the Head of State's directive to ensure the annual introduction of water-saving technologies across an area of 150,000 hectares. From 2024, a two-part incentive mechanism was established: the reimbursement rate for infrastructure development and equipment procurement costs was increased from 50% to 80%, whilst the subsidy for irrigation water for users of water-saving technologies was raised from 60% to 85%, with an annual reduction of 10% for other categories. The measures taken have enabled the targets to be met: in 2024, the technologies were implemented across 152,800 hectares, and in 2025 across 153,600 hectares. The total area of irrigated land covered by water-saving methods reached 543,500 hectares, accounting for approximately 13% of the total area. Funding for investment subsidies for 2026–

2028 has been approved in the amount of 214.6 billion tenge, with an annual increase. From April 2025, subsidy functions were transferred from the Ministry of Agriculture to the Ministry of Water Resources and Irrigation, which ensured the consolidation of administrative and financial resources.

In the Turkestan Region of Kazakhstan, in 2025, for the first time in the country's history, drip irrigation technology was introduced across an area of 32,000 hectares [39]. This event was historic for Kazakhstan, as it was the first time in the country that such a large area had been converted to water-saving technologies simultaneously. This measure is of great importance to the region, as 70% of the water required comes from a neighboring state. It is noteworthy that a company has been established in the region to manufacture specialized equipment for drip irrigation systems, with the aim of ensuring the efficient use of water resources in agriculture. 1.2 billion tenge has been invested in the project.

In parallel with the introduction of water-saving technologies, a large-scale program to restore and develop hydraulic infrastructure is being implemented. Construction is underway on two reservoirs in the Turkestan Region with a combined capacity of 69.1 million m^3, and design and cost estimates are being drawn up for 17 reservoirs. Construction of the Akmola reservoir in the Zhambyl Region and the Karauzyak reservoir in the Kyzylorda Region is planned to commence with funding from the Islamic Development Bank.

The reconstruction of 14,500 km of canals has been identified as a priority: over 6,200 km were repaired between 2021 and 2025, and projects covering a total length of 4,225 km, worth 258 billion tenge, are being implemented with loans from international financial institutions. The implementation of these infrastructure measures will enable an additional 2.6 billion m^3 of water to be stored, 295,000 ha of new irrigated land to be brought into use, water losses in the canals to be reduced from 50% to 35%, and dependence on neighboring states to be reduced by 15%.

SYSTEMIC CONSTRAINTS AND FUTURE CHALLENGES

Despite the progress made, systemic barriers remain that reduce the effectiveness of government policy. The current differentiation of incentives is insufficient to drive a mass transition to water-saving technologies, and the distribution of subsidy functions across departments complicates the implementation of a unified approach. Staffing constraints are intensifying: there remains a shortage of water management engineers and digital metering specialists, which is holding back the introduction of modern management systems. Furthermore, technological and regulatory gaps persist: limited provision of on-farm infrastructure with metering devices, the absence of approved water consumption standards by crop type, and a piecemeal approach to canal reconstruction without comprehensive coordination with drainage solutions.

Removing these constraints requires strengthening incentive-based tariff and subsidy policies, completing the consolidation of subsidy functions within the relevant authority, launching targeted programs for staff training and retention, developing localized solutions in the field of water metering, and transitioning to a comprehensive modernization of irrigation infrastructure. In parallel, it is necessary to establish scientifically sound water consumption standards and ensure that key nodes are equipped with modern metering devices to improve the transparency and manageability of water use.

The institutional framework that has been established and the incentive mechanisms that have been introduced are enabling Kazakhstan to transition from an extensive model of water use to an intensive one. The results achieved in the implementation of water-saving technologies and the modernization of infrastructure confirm that the chosen course of action is the right one. The key task for the next stage is to remove systemic constraints, ranging from strengthening economic incentives to ensuring technological and human resource sovereignty, which together will guarantee the achievement of the country's long-term water security.

