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Review of uncertainties in water security decision-making in Central Asia

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Abstract

Water security has become increasingly significant in Central Asian republics due to the uncertainties and risks associated with climate change and growing water demand. This importance is amplified by the complex transboundary river basins, interconnected water-energy infrastructure in the Aral Sea basin, rising water distribution disputes among riparian countries, and the vulnerability of water resources to climate change. Effective decision-making at all levels regarding water resource allocation and management is assumed to contribute to achieving water security. This research paper focuses on exploring the sources of endogenous uncertainty in managing water resources with case studies of Kazakhstan and the Kyrgyz Republic. The study adopts qualitative methods, specifically content and narrative analysis, to gather and analyze data from two interview phases (involving decision-makers at national and local levels and university representatives), academic literature, and policy reports. The research emphasizes endogenous uncertainties arising from the decision-making system and identifies key factors to mitigate them, including improved data availability and analysis, resilient infrastructure, and enhanced capacity. The study acknowledges the potential rise in exogenous uncertainties caused by limited transboundary cooperation, climate change impacts, and growing water needs. It highlights the significance of recognizing and comprehending the nature and effects of uncertainties. By doing so, Central Asian countries can make more informed decisions and work towards achieving sustainable and resilient water security in the region.

Keywords: water security, endogenous uncertainties, decision-making, resilience, Central Asia

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Table of Contents

Introduction

The significance of water security has increased due to the uncertainties and risks associated with climate change and growing water demand (Beek & Arriens, 2014; IPCC, 2022; UN Security, 2007). Strengthening water security contributes to achieving sustainable development goals (Albrecht & Gerlak, 2022; AWDO, 2020; Taka et al., 2021). The United Nations defines water security as the "*... capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability…*" (UN ESCAP, 2013, p.vi). Researchers and policymakers underline the nexus of socio-economic-environmental systems and emphasize that water security encompasses multiple dimensions beyond just water availability (AWDO, 2016; Cook & Bakker, 2012; Octavianti, 2020). Various water security assessment frameworks and indices have been proposed to operationalize the concept at different scales and under different disciplinary perspectives (AWDO, 2013, 2016, 2020; OECD, 2013; Octavianti & Staddon, 2021). Yet, the interpretation of water security varies from region to region, particularly between areas with abundant water resources and those facing water scarcity. Hence, water security strategies need to be tailored to the local context, particularly given the increasing scale and intensity of water challenges and disasters which require robust decision-making in water security.

Water security has always been important for the Central Asian (CA) republics (including Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan), which share complex transboundary river basins because of interconnected water-energy infrastructure in the Aral Sea basin, water distribution disputes among riparian countries, and the vulnerability of their water resources to climate change (Abdolvand et al., 2015; Abdullaev et al., 2019; Gerlitz et al., 2020). Water security has been ensured in the CA region via water distribution practices among the republics established by large-scale water engineering infrastructure from the Soviet era. During this period, hydropower reservoirs in water-abundant upstream republics operated to release water during the vegetation periods for downstream riparian republics in exchange for cheap fossil fuels in winter. This former water-energy trade system collapsed after the breakup of the Soviet Union. Hence, water security challenges have escalated since the 1990s because of regional fragmentation and national water interests, with water-rich upstream countries interested in expanding hydropower electricity generation and energy-rich downstream countries needing water for irrigated agriculture in arid areas. This has caused water allocation disputes in the basins of the Syr Darya and Amu Darya rivers. In addition to limited transboundary cooperation on the regional level, countries face water challenges on national and local levels, such as inefficient water distribution and mismanagement of water resources, that might escalate water insecurity issues in the region (Abdullaev et al., 2019; Wegerich et al., 2015; Xenarious et al., 2020).

