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Mine Water Use in Kazakhstan: Data Issues, Risks, and Regulations

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Abstract: Kazakhstan experiences medium-high water stress, intensified by the rapid expansion of mining operations. Due to the scarcity of public data on water use in Kazakhstan's mining, we use a case study to make inferences about industry-level water use. Specifically, we apply the ICMM water accounting framework and assess water use at one of Kazakhstan's new copper mines. We find that this mine has managed to achieve a high level of water reuse and minimal impact on water quality. Yet, the company has a relatively high share of water entrained in waste and a high rate of increase in freshwater withdrawals. Our estimates suggest that the operation of this mine has resulted in a 1.5% increase in withdrawals of Kazakhstan's extractive industries. Considering that during the last decade, the number of mining companies increased by 50%, we can conclude that the cumulative water impacts of mining in Kazakhstan have been substantial. The forthcoming uptake of critical minerals production may further strain Kazakhstan's water resources. Thus, the rapidly increasing mine water use and rising risks due to climate change and the sharing of water with neighboring countries call for urgent strengthening of Kazakhstan's water governance and institutions.

Keywords: water footprint; intensity of use; critical raw materials; copper mining; conflict minerals

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1. Introduction

Energy transition and digital technologies are key sources of growing demand for minerals and the ongoing mining boom [1]. Our research uses Kazakhstan as a case study to underscore the importance of strengthening environmental governance in order to minimize the negative impacts of mining on water resources. Mines across the world source water from rivers, lakes, groundwater, precipitation, and runoff, accounting for 2–4.5% of national water demand in major mineral-producing countries [2]. When mining withdrawals are not matched by safe discharge, this often results in conflicts between mining companies and other water users, such as local communities, farmers, and environmental organizations [3]. Water withdrawals may affect the natural hydrological cycle and ecosystems, leading to decreased water quality and quantity, as well as biodiversity loss [4]. Mine excavation, water-table drawdown, wastewater discharge, storage, and handling of chemicals, reagents, and fuels may affect surface and groundwater quality. Metal ore mining has been associated with contamination of surface water with arsenic, copper, cyanide, lead, mercury, nickel, radium, and zinc, as well as elevated suspended solids and pH levels [5]. A particularly damaging water impact of mining is acid mine drainage, which occurs due to a reaction between sulfide-rich mine waste with oxygen and water. The resulting sulfuric acid dissolves metals and leads to very long-term heavy metal pollution that is highly toxic to biodiversity and human health [6,7]. For instance, Berkeley Pit, next to the city of Butte in Montana, USA, was a copper mine that closed in 1982. Rising water levels in the pit and its acidity led to continuous contamination of surface and groundwater for many years after the mine closure. Despite building a water treatment plant in 2019, Berkeley Pit continues to be considered a top environmental concern in the United States [4]. This is one example of water impacts from over 500,000 historic mines in the United States that require significant public funding for their remediation [8]. Nowadays, the rapidly increasing extraction of critical minerals poses new risks: 16% of such mines are located in countries that face high or extremely high levels of water stress [1]. For instance, lithium mining in Chile's major mining region of Salar de Atacama uses 65% of the total available water. This has affected indigenous communities that engage in agriculture, and a similar situation exists in Argentina [1]. Furthermore, artisanal mining in many parts of the world pollutes waters due to reliance on unsafe and outdated technologies [8,9]. These environmental challenges of mining, coupled with impacts on human rights, spurred a critical review of mineral supply chains and origin tracing of "conflict minerals" by NGOs, investors, and consumers [9].

As a result, the prevention of hazardous impacts of mining on water resources is the main focus of modern water management practices in mining [8]. These approaches involve limiting reactions between water and mine wastes, managing flows of impacted water, and treatment of effluents before discharge. Modern mines limit water use during ore grinding, separating of minerals, washing, moving materials, cleaning, dust control, and cooling equipment [10]. The ability of the mine to optimize its water use depends on the type of minerals produced, the size of operations, mining methods, ore processing technologies, and water recycling practices [11]. Regular monitoring of risks of acid drainage, appropriate design of tailings ponds and treatment systems, as well as site reclamation are important for mitigating water and related forms of pollution [6]. Adopting tailings thickening technology, capping and lining ponds, establishing closed-loop water supply systems, harvesting rainfall, and redirecting runoff lead to efficient minimization of water contamination and reducing the water needs of a mine [12]. In the early 2000s, international mining companies began disclosing water impacts using sustainability reports. However, the reliability and consistency of such data used to vary considerably [13,14]. In response to these challenges, in 2017–2021, the International Council on Mining and Metals (ICMM) developed a water accounting and reporting framework tailored to mining companies. In collaboration with the industry, the ICMM established categories of water inputs and outputs. It formulated definitions of raw, processed, and treated water, facilitating a uniform interpretation of reuse, recycling, and recirculation [15]. Such comprehensive and consistent water accounting has enabled mining companies to gauge their performance against their peers.