DEVELOPMENT OF THE PRODUCTION BASE

To reduce import dependency, a domestic manufacturing sector has been established: five factories producing sprinkler machines and drip irrigation equipment are currently in operation. Projects to manufacture components are being implemented in the Zhambyl region. In September 2025, during negotiations with the Chinese company Yellow River Engineering Consulting Co. Ltd., an agreement was reached on localizing the production of automation and digitalization systems for water metering in Kazakhstan, as well as on organizing professional development programs for Kazakhstani water management specialists [40].

An analysis of regional experience shows that Kyrgyzstan demonstrates the most systematic approach to the digitalization of metering, having developed its own software, level sensors and cloud-based data storage systems, and is implementing elements of artificial intelligence to forecast water consumption. Uzbekistan has automated around 7,700 facilities, reducing measurement error from 10% to 2–3%, which confirms the advisability of accelerating the development of domestic expertise in the field of water metering.

3.3. DIGITAL SOLUTIONS FOR FLOOD MANAGEMENT

The increasing frequency of floods, such as those that occurred in 2024, highlights the urgent need to implement advanced and innovative technologies for early warning systems and decision-support tools when such events occur. The implementation of such technologies, combined with a comprehensive territorial management policy, can significantly reduce the risks and consequences of future similar disasters.

International technology reviews note that by 2025, digitalization had become a fundamental tool for managing both urban and river floods, with the focus shifting towards early warning systems and decision-making support. In the context of Kazakhstan, this aligns with the overarching objective of transitioning from responding to consequences to data-driven risk management, forecasting and inter-agency coordination.

At the heart of the digital flood management framework are two interrelated categories of solutions: Decision Support Systems (DSS) and Early Warning Systems (EWS). DSS are designed to optimise management decisions in real time and for medium- and long-term planning, using predictive algorithms and big data analysis to identify trends and develop scenarios. EWS address the task of operational warning: they generate alerts with minimal lead time and ensure the activation of response plans; in doing so, they integrate data on the topography and characteristics of the territory with hydrological models to simulate the behaviour of rivers and canals during heavy rainfall.

In this context, an important role is played by tools such as:

- water level sensors in urban stormwater networks and on rivers as sources of real-time data;

- alert systems via mobile applications;

- GIS tools for identifying priority intervention areas by mapping flood-prone areas, taking into account topography, land use and historical flooding patterns;

- digital twins of territories and cities, which are used to simulate flooding scenarios and assess the impact of potential solutions prior to their implementation.

The forecasting component is further enhanced by big data and machine learning technologies, which improve the accuracy of forecasts by analyzing historical and operational data and identifying patterns in the frequency and severity of floods.

For Kazakhstan, the development of digital solutions also has a regulatory and administrative dimension: the digital framework must be integrated into state information systems and decision-making procedures. The Water Resources Management Concept for 2024–2030 provides for the creation of integrated information systems for the storage and management of water resources data, ensuring access to data, as well as the use of interactive monitoring dashboards and geospatial mapping to identify spatio-temporal patterns. In the same vein, the document highlights the role of hydrological modelling in assessing the impact of floods and the potential of machine learning methods to improve snowmelt modelling and river flow forecasting.

The Tasqyn digital system is currently being implemented in the country, designed to model flood scenarios and conduct rapid risk assessments in the most vulnerable areas. The system operates with regular updates and utilises data on the operating regimes of 86 reservoirs managed by the Kazvodkhoz State Enterprise. In parallel, digital hydrographs of the flow of 75 rivers have been created, including actual and forecast parameters for water levels and discharge. The calculations use data from the State Enterprise ‘Kazhydromet’ as well as the international GloFAS platform. In addition, the Ministry of Water Resources and Irrigation, in cooperation with UNDP, is implementing the Talsim system to forecast water inflows into reservoirs; at the current stage, modelling has been carried out for the Esil and Nura river basins, with subsequent expansion of coverage at the national level.

These measures are important for Kazakhstan, where a significant proportion of flood events are linked to a complex combination of precipitation, snowmelt and soil conditions.

