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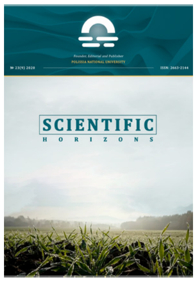

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Effective methods of rational water resource use in the agrarian sector of Kazakhstan

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Abstract. The study aimed to determine effective methods of rational water resources use in the agricultural sector of Kazakhstan. The impact of modern irrigation technologies, such as drip and sprinkler irrigation, as well as automated monitoring systems on crop productivity, soil condition and adaptability of farms to climate change was analysed. Drip irrigation was noted to reduce water losses by up to 40%, while sprinkler systems provided uniform coverage of large areas, optimising water resources. Automated monitoring systems using soil moisture sensors and weather

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forecasting reduced water consumption by 25-50% and increased crop yields by 15-30%. The study also determined that introducing such systems improved soil quality, reducing depletion and ensuring long-term productivity. An analysis of the experience of farms in Kazakhstan, Israel, Spain and China confirmed the economic feasibility of such approaches by reducing operating costs as well as dependence on external financing and increasing resilience to climatic stresses. In particular, automation of water supplies reduced water, energy and system maintenance costs, which ensured long-term farm stability. The practical value of the work was the formation of scientifically based recommendations for the introduction of innovative irrigation technologies to improve the efficiency of the agricultural sector of Kazakhstan, reduce the impact of climate change and ensure sustainable development

Keywords: irrigation; soil productivity; automated systems; crop yield; optimisation

INTRODUCTION

Rational use of water resources in the agricultural sector is one of the key challenges for Kazakhstan, which is limited, whereas agriculture remains a central sector of the economy. In the context of climate change, deteriorating water bodies and the growing need for water for irrigation, optimisation of water use is not only a necessity to improve production efficiency but also an important factor in the sustainability of agricultural enterprises. The introduction of modern irrigation technologies, such as drip and sprinkler irrigation, as well as the use of water monitoring and automation systems, is a promising way to reduce water losses, cut costs and increase yields. These technologies contribute not only to economic benefits but also to the improvement of soil quality and the sustainability of agricultural production in the context of changing climatic and natural factors.

The issue of rational use of water resources in the agricultural sector of Kazakhstan is relevant due to the limited water resources and the need to improve efficiency. M. Li *et al.* (2022) determined that optimisation of water use in agricultural farms significantly reduced water costs, which improved the financial performance of agricultural enterprises. The authors also stressed that such measures improved the environment in regions with limited water resources, creating a sustainable basis for agricultural development. W. Loiskandl and R. Nolz (2021) demonstrated that the introduction of drip and sprinkler irrigation minimised water losses and increased yields, thus increasing farm profitability. The authors also highlighted that such irrigation systems ensure a more rational distribution of water resources and reduce excessive consumption. T. Maraseni *et al.* (2021) highlighted that the use of automated water consumption monitoring systems improved the accuracy of water distribution, which significantly reduced water overruns. These technologies also contribute to the improvement of the overall efficiency of the agricultural sector by increasing the efficiency of available water resources. L. Jin-Yan *et al.* (2021) determined that the introduction of sensors and intelligent systems not only saves water but also prevents its overuse, which positively affects soil quality. The authors also noted that such technologies have increased crop productivity, ensuring sustainable production growth. E. Bwambale *et al.* (2022a) noted that modern irrigation technologies feature significantly reduced operating costs, which increases the profitability of agricultural enterprises. These technologies have also provided more stable financial results in the long term, contributing to the sustainability of agriculture.

