Water resource management as a factor of sustainable territorial development and public well-being

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Abstract. Effective water resource management is essential for sustainable regional development and maintaining quality of life in the environmentally sensitive Issyk-Kul Lake Basin. The main objective of the study is to examine existing water resource management issues, including transboundary distribution, as well as the impact of water usage on the water level in Lake Issyk-Kul. The study employed a secondary-data research design combining quantitative analysis of long-term hydrological and water-consumption records with qualitative analysis of water-management policies and institutional conditions based on long-term data (1980-2024), documentary analysis of water management reports, and seasonal comparisons of water consumption and precipitation patterns in the Issyk-Kul Lake Basin. The results show a substantial long-term reduction in irrigation and domestic water consumption, although agriculture remains the dominant water-consuming sector in the Issyk-Kul Lake Basin. It was also found that agriculture remains the largest consumer of water, especially between April and August, when increased rainfall is observed. However, the lack of synchronisation between natural water cycles and water consumption practices leads to negative effects on the water level of Issyk-Kul Lake. The analysis reveals that anthropogenic pressures, particularly agricultural expansion, outdated irrigation practices, and seasonal mismatches between water demand and availability, continue to exert significant stress on the lake's hydrological balance and coastal ecosystems. These findings indicate that existing water management practices are insufficient to ensure long-term ecological stability and sustainable regional development, highlighting the need for adaptive and integrated water resource management approaches. The practical value of this research lies in the development of specific recommendations for optimising the use of water resources, including the strategy for using rainwater during periods of maximum precipitation.
Keywords: ecosystem preservation, hydrological balance, climate change, Issyk-Kul Lake Basin.

Introduction. Water resources are fundamental to sustainable development, ecosystem stability, public health, food production, and socio-economic well-being. Climate change, population growth, and rising competition among agricultural, domestic, industrial, and environmental users are increasing variability in water availability and complicating management. Weak governance can intensify scarcity, reduce agricultural productivity, limit access to safe water and sanitation, and undermine the resilience of communities and ecosystems. In contrast, integrated and equitable water management supports climate adaptation, regional prosperity, and long-term ecosystem protection (United Nations, 2024).

These challenges are especially acute in Central Asia, where Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan rely on interconnected river systems and shared infrastructure. The Amu Darya and Syr Darya have long sustained irrigated agriculture, but large-scale water diversion has drastically reduced inflows to the Aral Sea, causing severe regression, rising salinity, biodiversity loss, and broader socio-economic impacts. This crisis illustrates how water abstraction without regard for basin level ecological limits can lead to long-term and partly irreversible consequences (Plotnikov et al., 2023).

Comparable interactions between climate variability and human water use occur in the Lake Issyk-Kul Basin. As an endorheic mountain lake, Issyk-Kul's hydrology depends on precipitation, snow and glacier melt, river inflow, evaporation, land-use change, and water abstraction (Doroshkevich et al., 2022; La Ferla et al., 2003). Irrigation remains the dominant consumptive use, while domestic, industrial, and recreational demands add further pressure. Changes in precipitation, runoff, and water demand can alter tributary discharge and the lake's balance, underscoring the need for adaptive management that integrates natural and anthropogenic factors (Alymkulova et al., 2016; Uwamahoro et al., 2024).

Among the studies conducted in the last five years, several aspects of water resource management have been examined. Ahmadov (2020) analysed water management in Azerbaijan, including the effectiveness of institutions and tariff policies, with the aim of formulating recommendations for sustainable development, highlighting key factors for efficient water use, the necessity of an integrated approach, and the importance of transboundary cooperation in the water sector. Nainwal (2021) emphasised the importance of integrated water resource management for sustainable urban development, analysing key strategies, challenges, and opportunities aimed at ensuring long-term environmental, social, and economic sustainability. Li and Wu (2024) defined key aspects of sustainable water management, examining quality, anthropogenic impact, strategic approaches, and technological innovations, stressing the need for continuous research and innovative solutions to ensure global water security and sustainable development. Suriyanarayanan et al. (2024) presented innovative strategies for sustainable water management in developing countries, combining the expertise of specialists from 14 countries and proposing solutions for preserving water quality and quantity, which is valuable for researchers, practitioners, and policymakers. Obaideen et al. (2022) highlighted the crucial role of wastewater management in achieving 11 of the 17 UN Sustainable Development Goals, showing its contribution to water resource security, health protection, economic growth, energy security, and reducing environmental impacts, while offering indicators to improve the effectiveness of these processes. Xiang et al. (2021) proposed an adaptive intelligent dynamic water resource planning system (AIDWRP) based on artificial intelligence for sustainable water development, demonstrating its effectiveness in optimising water use, improving ecological planning, and enhancing economic efficiency. Kılıç (2020) analysed the issue of water scarcity, increasing consumption, and water pollution, emphasising the need for mindful water use and urgent measures to prevent a water crisis.

