

Economic instruments of water resource management on the example of enterprises of KAZ minerals under non-stationarity of climate

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DS, 0009-0004-0894-2657

ABSTRACT

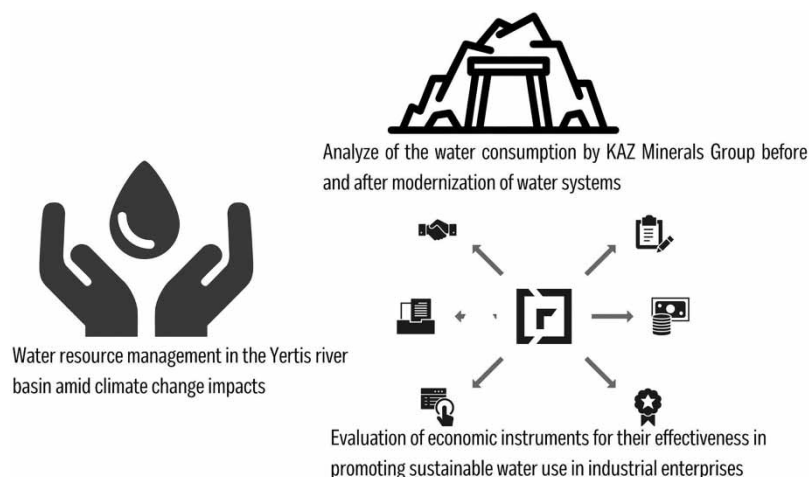
Water resource management challenges are shaped by territorial and natural conditions, and each country's specific context and international commitments. Growing water scarcity poses a significant issue at both national and regional levels. Integrated water resource management in the Yertis (Irtys) river basin is particularly crucial due to its transboundary nature, involving China, Kazakhstan, and Russia. This study assesses water resource pressure in the Yertis basin using the 'water stress' indicator from water management plans of the three states. The Yertis River basin in Kazakhstan is highly industrialized, making it a focal point for analyzing water consumption by industrial enterprises, including KAZ Minerals Group. The research compares water use levels by KAZ Minerals Group before and after modernization of water systems from 2015 to 2020. The study highlights the successful implementation of economic instruments, such as water extraction taxes and modernization of water systems, which have led to reduced water abstraction and improved water recycling. These measures have contributed to mitigating water stress and ensuring a reliable water supply amid increasing demand and climate change impacts. The findings emphasize the importance of transboundary cooperation and the integration of economic, administrative, and technological tools to enhance water resource sustainability.

Key words: economic instruments, integrated water resource management, sustainable development, water stress, water stress level

HIGHLIGHTS

- The study examines water resource management in the Yertis river basin amid climate change impacts.
- It analyzes water consumption by KAZ Minerals Group before and after modernization of water systems from 2015 to 2020.
- Economic instruments are evaluated for their effectiveness in promoting sustainable water use in industrial enterprises.

GRAPHICAL ABSTRACT



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1. INTRODUCTION

Integrated water resource management (IWRM), along with the protection and rational use of water resources, is crucial for improving the quality of life and economic development in the Republic of Kazakhstan. A key principle of IWRM is ensuring financial stability in water management through the use of economic instruments such as taxes, obligatory payments, tariffs, subsidies, and government support measures. These economic tools, when combined with administrative, informational, and market tools, can significantly enhance the effectiveness of efforts to improve water use sustainability. State water management programs in Kazakhstan employ these integrated approaches to address water resource challenges effectively (Derevjago & Dubenok 2019; Nurgaliyeva *et al.* 2024).

The UN General Assembly (A/RES/64/292 2010) declared access to clean water and adequate sanitation a human right. Currently, hundreds of millions worldwide face serious water-related challenges, including water scarcity, poor water quality, and natural disasters like droughts, mudflows, and floods. Natural disasters, such as floods and droughts, are often linked to water, as droughts usually involve low water levels. Landslides are also often associated with water. By 2030, nearly half of the world's population is expected to live in areas under severe water stress (Guidance on... 2009). Water should be viewed as an exhaustible and vulnerable resource, an economic good, and a natural resource with cultural, social, and ecological value (Koptuyug 1992; Meyer *et al.* 2016). The need for sustainable socio-economic development, environmental management optimization, and water resource protection is becoming increasingly important amid intensive human activity and growing anthropogenic impact on ecosystems (Stoyashcheva & Rybkina 2013). Global energy demand is projected to rise by over 25%, with industry, including the energy sector, consuming 19% of the world's freshwater. This share is expected to reach 24% by 2050. Water use by the energy sector is predicted to increase by 60% by 2040, exacerbating scarcity in water-stressed areas. Agriculture, the primary water consumer, contributes significantly to water scarcity due to low efficiency in water use, primarily for irrigation. In industry, major water consumers include metallurgy, oil refining, petrochemicals, chemicals, pulp and paper, and power generation. Producing 1 ton of steel can consume up to 220 m³ of water, and 1 ton of copper up to 300 m³, depending on the processes used (Kondratyev *et al.* 2019). Introducing recycling, reuse, and recirculation technologies in industry is an optimal solution for saving water.

Bachtiar *et al.* (2023) analyzed the optimal operation pattern for the integrated cascade reservoirs of Duriangkang-Muka Kuning in Batam City, Indonesia, to support the growing raw water demand driven by industrial and population growth. Their study employed linear programming and simulation models to optimize reservoir operations, highlighting the importance of effective reservoir management in ensuring sustainable water supplies. In coastal areas, Sukri *et al.* (2023) examined the utilization management to ensure clean water sources, addressing the difficulties coastal communities face due to tidal water sources and substandard surface water quality. Hong & Nguyen (2023) focused on surface water quality monitoring in the Lung Ngoc Hoang Nature Reserve in the Mekong Delta, Vietnam, using multivariate statistical methods. Their research assessed the physicochemical properties of water samples and identified key pollution sources, such as sulfate-acid soils, livestock, fertilizers, and domestic activities.