Scholarly research has thus far addressed water security framing and prioritization in CA countries (Abdolvand et al., 2015; Assubayeva et al., 2022; Stucki & Sojamo, 2012; Wegerich et al., 2015; Xenarious et al., 2020). Analysis of the water–energy–security nexus in CA has revealed that the primary challenges in the region are related to politics, governance, economic structure, and the broader global political economic context, along with associated uncertainties, rather than strictly to resource scarcity (Stucki & Sojamo, 2012, p.413). Abdolvand et al. (2015) discuss potential threats to water security in the region and highlight population growth, geopolitical interests, conflicting strategies among riparian countries in agriculture and hydropower developments, and limited capacities in effective water management policies. Wegerich et al. (2015) investigated the significance of water supply in enhancing water security, specifically improving existing water supply bureaucracies. Xenarios et al. (2020) conducted a bibliometric review of the literature on water security, revealing a predominant emphasis on environmental aspects, particularly driven by uncertainties associated with the effects of climate change on glacier melt, water availability, variability in transboundary rivers, and human-induced environmental degradation. A Delphi survey conducted among regional experts suggests that water professionals emphasized the need to improve of water infrastructure to strengthen water security by increasing water use efficiency in agricultural irrigation, which is the main driver of water consumption in the region (Assubayeva et al., 2022).

Since water security can be perceived and framed differently, the main assumption of this paper is that effective decision-making about water resource allocation and management at all levels could contribute to achieving water security. Water security is often interpreted as a water scarcity or water supply problem linked with external threats such as reliance on transboundary rivers, water pollution, and the impacts of climate change. Yet, strengthening water security within is greatly influenced by decisions on water allocation, which are often underestimated (Albrecht & Gerlak, 2022; Briscoe, 2009; Octavianti, 2020). It is particularly important to identify the sources of uncertainties in water resources management and acknowledge these uncertainties for adaptive water resources decision-making (Ajami et al., 2008; Enfani et al., 2020; Warmink et al., 2010).

This study attempts to uncover the sources of uncertainty in water resources management and explore factors affecting decision-making on water allocation in CA using case studies from Kazakhstan and the Kyrgyz Republic as examples of upstream and downstream riparian countries in the CA region. Even though these two riparian countries differ in economic, political, and social development, they provide insights into distinct contexts with a commonly shared history in water resources management. However, it is important to note that this paper does not address transboundary cooperation between the two countries and the decision-making process regarding transboundary issues among countries. This study contributes to the literature by exploring the sources of uncertainties and effects of these on national decision-making processes for water allocation, which has received limited attention in previous studies. The subsequent section of the paper discusses a literature review on uncertainties in decision-making for water resources management, followed by a description of the research design employed in this study. The Results and Discussion section presents research findings on prioritizing water needs and sources of endogenous uncertainties in water management. The final part concludes by summarizing the key points and suggesting potential areas for future research.

Literature review

Decision-making in water resources management is a complex process which takes into consideration various factors, multiple and competing stakeholders, and objectives. Historically, water resources management was based on technical solutions with an "optimal plan" for the "most likely" future (Haasnoot et al., 2013). In arid and semi-arid zones in particular, including the CA region (Abdullaev et al., 2019), the focus was on water supply planning and management using extensive "hard" water infrastructure solutions developed by technocrats and engineers (Serrat-Capdevila et al., 2011; Miro et al., 2021). Such infrastructure solutions, also called a "hydraulic mission" in water resources management, include designing and constructing water supply systems, irrigation networks, dams, wastewater treatment, and flood control measures. Over decades, due to growing water consumption, negative environmental impacts, and costly maintenance and repair of aging water infrastructure, these water resources management strategies have started transitioning to water demand approaches in addition to water supply strategies (Erfani et al., 2020; Miro et al., 2021). The Integrated Water Resources Management (IWRM) paradigm emerged as a response to the challenges and limitations of traditional sectoral water resources management involving hydraulic engineering solutions. IWRM utilises a holistic approach to ensure equitable management of water resources, highlighting the interconnectedness of multiple sectors, prioritising environmental sustainability, and integrating stakeholder engagement in decision-making (Kolkman et al., 2011; Miro et al., 2021; Pahl-Wostl, 2007). This makes the decision-making process even more complex but also more inclusive, adaptive, and participatory, asking for "soft" solutions in allocating water resources and managing conflicting water needs.