In addition, consistent data reporting is essential for public regulation of mining activities, as well as stakeholder engagement. Regulators in Australia, Canada, and the USA require a comprehensive assessment of water impacts and designing water management systems as part of approval of mine plans and permitting [8]. Ongoing monitoring of water management and reporting are required from pre-production to mine closure. The government of Chile developed a comprehensive 2050 National Mining Policy that requires that mining companies increase the use of alternative water sources (such as seawater), avoid damaging glaciers, and reduce the generation of conventional, i.e., water-intensive, types of tailings [16].

Thus, the reviewed literature implies the following. On the one hand, water impacts continue to be significant due to the concentration of critical minerals extraction in water-stressed regions and artisanal mining in developing countries. On the other hand, mining companies in advanced economies introduced systems that reduce their negative impact on water resources. This important work was supported by the regulatory systems and initiatives of industry associations. However, the state of affairs with respect to mining water impacts in many low- and middle-income countries, such as Kazakhstan, remains under-researched [3,17]. Our study, therefore, evaluates the following questions: Do Kazakhstan's mines use water in ways that are similar to their international peers? What risks do current practices present for the mines and other water users in Kazakhstan? How can the governance of water use in Kazakhstan's mining be improved to obtain sustainable outcomes?

A large petroleum exporter, Kazakhstan ranks among the top ten countries producing uranium, chromium, titanium, barite, magnesium, silicon, manganese, and vanadium [18]. In addition, Kazakhstan is among the top twenty producers of aluminum, copper, lead, and zinc [19]. During 2001–2022, the output of Kazakhstan's mining and investment increased by 5.6% and 7.4% per year on average. Kazakhstan is poised to elevate its standing in global non-fuel mineral markets: in 2023, the governments of Kazakhstan and the EU entered into a strategic partnership to support critical minerals production [20]. In addition, Kazakhstan's government has developed a program aimed at ramping up exploration and investment, including the revision of regulations to achieve a 40% increase in the output of rare earth elements during 2024–2028 [21]. The growth of mining in Kazakhstan has been important for creating jobs and business opportunities in the private sector, as well as generating tax revenues for the government [22]. However, due to the high resource intensity of mining operations, it is important to analyze the effect of a rapid expansion of mineral production in Kazakhstan on its natural resources, including water.

Our concern about the environmental sustainability of mining in Kazakhstan is related to the fact that Kazakhstan is the largest land-locked country that, has 40% of its river flows originating outside its borders. These flows are expected to decrease due to climate factors and growing water use in the neighboring countries [23,24]. Compared to the previous century, droughts in Kazakhstan's southern and western regions became more frequent and severe, while precipitation in other parts of the country remained the same or increased slightly [25,26]. Kazakhstan's water stress, defined as the ratio of water demand to renewable supply, is currently within the range of 20–40%. This level of water stress is considered medium-high, similar to that of Australia, China, and the United States [27]. The rapid increase in the population and high rates of economic growth [28] pose serious threats to future water availability in Kazakhstan and its ability to achieve sustainable development goals [29,30].

Compared to the previous decade, during 2012–2022, the average annual volumes of water use and withdrawals in Kazakhstan increased by 2.3% and 3.6%, respectively [31,32]. Differences in these growth rates reflect the widening gap between volumes of water used and its intake. In 2020–2022, water use represented only 82% of withdrawals, reflecting the widespread losses due to aging infrastructure, mismanagement, and lacking incentives for water saving [33]. Water consumption in Kazakhstan is akin to that of East Asia, where the share of industrial water withdrawals is around 22% and reflects the prominence of its manufacturing industries [34]. Similarly, Kazakhstan's industrial sector accounts for around 20–30% of total withdrawals by all sectors. Unlike East Asia, large industrial water withdrawals in Kazakhstan are related to the country's specialization in resource extraction [28].

The environmental performance of industrial companies in Kazakhstan is regulated by the 2021 Environmental Code, which requires the adoption of the Best Available Technology and the polluter-pays principle. Legislation that pertains to water use in Kazakhstan is the 2003 Water Code, which defines terms of water use as part of agreements between government agencies and a particular company, handled on a case-by-case basis. Inadequacies in current water management practices in Kazakhstan are exacerbated by incomplete records on water intake and discharge, as well as a lack of crucial information on the time, scale, and intensity of water-related activities within catchments. The ongoing difficulties in Kazakhstan's water sector have pressed the government to establish a separate Ministry of Water Resources and begin revision of the Water Code to promote water saving, reduce water losses in agriculture, adopt water reuse and recirculation in industry, increase investment in water infrastructure, as well as promote public oversight and data collection and dissemination. However, it is not clear whether the revision of regulations of water use by the extractive industries is on the agenda of lawmakers.