In this paper, we present the Yertis (Irtysh) basin, its management, recycling of used waters and economics instruments of water resource management, by example of the KAZ Minerals Group.

2. GLOBAL WATER AVAILABILITY, MANAGEMENT AND METHODS

According to the United Nations World Water Development Report, global water use has increased six-fold over the past century and continues to rise steadily, at about 1% per year, driven by such factors as demographic growth, economic development, and changing consumption patterns. Climate change, combined with an uneven and unstable supply of water resources, will further complicate the situation in regions where these resources are already under severe stress and will cause problems where water is currently abundant. Climate change imposes additional risks for water infrastructure, which results in an ever-increasing need for adaptive measures. Water-related extremes intensified by climate change increase risks to infrastructure such as 'water, sanitation, hygiene for all.' The impact of climate change on water resources can create risks for industry and energy; water stress can lead to disruptions in production, disturb the organization of work, affect the supply of raw materials, and disrupt supply systems.

It should be noted that economic tools create incentives for changing the behavior of water users and influence their priorities, raise budget revenues, thereby providing financing of necessary public measures. At the same time, economic tools do

not replace but supplement other water management tools: water accounting and control, monitoring of water bodies and pollution control, etc.

The economic mechanism of water use functionally contains the following main elements:

- fees for the use of water bodies and resources;
- compensation payments for harm (damage) caused to water bodies in violation of water legislation;
- financing of water protection and water management measures aimed at preserving (restoring) water bodies and protecting the population and sectors of the economy from the negative impact of water;
- privileges and preferences (economic incentives for rational water use).

The study employs a comprehensive approach to analyze water management practices and their impact on the sustainability of the Yertis River basin. The research utilizes both quantitative and qualitative methods to gather and analyze data. Quantitative data on water flow rates, water abstraction, and consumption were collected from various sources, including the Committee on Water Resources of the Ministry of Ecology, Geology and Natural Resources, and the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan. These data points span from 2010 to 2020, providing a detailed overview of the trends in water resource usage and management over a decade. Additionally, the research includes an analysis of payments and taxes related to water usage, which provides insights into the economic instruments used for water resource management.

Qualitative data were gathered through case studies of specific water management projects, such as the construction of the Belokatun hydropower plant and the initiatives by KAZ Minerals. These case studies provide a deeper understanding of the practical implementation of water management strategies and their outcomes. Furthermore, the study examines the legislative and policy frameworks governing water resources in Kazakhstan, including the Sustainable Development Goals (SDGs) and Millennium Development Goals (MDGs) indicators. This research study will examine the activities of KAZ Minerals Group enterprises located in the territory of the Republic of Kazakhstan. Bozshakol is a large scale, open pit copper mine located in the Pavlodar region (water supply from the Kanysh Satpayev Canal). Aktogay is a large scale, open pit mine in East Kazakhstan, 250,000 m from the Kazakhstan–China border, located in the Ayagoz district of the East Kazakhstan Region (water supply through groundwater from underground wells).

The research methodology includes statistical analysis to interpret the quantitative data, identifying trends and correlations between water usage, population growth, and industrial activities. The qualitative analysis involves a detailed examination of policy documents, project reports, and expert opinions to understand the effectiveness of various water management strategies. The article addresses the specific impacts of climate change on water resource availability in the Yertis River basin by analyzing historical data on river flow rates and water abstraction patterns, as well as incorporating climate projections to predict future water availability. The study highlights the variability in water availability due to seasonal and annual changes, exacerbated by climate change, which affects the timing and volume of river flows. To assess water stress and consumption levels, the research utilizes a combination of quantitative data analysis and qualitative assessments. This includes calculating the water stress indicator. The calculation of the water stress indicator in our study is based on the ratio of total freshwater withdrawals to total renewable freshwater resources, after considering environmental flow requirements (EFRs). EFRs represent the volume of water necessary to maintain essential ecological functions. For each specific ecosystem, EFR values are determined based on local climate conditions and ecosystem needs. In our research on the Yertis River basin, we used an average global EFR estimate of approximately 30% of total renewable freshwater resources, as recommended by the International Water Management Institute. This percentage was incorporated into the calculation for each year of the study, allowing us to accurately reflect the pressure on water resources while accounting for both human activity and ecological sustainability.

The article ensures the accuracy and reliability of data by sourcing information from authoritative organizations such as the Committee on Water Resources and the Bureau of National Statistics of Kazakhstan. Statistical analysis techniques are used to interpret quantitative data, employing standardized indicators like the water stress indicator and water exploitation index. Additionally, qualitative assessments through case studies and expert opinions provide contextual understanding, further corroborating the findings. This comprehensive approach ensures the data used for analyzing water consumption and economic instruments is both accurate and reliable.

Overall, this mixed-methods approach allows for a comprehensive assessment of water management practices in the Yertis River basin, evaluating their sustainability and identifying areas for improvement. The study's findings are intended to inform

policymakers and stakeholders about effective water management strategies and the importance of continuous monitoring and adaptive management in addressing water scarcity and ensuring the sustainable use of water resources.

3. RESULTS AND DISCUSSION

3.1. Yertis River watershed

Water resources of the Yertis water management basin (where the study objects are located) are widely used for various needs of industry, housing and agriculture (regular irrigation, flooding of estuaries and hayfields, watering of pastures, power generation, etc.) (Figure 1). There are 82 reservoirs and ponds on the territory of the Yertis water management basin, the main part of which – 75 reservoirs and ponds with total design capacity of 53,000,000,000 m³, which is 56% of the capacity of all reservoirs of Kazakhstan – are located in the East Kazakhstan region. Seven reservoirs have a capacity of more than 10 million m³, three large reservoirs of which (Bukhtarma, Ust-Kamenogorsk, and Shulba) of the Irtysh cascade with a capacity of 52,700,000,000 m³ have a complex purpose. Besides, in the concerned region there is a unique canal on transfer of flow of the Yertis River – the canal named after Kanysh Satpaev with total length of 458,000 m and elevation on watersheds of the Shiderty and Nura rivers (the canal is a source of freshwater for Bozshakol mining and processing plant as well).