4. STRATEGIC PRIORITIES FOR WATER SECURITY

4.1. INSTITUTIONAL STRENGTHENING OF REGIONAL COOPERATION

Given the current situation of projected water scarcity in Kazakhstan and neighbouring states, it is becoming essential to move towards the full application *of international water law*, which can transform existing agreements into legally binding regulations.

The implementation of principles *governing the equitable and reasonable use* of transboundary watercourses will enable a shift from ad hoc compromises to a sustainable quota system. This will ensure a balance between the energy priorities of upstream countries and the irrigation needs of downstream countries. Institutionalizing accountability mechanisms and establishing a unified digital monitoring system will not only reduce the risk of shortages by 2040, but will also guarantee *the investment attractiveness* of water-intensive sectors across the entire region.

The multilateral framework for transboundary water cooperation in ***Central Asia*** was established by the 1992 Agreement on the Joint Management [41], Use and Protection of Transboundary Water Resources. In subsequent years, this framework was supplemented by a number of multilateral agreements and declarations by heads of state, initially aimed at preserving the existing water distribution arrangements between the former Soviet republics. However, the current legal framework largely retains a narrow scope of regulation and does not fully reflect the region's current economic, demographic and climatic conditions. In particular, there remain gaps in the coverage of water relations (including in relation to specific basins), there is insufficient coordination between water and energy management in the Aral Sea basin, and a number of provisions are of a declaratory nature and are only partially implemented.

From an institutional perspective, regional *structures* were established in the early years of Central Asian states' independence and initially focused on water allocation within the mandate of the Interstate Water Coordination Commission (IWCC). The subsequent development of the institutional architecture was linked to the 1999 Agreement on the Status of the International Fund for Saving the Aral Sea (IFAS) [42], which represents the most advanced mechanism for regional cooperation. However, the activities of the IFAS were complicated by coordination constraints and ambiguities in the distribution of powers among its bodies. The integration of the ICAC and the Interstate Commission on Sustainable Development (ICSD) into the IFAS structure without a clearly defined hierarchy and competences led to the fragmentation of mandates and a reduction in managerial coherence. A separate factor was the suspension of the Kyrgyz Republic's participation in the Fund's activities from 2016, which further weakened the integrity of the regional framework, given the country's role in shaping the flow of the Aral Sea basin.

A key area of institutional strengthening is *the development of water-energy coordination.* An attempt to establish water-energy cooperation on a multilateral basis was made in 1998 under the Syr Darya Basin Agreement; however, since the early 2000s, its practical implementation has significantly declined. In the subsequent period, initiatives to establish regional coordination mechanisms (including consortium formats) were discussed, but no lasting consensus was reached on them.

Against this backdrop, the development of trilateral cooperation between Kazakhstan, Kyrgyzstan and Uzbekistan on water and energy issues, including the 2024 agreement on preparations for the construction and operation of the Kambarata HPP-1 and regular coordination meetings in 2025–2026 on system operating regimes and spillway parameters [43]. However, the long-term sustainability of such coordination mechanisms requires further institutional consolidation and broader coverage.

Alongside the multilateral format, *the role of bilateral agreements and specialised commissions in the region has strengthened, reflecting a shift towards a combined regulatory model.* Kazakhstan is developing bilateral mechanisms with neighbouring states for specific basins and water bodies, including cooperation with Kyrgyzstan on the Chu and Talas rivers and the establishment of a new legal framework with Uzbekistan for the joint management and use of transboundary water bodies (2025 Agreement) [44].

At the same time, there remains a call for *the renewal of the regional architecture.* In this regard, initiatives to discuss a regional-level framework document, including Kazakhstan's proposal to consider the adoption of a Framework Convention on Water Use in Central Asia [45], reflect a desire to restore greater consistency and predictability to the regional format.

It should be noted that the current institutional agenda for strengthening water cooperation in Central Asia is being shaped by *new challenges:* a lack of comparable water data, the need for climate adaptation, and insufficient levels of social inclusion in water resources management.