As a result, our study contributes to the public discourse in Kazakhstan and other mining jurisdictions on improvements to water governance. Specifically, we investigate the performance of one of the new copper mines and interpret our results in the context of the mine's catchment. This operation represents non-ferrous mining, which is the largest (accounting for 50% of total mining industry output and 82% of its investment) and fastest-growing (with an annual output growth rate of 7% since early 2000) segment of the mining industry in Kazakhstan. We find that the expansion of operations of such mines was accompanied by a rapid increase in freshwater withdrawals. The lack of data does not allow us to evaluate changes in volumes of mining industry effluents and their impact on water quality. However, our finding of rapidly increasing freshwater withdrawals implies that the continuation of current water use practices in Kazakhstan's mining may contribute to growing conflicts with other water users, aggravation of water stress, and disputes with neighboring countries.

2. Materials and Methods

Below, we describe the ICMM (2021) approach to quantifying water use in mining. The ICMM water accounting framework requires establishing a comprehensive water balance of all inflows to and outflows from a mine site:

$$\textit{Water inputs} = \textit{Water outputs} + \textit{Change in storage} \tag{1}$$

To obtain the overall balance at the entire mine it is required to establish sub-balances of outflows and inflows at key elements of the mine, such as the processing plant and the tailings storage facility. The derivation of water balance presents a foundation for determining ICMM minimal reporting metrics of total mine site withdrawal, consumption, and discharge. These categories are related to each other as follows:

$$\textit{Withdrawal} = \textit{Discharge} + \textit{Consumption} + \textit{Change in storage} \tag{2}$$

$$\textit{Withdrawal} = \textit{Operational Water} + \textit{Other managed water} \tag{3}$$

The ICMM defines these flows and other relevant terms as follows:

Withdrawals refer to water inflows to a mine site. They consist of flows from surface water bodies (streams, lakes, etc.), precipitation, runoff, groundwater (including dewatering), and more moisture.

Water discharge refers to water that is released into the surrounding environment from a mine site.

Water consumption is the difference between all water withdrawn and the sum of water stored in a mine site and water discharged.

Change in storage may be positive or negative. It reflects the presence of unrecorded flows and errors, which the ICMM framework interprets as system losses. The ICMM recommends that such losses do not exceed 5–10% of withdrawals.

Operational water is water that is required to meet operational needs such as for ore processing, waste storage, dust suppression, and processing.

Other managed water refers to water not meant for operational purposes that is actively controlled or manipulated, such as through physical pumping (e.g., dewatering).

Dewatering involves removing groundwater from the mine pit to create dry conditions for safe mining activities.

A tailings storage facility (TSF) is a specially engineered pond where the waste material from extracting the concentrate is stored and managed.

Recycled water: Water treated from one or more sources before usage.

Reused water: Water that is reused after one or more tasks without being treated.

Reclaim water: Water redirected from the TSF. Reclaimed water is a type of reused water.

High quality: This category of water requires a low to moderate level of treatment, such as disinfection, neutralization, and removal of solids or traces of chemicals. Water almost meets drinking quality standards.

Low quality: This water is unsuitable for most purposes and may have limitations for supporting the desired ecosystem function. However, it may be acceptable for industrial use. Due to the high pH level, high total dissolved solids and elevated levels of dissolved metals treatment of low quality water is very energy-intensive and costly.

Water intensity is the ratio of water consumption to the quantity of processed ore. This definition is commonly used in mining companies' sustainability reports and in academic research [11].