D. Mengistu *et al.* (2021) studied the impact of climate change on water resources and recommended adapting water use methods to changing conditions to minimise risks to agriculture. The authors stressed that these measures increase the sustainability of agricultural production in the context of global climate change. J. Fito and S. W. Van Hulle (2021) argued that water use optimisation reduces land rehabilitation costs and the dependence of farms on external financing. This also improves the financial stability of farms and reduces their vulnerability to economic crises. A.L. Srivastav *et al.* (2021) demonstrated that rational water use reduced the need for additional investments, which improved the financial stability of agricultural enterprises. The authors also noted that this improves the long-term sustainability of enterprises and ensures more efficient use of available resources. M. Mallareddy *et al.* (2023) highlighted the importance of sustainable water management practices for increasing the resilience of agricultural farms to adverse natural factors such as droughts and overheating of the soil. They stressed that such methods also help improve the quality of agricultural products and increase their competitiveness. C. Ingrao *et al.* (2023) proved that the introduction of economically viable irrigation methods was a key factor in stabilising agricultural production in conditions of limited water resources. These methods have increased the efficiency of agricultural production and reduced the risks associated with climate change and water shortages. However, despite the wide range of studies, some gaps require further research, such as a more detailed study of the impact of new technologies on soil, an in-depth study of the economic impact on small and medium-sized farms, and more accurate models for predicting water consumption in light of climate change.

The study aimed to identify the most effective methods of water management in Kazakh agriculture.

MATERIALS AND METHODS

A comprehensive methodology, including several interrelated methods, was used to conduct a comprehensive assessment of the state of water resources and the efficiency of their use in the agricultural sector of Kazakhstan. For a more detailed analysis, a geographic information system (GIS) and mapping methods were used to conduct a spatial assessment of water availability for agriculture. This identified problem areas where water resources are scarce, creating risks to the sustainability of agricultural production.

A comparison was made to evaluate the efficiency of different irrigation methods such as drip and sprinkler irrigation. This analysis addressed the impact of each method on parameters such as yield, water use and water losses. The comparison established how each method affects water utilisation and production results. System analysis and modelling techniques were used to assess the impact of intelligent monitoring systems on water use. This approach was used to evaluate existing technologies such as soil moisture sensors and automated water use monitoring systems. These systems were studied to determine their role in optimising water allocation and improving water management in agricultural enterprises. Economic modelling and cost analysis techniques were used to estimate the economic benefits of implementing rational water use practices. Models were constructed from water expenditure and yield data to show that the introduction of more efficient irrigation methods and automation leads to lower costs and higher yields. These results were also used to assess the impact of water use optimisation on the resilience of agricultural farms to climate change, improving their adaptability to extreme weather conditions.

Water management practices in the agricultural sector were analysed, highlighting irrigation systems and water supply management. The experience of successful farms and international examples of efficient water use were also reviewed. Specific enterprises were reviewed, such as Baiserke-Agro (2024) in Kazakhstan and Netafim Company (2024) in Israel, as well as Citrus Valley (Valencia's Citrus Coast, 2024) in Spain and Shandong Green Agriculture (2024) in China. Experiences with technologies such as drip irrigation, automation of water supply and the use of sensors to monitor soil moisture, and their impact on reducing costs, increasing yields and improving resilience to climate change were analysed as part of the work. This approach highlighted how the introduction of innovative water management technologies has reduced costs, increased profitability and improved farm resilience to climate change.

The study analysed methods of rational use of water resources in the agricultural sector and assessed their impact on the economic efficiency of agricultural farms. Various irrigation and water automation technologies were considered, as well as their impact on cost reduction and yield increase. The method of strategic analysis was applied to develop recommendations for improving water use in the agricultural sector. Based on the findings, measures were proposed to introduce innovative technologies, improve water use monitoring and enhance the skills of specialists. These recommendations were designed to ensure sustainable agricultural development in the context of limited water resources and climate change.