IWRM of the concerned region is of particular importance and relevance due to the fact that the Yertis belongs to trans-boundary rivers and its water resources are intensively used by three neighboring states – the People's Republic of China, the Republic of Kazakhstan and the Russian Federation.

3.2. Water management

The results of research (Stoyascheva & Rybkina 2013) indicate that at present there is a tense water-ecological situation (water stress) in the Irtysh basin (in the Russian Federation), as the Yertis River basin is one of the most industrially developed regions in the Republic of Kazakhstan.

The concept for the definition of the 'water stress' indicator demonstrates the following – this indicator is an assessment of the pressure on the renewable freshwater resources of the country created by all sectors. A low level of water stress indicates a situation in which the total water extraction by all sectors is insignificant in relation to the overall resources and thus has little potential impact on its sustainability or potential competition between users. High levels of stress indicate a situation in which the total water extraction by all sectors is a significant proportion of all renewable freshwater resources and may have a more serious impact on their sustainability and potential conflict and competition between users.

Ultimately, the purpose of this indicator is to represent the extent to which water resources are used to meet the demand for water in the country. It measures the country's pressure on its water resources and, therefore, the problem of sustainability of water use in the country. This indicator shows the extent to which water resources are already being used and indicates the importance of effective supply and demand management policies. An increase in the level of pressure on water resources has the potential to negatively affect the sustainability of natural resources and economic development (FAO & UN Water 2021).

The indicator on water stress also existed in the MDG monitoring mechanism and was formulated as 'the proportion of all water resources used'. Although the definition of this indicator does not differ from the one proposed for SDG (Sustainable Development Goal) indicator 6.4.2, it does not take into account EFR, being limited to considering the water resources needed for human activities compared to the total resources available. This has been addressed in the definition of the water stress indicator 6.4.2 currently in use and in the *Integrated Monitoring Guide for SDG 6 (2017)*. The definition of the water stress indicator is summarized as follows: ratio between total freshwater withdrawn by all major sectors and total renewable freshwater resources, after taking into account EFR.

According to the standards of the International Standard Industrial Classification of All Economic Activities, major sectors may include agriculture, forestry, fisheries, manufacturing, electricity and municipal services. Data on freshwater abstraction is also used to calculate Indicator 6.4.1 on water use efficiency, and data on EFR is used to calculate Indicator 6.6.1 on water-related ecosystems.

For the MDG indicator (MDGs), three levels of water stress were considered as thresholds: 25% and below – no water stress, 60% – close to water stress, and 75% and above – severe water stress. However, for indicator 6.4.2, the notion and values of EFR are added into the calculation. It means that the volume of water necessary for functioning of the main ecological systems is already calculated and is not taken into account at the moment of calculation of the indicator.



Figure 1 | Yertis River basin.

Despite the difference in EFR value (EFR) for different ecosystems and climate types, according to estimates of the International Water Management Institute, its share is about 30% on average in the world, if EFR is considered in calculation of the indicator, in principle, environmental water scarcity should not be considered at the value of indicator up to 100%.

However, in terms of water use for human needs, there are forms of water consumption, such as shipping and recreation, which do not require water extraction. But they consume water in volumes exceeding the EFR, therefore, at a value of 70% it

is assumed that there is a serious shortage of water (nevertheless, target levels for each country should be determined on a case-by-case basis, taking into account various factors: level of development, population density, availability of unconventional sources and general climatic conditions). It is supposed to classify the level of water stress in three main categories (levels): low, high and very high. Thresholds for this indicator can be specific for each country; alternatively, unified thresholds can be proposed, taking into account ecological requirements for water. Table 1 shows the data on the level of pressure on water resources of the Republic of Kazakhstan.

The statistics in Table 1 clearly show the growth of the population of Kazakhstan, and if freshwater withdrawal for the period from 2010 to 2019 is relatively at the same level, the picture with renewable freshwater resources is slightly different – so if in 2010, renewable freshwater resources were 180,820 million m³, in 2012 renewable freshwater resources were 78,420 million m³ (2 times less than in 2010), and freshwater withdrawals from year to year (2010–2019) are about at the same level. Information on the volume of renewable freshwater resources is based on river flow data according to the State Water Resources Cadastre of the RK.

According to research (Danilov-Danilyan & Losev 2006), the value of water stress is determined by the ratio of water abstraction from surface water sources to available renewable water resources (mean annual values of river flow), if the value is less than 10%, then water stress is not observed, from 10 to 20% – weak water scarcity exists, 20–40% – moderate, exceeding 40% means high level of water deficit.

Annually, more than 4,000,000,000 m³ is withdrawn from the Irtysh River, of which 75% is the share of the Republic of Kazakhstan (the Yertis River), and 25% of water is shared between the People's Republic of China and the Russian Federation (Li *et al.* 2024). Water stress within the Kazakhstan part of the basin, taking into account average annual flow values, is 13%, which corresponds to a weak degree of water scarcity, but in low-water years and autumn-winter low-water periods, when the river water availability is much less than average annual values, withdrawal of river flow can reach up to 20%, in which case water stress is already estimated as moderate, and water as a resource will be considered as a factor limiting development of the territory. The situation is also complicated by the following factor – the increase in water abstraction from canals:

- Irtysh – Karamay (focused on water supply to oil and gas production enterprises in the Karamay field area);
- Black Irtysh – Urumqi (focused on water supply to the Tarim field in the Takla-Makan desert);
- Yertis – Karaganda (water supply to industrial areas and agriculture).