In their analysis of long-term intra-annual runoff dynamics in the Lake Issyk-Kul Basin, Alifujiang et al. (2021) show that human activity and climate variability have both caused discernible changes in runoff seasonality. The study demonstrated how rising water abstraction and variations in temperature and precipitation patterns have changed the timing and size of river inflows to the lake, impacting the hydrological stability of the basin. These results emphasised the significance of comprehensive basin-scale water management and demonstrated how sensitive the water balance of Issyk-Kul is to combined natural and man-made causes. Kong et al. (2024) evaluated the temporal organisation and intensity of the water cycle in the Issyk-Kul Basin using wavelet coherence analysis and a Bayesian estimator algorithm. Their findings showed that there were significant non-stationary correlations between climatic and hydrological variables over a range of time scales, suggesting that the regional water cycle is becoming more complicated and volatile. The study offered cutting-edge analytical proof that the Issyk-Kul Basin's hydrological processes are becoming more dynamic, highlighting the necessity of adaptive water resource management in the face of shifting climate circumstances. Mishra et al. (2021) discussed water supply issues and water scarcity, highlighting the need to reconsider water strategies in the context of climate change and demographic shifts, and proposing technological solutions and alternative water sources to improve water use efficiency. The study by Saravanan et al. (2021) provides a comprehensive overview of the concept of water security, analysing its evolution under the influence of urbanisation, socio-economic changes, and climate factors, while proposing sustainable solutions for ensuring reliable water access for present and future generations. Olley et al. (2024) analysed the complex issues of sustainable water management in South Africa, identifying problems with uneven water distribution, insufficient cooperation between stakeholders, and challenges in implementing water policies, while offering solutions through integrated approaches and cooperation.

Although prior studies have analysed historical water use and modelled climate and land-use impacts on the Issyk-Kul water balance, less attention has been given to the combined effects of long-term water-use dynamics, seasonal variability, institutional constraints, and their implications for sustainable development and quality of life. This study addresses this gap by integrating quantitative analysis of water consumption and hydrological data with an assessment of institutional conditions shaping water management in the Kyrgyz Republic. Accordingly, the main focus of this study is water management, which is essential to the sustainable use of natural water resources. It examines the effects of water management techniques on the long-term availability of water resources, the resilience of regional ecosystems, and the ecological balance of aquatic systems. In this context, the study also considers the impact of water consumption affects population quality of life and sustainable regional development, highlighting the connection between socioeconomic well-being and environmental sustainability. The aim of this study is to provide a comprehensive analysis of current water resource management challenges, with a focus on transboundary distribution and the impact of water usage on the hydrological state of Issyk-Kul Lake.

Material and Method

Research design. This study was designed as an empirical secondary-data research paper rather than a systematic or narrative review. It combined quantitative analysis of previously collected water-consumption, lake-level, and precipitation data with a qualitative analysis of institutional and policy documents concerning water resource management in the Kyrgyz Republic. The quantitative component was intended to identify long-term and seasonal changes in water consumption, precipitation, and the hydrological condition of Lake Issyk-Kul. The qualitative component was used to examine the institutional, administrative, financial, and technical constraints affecting water resource management.

Data sources. The primary materials of the study included water consumption statistics provided by the National Statistical Committee of the Kyrgyz Republic (2025), as well as local data gathered from water management organisations and local authorities. These documents include annual reports on the state of water resources, water management programmes, water supply and drainage data, as well as regional reports and studies on water quality and sustainable water resource use. The collected data covers a period from 1980 to 2024, and includes information on irrigation and domestic water consumption, allowing for a full analysis of changes in water resource usage over more than five decades. This enabled long-term trends to be taken into account and the main issues related to changes in water use across various regions of the country to be identified. Precipitation data were obtained from meteorological stations in Cholpon-Ata, Balykchy, Kyzyl-Suu, and Karakol, located around the Issyk-Kul Lake Basin (Climate Change Knowledge Portal, 2023).

Data processing. The collected quantitative data were organised according to observation period, sector of water consumption, and month. Water-consumption values were expressed in million m^3, precipitation in millimetres, and lake levels in metres above sea level. Microsoft Excel 2019 and SPSS Statistics 26 were used to organise the datasets, calculate descriptive indicators, compare values across periods, and prepare tables and graphical representations. Before analysis, the records were reviewed for consistency in measurement units, reporting periods, and sectoral classifications. Water-consumption data were grouped into agricultural, industrial, and domestic categories. Precipitation records were arranged by month, while lake-level observations were ordered chronologically.