Decision-making in water resources management consists of several phases: defining water problem and the objectives of water resources management (ensuring water availability, improving water quality, preserving aquatic ecosystems, etc.), gathering data and assessing available water resources (surface water, groundwater, precipitation patterns, climate change predictions), and formulating policy solutions and mitigation of potential impacts (Haasnoot et al., 2013; Hipel & Ben-Haim, 1999). Various decision-support tools, simulations and hydrological models, such as multicriteria decision analysis, multiobjective programming, robust decision-making models, cost-benefit analysis, and many more (Cunha, 2023; Miro et al., 2021; Serrat-Capdevila et al., 2011), can be applied depending on data availability and relevant knowledge. There are numerous constraints, uncertainties, and specific assumptions which can impact different stages of the decision-making process. There are also differences between decisions under risk, decisions under ignorance, and decisions made under uncertainty. The probability of possible outcomes is known in a decision under risk, while in decisions under ignorance, there is a lack of or limited information about possible outcomes and their probabilities (Erfani et al., 2020; Peterson, 2009). Decisions under uncertainty take place under unknown or ambiguous probabilities of possible outcomes because of limited historical data, poor understanding of complex systems and consequently limited information, unpredictable events, and/or limitations in expertise in assessing probabilities (Hipel & Ben-Haim, 1999; Thunnissen, 2003). A decision under ignorance can be transformed into a decision under risk by gathering additional information about possible alternatives and assessing possible outcomes.

Various sources and effects of uncertainties are present in water resources management, including data inadequacy, inherent complex systems, and unpredictable factors (Ajami et al., 2008; Cunha, 2023; Erfani et al., 2020; Hipel & Ben-Haim, 1999; Miro et al., 2021). For example, Miro et al. (2021) grouped uncertainties in water resources management into climate and hydrological uncertainties related to change and variability in precipitation, changes in temperature, socio-economic uncertainties associated with population growth and per capita water use, and technological uncertainties related to water infrastructure and technological developments. Another approach to categorizing uncertainties in decision-making for water management is differentiating between uncertainties related to water demand and those related to water supply. Water demand uncertainties arise from challenges in accurately predicting changes to water requirements due to population growth, economic development, and/or varying needs across residential, agricultural, and industrial sectors (Basupi & Kapelan, 2015). Conversely, uncertainties in water supply stem from limited historical data regarding surface water, groundwater availability, precipitation patterns, water levels in aquatic ecosystems, water supply infrastructure, and other factors (Chung et al., 2009).

Uncertainties related to decision-making in water management can be further classified into endogenous and exogenous uncertainties (Kreye et al., 2011). Exogenous uncertainties in water resources management refer to external factors influencing decision-making processes. These uncertainties encompass a range of factors, including the impacts of climate change, socioeconomic developments, economic fluctuations, political situations, and technological advancements (Ajami et al., 2008; Cunha, 2023; Erfani et al., 2020; Haasnoot et al., 2013). In the context of transboundary rivers, downstream riparian countries have an additional layer of uncertainty due to socio-economic developments, transboundary agreements, and the political situation in upstream countries. In the context of the CA region, it is crucial to explore how CA countries set priorities among competing water needs under climate change variability. Despite various climate change estimations on glaciers, snow, and river flow, uncertainties persist regarding surface hydrology, seasonality of river flow, and water availability in CA (Gafurov et al., 2019; Gerlitz et al., 2020; Xenarios et al., 2020).

On the other hand, endogenous uncertainties in water resources management pertain to uncertainties that originate from the decision-making system itself. These uncertainties encompass factors such as the availability and analysis of water-related data, the adequacy of water infrastructure, institutional and governance frameworks, and the capacity of individuals to adapt to changes and make informed decisions (Ajami et al., 2008; Erfani et al., 2020; Kreye et al., 2011). Therefore, the capacity of individuals and institutions is crucial in achieving effective decision-making for equitable water resources management, particularly when dealing with uncertainties stemming from limited data on variability and uncertainty of river flow, climate variability, hydrological patterns, drought risks, limited utilization of modelling and scenario planning, and the need to address conflicting interests and diverse water usage requirements in water allocation. Hence, the human-technology-environment system encounters increasing uncertainties and complex challenges (Pahl-Wostl, 2007; Thunnissen, 2003).

Methods

The research objectives of this study are to investigate the sources of endogenous uncertainty in managing water resources and to explore the decision-making process for water allocation under uncertain conditions. The selected case studies for this research are Kazakhstan and the Kyrgyz Republic, which represent countries located downstream and upstream respectively in the CA region. The research design of this study incorporates qualitative methods, specifically content and narrative analysis of interviews, academic literature, and policy reports. Using interviews as a data collection method was chosen to obtain in-depth data and contextual understanding. The interviews were conducted in semi-structured and unstructured formats tailored to the participants' experiences. Interview participants were selected through purposive and snowball sampling considering relevant work experience, occupation, and availability for participation. All interviews were transcribed, coded (INT01, INT02...), and analysed with the NVivo qualitative data analysis tool.