RESULTS

In the Kazakhstan agricultural sector, water resources are essential for sustainable agricultural production, especially in the context of significant climatic changes and limited water sources. The economics of water use in this context includes a set of methods, technologies and strategies aimed at optimising the use of water resources and reducing the costs of their consumption. Kazakhstan, one of the largest countries in Central Asia, faces a water shortage challenge. This is determined not only by geographical peculiarities but also by the rapid growth of agriculture, especially in regions where irrigation is the main method of agricultural production. The state of water resources in Kazakhstan requires careful analysis, especially in the context of their regional distribution, accessibility for the agricultural sector and existing management problems. The volume of water resources in Kazakhstan is estimated at 100-120 cubic kilometres of water per year (Table 1). However, most of the water resources are concentrated in river basins such as the Irtysh, Syr Darya and Amu Darya, which flow through neighbouring countries, making them difficult to manage.

As a result, much of the water resources, especially in the southern and western regions, are subject to international agreements, limiting their availability for domestic consumption (Kenzhegulova *et al*., 2023). For Kazakh agriculture, irrigation water is critical, accounting for approximately 80% of the national total water needs. In the southern and eastern regions, such as Zhambyl and Almaty regions, where the main agricultural areas are located, irrigation plays an important role in ensuring crop yields. However, these regions face water resource constraints, leading to increased competition for water among agriculture, industry and the population (Abraliyev *et al*., 2024).

***Table 1**. Water use in the agricultural sector of Kazakhstan by years*

Year	Total water use (billion cubic metres)	Water volume for irrigation (billion m³)	Water volume for livestock production (million m³)	Water volume for other needs (billion m³)	Share of water for irrigation (%)
2020	100	60	30	10	60%
2021	105	63	33	9	60%

Table 1. Continued

Year	Total water use (billion cubic metres)	Water volume for irrigation (billion m^3)	Water volume for livestock production (million m^3)	Water volume for other needs (billion m^3)	Share of water for irrigation (%)
2022	110	65	35	10	59%
2023	108	62	34	12	57%
2024 (estimate)	112	67	36	9	60%

Source: *compiled by the authors based on Bureau of National Statistics (2024)*

One of the primary issues in Kazakhstan is outdated water supply and irrigation systems that not only do not ensure rational use of water but also cause significant water losses. Examples are canals and water supply networks that have a low degree of insulation, which favours evaporation and water leakage. In addition, due to the lack of coordination between different levels of government and the absence of a unified water management system, inefficient water distribution occurs. Local agricultural producers often face difficulties in accessing the necessary volumes of water, while other sectors such as industry or energy also require significant amounts of water. Ecosystems that suffer from water overload are especially notable. Environmental problems such as the shallowing of rivers and reservoirs, degradation of aquifers, and pollution of water resources have a long-term impact on the health of ecosystems and agricultural development (Berezhniak *et al.*, 2022).

Irrigation is an integral part of agricultural production, especially in regions with limited water resources. In the context of Kazakhstan, where agriculture is highly dependent on water supply, the choice of irrigation methods is essential to improve the economic efficiency and sustainability of the agricultural sector. The development of irrigation technologies such as drip and sprinkler irrigation in recent decades was central to optimising water use and increasing crop yields. Each of these systems has unique features that can significantly affect the production results and financial sustainability of agricultural enterprises (Table 2).

Table 2*. Water use optimisation methods*

Optimisation method	Description	Advantages	Disadvantages
Drip irrigation	A technology in which water is supplied directly to the roots of plants through drippers, which minimises water loss.	Reduced water losses, increased yields, reduced soil erosion.	High initial investment, and difficulty in maintaining and repairing the system.
Sprinkler irrigation	Water is sprayed through special devices that simulate rain.	Uniform water distribution, increased yields over large areas.	Water losses due to evaporation, and high operating costs in strong winds.
Automated water consumption control systems	The use of sensors and humidity sensors to automatically adjust the water supply according to the needs of the plants.	Increased accuracy, water savings, and reduced labour costs.	High cost of implementation and maintenance, requires technical training of personnel.