After the minimal reporting metrics are established, we follow the ICMM recommendation and interpret them in the context of catchment-level risks. For this purpose, we use Aqueduct 4.0 risk metrics developed by the World Resources Institute [35]. It is based on the global hydrological model PCR-GLOBWB 2. Overall risk is measured using three categories: physical risk—quantity, physical risk—quality, and regulatory and reputational risk. Quantity physical risk measures scarcity or abundance of water by aggregating over 8 indicators (water risk, water depletion, inter-annual variability, seasonal variability, groundwater table decline, riverine flood risk, coastal flood risk, drought risk). Quality physical risk measures the risk of water being unfit for use and includes indicators of untreated connected water and coastal eutrophication potential. Regulatory and reputational risk measures regulatory uncertainty and water conflict with the public based on three indicators: unimproved/no drinking water, unimproved/no sanitation, and ESG risk. The overall water risk aggregates the three types of water risks using the weights of 70, 12, and 18%. For mining, these weights are 61, 2, and 37%. Such adjustment to weighting reflects lower water quality requirements for use in mining compared to other users and heightened ESG challenges faced by mining. In addition to the baseline assessment of risk exposure, Aqueduct 4.0 provides future projections for 2030, 2050, and 2080. Future projections are based on socio-economic and climate scenarios based on changing global temperatures by 2100 by 1.3–2.4 °C (optimistic), 2.8–4.6 °C (business as usual), and 3.3–5.7 °C (pessimistic). Finally, Aqueduct 4.0 risk categories are rated on a scale of 0–100%: low (<10%), low-medium (10–20%), medium-high (20–40%), high (40–80%), and extremely high (>80%).

In addition, we use the Water Risk Filter developed by the World Wildlife Fund [36]. WWF risk categories are rated on a scale from 0 to 5: very low (1), low (2), medium (3), high (4), and very high (5). This tool assesses three types of risk in a particular basin:

Physical risk refers to availability of water, which may be impacted by water scarcity, flooding, water quality, and the requirements of ecosystem services.

Regulatory risk measures uncertainty related to the enabling environment (laws and policies), institutions and governance (ability to convene and engage), management instruments (data and enforcement), and infrastructure and finance.

Reputational risk relates to how stakeholders view the use of water by businesses. This includes the cultural importance of water to local communities, biodiversity importance, media scrutiny of water issues, and conflict in the river basins.

We analyze Kazakhstan's mining industry using official data on production, investment, and number of firms [37]. Next, we will conduct a case study that allows us to make inferences about water use by Kazakhstan's mining industry. The object of our research is a specific copper mine that was developed by one of many new mining companies that started operating during the 2010s. We analyze this mine during a seven-year period based on publicly available data as well as internal company information. Let us refer to this mine as MineX since the identity of the company cannot be disclosed. MineX is located in a region that specializes in mining, electricity generation, and manufacturing, including metallurgy. Industrial water withdrawals in this region grew from 1215 million m^3 in 2001 to 2135 million m^3 in 2021. The region where MineX is located has an annual precipitation rate of 300–500 mm and an extreme continental semi-arid climate. Winters are long, cold, and snowy, while summers are long and hot. This region lies in the basin of a River that flows through Kazakhstan and two neighboring countries. The basin serves as a crucial water resource for agricultural and industrial activities in the three countries. In Kazakhstan's territory, the River has undergone significant hydrological changes, including the construction of large dams and canals. In addition, growing urban areas in Kazakhstan represent a significant pressure on the basin resources. Similarly, in the upper reaches of the river in the neighboring country, rapid economic development is occurring. Growing population, irrigation of expanding cultivation areas, and accelerating resource extraction drive water demand on the River in this neighboring country. The resulting degraded water quality, coupled with reduced flows, heightens tensions between nations upstream and downstream of the River [32,38,39].

3. Results

During the last 20 years, Kazakhstan's mining industry experienced high growth rates (Figure 1). For example, copper output increased by 1.4% per year during 2000–2014 and then by 20% per year during 2015–2022. Values of the output of coal, metal, and non-metal minerals mining (adjusted for inflation) increased at 7% and 4% per year during 2001–2011 and 2011–2022, respectively. Investment in these industries increased at even higher rates: 9% and 7.4% during 2001–2011 and 2011–2022, respectively. Between the two decades, the number of firms increased by 50% on average for each mining industry (See Table 1).