Planning by the People's Republic of China to increase water extraction from 4,000,000,000 to 6,000,000,000 m³/year, which is 5% of the average annual flow of the Yertis River in the site of the China–Kazakhstan border, will lead to maximum water use in the region. According to international standards this will correspond to a high level of water shortage or water stress (Dostai *et al.* 2012).

Table 1 | Level of pressure on water resources of the RK

Year	Renewable freshwater resources (annual resources of river flow), million m ³	Freshwater withdrawal, million m ³	Freshwater withdrawal per capita, m ³	Water exploitation index ^a , %	Water stress level, %	Average annual population, people
2010	18,0820	23,812	1,459	13.2	33.0	16,321,872
2011	99,800	21,948	1,326	22.0	30.4	16,557,201
2012	78,420	21,389	1,274	27.3	29.7	16,792,089
2013	131,340	22,530	1,323	17.2	31.2	17,035,550
2014	108,100	23,078	1,335	21.3	32.0	17,288,285
2015	115,600	21,661	1,235	18.7	30.0	17,542,806
2016	160,000	21,634	1,216	13.5	30.0	17,794,055
2017	122,100	22,454	1,245	18.4	31.1	18,037,776
2018	110,700	23,542	1,288	21.3	32.7	18,276,452
2019	107,600	23,516	1,270	21.9	32.6	18,513,673

Source: Committee on Water Resources of the Ministry of Ecology Geology & Natural Resources (2024), Bureau of National Statistics of the Agency for Strategic Planning & Reforms of the Republic of Kazakhstan (2024).

^aWater exploitation index – the ratio of freshwater withdrawal to renewable freshwater resources.

When assessing water stress, it is necessary to keep in mind that water availability may vary from season to season, the averaged annual data do not show periods of water scarcity. The results of studies on the Yertis water management basin show that in the Yertis River – Ust-Kamenogorsk city, the spring runoff has decreased to 20% regardless of the year water availability, the winter low-water flow in high and low water years has increased by 17 and 13%, respectively, which is due to the energy regime of reservoir operation. In the lower reaches of the Yertis River, the reduction of spring runoff is about 13%.

As all over the world in the Republic of Kazakhstan, the growing water scarcity is directly related to the rapid growth of the economy and irrational use of water in some sectors, the growth of water consumption is directly linked to significant volumes of its use in agriculture, industrial production and the housing and communal sector (Table 2).

Analysis of Table 2 shows that for the period from 2010 to 2019 the volume of freshwater used for agricultural irrigation is from 40 to 50%, for the given decade in the country the volume of freshwater used by industry is from 25 to 30%.

In the Yertis River basin in the Republic of Kazakhstan, the water management plans are aimed at inter-basin and trans-boundary river flow transfers to water-deficient regions through the construction of the Trans-Kazakhstan canal with water extraction from the Shulba reservoir (second stage) with five branches – one main route and four additional ones – Astana, Petropavlovsk, Kostanay and Aktobe. In addition, to preserve Lake Balkhash, which is of national importance to the country, the scenario of transferring part of the flow of the Yertis River in the direction of the Bukhtarma river – Lake Balkhash has been proposed. To compensate withdrawal of river flow of the Kara-Irtysh River to the PRC, Kazakh scientists and engineers proposed an ‘updated scheme’ of mutually beneficial use of Russian river flow in the Upper Katun direction, excluding construction of large reservoirs and focused on a tunnel (or pumping) option to overcome the watershed (Liu *et al.* 2023).

In the Irtysh river basin in the territory of the Russian Federation, water management plans are aimed at implementing such projects as the construction of the Belokatun hydropower plant by transferring to the Irtysh river basin the Tikhaya river (the Katun river basin), as well as turning of Ak-Kaba and Kara-Kaba rivers, which originate in the ridges of Katon-Karagai district of the Republic of Kazakhstan and flow into the Black Irtysh river already in the territory of the PRC. According to this project, it was proposed to channel these rivers by a 20,000 m tunnel into the Black Irtysh already on the Kazakhstan side, compensating Kazakhstan for the excessive withdrawal from the Irtysh water in the PRC and providing conditions for the conservation of Lake Zaisan and its fishery value (Abishev *et al.* 2016). It is certain that with all three states’ water management plans, water stress levels will continue to increase as demand for water increases and as the effects of climate change worsen.

The Yertis basin faces significant water stress due to industrial development and the increasing demands of agriculture, industry, and municipal services. Figure 2 is a summary of the existing and planned water management strategies aimed at addressing these challenges.

The current water management strategies in Russia, particularly in the Irtysh river basin, reflect a comprehensive approach to addressing water scarcity and resource management. The construction of the Belokatun hydropower plant is a significant

Table 2 | Effectiveness of water use in the RK

No.	Characteristics	Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	Total available freshwater volume	mln m ³	22,611	20,989	20,268	21,758	21,299	21,378	20,213	20,520	20,659	20,955
	of which by industry:	mln m ³										
2	Households	mln m ³	751	790	724	711	732	730	727	762	591	792
3	Agriculture, Forestry and Fisheries	mln m ³	11,703	9,373	9,141	9,774	12,147	13,082	12,104	13,222	12,988	13,201
3.1	of which were used for agricultural irrigation	mln m ³	9,050	9,066	8,840	9,486	9,485	9,828	9,019	9,511	9,491	10,300
4	Industry	mln m ³	5,604	5,918	5,985	6,222	6,337	5,887	4,176	4,033	4,813	5,600
5	Other activities	mln m ³	4,553	4,908	4,418	5,051	2,083	1,679	3,206	2,503	2,267	1,362

Source: Committee on Water Resources of the Ministry of Ecology Geology & Natural Resources (2024), Bureau of National Statistics of the Agency for Strategic Planning & Reforms of the Republic of Kazakhstan (2024).