Existing regional mechanisms do not yet provide sufficient tools to address these issues. In this context, *the importance of the international legal framework,* to which some states in the region have acceded, *is growing,* as are practices focused on digitalization and forecasting. A telling example is the development of mechanisms for the automation and exchange of hydrological data between individual countries in the region. The climate agenda requires a strengthened basin approach and the integration of water, land and environmental policies, including the implementation of regional adaptation strategies.

Social inclusion entails the development of procedures for access to information, stakeholder participation in decision-making and legal protection mechanisms, which must be embedded within a modernised institutional framework for water resources management.

Overall, institutional strengthening of regional water cooperation requires updating the legal framework, clarifying the mandates of regional bodies, establishing sustainable financing mechanisms, and developing practical coordination tools for data, reservoir regimes and water-energy linkages. This will improve the predictability of water allocation, reduce the potential for conflict and ensure that the regional management system adapts to long-term climatic and socio-economic changes.

In order to reduce environmental and infrastructure risks and improve the predictability of management under a changing hydrological regime, further institutional strengthening of the Caspian dimension is required. For Kazakhstan, institutional strengthening in **the Caspian region** focuses on three priorities:

- establishing a sustainable governance architecture for Caspian risks with a clear division of responsibilities;
- establishing a comparable monitoring framework and data on water levels, water quality and the state of ecosystems;
- introducing regulations for the assessment and mitigation of man-made and accident risks, including requirements for the environmental safety of coastal infrastructure.

These priorities are implemented through institutionalized mechanisms for cooperation with other states in the Caspian region. Kazakhstan relies on the multilateral *legal framework of the Tehran Convention* [46] and its protocols. The Tehran Convention is the first legally binding regional agreement signed by all five Caspian littoral states (Azerbaijan, the Islamic Republic of Iran, the Republic of Kazakhstan, the Russian Federation and Turkmenistan). It sets out general requirements for the protection of the Caspian region's environment and provides for the establishment of the necessary institutional mechanisms, including the 'Aktau Protocol' [47] on oil spill preparedness and response. Kazakhstan also participates in the harmonization of monitoring approaches, data exchange and joint programs on environmental threats to the Caspian Sea. Project formats supported by international organizations play a complementary role, aimed at improving the compatibility of methodologies, strengthening the technical base and implementing agreed measures.

The strategic objective of institutional strengthening regarding Caspian issues is to *establish a functioning system of intergovernmental coordination that ensures the predictability of management decisions and reduces risks in the Caspian Basin.* For this reason, President Tokayev proposed establishing a Centre for the Analysis of Water Issues in Astana under the auspices of the SCO. In practical terms, this means a transition to regular joint assessments of the state of the marine environment, coordinated response protocols, comparable data and a sustainable mechanism for implementing measures, integrated into the national planning and international commitments of the participating parties.

Work in sensitive transboundary basins *with China* requires particular attention. Interaction and cooperation with China involves establishing a stable and predictable regime for the management of transboundary water resources, reducing the risks of shortages and enhancing the sustainability of water supply in the eastern and south-eastern regions of Kazakhstan. Kazakhstan is focused on developing a contractual and procedural framework that ensures the regular exchange of hydrological information, the harmonization of approaches to water abstraction accounting, and increased transparency regarding flow parameters.

Institutional strengthening in this area focuses on three priorities:

- improving the predictability of water supply in sensitive basins (primarily the Ili-Balkhash and Irtysh) through the formalization of cooperation rules;
- establishing a comparable framework for monitoring and exchanging hydrological data for scenario planning and setting limits;
- consolidating procedures for agreeing water use regimes that take into account the water supply needs of the population, the economy and environmental requirements in the lower reaches.

Kazakhstan is currently actively involved in international mechanisms for the management of transboundary waters: various intergovernmental agreements are in force, and regular negotiations are ongoing with China, Uzbekistan, Russia and Kyrgyzstan. With the support of the UN, the European Union and the Global Environment Facility, projects are being implemented to standardise accounting systems, reduce the risk of conflict and modernise water management infrastructure.