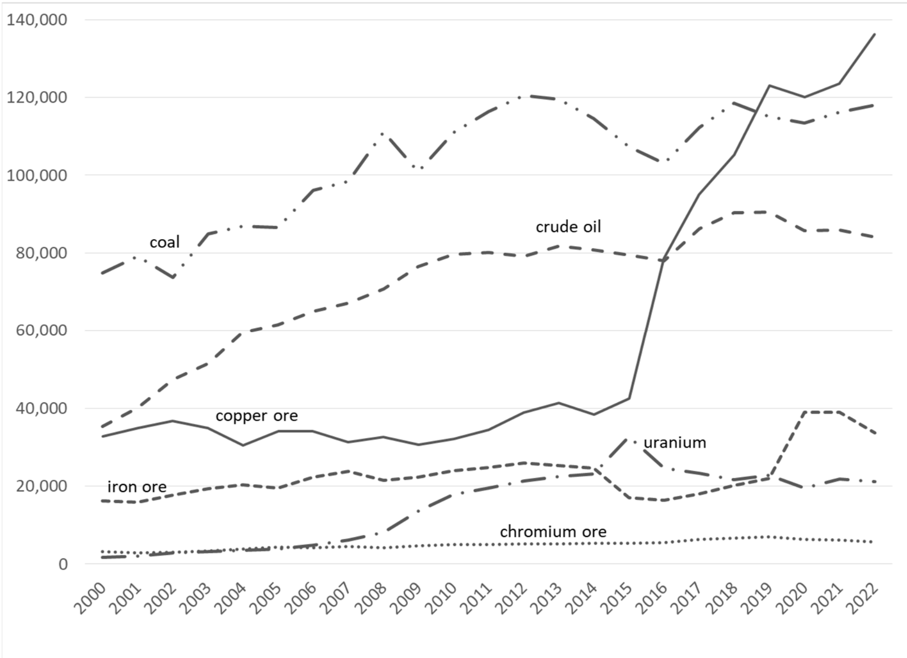

Figure 1. Production of key minerals (tons of uranium; 1000 tons of other products). Source: Government of Kazakhstan [37].

Although Kazakhstan's government publishes relatively detailed information on the economic performance of mining industries, such information on their environmental outcomes is not available from public sources. Information on industrial water use in Kazakhstan is reported for manufacturing, energy generation, and all other sectors combined [40,41]. The "Other sectors" category primarily refers to the extractive industries (EI), including the production of crude oil, natural gas, coal, metal mining, and quarrying. Both the petroleum industry and mining use water intensively. In the upstream petroleum industry, water is important for enhanced oil recovery and hydraulic fracturing. While the former production method is widely used in Kazakhstan, the latter has not been adopted yet [42,43]. As follows from Figure 2, EI water use has been falling over time, which may reflect the effect of improved technologies financed by growing investment, as documented above. During most years, EI withdrawals were below water use, which is normal for extractive industries due to practices of water recycling and reuse. However, we note that from 2015 to 2016, water withdrawals exhibited high growth. By 2020, withdrawals reached the level of water use. The latter fact is worrisome as it implies minimal water reuse by the EI in recent years. This fact may also reflect output contraction during the COVID-19 pandemic. Note that joint consideration of trends in Figures 1 and 2 suggests that the recent acceleration in EI water withdrawals may be caused by the extremely rapid increase in copper mining starting from 2015.

Table 1. Performance of extractive industries. Source: Government of Kazakhstan [37].

Extractive Industry	Investment (Average Annual Growth Rate, %)		Output Value (Average Annual Growth Rate, %)		Number of Firms (Period Average)	
	2001–2011	2012–2022	2001–2011	2012–2022	2001–2011	2012–2022
Coal mining	16.6	8.4	8.2	5.1	42	34
Iron ore mining	12.1	4.4	15.7	−1.6	9	14
Non-ferrous metal ores mining	14.1	7.7	8.2	7.6	48	69
Mining of nonmetal minerals, excluding fuels	17.4	20.4	9.7	2.6	256	520
Crude oil production	−0.6	8.1	10.7	0.4	57	77

Note: investment and output values are deflated using the 2010 producer price indices of each industry.

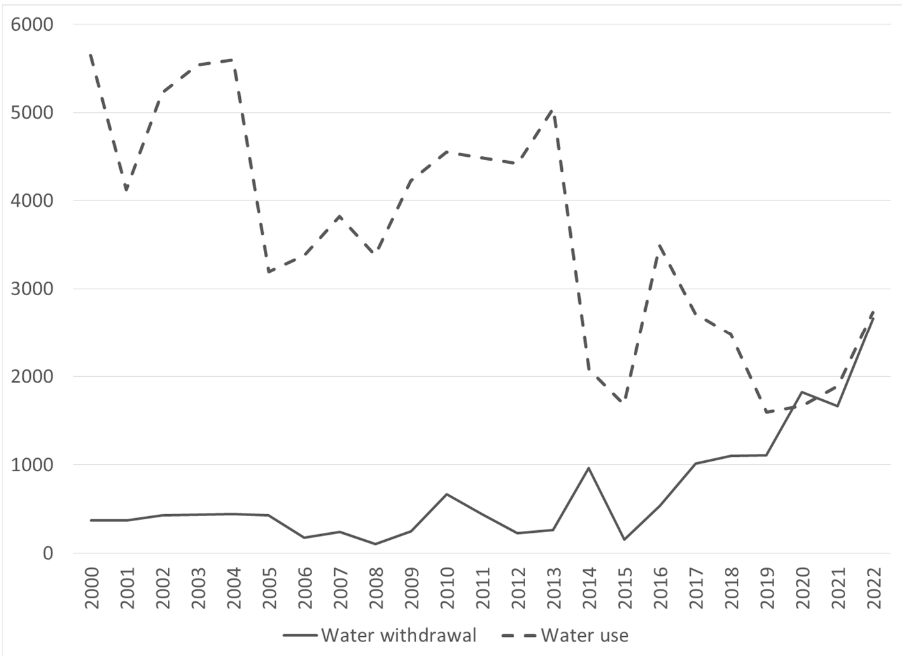

Figure 2. Water use and withdrawal by extractive industries. Source: Government of Kazakhstan [40]; FAO [41].