Analytical methods. Seasonal precipitation and agricultural water-consumption data were analysed on a monthly basis. The months of maximum and minimum precipitation were identified and compared with periods of peak agricultural water demand, particularly from April to August. This comparison was used to determine the degree of correspondence between natural hydrological cycles and existing water-use practices and to identify seasonal mismatches between water availability and demand. Institutional and policy documents were analysed qualitatively to identify recurring constraints related to water pricing, administrative coordination, infrastructure, funding, and stakeholder participation. Evidence-based recommendations for optimising water resource use were developed by integrating quantitative comparisons of seasonal water demand, precipitation, and hydrological cycles with a qualitative assessment of institutional water-management constraints.

Results

Hydrological characteristics, water quality, and lake-level dynamics. With a reported mean absolute salinity of roughly 6.06 g kg^{-1}, Lake Issyk-Kul is classified as a slightly brackish, mostly oligotrophic environment, suggesting persistent mineralisation at the lake-wide scale (Vollmer et al., 2002). Consistent process-based interpretation is provided by Saitoh et al. (2021), who estimate that salinity increases persist at ~27.5 mg L^{-1} $year^{-1}$, reflecting net salt accumulation in the water column over time. Additionally, optical and bio-optical measurements show that open-water zones typically have great clarity: An overall oligotrophic trophic status (with localised increases near river mouths) is supported by the low particulate loading in the open part, with mineral-suspended matter <1 mg L^{-1} and chlorophyll-a typically <1 µg L^{-1}. Secchi depth has been reported to be between 15 and 18 m in clear littoral-offshore transition areas.

Lake Issyk-Kul has long supported irrigation, recreation, construction, and other forms of economic activity (la Ferla et al., 2010; Kuliev et al., 2024). Agricultural water withdrawal from the lake's tributaries has been an important factor affecting its water balance. In 1998, irrigation withdrawals accounted for 43% of the total runoff from tributaries entering Lake Issyk-Kul (Karmanchuk, 2002). This substantial level of abstraction demonstrates the considerable pressure exerted by irrigated agriculture on the lake's inflows. The dynamics of the water level in Lake Issyk-Kul over recent decades are characterised by slight seasonal and long-term fluctuations, related to both natural and anthropogenic factors (Shuka et al., 2011; Pinardi et al., 2016). Based on Zhang et al. (2022), the water level of Lake Issyk-Kul after 1980 continued the long-term decline observed since the mid-20th century and reached its lowest values by the late 1990s (1606.06 m in March 1998). However, starting from 1998, there was a gradual rise in the water level, which peaked in 2006 (1607.09 m), followed by a slight decrease. These changes could be due to water use, including abstraction for irrigation and other economic needs, as well as climate changes affecting regional water resources.

One of the possible factors for this reduction is the dissolution of the Soviet Union between 1989 and 1992, which led to a change in the structure of water users: a significant portion was reduced, while the remaining users were redistributed to other regions, where alternative water sources were used (Alymkulova et al., 2016). This process has become a subject of state regulation aimed at maintaining the water balance of the lake. Measures taken include the use of other water bodies and basins for water supply, management of the lake's inflows, soil erosion control activities, and the introduction of rainwater harvesting and usage technologies (Firoozi & Firoozi, 2024). Despite the reduction in water demand, agriculture remains the largest water consumer of the lake compared to industry and domestic consumption.

According to Alymkulova et al. (2016), water consumption in the Lake Issyk-Kul Basin decreased substantially between 1980 and 2014. Agricultural water use declined from million m^3 in 1980–1989 to 981.00 million m^3 in 1990–1999 and 461.76 million m^3 in 2000–2014. Industrial water consumption decreased from 17.74 to 9.46 and then to 8.74 million m^3 over the same periods, while domestic consumption declined from 27.02 to 18.06 and subsequently to 16.55 million m^3. Despite these reductions, agriculture remained the dominant water-consuming sector and continued to exert the greatest pressure on the basin's water resources. However, agricultural water demand varies considerably depending on the types of crops cultivated, as water-intensive crops require substantially greater volumes than drought-resistant varieties. For example, moisture-loving crops require more resources, while drought-resistant varieties help reduce the pressure on water sources. Additionally, the choice of irrigation methods plays an important role. Traditional methods like flooding and spraying contribute to significant water losses and can cause adverse environmental effects, including soil salinisation and contamination of water bodies. Meanwhile, drip irrigation is considered one of the most efficient methods of rational water use, as it provides plants with the necessary moisture while minimising losses and reducing overall water consumption (Bian et al., 2024).