Collective action is crucial for strengthening local and regional governance in regions at high risk of water scarcity. Only on the basis of broad legitimacy can governments successfully manage local resources at the river basin level.

4.2. CLIMATE ADAPTATION

Effective climate adaptation in Kazakhstan requires a combination of engineering, institutional and nature-based solutions. Hydraulic structures alone are insufficient if pastures degrade, floodplain forests disappear and wetlands are depleted. But environmental discourse alone is insufficient if irrigation networks are not modernized, monitoring systems are not developed and the quality of governance is not improved.

The sustainability of Kazakhstan's water system will be determined precisely by the ability to combine these approaches into a single policy: prioritizing the most vulnerable basins, integrating climate scenarios into the water balance, restoring ecosystems, supporting the agro-ecological transition, strengthening early warning systems, and linking all of this to budgetary, sectoral and territorial decisions

In practical terms, climate adaptation in the water sector must be based on three interrelated approaches. Firstly, the introduction of a scenario-based approach to planning: resource allocation, distribution and investment decisions must take into account a range of hydrological scenarios (normal year, drought, flood period), as well as projected changes in evaporation and seasonal flow patterns.

Secondly, enhancing the resilience of infrastructure and management regimes: the modernization and operation of hydraulic structures, reservoirs and irrigation systems must ensure preparedness for extreme conditions and reduce internal water losses.

Thirdly, strengthening preparedness and early warning: developing monitoring systems, early warning systems and inter-agency response protocols to minimize damage from droughts and floods.

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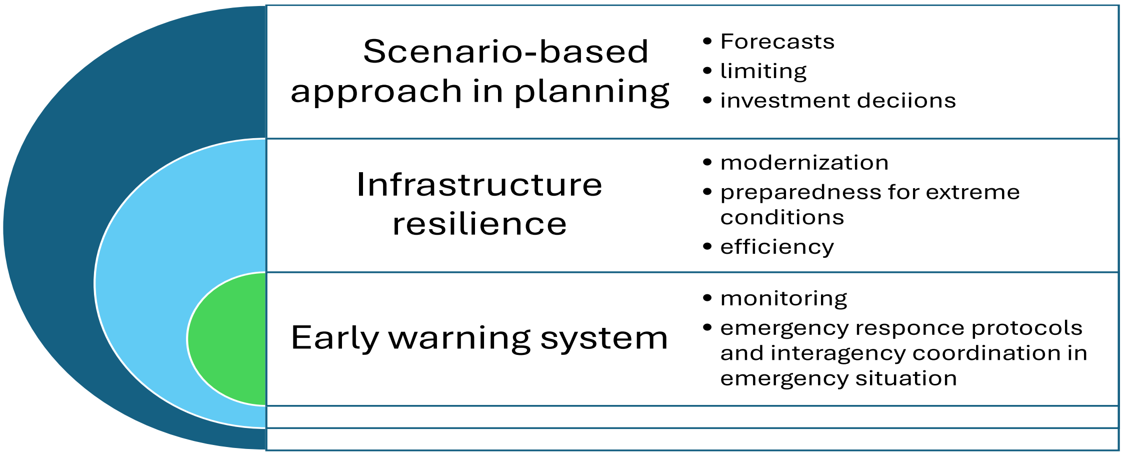
Figure 10. Mechanisms for adapting to climate change



Source: compiled by the authors

It is precisely within this framework that the international and national adaptation agenda in Kazakhstan is currently taking shape, including efforts to integrate water-related risks into macroeconomic planning and to assess the impacts of various climate scenarios. Water legislation is already being revised, flood forecasting capabilities are being enhanced, and digital solutions are being implemented, including the Skymax early warning system and a digital flood path map. In addition, the hydro.gov.kz platform is being developed, featuring data on water bodies and a cadaster to monitor the allocation of land plots in water protection zones.

Climate adaptation also involves prioritizing measures in the most vulnerable basins and areas where water scarcity and extreme events pose risks to agriculture, energy, urban infrastructure and the quality of life of the population.