Source: *compiled by the authors based on H. Li et al. (2021)*

Drip irrigation is one of the most efficient irrigation methods in water-limited environments (Manda *et al.*, 2021). This method involves the precise delivery of water directly to the root system of plants through special pipelines with drip elements. This reduces water consumption and plants receive moisture evenly, which significantly increases crop yields. With traditional irrigation methods, such as sprinkling, water is applied to the entire field area, which results in significant water losses due to evaporation, run-off and uneven distribution. For instance, irrigation of one hectare of wheat requires approximately 5,000 m^3 of water, thus creating high water supply costs. This approach is not optimal as most of the water is used inefficiently, increasing water supply costs and reducing water use efficiency. Drip irrigation can significantly reduce the volume of water used for irrigation. By precisely metering water and delivering it directly to the root system, water consumption per hectare is reduced by up to 3,000 m^3. This saves 40% of water compared to traditional irrigation methods. At a water cost of 5 tenge per m^3, the cost of water supply per hectare before the introduction of drip irrigation is 25,000 tenge (5000 m^3×5 tenge). After the introduction of drip irrigation, the costs are reduced to 15,000 tenges (3000 m^3×5 tenges), which gives a saving of 10,000 tenges per hectare.

Sprinkler irrigation is a method in which water is distributed through rotating sprayers that irrigate a large area (Chauhdary *et al.*, 2023). Although this method is less efficient compared to drip irrigation, it has low cost and is affordable for many farms. For traditional sprinkler irrigation methods or with low-efficiency systems, water consumption is high, often in unharvested areas. However, when sprinklers are used, approximately 6000 m^3 of water is used per hectare of wheat, which is 20% more than drip irrigation. Compared to conventional irrigation methods, sprinkler irrigation reduces water costs because water is applied uniformly, but still not as accurately as with drip irrigation. For 6000 m^3 of water per hectare, the cost of water supply is 30,000 tenge (6000 m^3×5 tenge). The use of sprinkler irrigation reduces water costs compared to traditional methods, but it is still less efficient than drip irrigation.

Automated water use control systems use soil moisture sensors, weather forecasts and other technologies to automatically adjust water inputs (Ray & Majumder, 2024). This enables efficient irrigation management, reducing water use in the event of rainfall or other natural factors affecting irrigation demand. Without automated systems, irrigation is usually done manually or based on standardised calculations that do not always match the actual needs of the plants. Therefore, water supply costs can be inflated due to unnecessary irrigation. With automation, water supply costs are reduced by 15-20%. Water consumption for irrigation of one hectare is reduced to 4000 m^3. The cost of irrigation after the introduction of automated systems is reduced to 20,000 tenge (4000 m^3×5 tenge). This provides savings of up to 5,000 tenge compared to traditional irrigation methods and ensures greater accuracy and efficiency of water inputs.

Every year, water scarcity is becoming an increasingly urgent problem for agriculture. Effective water management is critical for the sustainability of agricultural farms, especially in the face of climate change and increasing water demand. In recent years, modern technologies for monitoring and managing water use, such as sensors and intelligent control systems, are increasingly relevant to this process. These technologies not only improve the accuracy of water allocation but also significantly reduce water costs, which affects the economic efficiency of agriculture. One of the most important steps in improving water use has been the introduction of intelligent systems that allow real-time monitoring and regulation of irrigation (Palakshappa *et al.*, 2024). These systems use sensors to measure soil moisture levels, temperature, and other parameters necessary for optimal water distribution. For instance, moisture sensors detect changes in soil moisture levels, which allows the irrigation system to automatically switch the irrigation system on or off depending on the actual water demand of the plants. This eliminates water wastage and makes irrigation more precise. Intelligent systems not only make irrigation more efficient but also enable remote management. Using mobile applications or computer systems, farmers can monitor water supply parameters, obtain data on soil conditions and forecast water requirements based on weather conditions. This approach reduces human error and increases the efficiency of water management.