Ecological pressures, eutrophication, and coastal ecosystem vulnerability. The water level in Lake Issyk-Kul has undergone significant changes due to both natural and anthropogenic factors. One key natural factor is the increase in precipitation, which influences the volume of inflow into the lake. However, alongside natural processes, human activity also plays a substantial role in changing the water level, including the expansion of irrigated land with intensive irrigation, increased industrial water consumption, recreational pressure, and the growth of domestic water use in lakeside settlements (Priya et al., 2023). These changes pose serious risks to the ecological sustainability of the lake. The decrease in demand for water from Lake Issyk-Kul could be due to several factors, including regional characteristics, climatic conditions, and the implementation of water resource management strategies (Asif et al., 2023). However, despite this reduction, it is important to note that the lake's basin remains an important water source used for various purposes, including ecological, recreational, agricultural, and socio-economic needs (Panagopoulos & Dimitriou, 2020). The complex use of the water resources of Lake Issyk-Kul results in the lake being under constant pressure from both natural and anthropogenic factors. On the one hand, climate change, fluctuations in precipitation levels, and glacier melt significantly impact the water balance. On the other hand, human activities related to the expansion of irrigated lands, tourism development, the growth of populations in the surrounding areas, and industrial water consumption also alter the lake's water regime.

Climate change has a significant impact on the quantity and quality of water resources, causing fluctuations in the hydrological balance and altering the availability of water for various needs (Voloshina et al., 2019; Kozyatnyk et al., 2013). In Asian countries, significant changes in precipitation levels are observed, leading to irregular water inflows, changing river seasonal patterns, and an increase in the frequency of extreme weather events, such as droughts and floods (Rahman et al., 2024). These climatic shifts are expected to intensify in the future, exerting even greater pressure on water resources. Rising temperatures could accelerate evaporation, lowering groundwater levels and reducing the overall volume of available fresh water. At the same time, changes in the amount and distribution of precipitation could lead to reduced water body replenishment, diminished glacier reserves, and deteriorated water quality due to increased concentrations of pollutants. Regions where water resources are already scarce or heavily dependent on seasonal rains and glacial melt are particularly vulnerable to these processes.

The process of eutrophication in big, deep lakes is influenced by shoreline pressure, changes in hydrological balance, and the spatial concentration of human activity in addition to ongoing nutrient enrichment (Alexyuk et al., 2021; Glevitzky et al., 2025). Instead of a basin-wide change in trophic status, eutrophication usually takes the form of a localised, episodic phenomenon in oligotrophic systems like Issyk-Kul, mainly in nearshore zones and river-influenced areas (Zhang et al., 2025). The vulnerability of coastal waters to algal blooms, turbidity increases, and oxygen stress in benthic habitats is exacerbated by decreased inflow, water-level changes, and increased fertiliser supply from wastewater and surface runoff (Table 1).

Table 1
Sediment biomarker indicators of hydrological control on eutrophication dynamics in Lake Issyk-Kul

Indicator/proxy	*Observed pattern or verified range*	*Ecological implication*
Aquatic macrophyte proxy (Paq)	High values during 1674–1820 CE, followed by a marked decline around the 1820s	Indicates the transition from high-water conditions with extensive aquatic vegetation to a hydrologically altered lake ecosystem
n-C16 acid abundance	Progressive increase following the lake-level decline beginning in the mid-19th century	Indicates the expansion of Chara macroalgae under lower-water conditions
Microalgal biomass	Sharp increase during the 2000s, particularly in shoreline areas	Indicates accelerated localised eutrophication associated with anthropogenic nutrient inputs
Total organic carbon in surface sediments	0.1-6.4%, with the highest values recorded in the shallow western littoral zone	Reflects enhanced aquatic productivity and organic matter accumulation in shallow nearshore environments
Terrigenous and siliciclastic sediment input	Highest near major eastern and southern river inflows and generally decreasing toward the central lake basin	Demonstrates stronger catchment and riverine influence on nearshore sedimentation

Source: compiled by the authors based on Lenz et al. (2023) and Zhang et al. (2025).

According to Zhang et al.’s (2025) synthesis of sediment biomarker data, eutrophication signals in Issyk-Kul are largely shaped by hydrological variability as opposed to a linear build-up of nutrients. As a systemic modulator, declining water levels reorganise ecological processes, leaving the open lake mostly oligotrophic while increasing biological activity and organic matter retention in the littoral zone. This structure encourages short-lived productivity responses that are geographically limited to nearshore habitats due to decreased water volume and weaker hydrodynamic flushing, which also lengthens the duration that nutrients are in residence. These hydrologically mediated processes directly affect coastal integrity and recreational quality from the standpoint of ecosystem services. Along the coast, where human usage is most intense, the concentration of biological activity and organic waste increases the likelihood of localised blooms, turbidity, and aesthetic degradation (Valujeva et al., 2017; De Serio & Mossa, 2016). The findings thus lend credence to the idea that eutrophication in Issyk-Kul is a process of spatial redistribution and amplification brought on by changes in the water balance, emphasising that hydrological regulation must be prioritised in addition to traditional nutrient management techniques for effective mitigation.