Integrating climate scenarios into a unified water balance and management decisions makes it possible to improve the predictability of water supply, reduce socio-economic losses and ensure the long-term sustainability of the system.

Water security is closely intertwined with climate change adaptation and biodiversity conservation. Integrating nature-based solutions, such as wetland restoration, sustainable land management and reforestation, into water policy to enhance resilience, improve water access and ensure long-term sustainability are important steps in developing systemic solutions. Policies that promote sustainable agriculture, reforestation and improved land-use planning can strengthen sustainable water management, whilst supporting broader objectives for climate change adaptation and biodiversity conservation. For example, Kazakhstan's national reforestation program, which aims to restore more than 1.5 million hectares of degraded land by 2030, is expected to improve groundwater recharge, enhance soil moisture retention and reduce flood risks.

4.3. GLOBAL INITIATIVES AND THEIR ROLE IN CONSERVING WATER RESOURCES

Water security is a key challenge requiring resource diplomacy to ensure stability not only in the region but also globally. In recent years, the global water agenda has shifted from sector-specific discussions to issues of sustainable development and security. In this context, Kazakhstan positions water security as a component of global sustainability and promotes initiatives aimed at strengthening international coordination, consolidating scientific and monitoring capabilities, and establishing a more effective institutional architecture within the UN system.

The first focus of Kazakhstan's position relates to the problem of fragmentation in global water governance. In his speeches, President K. Tokayev has proposed the creation of a specialized international body within the UN system – the UN Water International Organization [48], capable of consolidating disparate mandates and enhancing the manageability of the global water agenda. This initiative aims to improve coordination between international institutions, ensure a coherent approach to water as a strategic resource, and strengthen the practical focus of international solutions (standards, data, projects, technologies). The initiative was announced at a forum dedicated to the International Year of Peace and Trust, International Neutrality Day and the 30th anniversary of Turkmenistan's permanent neutrality.

Kazakhstan's second priority is to strengthen the scientific and predictive basis for global water security through the agenda of preserving "water towers" and the cryosphere. At the first One Water Summit, held in 2024 as a joint initiative of the heads of state of Kazakhstan and France, the Kazakh side proposed the Water Towers Partnership [49], aimed at systematizing support for glaciological science and consolidating the efforts of global research centers to study and protect glaciers, which is seen as a prerequisite for long-term predictability of runoff in water-dependent regions. The initiative logically complements international decisions aimed at advancing cryosphere science and establishes a scientific coordination track within the water agenda.

The third focus relates to translating global initiatives into regional and project-based mechanisms. Kazakhstan proposes using international platforms to harmonize approaches to climate, water and the 'green' transition, including **hosting the Regional Environmental Summit in Astana in April 2026** and launching consultations on an international water initiative within the UN system on the sidelines of the event. The aim of this format of cooperation is to ensure regular dialogue on the coordination of measures, to maintain compatible approaches to data and monitoring, and to develop a portfolio of practical solutions (water conservation, modernization of management, remote sensing, etc.) with the participation of international partners.

The 2026 Regional Environmental Summit (RES 2026) was initiated by Kassym-Jomart Tokayev, President of the Republic of Kazakhstan, at the 78th session of the UN General Assembly in September 2023. At the Astana International Forum in May 2025, it was announced that the Summit's agenda would be expanded from climate to environmental issues [50].

CONCLUSION

Kazakhstan's water security is becoming one of the key prerequisites for the country's sustainable development, economic stability and territorial integrity. The study revealed that risks in this area are shaped by the combined influence of several interrelated factors: high interannual variability in river flows, increasing climate uncertainty, infrastructure deterioration, low water use efficiency, deteriorating water quality and significant dependence on transboundary inflows. Taken together, this turns the water issue into a systemic challenge affecting the economy, the social sphere, the environmental condition of territories and national security parameters.