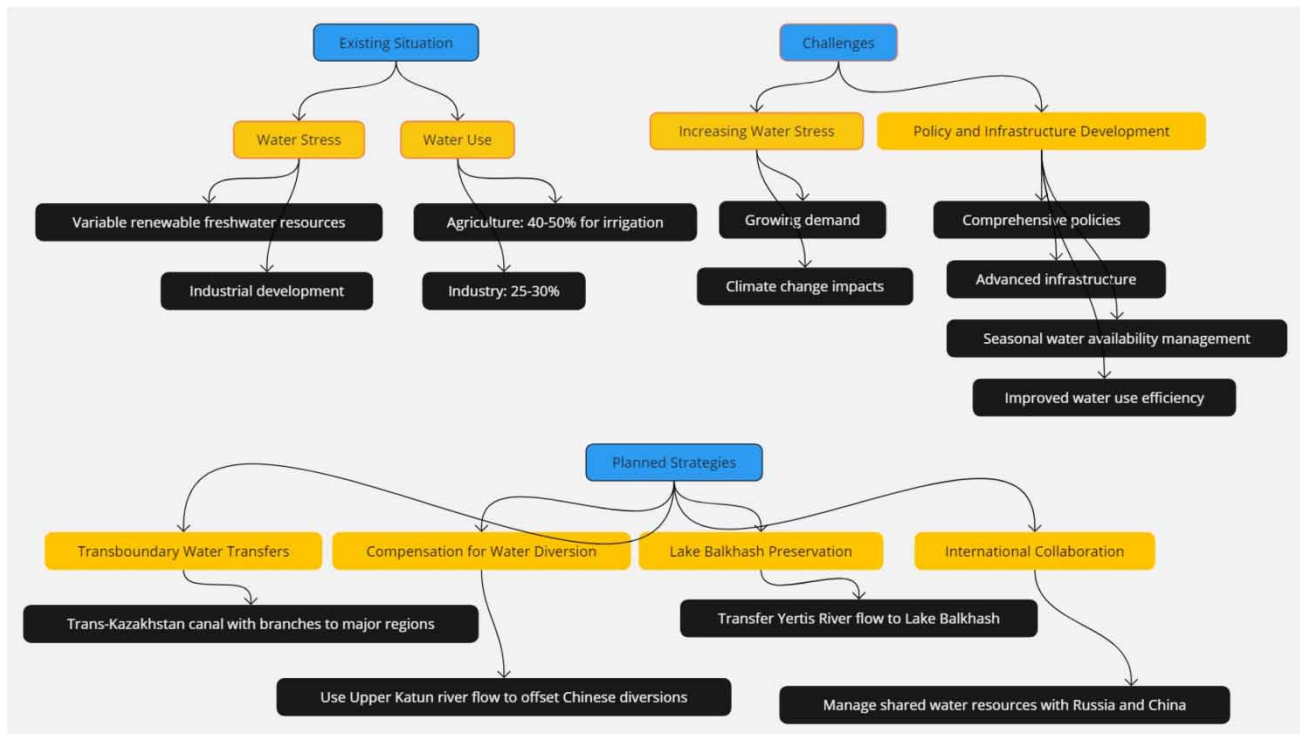


Figure 2 | Existing and planned water management strategies.

component of these strategies. This project involves the transfer of water from the Tikhaya river (part of the Katun river basin) into the Irtysh river basin (Figure 1). Additionally, plans include channeling the Ak-Kaba and Kara-Kaba rivers, originating in the Katun-Karagai district of Kazakhstan, into the Black Irtysh river through a 20,000-meter tunnel on the Kazakhstan side (Figure 1). The primary objectives of these projects are to compensate for the excessive withdrawal of Irtysh water in China and to ensure the conservation of Lake Zaisan and its fishery resources (Figure 1). By implementing these plans, Russia aims to mitigate the impact of water scarcity, enhance the sustainability of water resources, and address the increasing water demand exacerbated by climate change. These initiatives are part of a broader transboundary water management strategy, highlighting the importance of cooperation among Russia, Kazakhstan, and China to achieve sustainable water resource utilization and ecological balance in the region.

Climate change poses significant challenges to water resource management in the Yertis River basin. Increasing temperatures and altered precipitation patterns are expected to exacerbate water scarcity, impacting the availability and reliability of freshwater supplies. These changes can lead to more frequent and severe droughts, reducing river flow and reservoir levels, while also intensifying floods and mudflows. The study underscores the need for adaptive management strategies that incorporate climate projections to ensure sustainable water use and resilience against the impacts of climate change. This includes enhancing cross-border cooperation and optimizing economic instruments to manage water resources effectively in the face of these evolving climatic conditions.

3.3. KAZ Minerals: water abstraction, release and recycling

KAZ Minerals is one of the largest copper producing companies focused on the development of copper mining and new mining operations in Kazakhstan. KAZ Minerals operates the Bozshakol open pit copper mine in the Pavlodar region and the Aktogay open pit copper mine in East Kazakhstan, three underground mines in the East Kazakhstan and the Bozymchak copper-gold mine in Kyrgyzstan. In January 2019, the Group acquired the Baimskaya copper project in the Chukotka Autonomous District of the Russian Federation.

KAZ Minerals is committed to rational water consumption and tries to ensure the reuse of this resource. The main sources of water for reuse are tailings dams and mine water inflow. According to calculations by Chanturiya & Chekushina (2016), at the sulfide ore processing enterprises of Aktogay and Bozshakol mining and processing plants, 75% of water taken from

natural sources and used in the technological process is reused. This reuse significantly reduces potential water losses during evaporation. Table 3 shows the volume of water use at KAZ Minerals Group plants.