The growth of tourism, urbanisation, and changes in land use along the lake's shoreline have all contributed to the significant increase in anthropogenic pressure on Lake Issyk-Kul in recent decades (Valujeva et al., 2018; Floqi et al., 2009). Even though there aren't many accurate current water quality data, previous research showed that more tourists and the infrastructure that goes along with them increase the amount of solid waste and wastewater that enters near-shore waters. Additionally, after the tourist season, some bays had higher concentrations of nutrients like nitrite and ammonium. These alterations indicate increasing human impact on the hydrochemical conditions that support ecosystem services and functioning, even though they do not yet result in widespread chemical pollution throughout the lake's enormous volume (Asankulov et al., 2018). The concentration of recreational infrastructure surrounding Lake Issyk-Kul is strongly linked to increased socioeconomic and environmental stress on the shoreline, according to quantitative assessments reported in recent coastal vulnerability studies (Totubaeva et al., 2024). Composite vulnerability indices are higher than 0.60-0.65 (on a normalised scale from 0 to 1) in districts with the largest density of resorts, boarding houses, and urban development, while they are lower than 0.35 in less developed coastal parts. Together with significantly higher scores for anthropogenic effect indicators like population load and land-use intensity, these high-pressure zones also show a 30-50% decrease in the natural coastal buffer width due to shoreline modification and development. The analysis also shows that, although making up a much smaller portion of the lake's perimeter, tourist-heavy coastal areas make up almost 70% of the entire length of high-risk shoreline. The long-term ability of Issyk-Kul to maintain high-quality recreational ecosystem services is directly impacted by the growth of recreational infrastructure, which not only concentrates socioeconomic activity but also distorts habitat structure and reduces the natural resilience of coastal ecosystems.

Recreational ecosystem services, including as water-based recreation (boating and swimming), aesthetic pleasure, and cultural attachment to the lakefront landscape, are directly impacted by these stressors. According to sociological surveys and expert assessments summarised by Kaptagaeva et al. (2020), over 55-60% of local residents and stakeholders reported a noticeable deterioration in environmental conditions in the Issyk-Kul coastal zone over the past decade, primarily referring to declining water transparency, shoreline littering, and degradation of natural beaches. Simultaneously, expert assessments show that almost 40% of evaluated recreational coastal locations are currently deemed to be under moderate to high anthropogenic stress, which adversely affects their appropriateness for leisure activities including bathing. These findings indicate a growing disparity between short-term economic gains and the long-term sustainability of ecosystem services that maintain Issyk-Kul's recreational appeal, even though tourism produces significant socio-economic benefits – seasonal income for a sizable portion of households in lakeside communities. The lake's visual and sensory qualities, which are essential to its function as a recreational and cultural resource, are directly threatened by the documented deterioration in environmental quality.

Seasonal hydroclimatic variability and water-management implications. Climatic factors, such as uneven rainfall distribution, prolonged droughts, and changes in seasonal rainfall patterns, directly affect the volume of available water resources, exacerbating the problem of water scarcity, particularly in arid regions (Konapala et al., 2020). In this regard, alternative water supply methods, such as rainwater collection and storage, are being proposed. This approach allows for the accumulation of rainwater during high-humidity periods for subsequent use during dry seasons, thereby reducing dependence on traditional water sources and ensuring more stable access to water. Moreover, a key element of sustainable water use is actively involving local communities in water resource management processes. The participation of the population, which bears the brunt of water scarcity, helps to ensure more efficient and equitable water distribution and allows for the consideration of local characteristics and needs (Remeshevska et al., 2021; Batykova, 2025). Furthermore, involving the public in decision-making on water use increases awareness of the need for rational resource use, encourages the development of water-saving technologies, and fosters a culture of responsible water consumption. The introduction of such strategies not only improves continuous access to safe and clean water but also strengthens the mechanisms for managing water resources, ensuring their effective and long-term use (Tsani et al., 2020).

Seasonal precipitation patterns in the Issyk-Kul basin show a pronounced intra-annual structure. According to the precipitation reported by Alymkulova et al. (2016), monthly precipitation increases from spring and reaches its maximum in July-August, after which it declines steadily toward autumn. This distribution indicates that the highest natural water input occurs in mid-summer, while significantly lower precipitation levels characterise September and October (Figure 1). This imbalance between periods of high-water demand and natural water availability indicates a structural problem in water management, which is confirmed by previous research (Zhang et al., 2023).