The main conclusion is that Kazakhstan's future sustainability will be determined not so much by the volume of available water resources as by the state's ability to manage their scarcity, seasonal and inter-annual instability, and the consequences of extreme hydro-climatic events. As the analysis has shown, the most vulnerable areas are those basins and regions where water scarcity intersects with high pressure from agriculture and industry, transboundary dependence and environmental degradation. Under these conditions, water security becomes a factor in regional competitiveness, the quality of life of the population and the country's investment attractiveness.

Particular attention should be paid to the fact that Kazakhstan's water risks are becoming increasingly complex. The country is simultaneously facing the threat of water scarcity, increasing droughts, flood risks, the degradation of aquatic ecosystems and the deterioration of resource quality. This dual—and in some places even triple—burden means that the previous approach of reacting to individual crises is no longer sufficient. A shift is required towards a model in which management is based on forecasting, scenario analysis, a basin-based approach, digital monitoring, and closer integration of water policy with agricultural, energy, climate and regional agendas.

At the same time, Kazakhstan possesses significant opportunities to strengthen its water security. These opportunities include the development of groundwater as a strategic reserve, the modernization of irrigation, the introduction of water-saving and digital technologies, the strengthening of early warning systems, the restoration of ecosystems, and the improvement of the institutional governance framework.

The adoption of a new Water Code, the development of relevant institutions and the updating of medium-term planning lay the foundation for a transition from a predominantly reactive model to more proactive and adaptive management. However, the outcome of this transition will depend not so much on the existence of individual programmes and initiatives, but on their coherence, the sustainability of funding and the quality of their practical implementation.

Thus, the state's strategic objective is to establish a comprehensive water security system capable of operating under conditions of growing uncertainty. Such a system must be based on a managed water balance, improved resource efficiency, institutional coordination, ecological restoration and the strengthening of transboundary cooperation. This approach will enable the creation of a more reliable, flexible and balanced water management system that serves the interests of the economy, ecosystems and the population, both now and in the long term.

KEY FINDINGS

1. Kazakhstan's water security is becoming of strategic importance for sustainable development. Water risks are increasingly moving beyond the sectoral agenda and affecting economic growth, food security, energy sustainability, regional development and the quality of life of the population.

2. The main threats are complex and interrelated. The country's water system is under pressure from climate variability, increasing pressure on resources, transboundary interdependence, infrastructure constraints and declining environmental sustainability of aquatic ecosystems.

3. Interannual variability in runoff is becoming one of the key risk factors. For Kazakhstan, it is not only the average volume of available water resources that is critical, but also the high volatility of water supply, including periods of low water, droughts and flood events.

4. Basins with high pressure on water resources and significant transboundary interdependence remain the most vulnerable. Particular attention is required for regions where the risks of water scarcity, intensive agricultural water use and sensitivity to external hydrological factors converge.

5. Existing structural constraints exacerbate the sector's vulnerability. Key constraints include the deterioration of water management infrastructure, low water use efficiency, insufficient coordination between sectors, and the limitations of modern monitoring and forecasting systems.

6. Kazakhstan retains significant potential for improving water resilience. Key priorities remain the modernization of irrigation, the development of water-saving technologies, the use of groundwater as a strategic reserve, the digitalization of water metering, and the strengthening of early warning systems.

7. The transition to proactive water risk management must be a priority. This entails the introduction of scenario planning, the development of a basin-based approach, the integration of climate risks into water policy, and the strengthening of institutional coordination at national and regional levels.

8. Cross-border cooperation remains a prerequisite for long-term water security. Strengthening mechanisms for coordination, data exchange and the harmonization of water use regimes with neighbouring countries will be crucial for reducing external risks and improving the predictability of water supply.

9. Long-term sustainability requires a combination of infrastructural, institutional and nature-based solutions. Effective water policy must simultaneously address the modernization of infrastructure, improved governance, ecosystem restoration and adaptation to climate change.

10. Overall, Kazakhstan has the potential to move from crisis response to the development of a sustainable model of water security. However, realizing this potential will depend on the consistency of reforms, the quality of governance, the adequacy of investment and the ability to integrate the water agenda into the broader context of national and global development.

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