At the Group level, water abstractions doubled in 2016 compared to 2015. In 2017 water abstractions increased by 62% compared to 2016 because the Aktogay concentrator required significant volumes of water during the initial production increase in the sulfide ore processing which commenced operations in February 2017. This situation was similar to the increase in water usage at the Bozshakol during the same ramp up phase in 2016. The Group's water usage levels in 2018 declined for the first time since the Group's restructuring in 2014, decreasing by 13% compared to 2017. Bozshakol was the main source of reduced water usage, despite increased processing volumes, Bozshakol processes large volumes of water from the tailings dam due to increased water recycling. The Group's water usage decreased by 30% in 2019 as the clay plant at the Bozshakol mining and processing plant was closed for three months for modernization. Following the upgrade of the process and recycled water systems, freshwater consumption was significantly reduced and the use of recycled water from the tailings dam facility increased. Water consumption at Aktogay increased in 2019 as a result of increased production at the sulfide ore processing plant to 14.4 million m³; in 2018, water consumption was 12.1 million m³. Analysis of the data in Table 3 shows an increase in water use by 6% in 2020 as a result of continuous operation of the clay plant, the high level of recycled water in the tailings partially compensated the water consumption.

The projects of Bozshakol and Aktogay concentrators provide for reuse of up to 75% of water abstraction from local sources. Sludge and wastewater from the plant are piped to the tailing's storage facility, where the water in the tailings is reduced to 40%, the minimum level to maintain the flow viscosity. The tailings are then transferred to the tailing's storage facility, where the water is pumped out and recirculated for use at the plant. The only significant loss of water in the system is due to evaporation in the tailings dam. Production at the Bozshakol sulfide and clay plant commenced in 2016. Large volumes of water were withdrawn from the Yertis-Karaganda canal in the initial phase as production ramped up to design capacity. After significant volumes of water began to be obtained from tailings, water abstractions from the Yertis-Karaganda canal decreased to 6.60 million m³ in 2019.

Total water abstraction by industrial enterprises in the concerned region, total water abstraction of the Group broken down by sources (surface water and groundwater), water abstraction from the Yertis-Karaganda canal for the Bozshakol mining and processing plant and total water discharge into the environment by the Group's enterprises are shown in Figure 3.

The level of 2015, the total water abstraction (surface water) by industrial enterprises in the region was 52.2 million m³, and water ex abstraction (surface water) by KAZ Minerals Group enterprises was 6.74 million m³ (13%). After ramping up production at the level of 2017, water abstraction (surface water) of the Group's enterprises was 32.8 million m³, which amounted to 70% of the total water abstraction by industrial enterprises in the concerned region (Figure 3).

At the level of 2020 after implementation of works on modernization of process and recycling water systems at the enterprises of the Group, water abstraction from surface sources amounted to 10.4 million m³ – 22% of total water abstraction from surface sources of all industrial enterprises of the concerned region.

Total water abstraction in 2019 was 29.9 million m³ (Group as a whole), of which 9.98 million m³ from surface sources, including rivers and municipal water supply, 19.9 million m³ from groundwater wells. The increase in water abstraction from groundwater wells was due to increased production at the Aktogay mining and processing plant in 2019, where water comes primarily from groundwater sources. The decrease in surface water abstraction from the Irtysh-Karaganda canal was due to an increase in water recirculation at the Bozshakol mining and processing plant following the completion of the modernization of the ore processing plant.

Table 3 | Water use at the group's mining and processing plants, million m³

Mining and processing plants	2015	2016	2017	2018	2019	2020
Aktogay	0.35	1.11	8.55	12.1	14.4	15.5
Bozshakol	0.02	15.9	29.0	22.7	6.54	7.57
Eastern Region	14.8	13.3	11.4	7.87	8.53	8.15
Bozymchak	0.19	0.23	0.28	0.30	0.42	0.33
Group	15.4	30.5	49.2	43.0	29.9	31.6

Source: KAZ Minerals (2020).

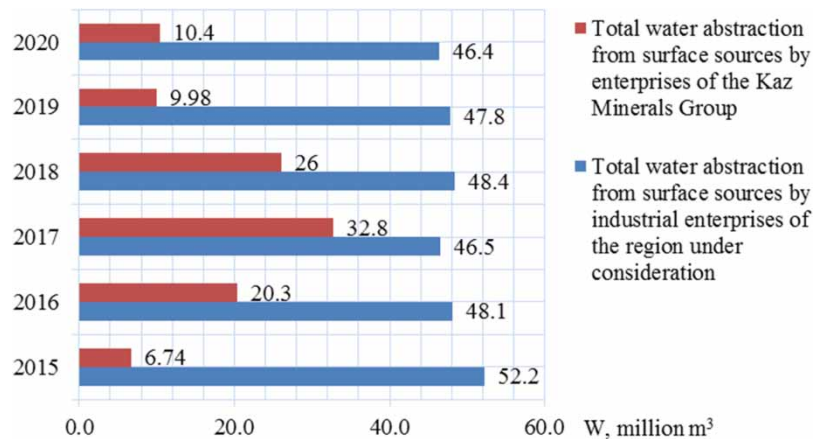


Figure 3 | Dynamics of water abstraction from surface sources by industrial enterprises of the concerned region and enterprises of KAZ Minerals Group.

Total water discharges to the environment increased in 2020 to 2.24 million m³ (in 2019–1.48 million m³). There are three water discharge points in the East Region. Two of them are in underground mining areas located far away from processing plants, and pumping water for reuse seems unprofitable. The third source of water discharge is the waste dumps adjacent to the depleted pit, where acidic effluents are collected. At each of these locations, the volume of water inflow and discharge varies depending on precipitation events. All discharged water is monitored and treated prior to discharge to the environment.

Economic instruments of water resource management are quite varied and their application in the country depends, first of all, on the level of economic development of the country.

The main economic tool is the fee for water use, and the rates of payment for extraction (water abstraction) may depend on the purpose of water use (for drinking and domestic water supply, for the needs of industry, energy, for irrigated agriculture, use of water bodies without water abstraction), as well as on the amount of available water resources in each particular basin.