The seasonal structure of agricultural water use follows a partially different pattern. As illustrated by Alymkulova et al. (2016), irrigation demand rises from spring and peaks during the main growing season, broadly overlapping with the period of increased precipitation. However, Figure 2 also shows that agricultural water use does not decline synchronously with precipitation after August and remains relatively high into early autumn.

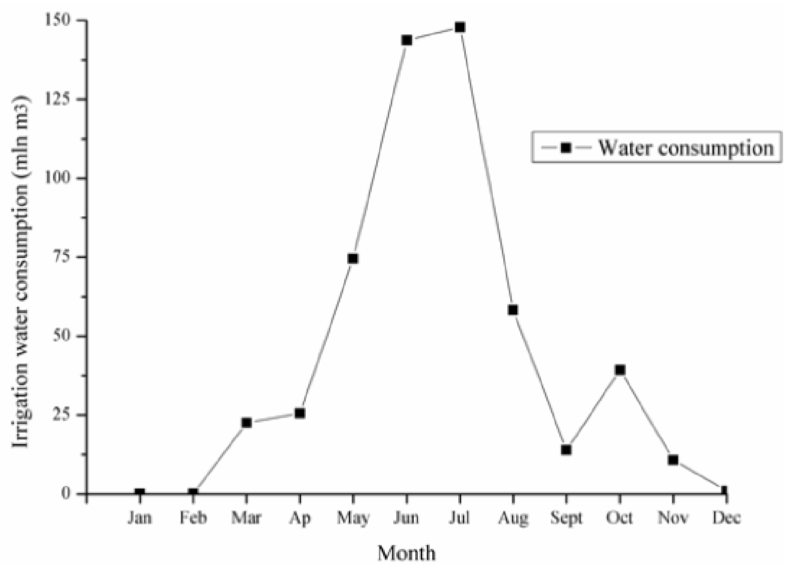

Figure 1. Issyk-Kul Lake monthly agricultural water consumption in 2013 (Alymkulova et al., 2016).

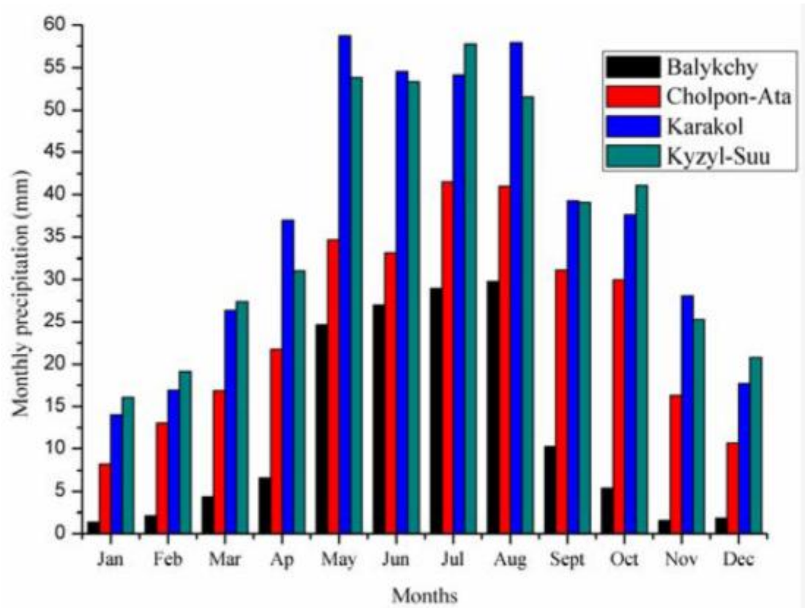

Figure 2. Averaged monthly precipitation in 2013 per station (Alymkulova et al., 2016).

A partial seasonal association between precipitation and agricultural water use can be seen when comparing the two statistics. Early and midsummer precipitation peaks roughly correspond with peak irrigation demand, indicating some degree of coordination between agricultural activities and natural moisture supply. However, the fact that relatively large irrigation withdrawals in June and July continue to occur despite very considerable rainfall and then increase again in October, when precipitation has significantly decreased, shows that agricultural water use is not directly correlated with precipitation. Rather than short-term precipitation dynamics, planting schedules and management techniques are the key drivers of irrigation demand, resulting in times when water abstraction is high even with fewer natural inputs. According to these studies, agriculture remains the largest water consumer globally, and it is predicted that its water consumption will continue to rise as the population increases. This underscores the need for developing and implementing adaptive water use policies that can balance demand and supply. In addition, the population living in the Issyk-Kul region has increased from 441.3 thousand people in 2010 to 458.5 thousand in 2014 (Uwamahoro et al., 2024). This growth leads to an increased demand not only for food but also for domestic needs and resources necessary for the socio-economic development of the region. In the context of population growth and changing climatic conditions, the region's water resources are under additional pressure, necessitating the search for comprehensive solutions for their sustainable use. One such solution could be the combined use of lake and rainwater (Ciampittiello et al., 2024; Seraya et al., 2025). Despite the measures taken for integrated water resource management, there remains a need to consider factors such as climate change, population growth, and increasing water demand for various purposes. These challenges require a more profound and long-term approach to sustainable water resource management, particularly in vulnerable regions such as the Issyk-Kul Lake Basin (Yapiyev et al., 2021). Although the results of this study have recorded a general decrease in water consumption, it is important to note that this reduction may be temporary and dependent on a variety of factors, including economic, social, and climate changes. Therefore, effective water resource management requires not only responding to current trends but also developing adaptive strategies that can account for future changes. One key aspect is the impact of climate changes, which affect the hydrological regime of the region. Data analysis shows that weather fluctuations, including changes in the amount and intensity of precipitation, have a significant impact on water availability.