Sensors used in modern irrigation systems are crucial to the accuracy of water distribution (Bwambale *et al.*, 2022b). For instance, sensors installed in the soil measure its moisture content and can transmit the data to the control system. This allows not only precise water dosing but also accommodates changes in plant demand due to weather conditions, growth phases or even time of day. As a result, irrigation is carried out according to the actual needs of the plants, which significantly reduces water wastage. The use of sensors also reduces the number of irrigations, which are traditionally carried out according to fixed schedules, regardless of actual conditions. This in turn minimises unnecessary evaporation and water loss, especially in hotter years. In regions where water resources are limited, this approach becomes particularly valuable as it maximises the use of every drop of water.

The use of water monitoring and management technologies has a direct impact on reducing water costs. Traditional irrigation systems often experience high water losses due to over-irrigation or improper water distribution. The introduction of modern technologies eliminates these issues. For instance, automated systems that respond to changes in soil moisture and weather conditions can adjust the amount of water based on current needs rather than on a predetermined schedule. In addition, such systems help reduce energy costs by eliminating the operation of pumps and other devices outside of normal business hours or when not needed. This also reduces equipment maintenance costs and contributes to the longevity of the system, as it is not subjected to excessive stress.

Rational use of water resources in agriculture is becoming not only an environmental necessity but also an economic benefit. Under conditions of limited water resources, climate change and increasing demand for agricultural products, efficient water use management is of key importance for improving the economic sustainability of rural households. The introduction of modern irrigation methods and water use control systems can significantly reduce water costs, increase crop yields and improve financial results, as well as strengthen farm resilience to changes in climatic conditions (Table 3).

***Table 3**. Economic benefits of using sensors and intelligent systems*

Parameters	Before system implementation	After system implementation	Savings
Water consumption (m^3/ha)	1,000	700	300
Cost of water supply (USD/ha)	500	350	150
Energy costs (USD/ha)	200	160	40
Total water supply costs (USD/ha)	700	510	190

***Source:** compiled by the authors based on K. Obaideen et al. (2022)*

Optimisation of water use implies the introduction of technologies that accurately dose the amount of water required for irrigation and reduce losses. For instance, a shift from traditional irrigation methods such as open canal irrigation to more modern methods such as drip and sprinkler irrigation significantly reduces water losses. These methods deliver water directly to the plant roots or spray it evenly over the surface, minimising evaporation and wastage. Such technologies allow farmers to significantly reduce water supply costs, which is especially important for regions with limited water resources, such as Kazakhstan. Moreover, the automation of the irrigation process through sensors and intelligent control systems reduces energy costs, as pumps and control systems are only started when they are needed. This significantly reduces operating costs and makes water use more economical and efficient.

One of the main factors in increasing the economic efficiency of agricultural production is the increase in crop yields. The introduction of rational water management practices improves conditions for plant growth, reducing the risk of water shortages that can reduce crop yields. Modern irrigation systems, such as drip irrigation, ensure uniform water distribution, which enhances nutrient uptake and improves overall crop health (Yeraliyeva *et al.*, 2017). In addition, precise water management improves water efficiency for different crops depending on the needs. For instance, some crops, such as vegetables or fruits, require more intensive irrigation, while others, such as cereals, may need smaller quantities of water. This improves overall agricultural productivity and, as a result, increases the profitability of the enterprise.

Climate change has a significant impact on agricultural production by causing extreme weather conditions such as droughts and heavy rains (Habib-ur-Rahman *et al.*, 2022). Under such conditions, the resilience of agricultural enterprises to climate variability becomes a critical challenge. Rational use of water implementation of modern irrigation techniques and monitoring of water consumption are essential in this process. Automatic control systems and soil moisture sensors ensure a rapid response to changes in weather conditions, adjusting the amount of water needed to supply the plants according to current needs. This reduces crop losses during periods of drought and minimises damage from overwatering in the event of heavy rainfall. In this way, farmers can adapt water management practices more precisely to changing climatic conditions, increasing their resilience to extreme weather events.