The data for this research was collected through two interview phases. In the first phase, decision-makers at national and local levels were interviewed to examine the decision-making process for water allocation under uncertain conditions, identify sources of uncertainties, and identify challenges that hinder effective decision-making in the water sector. In Kazakhstan, interviews were conducted with representatives from the Ministry of Ecology, Geology, and Natural Resources; the Ministry of Foreign Affairs; the Scientific-Information Center of the Interstate Commission for Water Coordination of Central Asia; and the Kazvodkhoz in the Almaty and Akmola regions. In the case of the Kyrgyz Republic, interviews were conducted with representatives from the Water Resources Service of the Ministry of Agriculture, State Inspection on Ecological and Technical Security, the Institute of Water Issues and Hydro Energy, and international water projects. The interviews aimed to address the following questions:

- *How do you allocate water resources among various users as the demand for water increases?*
- *How do you prioritize the needs of different water users?*
- *What factors contribute to inherent uncertainties in the decision-making process and water resources management?*
- *How do you navigate decision-making and the management of water resources when faced with uncertain conditions?*

Additionally, interviews were conducted with representatives from universities in Kazakhstan and the Kyrgyz Republic to examine the current status of capacity development among water professionals. Many interview participants emphasized the significance of human resources and capacity building in the water sector. The universities with water-related programs included in the interviews were the American University of Central Asia, Kyrgyz National Agrarian University, Kyrgyz Russian Slavic University in the Kyrgyz Republic, and German-Kazakh University, Eurasian National University, and Korkyt Ata Kyzylorda University in Kazakhstan. Furthermore, representatives from regional and international organizations providing capacity-building activities in water resources management were also interviewed. These interviews aimed to address the following questions:

- *What are the current trends in implementing water resources programs at your university?*
- *What are the main motivations for students enrolling in water resources programs?*

- *What approaches and strategies are being implemented at the university, national, or regional levels to enhance capacity building?*

Between July and October 2022, twenty semi-structured and unstructured interviews were conducted in Russian, Kazakh, and English. These interviews took place both in-person and online. However, it is important to acknowledge certain limitations associated with the interview data collection process, including participants' inherent biases, the author's sampling bias, and the limited number of interview participants. Thus, academic literature and policy reports were also reviewed to validate findings and provide additional support and justification for the results.

Results and Discussion

Prioritization of water needs among different users

Interview participants mentioned the principles of prioritizing water needs among different water users in the relevant Water Codes in both states. Predefined plans and schemes for high and dry water years are used by decision-makers (INT03, INT09, INT10). In Kazakhstan, according to the Water Code (2003), water use limits are set according to the basin schemes and regulated by the basin inspectorates. All water users submit requests for water use, and water allocation depends on forecasts for the water year. Article 82 of the Water Code (2003) states that in dry years water use limits and water allocation prioritizations are the following (in descending priority): drinking water supply, environmental releases, industrial enterprises (designed for guaranteed supply in dry years), irrigated agriculture, and estuary irrigation. Moreover, in dry seasons, water use limits are also reduced proportionally among water users to satisfy basic water needs for water users (INT04). In the case of the Kyrgyz Republic, water uses are prioritized in the following order (in descending priority): drinking water supply, irrigated agriculture and livestock, hydropower generation, industry, fishery, and others (Article 24, Water Code 2005). In dry water seasons, the Government can impose restrictions on water use and change water allocation by prioritizing regions prone to droughts and water shortage (Article 74, Water Code 2005). Most schemes/plans on water resource use and protection are outdated and do not consider additional pressures on water resources, such as the impacts of climate change, population growth, and the increase of irrigated areas (INT06). The interviews indicated that both countries have inherited a top-down, centralized approach to water policymaking, prioritizing the provision of drinking water supply. However, Kazakhstan places greater emphasis on environmental water needs, while Kyrgyzstan gives higher priority to agricultural and hydropower development.