Water plays a central role in ensuring vital processes such as the development and preservation of economic activity, which is connected to human needs in daily life. Water also serves as a link between the climate system, the environment, and human society, influencing all of these elements and supporting their interaction (Li et al., 2024). If water is managed effectively and equitably, it will become the foundation for achieving sustainable development and ensuring many aspects of life, including food security, healthcare, and ecosystem preservation (Klimenko et al., 2009; Montayev et al., 2024).

Water resource issues are especially urgent in East Asia, where water management faces numerous challenges, such as flooding, water salinity, the loss of freshwater due to agriculture, and pollution of water bodies with wastewater and industrial waste (Ongayev et al., 2024; Lyubchik et al., 2005). These issues negatively affect water supply and can have serious consequences for the health of local populations (Shan et al., 2020). To ensure sustainable water resource management in the Issyk-Kul Lake basin, where water is used for multiple purposes, it is crucial to consider several key factors. These include monitoring changes in water resources, the impact of climate change, which leads to fluctuations in the intensity and frequency of precipitation, affecting the lake's water sources. It is also necessary to manage changes in water demand and its use, as well as consider the opinions and participation of local communities and decision-makers. A comprehensive approach to the use, preservation, and protection of the lake's water resources is essential, requiring the joint efforts of all stakeholders to create a sustainable and effective water management system. The environmental state of the Issyk-Kul basin is directly impacted by the fragmented and poorly coordinated institutional architecture of water resource management in the Kyrgyz Republic (Food and Agriculture Organization of the United Nations, 2022). The division of duties across several organisations makes it more difficult to conduct systematic environmental monitoring, impairs data integration, and limits the ability to evaluate cumulative effects on ecosystem dynamics, lake levels, and water quality. Because of this, environmental indicators are frequently not routinely monitored, which makes it more difficult to react quickly to new ecological stresses. Furthermore, the efficacy of conservation efforts in the Issyk-Kul basin is limited by the lack of a cohesive national water strategy that specifically places a high priority on environmental preservation. The use of integrated management strategies is restricted, accountability is diminished, and the alignment of water use practices with ecological goals is weakened by fragmented governance. In addition to undermining the efficacy of environmental interventions meant to preserve Lake Issyk-Kul's hydrological and ecological stability, this institutional framework limits the ability of current management systems to support long-term ecosystem preservation.

Discussion. The impact of water management on sustainable regional development and the improvement of citizens' quality of life is a central issue that not only determines economic stability but also ecological well-being. In the Kyrgyz Republic, as in most Central Asian countries, water resource management and its impact on people's lives are not only economic but also social and environmental concerns. Water resources are crucial for agriculture, drinking water supply, energy, ecosystems, and the resilience of the entire national economy (Panchenko et al., 2018; Tkach et al., 2021). The results of the study show that the key issues in the water sector in KR are ageing infrastructure, insufficient funding, and a shortage of qualified personnel. The importance of these factors cannot be underestimated, as they directly affect the quality of water supply and drainage, which in turn impacts public health and economic development. Water management issues are multifaceted, encompassing both physical aspects (infrastructure, canals, pumping stations) and deeper economic and social factors, such as financial resource deficits and insufficient participation of water users in the payment process for water resources.