Next, we present our findings from the case study of MineX. Its management has prioritized safety, energy efficiency, low production costs, and the use of new technologies. The quantity of ore extracted and ore processed at the mine increased by 1.3% and 6.1% per year, respectively. MineX sources water for its processing plant and camp from the surface water body. Water from dewatering is used for dust suppression. The remaining dewatering volumes are transferred to the Tailing Storage Facility (TSF), which accumulates waste from the processing plant. In turn, water reclaimed from the TSF is reused at the processing plant. MineX does not use a water treatment plant, nor does it return water to the surrounding environment. In addition, MineX does not operate its own weather station. Therefore, we determine precipitation, evaporation, and runoff at the mine site by using point indicators from the nearby locations reported by the national weather service. This allows us to establish an inflow-outflow balance at the processing plant, the TSF, and the overall site. Our results for all years, except the initial one, comply with the ICMM recommendations on the acceptable level of system losses (i.e., change in storage). This leads us to restrict our analysis to six of the seven years of available data. System losses in our balance calculations are within 0.5–7% of total withdrawals. This robustness check allows us to consider our water flow estimates for MineX as reliable.

Establishing the water balance allows us to analyze levels and changes in MineX's water use over time. Operational water use at the mine increased by 5% per year on average, which bodes well with the 6% annual rate of growth of volumes of processed ore. Water reuse increased at 9% per year, with 84% of operational water reused. Water intensity decreased at 1.5% per year and was around 0.69 cubic meters of water consumed per ton of ore processed. We note that this value is 20% higher than the water intensity indicator reported by MineX. The main reason for this discrepancy is that the company's intensity indicator considers only withdrawals from the surface water body and does not take into account the high volume of precipitation, which represents 27% of the mine's high-quality withdrawals. Next, we find that total water withdrawals of the mine grew at an average of 2% per year. Withdrawals of surface water increased at 10% per year and represented 67% of total water withdrawals. Entrainment in waste increased at 11% per year and accounted for 66% of MineX water consumption. The remainder of water consumption was in the form of evaporation.

Let us consider these findings in the context of comparator companies. Ideally, we should compare MineX's performance with that of a specific mine that has similar characteristics of ore, technology used, water availability, and climate. However, international mining companies do not publish detailed site-level information on water use. As a result, we use their information aggregated at the firm level and use Barrick Gold (BG) and Freeport-McMoRan (FM) as comparators. We chose these companies because their output is somewhat similar to MineX. Most importantly, both reference companies follow the ICMM framework in quantifying and reporting their water use. It is important to note that BG (a Canadian company) and FM (a US company) have many operations in middle- and low-income countries, where environmental regulations may be lax. This implies that efforts directed at sustainable mine water management are a reflection of best practices that BG and FM adhere to despite the regulatory quality in some host countries. Table 2 below contains a comparison of the three companies across several indicators, averaged over 4–6 years.

Table 2. Water use indicators of selected mining companies. Source: Sustainability reports, various years.

Indicator	Unit	MineX	BG	FM
Intensity	m^3 per ton of ore processed	0.69	2.0	0.50
Flows to TSF	% of consumption	66	41	-
Discharge	% of withdrawal	0	53	35
Discharge to surface waters	% of total discharge	0	88	-
High quality discharge	% of total discharge	0	65	27
Operational water reuse/recycle	% operational water use	84	79	83
Withdrawal from low quality sources	% total withdrawal	13	11	18

As follows from Table 2, the reuse rate and a share of low-quality withdrawals at MineX are close to those of the reference companies. The intensity of water use at MineX compares favorably with respect to BG but is above the value of FM. Next, we note high shares of withdrawals that are discharged by both reference companies. Such discharge is absent in the case of MineX. The advantage of no discharge is that MineX has produced negligible impacts on water quality in the surrounding environment. However, the absence of discharge may imply a higher level of water consumption than what would exist otherwise.