Sources of endogenous uncertainties in water decision-making

Challenges in data availability and access

Decision-making for efficient and equitable water allocation depends highly on data availability and analysis. In Kazakhstan, Kazhydromet conducts environmental, meteorological, and hydrological monitoring. According to Kazhydromet (2022), 377 hydrological posts provide hydrological data.

As was mentioned by interview participants, Kazhydromet's hydrological predictions are short-term with high variability (INT03, INT05). Moreover, there is limited data glacier changes, snow cover, and mountain rivers (INT05). KyrgyzHydromet conducts systematic metrological, hydrological, and agrometeorological monitoring and forecasting in the Kyrgyz Republic. The hydrological measurement network comprises 79 hydrological posts conducting water level, water flow, water quality, and water temperature measurements (KyrgyzHydromet, 2022). The scarcity of hydrometeorological data in mountainous catchments causes uncertainties about the water cycle and constraints on water resource allocation and management not only in upstream but also downstream countries in CA (Gerlitz et al., 2020). The number of hydrological posts in CA has fallen dramatically since the 1990s because of limited public funding (INT07). The challenge is not only data availability but also access to data because of data protection laws in CA (Gafurov et al., 2019; Gerlitz et al., 2020). Another challenge related to water data is fragmentation of data sources: surface water data is collected by Kazhydromet, drinking water quality at sanitary and epidemiological stations, and groundwater data from hydrogeological expeditions (Assubayeva, 2022; Gerlitz et al., 2020). Consequently, limited and fragmented data and poor hydrological forecasting hinder informed decision-making for sustainable water resources management needed to meet environmental, social, and economic needs.

Outdated water infrastructure

Decision-making on water allocation also depends on water supply infrastructure and whether water users receive water limits. In the context of CA in particular, large-scale water infrastructure was constructed in the 1960s-1980s, driven by the hydraulic mission. In the early 1990s, water infrastructure faced high budget deficits and, at present, high operation and maintenance costs (INT19). Aging irrigation infrastructure causes high losses and inefficient water allocation (INT03, INT06, INT14). Even though agriculture contributes to only 5.1% of GDP and 15% of total employment, annual freshwater withdrawal for agriculture constitutes over 60% of the total freshwater withdrawal in Kazakhstan (World Bank, 2022). Irrigated agriculture, with a total area of 1.6 million hectares (ha), is the main water consumer, with the potential increase of irrigated agriculture to 2.2 million ha by 2025 (Brekeshev, 2021). The total irrigated area with regular irrigation had previously decreased by 40%, from 2.3 million ha in 1991 to 1.4 million ha in 2014 (Kazvodkhoz, 2022). Furthermore, the total area with estuary irrigation was reduced by 74% from 870.36 thousand ha in 1991 to 229.44 thousand ha in 2014 (Kazvodkhoz, 2022). One of the reasons for reduction in irrigated land was the deterioration of irrigation and drainage systems, ownerless irrigation infrastructure, and limited public funding for the operation and maintenance of irrigation infrastructure. Indicatively, water losses in irrigation systems have reached about 40% (Tokayev, 2020), while on average, 60% of water supply infrastructure is outdated and needs modernization (EBRD, 2018).

In the case of the Kyrgyz Republic, agriculture contributes about 15% of the GDP, 19% of country-wide employment, and annual freshwater withdrawal of over 90% of the total freshwater withdrawal (World Bank, 2022). Moreover, there is a high dependency on electricity production from hydroelectric sources in the Kyrgyz Republic, at around 85%. Hence, in the case of the Kyrgyz Republic, not only is agricultural irrigation infrastructure critical for efficient water allocation and use, but also hydropower facilities. Due to infrastructure decay, water losses vary from 25% to 40% (NISI, 2022). About 70% of irrigation infrastructure and about half of water supply systems in the CA region urgently need investment in infrastructure restoration and rehabilitation (Abdullaev & Akhmedov, 2022). In addition to the deteriorated water infrastructure, there are plans to increase the irrigated areas in both countries and develop hydropower generation in the Kyrgyz Republic, requiring additional funding, proper planning, and effective water distribution mechanisms. Water infrastructure is crucial for achieving water security by providing clean and safe water, minimizing losses in the water distribution system, and building resilience to climate shocks (Abdullaev & Akhmedov, 2022; Briscoe, 2009; EBRD, 2018). Hence, outdated water infrastructure, limited information about the current state of water infrastructure, and chronic underfunding cause additional pressure and uncertainty in water decision-making, including in strategic planning, effective policy implementation, and resilience to water-related hazards.