The study confirms that one of the main reasons for weak technical infrastructure is insufficient government funding. An important point is that water management funding in KR traditionally depends on revenues from water usage fees, but this creates a vicious cycle because the low price of water, which does not cover the full costs of delivery and treatment, leaves state funds limited. The conclusion is that addressing the issue of ageing infrastructure requires not only increased funding but also a revision of pricing policies. Specifically, water prices should reflect the actual costs of delivery and treatment, which would improve the financial situation of water management entities and allow for infrastructure modernisation. This view is supported by other researchers, such as Madaliev et al. (2024), who emphasise the importance of effective water resource policies in ensuring sustainable development. However, funding issues are not limited to pricing policy. An important problem, also highlighted in our study, is the lack of personnel in the water sector. This, in turn, is directly related to low salaries and insufficient motivation to attract young professionals to the field. The water sector in KR faces a serious personnel problem: despite the generally high level of education and qualifications in the country, the sector fails to attract enough young specialists. Studies such as those by Wardle and Zakiriaeva (2022) note that in rural areas and small towns, there is often a shortage of water sector specialists, which leads to poor service of water resources. This creates a closed loop: the lack of specialists limits the ability to manage water resources effectively, which in turn impacts the quality of life and regional development. The shortage of qualified personnel in the water sector requires special attention. Solutions to this problem should include both increasing salaries and benefits for water sector employees and creating career incentives to attract young professionals. It is important to note that despite the involvement of local communities in water resource management in some regions of KR, as Wardle and Zakiriaeva (2022) state, this is insufficient for sustainable and effective water management on a broader scale. The problem is not only organisational but also the lack of professionals who can effectively manage water resources and ensure their sustainable use.

The study concludes that one of the key directions for solving the water management problems in KR should be improving coordination between various government institutions and increasing the role of local authorities in water resource management. It is important to note that despite the existing issues, KR has significant potential for improving water resource management, including developing transboundary cooperation, as emphasised by Kukueyeva et al. (2015), and further integrating innovative technologies into water management. This potential can be effectively harnessed to achieve sustainable development goals and improve the quality of life.

Comparing the results of this study with other research conducted in Central Asia shows both common trends and differences. For example, studies by Madaliev et al. (2024) and Kukueyeva et al. (2015) also highlight the importance of political and institutional components in addressing water sector issues. However, unlike our study, they focus on international aspects of water management, such as transboundary cooperation between Kazakhstan and China. While our research focuses on domestic issues in KR related to infrastructure and personnel, other authors broaden the context to include regional cooperation. Bespalyy's work (2023) on the quality of life in Central Asia also highlights the importance of water resources for ensuring ecological security. This theory confirms the significance of water resources for quality of life, but our study focuses on more specific problems, such as funding issues in the water sector and the shortage of qualified personnel. Including Nuralieva's (2022) research on KR's water potential within the context of our study allows for a deeper analysis of the impact of water management on the country's sustainable development and underscores the importance of a comprehensive approach to solving water resource issues. This research emphasises the economic development challenges linked to limited water resources and stresses that insufficient attention to water management may hinder effective economic growth. The author notes that KR faces serious challenges in ensuring the sustainable use of its water resources and in adapting water infrastructure to climate change and other external factors. Unlike the current study, which focuses on the regional level, the researcher analyses the issue within state policy, suggesting potential solutions through improved coordination between government bodies. Such differences show that to solve water management problems in KR and other Central Asian countries, it is essential to consider both internal and external factors. This requires a comprehensive approach that includes infrastructure modernisation, improvement of personnel policies, and active participation in international initiatives for managing transboundary water resources.

In conclusion, despite existing problems, KR has significant potential for improving water resource management. This requires a comprehensive approach, including not only improving existing infrastructure but also developing human resources, refining financial mechanisms, and creating effective regional and international partnerships. Solving these issues in the long term will not only improve the quality of water supply but also establish a sustainable and secure water system, which will positively impact economic development and the quality of life of the population.

Conclusions. The study determined that sustainable development and quality of life in the Issyk-Kul Lake Basin depend on more coordinated and efficient water resource management. Although water consumption declined substantially between the periods 1980-1989 and 2014-2024, agriculture remained the dominant water consumer and continued to place considerable pressure on the basin's water resources. The results revealed a seasonal mismatch between natural water availability and consumption. Agricultural demand is concentrated mainly from May to August and may remain high when precipitation begins to decline. This indicates that reduced total withdrawals alone cannot ensure sustainability unless irrigation practices and seasonal water allocation are also improved. The study also identified administrative fragmentation, inadequate pricing mechanisms, ageing infrastructure, insufficient funding, and a shortage of qualified personnel as the main institutional barriers to effective water management. These factors limit water-use efficiency and weaken the resilience of regional water systems. It is therefore concluded that the Issyk-Kul Basin requires an integrated and adaptive management approach based on efficient irrigation, rainwater harvesting, improved monitoring, stronger institutional coordination, and greater participation of local stakeholders. The study is limited by its reliance on aggregated statistical data, which restricts the assessment of short-term hydrological changes and the economic effectiveness of the proposed measures. Future research should apply high-resolution monitoring and scenario-based water allocation models.

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