In fact, the water intensity of MineX is close to the value of 0.76 m^3 per ton of ore used in base case simulations by Gunson et al. [11] in their analysis of the reduction of water needs of copper mining. Gunson et al. [11] demonstrated that copper mines may achieve a water intensity of 0.20 m^3 per ton of ore. Our comparative analysis points to ways that would allow MineX to reduce its water intensity. This would require reducing flows to the TSF or increasing outflows from the TSF. Currently, flows to the TSF at MineX account for a much higher proportion of water consumption than the reference companies. If MineX intends to continue having a near-zero discharge operation, it should recycle water from processing and dewatering. Alternatively, MineX should start treating and discharging wastewater. Both options require that MineX should invest in the construction of a water treatment plan. In addition, MineX should be prepared to bear higher operational costs because treatment and discharge costs are the largest components of water expenditures of mining companies in countries with stringent environmental regulations [31].

The main finding of our case study is that flows to TSF and flows from the surface water body at this mine both increased at 10–11% per year, while operational water use and quantity of ore processed grew at 5% and 6% per year, respectively. This high reliance on freshwater withdrawals by MineX raises our concerns about the sustainability of its water practices. As we jointly consider information on regional water use and our site-level water accounting, we conclude that MineX accounts for around 1% of total industrial water intake in its region. However, we should interpret this number in the context of the presence of many mines, metallurgical companies, energy producers, and other industrial water consumers in the same region.

Considering MineX's operation in the context of its catchment provides additional evidence of the unsustainability of MineX's current water use practices. According to the WWF Risk Filter, the highest source of uncertainty in the MineX basin is Regulatory risk and its components related to enabling environment, institutions, and governance. In fact, except for infrastructure and finance, all components of the regulatory risk in Kazakhstan are given higher risk ratings in comparison to the values of the neighboring countries. The physical risk of MineX catchment is low-medium because of challenges related to water quality and scarcity. Reputational Risk is assessed as low, except for its conflict component, which is given a medium risk rating. According to future projections, enabling environment (policy and laws), institutions, and governance would become even greater sources of the overall water risk. Management instruments, infrastructure and finance, and conflict are also given higher risk ratings in future projections by the WWF. (See Table 3). While the current assessment of catchment risk by WWF Risk Filter is low-medium, the WRI Aqueduct characterizes the current and future overall risk of the basin as medium-high. Water quality (untreated wastewater) and reputational (ESG) risks are particularly high. When the mining filter is applied, the quality, quantity, and regulatory/reputational risks of the basin where MineX is located are all assessed by the WRI as medium-high (See Table 4).

Table 3. Water risk assessment by WWF Risk Filter.

Risk Indicator	Current Assessment	Future Projection: 2050
Physical Risk	**2.53**	2.53
Quantity–scarcity	2.74	2.8
Quantity–flooding	1.93	1.84
Water quality	3.09	3.1
Ecosystem services status	1.95	1.9
Regulatory Risk	**2.87**	4.01
Enabling environment (policy and laws)	3.59	4.2
Institutions and governance	3.5	5.03

Table 3. *Cont.*

Risk Indicator	Current Assessment	Future Projection: 2050
Management instruments	2.24	3.72
Infrastructure and finance	1.21	2.1
Reputational Risk	**2.09**	2.2
Cultural importance	1.06	1.06
Biodiversity importance	2.31	2.38
Media scrutiny	2.12	2.12
Conflict	2.53	2.85
OVERALL Basin Risk	**2.29**	

Table 4. Water risk assessment by WRI Aqueduct.

Risk Indicator	Score	Interpretation
CURRENT Overall water risk		
Overall Physical Risks (Quantity)	2–3	Medium-high
1. Water stress	20–40%	Medium-high
2. Water depletion	<5%	Low
3. Interannual variability	0.25–0.50	Low-medium
4. Seasonal variability	<0.33	Low
5.Groundwater table decline		Insignificant trend
6. Riverine flood risk	1–2 in 1000	Low-medium
7. Coastal flood risk	-	-
8. Drought risk	-	-
Overall Physical Risks (Quality)	2–3	Medium-high
9. Untreated connected wastewater	60–90%	Medium-high
10.Coastal eutrophication potential	negative 5 to 0	Low-medium
Overall Regulatory and Reputational Risk	1–2	Low-medium
11. Unimproved/ no drinking water	5–10%	Medium-high
12. Unimproved/no sanitation	<2.5%	Low
13. Peak ESG risk	50–60%	Medium-high
CURRENT Overall water risk (MINING FILTER)		
Overall water risk	2–3	Medium-high
Physical Risks (Quantity)	2–3	Medium-high
Physical Risks (Quality)	2–3	Medium-high
Regulatory and Reputational Risk	2–3	Medium-high
FUTURE projection: Water stress		
Business as usual 2030	20–40%	Medium-high
Business as usual 2050	20–40%	Medium-high