Differentiation of payments in accordance with the priorities of preferential and safe (sustainable) water use within a given territory sets the basis for the interdependent integrated approach in the implementation of water policy. The fee for the use of water resources through water abstraction is collected in almost all developed countries of the world in various forms of water tax or fee for water extraction (abstraction) and use of water bodies. The implementation of a water tax has a significant impact on water withdrawals by incentivizing more efficient use of water resources. By imposing a financial cost on water extraction, the tax encourages industries, agriculture, and municipalities to reduce consumption and invest in water-saving technologies. This economic instrument effectively discourages wasteful practices and promotes the reuse and recycling of water. In the context of the Yertis River basin, the water tax helps to manage demand and mitigate the pressures on freshwater resources, ensuring a more sustainable allocation of water among various sectors. Additionally, the revenue generated from the water tax can be reinvested into water management infrastructure and conservation programs, further enhancing the sustainability of water resources in the region. Overall, the water tax serves as a critical tool in balancing water demand with available supplies, particularly in areas facing severe water stress.

In its economic nature, it is one of the types of resource payments aimed at solving the main tasks: regulating the volume and structure of water use, accumulating financial resources in the national, regional and local budgets, including for subsequent use of water bodies and development of water infrastructure. Table 4 shows the data on payments to the Republic of Kazakhstan by KAZ Minerals Group for the period from 2015 to 2020.

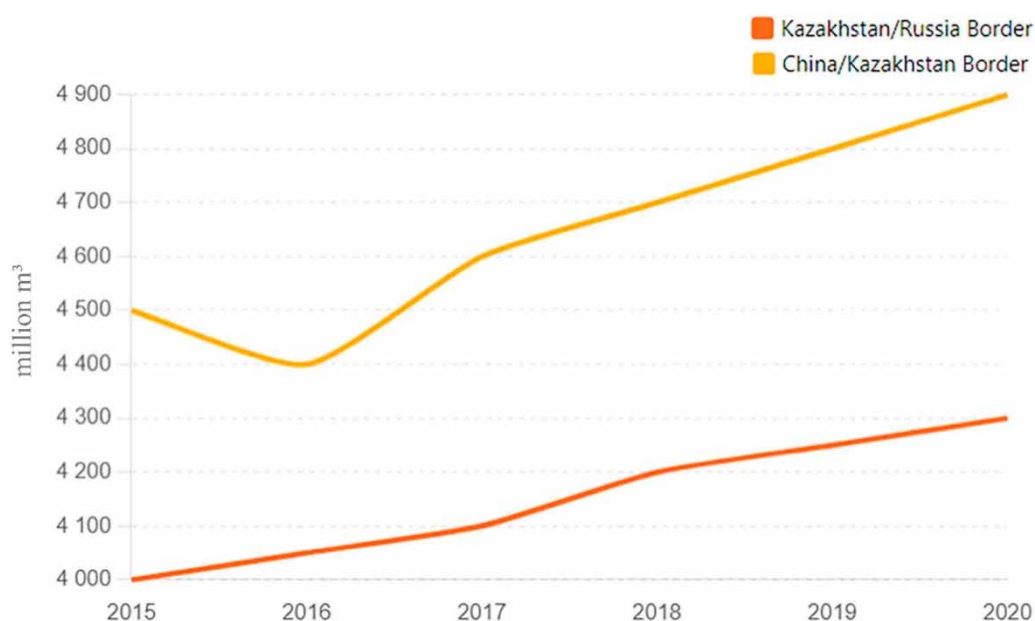
The data in Table 4 indicate that the mineral extraction tax and royalties (including the tax paid for water extraction) range from 40 to 70% of total payments to the state. Payments to the Republic of Kazakhstan from KAZ Minerals are distributed between two main recipients: the State Revenue Committee and local authorities. From 15 to 25% of revenues are received by local authorities, while the remaining 75–85% is received by the State Revenue Committee.

Figure 4 illustrates the average annual flow rates of the Yertis River at the China/Kazakhstan and Kazakhstan/Russia borders, providing insights into the effectiveness of water management practices. At the China/Kazakhstan border, the flow rates

Table 4 | Payments in favor of the Republic of Kazakhstan, mln. USD

Payments	2015	2016	2017	2018	2019	2020
Corporate income tax	34	39	62	51	69	109
The Mineral Extraction Tax and royalties (MET is payable in Kazakhstan on the value of the mineral resources extracted based on the average price of the minerals on the London Metal Exchange, MET includes taxes paid on water extraction)	58	115	183	199	201	106
Total payments to the state	120	165	305	302	314	244

Source: State Revenue Committee Ministry of Finance of the Republic of Kazakhstan (2024).

**Figure 4** | Average annual flow rates of the Yertis River (2015–2020).

show a steady increase from 4,500 million m³ in 2015 to 4,900 million m³ in 2020. This upward trend indicates that the measures taken to limit water withdrawals and enhance water management practices have been effective in maintaining or even increasing the river flow at this border. Similarly, the flow rates at the Kazakhstan/Russia border have increased from 4,000 million m³ in 2015 to 4,300 million m³ in 2020. This positive trend suggests that the economic instruments and water management policies implemented by the government are effectively ensuring sufficient flow rates downstream. The overall increase in flow rates at both borders indicates that the current water management practices are sustainable. These practices appear to be successfully mitigating the pressures on water resources, ensuring that the flow of the Yertis River remains adequate to meet both ecological and human demands. However, continuous monitoring and adaptive management are crucial to address any emerging challenges and sustain these positive trends (Nadtochiy *et al.* 2023).