Weak decision-making capacity

Effective decision-making in water distribution and management depends highly on capacity. The OECD (2008) defines capacity as "*the ability of people, organizations, and societies as a whole to manage their affairs successfully*" (p. 244). Regulations on water resources management, policy, the institutional landscape, structural factors, and informalities shape the decision-making process. The enabling environment of water governance in CA was affected by the shift in water resources management in the region from an interconnected water-energy exchange system to conflicting interests in water between riparian republics, changes in the political system from communist to authoritarian and hybrid regimes, and economic reforms from centrally planned to transition economies (Abdolvand et al., 2015; Sehring, 2020). CA countries inherited a centralized, top-down water resources management system organised mainly through extensive engineering infrastructure. This was reflected in an educational system focused on technical hydrological and engineering knowledge. Water policy in water resources management and allocation decisions were made in Moscow, with the Soviet Socialist Republics responsible only for water policy implementation. Interview participants highlighted the limited capacity of the national institution, the Committee of Water Resources of the Ministry of Ecology, Geology, and Natural Resources, responsible for water policy formulation and water resources management in Kazakhstan due to limited evidence-based decisions (INT01), ad hoc solutions, poor scenario planning and forecasting (INT02, INT19), and limited coordination of water resources aspects (INT05). Despite different organizational structures, CA countries share similar water management challenges: multiple agencies with overlapping functions responsible for water management, limited inter-agency coordination, poor water reform implementation, and weak decision-making capacity at basin and provincial levels (Abdolvand et al., 2015; Abdullaev et al., 2019; Cassara et al., 2019; Wegerich et al., 2015). Effective water policy and management depend on leadership and decision-making capacity. One of the key challenges in the water sector is the lack of succession, continuity, and transfer of knowledge and practice (INT16). In the mid-1990s huge brain drain occurred in the water sector because of financial droughts in the CA region, leaving only aging water specialists from the Soviet engineering school and a young generation of water experts with weak motivation. This has resulted in a knowledge gap and differing value and knowledge systems between the younger and older generations of water experts.

Mismatch of supply and demand of water specialists

Interview participants mentioned the deficit of water experts in both countries. However, the number of graduates with water-related specializations is increasing, especially the number of scholarships and public educational grants in these areas in both countries (INT08, INT10, INT12, INT14). According to Ibatullin et al. (2019), in Kazakhstan, nine universities offer water-related study programs for bachelor's and master's degrees, and in the Kyrgyz Republic, three universities offer water-related bachelor and master's programs, such as water resources and water use, hydrology, melioration, water supply, sanitation, hydraulic engineering, etc. Moreover, both countries' have a wider range of academic programs, such as ecology, environmental management, geography, and fisheries, which also include of water resources-related courses. According to interview participants, almost all students, especially in "water resources and water use," "hydrology," and "hydraulic engineering," get scholarships (INT12, INT13, INT15, INT18). Thus, there are graduates and there is a demand for water specialists. Still, there is a demand and supply mismatch in water-related specializations in the labour market in both countries. According to Ibatullin et al. (2019), only one-fifth of Kazakhstan's water-related study program graduates are employed in their field of specialization.

Water-related professions are no longer as attractive for the younger generation as they were during the Soviet times (INT01, INT05, INT12, INT18). Even though the number of scholarships for water-related study programs remains stable or is even growing, the number of applications is declining (INT12, INT14, INT16). In the case of Kazakhstan, applicants pass the United National Testing after graduation from secondary school and, based on their results, apply for scholarships according to subject areas. Students passing geography usually apply for scholarships in economics, tourism, and ecology majors, but scholarship competition for these specialties is usually high. Hence, students with low United National Testing grades often apply for water sector-related specialties in order to get scholarships rather than for reasons of internal motivation and interest in this area (INT16). Furthermore, potential employers complain about graduates' low capacity regarding practical knowledge and skills in water specializations (INT02, INT03, INT07). Indeed, interview participants mentioned poor technical equipment and laboratories, a lack of capacity building for university faculty, outdated curriculums, limited internship opportunities, and other factors (INT14, INT15, INT16, INT17). After graduation, young specialists seek well-paid employment opportunities. However, in the water labour market, the salaries for water engineers and hydrologists remain low despite incremental increases in salaries in recent years (INT15, INT16). In contrast, in the Soviet times, there was a high demand for water engineers and they received beneficial compensation packages because of the extensive engagement in hydraulic missions for cotton cultivation and investment in water supply and sanitation (INT16).