Catchment level analysis based on WWF Risk Filter and WRI Aqueduct risk assessments has several implications for MineX. First, if the mine continues increasing surface water intake and flows to the TSF at 10–11% per year, it may be facing water shortages and increasing chances of conflict with other users. Second, governance and institutions do not provide incentives for responsible water use. Therefore, meeting current regulations does not assure that the company protects itself against water related risks and conflicts. Third, application of management instruments may help reduce the impact of current and future risks if the company goes beyond regulatory requirements and increases the efficiency of its water use.

4. Discussion

In our case study, we find that a local mining company that applies new technologies has been successful in minimizing water pollution and reusing 80% of operational water. At the same time, the mine has been rapidly increasing withdrawals of fresh water. Although the volume of freshwater intake by this mine was high and rapidly increasing, the government water permit allowed the company to withdraw up to 30% more than what the mine actually used. This means that government agencies use outdated standards for water allocation that do not take into account improved mining technology and increased overall water demand. Another possible reason for the mine's excessive reliance on freshwater withdrawals may be the low level of industrial water prices in Kazakhstan, around USD 0.04–0.10 per m^3, compared to the global average price of around USD 2.5–3.0 per m^3 [44]. In such a situation, it may be cheaper for the mine to use fresh water rather than treat, recirculate, or discharge wastewater. Finally, the lack of discharge at the analyzed mine may be related to the absence of unified regulations of discharge quality. Limits on harmful substances and other characteristics of effluents of industrial companies are determined by Kazakhstan government agencies on a case-by-case basis [45]. The resulting lack of transparency and high uncertainty lead to a high level of regulatory risk and compliance costs.

In addition, findings from our site-level water accounting allow us to approximate the cumulative effect of the expansion of mining activities in Kazakhstan. Our results imply that MineX contributes around 1.5% of the country-level water withdrawals by the EI. According to Table 1, the number of firms in metal mining increased from 57 on average during 2002–2011 to 73 during 2012–2022. Let us assume that each new metal mine increased total EI withdrawals by 1.5% and equate the number of new companies to the number of new mines. Then, new metal mining companies, taken together, should have increased total Extractive Industries water use by at least 40%. This value underestimates the actual change in water demand, as our assumption that one company operates one mine is very conservative. In addition, our estimate does not take into consideration the growing production of existing firms and the older technologies they use. Nevertheless, our analysis indicates that the expansion of mining operations in Kazakhstan has resulted in a rapid increase in industrial water demand (See Figure 2) that may quickly exacerbate water risks, currently assessed as medium-high. We acknowledge that this extrapolation is based on findings from analyzing a specific copper mine that may not be representative of a "typical" metal mine in Kazakhstan. This limitation of our study originates from a lack of public information on water use in mining. Future research should access mining industry-level or firm-level water data and obtain precise estimates of the impact of Kazakhstan's mining industry on water resources.

5. Conclusions

Our study analyzes the use of Kazakhstan's natural resources from a sustainability point of view and calls for monitoring and regulating the rapidly growing mining water use. First, the government should bring industrial water prices in line with the international levels. This is essential for incentivizing water saving and, in particular, conservation of high-quality water by domestic mining companies. Second, industrial water regulation in Kazakhstan should move away from regulating on a case-by-case basis and adopt consistent and transparent regulations. The high water intensity of mining, its ability to cause long-term detrimental effects on water quality, the complex technologies used, and the remote locations of mining operations justify the development of specialized regulations. The policymakers in Kazakhstan should learn from specialized mining discharge regulations that, over time, reduce both the water quality and quantity impacts of mining in Canada and the USA. Third, monitoring the effectiveness of any such regulations would require that the Kazakhstan government provide the public with access to data on mine water use. This would enable the government to set specific goals for mitigating the water impacts of mining, such as those developed by the 2050 National Mining Policy of Chile. Next, water accounting that is consistent with international best practices is important for domestic mining companies to benchmark their own performance against leading international firms. Water reporting based on such a framework would enable stakeholders to assess the sustainability of specific domestic mining operations. Finally, mining companies in Kazakhstan should proactively manage the regulatory risk and adopt best practices that go beyond the current regulations. This is important in order to avoid aggravating the water stress and tensions between competing water users in Kazakhstan and its neighbors that share common water resources. In addition, this would allow domestic mining companies to prepare for growing international stakeholder scrutiny with respect to responsible sourcing and conflict-free mineral supply chains.

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