Optimisation of long-term water use contributes to the sustainability of agricultural farms, both economically and environmentally. Lowering water and energy costs reduces the dependence of agricultural enterprises on external sources of financing, which is particularly relevant in an unstable economy. Effective water management contributes to soil sustainability by reducing the risks of soil depletion and improving soil quality. In addition, efficient water management minimises negative environmental impacts by reducing waste and water losses, which also contributes to the long-term sustainability of agricultural production. Optimisation of water use in agriculture is an important factor in ensuring economic efficiency and sustainability of agricultural enterprises. With global climate change, water scarcity and increasing competition for water, the implementation of innovative water management practices is becoming a necessity. In this context, examples of successful agrarian enterprises in Kazakhstan and foreign countries can serve as a reference point for other farms seeking to improve their efficiency through the rational use of water resources.

A notable example of successful water use optimization in Kazakhstan is the Baiserke-Agro agricultural enterprise (2024), located in Central Kazakhstan. Specializing in the cultivation of grain and vegetable crops, this enterprise has significantly enhanced its economic efficiency by achieving a 15-20% increase in yields and a 30% reduction in water usage. These improvements were made possible through the implementation of advanced drip irrigation systems and the automation of water supply processes (Atakulov *et al.*, 2023). In 2023, companies made significant advancements in irrigation by introducing soil moisture sensors and automatic water flow control systems. Previously reliant on traditional irrigation methods that often resulted in substantial water losses, farmers achieved notable improvements by transitioning to drip irrigation (Farms in North Kazakhstan region are…, 2023). The introduction of these advanced technologies also led to a reduction in the energy consumption needed to operate pumping stations. Thus, this farm has demonstrated how modern irrigation techniques can not only reduce costs but also increase profitability.

Israel stands out as one of the global leaders in water management, with its innovative practices and technologies serving as a valuable example for other nations (Dai, 2021). In the face of freshwater scarcity and frequent droughts, Israel has developed advanced technologies in drip irrigation, which has significantly improved agricultural efficiency. Netafim (2024), a company based in Israel, has pioneered the development and implementation of drip irrigation systems, which are now widely used in agriculture worldwide (Israeli Climate Innovation for…, 2024). Drip irrigation systems developed by Netafim enable precise dosing of water, delivering it directly to the roots of plants, minimising water loss and increasing crop yields. This method is particularly effective in arid areas such as Southern California, Australia and the Middle East where water resources are limited. As a result of the introduction of drip irrigation, agricultural enterprises using this technology have achieved significant yield increases with minimal water use, making them more economically sustainable and profitable.

Spain, one of the driest countries in Europe, has also made significant strides in optimising water use in agriculture. In the Valencia region, where citrus and other crops are grown, farmers are actively adopting irrigation control systems and automated technologies that help use water efficiently. In particular, the Citrus Valley agricultural complex (Valencia's Citrus Coast, 2024), an example of efficient water use, employs soil moisture sensors and systems that automatically adjust the amount of water applied based on the plant's needs (Poveda-Bautista *et al.*, 2021). The results showed that the adoption of such technologies enabled farmers to reduce water consumption by 20%, while yields increased by 20%. The water savings significantly reduced water purchase and transport costs, which is important in the context of limited water resources and high-water prices. It has also contributed to improved product quality, making Spanish farmers more competitive in international markets.

In China, where water problems have become more pronounced, agricultural enterprises are actively adopting water management technologies. One example is an agricultural complex in Shandong Province specialising in fruit and vegetable production, known as Shandong Green Agriculture (2024). This complex has successfully applied innovative drip irrigation systems and remote monitoring systems for water use, which significantly reduced water losses and increased crop yields (Guo *et al.*, 2024). The complex also introduced water recycling and reuse systems to minimise water consumption and reduce water supply costs. The results of implementing these technologies were as follows: water costs were reduced and crop yields increased (Yang *et al.*, 2023). This experience shows how the use of innovative water use technologies not only helps to manage water resources efficiently but also to make agriculture more resilient to external economic and environmental challenges. It is worth noting that the introduction of modern irrigation systems has a significant impact on the efficiency of water use and the yield of agricultural enterprises. Various innovative methods, such as drip irrigation and water supply automation, significantly reduce water consumption while increasing agricultural productivity. Table 4 shows the impact of these technologies on water use and yields in agricultural enterprises.