Enhancing regional capacities: examples of initiatives

Capacity development in the water sector in the CA region on different levels (enabling environment, organizational level, individual level) has been on the agenda of international development partners hoping to strengthen transboundary cooperation in the region. Along with infrastructure investment, technical assistance, support for institutional reforms, development of databases and information systems, donor organizations, international projects, and development banks invest in capacity development and water education through long-term and short-term training and programs (Cassara et al., 2019; Dukhovny et al., 2016; Sehring et al., 2019). For example, the regional master program 'Integrated Water Resources Management' at the German-Kazakh University was established in 2011 as part of the "Berlin process" (German Water Initiative for Central Asia). More than 100 graduates from five CA countries and Afghanistan have received scholarships from DAAD, the Ministry of Foreign Affairs in Germany, and international projects financed by the US Agency for International Development (Smart Waters, WAVE) and other international organizations (INT12, INT19, INT20). Another example is the European Union Water Initiative to improve the enabling environment and stakeholder cooperation and coordination by creating National Policy Dialogues in CA countries. There are also short-term activities in capacity development such as Blue Peace Central Asia, financed by the Swiss Agency for Development and Cooperation in the form of the organization of a series of Training for Trainees, and the Central Asia Water and Energy Program of the World Bank which aims to create the Central Asia Knowledge Network as a platform for cross-regional knowledge cooperation in the form of development syllabuses for water programs (INT08, INT12, INT14). According to interview participants, these trainings offer not only new knowledge, models, or methods but also an opportunity for networking, exchange of experiences, and peer learning (INT16, INT17, INT20). However, capacity development and water education activities were criticized for lack of coordination, overlapping agendas, fragmented and short-term activities, and difficulty measuring the impact and outcome of these activities (Abdolvand et al., 2015; Dukhovny et al., 2016; Sehring et al., 2019).

Conclusions

This study aimed to explore how CA countries prioritize competing water needs and identify the sources of endogenous uncertainties in water resource decision-making. Water security is fundamental to achieving sustainable development goals in CA, and effective decision-making is critical in strengthening water security by managing water resources, investing in water infrastructure, responding to water-related disasters, and adapting to climate change. This paper focused on endogenous water resource management uncertainties originating from the decision-making system. The analysis revealed that better data, resilient infrastructure, and improved capacity are key to reducing endogenous uncertainties. However, the region faces challenges such as a decrease in hydrological posts since the 1990s, limited hydrometeorological data in mountainous catchment areas, fragmented water data, and poor hydrological forecasting (Gafurov et al., 2019; Gerlitz et al., 2020). Additionally, the outdated water infrastructure built in the past decades in the region requires significant maintenance and poses risks to water distribution and overall water security (Abdullaev & Akhmedov, 2022). Furthermore, capacity development at different levels is crucial for effective water decision-making. This includes creating an enabling environment for decision-making, ensuring that water organizations are adequately resourced, and investing in capacity building to reduce epistemic uncertainties caused by incomplete information and incomplete knowledge.

While water security prioritizations may vary among CA countries, the challenges in water decision-making remain common. This study also acknowledges the potential increase in exogenous uncertainties due to limited transboundary cooperation, the impact of climate change, and growing water needs. Future research should explore factors contributing to exogenous uncertainties in water management and investigate the psychological factors influencing decision-making processes. Additionally, this study did not cover the decision-making process for transboundary water issues, which could be a promising area for future research. Understanding and improving transboundary cooperation would contribute significantly to addressing water security challenges in the region.

In conclusion, achieving water security in CA requires addressing endogenous uncertainties by strengthening infrastructure, enhancing data availability and forecasting capabilities, and investing in capacity development. Future research should continue to assess both endogenous and exogenous uncertainties. By acknowledging the presence of uncertainties and understanding the nature and effects of these uncertainties, CA countries can make more realistic decision and work towards sustainable and resilient water security in the region.

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to work on the revision of this paper.

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