The Group has established a policy on social investment and monitors funded projects to ensure they are consistent with its goals and objectives. The Group seeks to support the following types of projects (Kyfyak *et al.* 2024):

- projects located in the Group's operating sites and aimed at the development of health, education, culture and sports (supporting local colleagues by providing equipment and training material as part of skills development in the mining industry); in December 2016, mining operations at the Yubileyno-Snegirikhinsky mine (East Kazakhstan) ceased as its mineral resources were fully exploited, in October 2019, the closure of the mine was completed, the Kazakhstan Regional Environmental Commission approved the closure of the mine, forestry reclamation is being carried out at the former site with Group funding to restore the landscape to its original condition, and young seedlings start to appear in 2020;

- government projects implemented in health, education, culture and sports (KAZ Minerals is committed to supporting local communities and the government in the response to COVID-19, the Group provided in 2020 4.6 billion USD as part of the program to help 470.000 families in Kazakhstan, purchased medical supplies for local hospitals and supported the renovation of local healthcare infrastructure);
- culture promotion projects (support for the construction of a new cultural center in the city of Astana).

As required by subsoil use legislation, the Group gives preference to local procurement and supply to support a diversified economic growth in Kazakhstan; in East Kazakhstan the local procurement and supply rate in 2020 was 66% of total costs, in 2019 this rate was 68%.

Properly applied economic instruments are an effective regulator of water demand and can be a very effective way to reduce overall water consumption by saving water.

The group has set goals for improving efficiency (sustainability goals) in four key dimensions of sustainability, with an implementation deadline of December 2024:

- safety and health regulations (elimination of fatal occupational accidents);
- CO₂ emissions per tonne of processed sulfide ore – reduction by 5%;
- water consumption per tonne of processed sulfide ore – reduction by 5%;
- social aspect – maintenance of social and cultural expenses at the level of not less than 15 million USD per year.

The modernization processes of the water systems at KAZ Minerals Group involved several key initiatives that significantly reduced water abstraction. These initiatives focused on enhancing the efficiency of water use and increasing the reuse of process water. At the Bozshakol mining and processing plant, substantial upgrades were made to the ore processing facilities, which included the implementation of advanced water recycling systems. These systems allowed for the recirculation of water from the tailings dam back into the processing cycle, thereby reducing the need for fresh water intake. The introduction of high-efficiency pumps and improved pipeline infrastructure also minimized water losses during transportation and storage. Additionally, at the Aktogay mining and processing plant, similar technological advancements were introduced, particularly in the sulfide ore processing operations. These advancements included state-of-the-art filtration and dewatering equipment, which optimized the water content in the tailings, allowing for more effective water recovery and reuse. The modernization efforts also extended to the expansion of groundwater wells, which supplemented water supply without over-reliance on surface water sources.

These modernization processes not only reduced the total volume of water abstracted from natural sources but also enhanced the sustainability of water use across the Group's operations. By integrating these technological improvements, KAZ Minerals Group successfully decreased its environmental footprint and improved its water management practices, contributing to more sustainable mining operations (Kyfyak *et al.* 2024).

The study's findings have significant policy implications for the three countries sharing the Yertis River basin: China, Kazakhstan, and Russia. The observed trends in water flow rates and the effectiveness of water management practices underscore the need for enhanced transboundary cooperation to ensure sustainable water use. The study highlights the importance of implementing and strengthening economic instruments such as water usage fees and taxes, which can effectively regulate water demand and promote conservation efforts across borders. For China, the findings suggest the necessity of revisiting water extraction policies, particularly in the context of plans to increase water withdrawal from the Yertis River. Coordinated efforts with Kazakhstan are essential to avoid exacerbating water stress downstream. Kazakhstan's policy implications involve optimizing water management practices to maintain the positive trends observed, such as continuing modernization of water systems and improving water recycling initiatives. For Russia, the findings support the need to collaborate with upstream neighbors to secure adequate water flows and protect ecological systems. The study recommends establishing joint monitoring and data-sharing mechanisms to ensure transparent and informed decision-making. Furthermore, integrating climate change projections into water management strategies will be crucial for all three countries to adapt to potential future variability in water availability.

By addressing these policy implications and implementing the recommended actions, the countries sharing the Yertis River basin can enhance water sustainability, mitigate conflicts over water resources, and ensure the long-term ecological health and economic prosperity of the region.

4. CONCLUSIONS

- (1) Water resources of the Yertis River are intensively used by three neighboring states – the People's Republic of China, the Republic of Kazakhstan, and the Russian Federation. In the process of implementing water management plans of all three states, water stress levels will continue to rise as demand increases and the effects of climate change worsen.
- (2) Water abstraction from surface sources of industrial enterprises of the region under consideration and enterprises of KAZ Minerals Group for the period from 2015 to 2020 was assessed. The following results were obtained – water abstraction from surface sources decreased by three times after the modernization of systems of process and recycled water at the enterprises of the Group.
- (3) Economic instruments of water resource management are quite variable and the main economic instrument is a tax on natural resources. Data on payments to the Republic of Kazakhstan by KAZ Minerals for the period from 2015 to 2020 were analyzed and the following results were obtained: mineral extraction tax and royalties (including tax paid for water extraction) make up from 40 to 70% of the total payments to the state. Payments to the Republic of Kazakhstan from KAZ Minerals are distributed between the two main recipients: the State Revenue Committee and local authorities of Kazakhstan, payments are distributed as follows – 15 to 25% of revenues are received by local authorities, the remaining 75–85% is received by the State Revenue Committee.

Thus, a tax on water extraction, combined with collaborative Yertis River management with China and Russia, could lead to a significant reduction in water consumption. Future research should investigate the potential of IWRM practices, technological innovations in water conservation, and the role of public–private partnerships in enhancing water sustainability. Additionally, examining the socio-economic impacts of water management policies on local communities and industries would provide a more holistic understanding of their effectiveness.

ACKNOWLEDGEMENTS

This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP19679134 Development and improvement of methodological bases for calculating minimum flow of plain rivers Kazakhstan's in conditions non-stationary climate and flow).

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 27 May 2024; accepted in revised form 14 December 2024. Available online 24 December 2024