***Table 4**. Impact of modern irrigation systems on water use and yields in agricultural enterprises*

Company/Location	Irrigation technology	Impact on water usage	Impact on yield	Additional information
Baiserke-Agro (Kazakhstan)	Drip irrigation	Reduced water consumption by 30%, saving 500,000 cubic metres annually	Increase in grain and vegetable yields by 15-20%	Improving water use efficiency and yields, reducing water costs
Netafim (Israel)	Drip irrigation systems	Reduced water consumption by up to 50% in some regions	Increase yields by up to 30% for certain crops	Leader in irrigation technologies for water-limited areas
Citrus Valley (Spain)	Automated water supply management systems	Reduce water bills by 25%, saving 1 million litres annually	Increase in citrus yields by 20%	Automated irrigation improves yields and reduces operating costs
Shandong Green Agriculture (China)	Combined irrigation technologies	Reduction of water consumption by 40%	Increase in productivity by 25%	Focused on sustainable agriculture and high-technology irrigation

***Source:** compiled by the authors based on T. Atakulov et al. (2023), Israeli Climate Innovation for Energy and Water Security Solutions (2024), R. Poveda-Bautista et al. (2021), B. Guo et al. (2024)*

Sustainable water use is an important element of the strategic development of the agricultural sector in Kazakhstan, which faces limited water resources and changing climatic conditions. Innovative methods and strategies need to be introduced to improve the efficiency of water resources utilisation and ensure the sustainability of agriculture. The study made the following recommendations:

Drip irrigation is one of the most effective methods of water use, which allows to significantly reduce water losses and increase crop yields. In Kazakhstan, especially in arid and semi-arid regions, such systems can be introduced in most agricultural enterprises specialising in growing cereals, vegetables and fruits. It is necessary to support farmers in the transition to drip irrigation through state subsidies and tax incentives, as well as to provide training for farmers in new technologies and methods of water management.

Monitoring and automation systems for water management are instrumental in improving water use efficiency. The introduction of soil moisture sensors, as well as systems that regulate water supply according to the actual needs of plants, will optimise water resources, eliminating unnecessary expenditure. It is necessary to integrate such systems within the framework of the state project on the digitalisation of agriculture, which will provide farmers with access to up-to-date information and increase the accuracy of irrigation decisions. For effective implementation of innovative water use technologies, it is necessary to train highly qualified specialists in agronomy, hydrology and engineering. It is important to develop educational programmes that will focus on the use of new irrigation methods and water management technologies. It is also necessary to establish a system of certification and advanced training for agrarians, which will enable them to keep abreast of the latest trends and effective practices in water use.

One of the promising directions for improving water use in the agricultural sector is the system of water reuse. The introduction of such technologies as filtration and wastewater treatment will reduce the consumption of fresh water for irrigation. The implementation of such solutions may be particularly relevant for regions with limited water resources. In addition, it is necessary to develop infrastructure for water recycling at the level of large agricultural complexes and processing plants, which will provide additional savings. To accelerate the introduction of innovative water-use technologies in the agricultural sector of Kazakhstan, it is necessary to attract more private investment and develop partnerships with international organisations working in the field of sustainable development. Mechanisms for attracting financial resources, such as green bonds and grants, can contribute to the development of environmentally sustainable technologies and the introduction of best practices in water use. Joint projects with international partners, such as the World Bank or the United States Agency for International Development, will allow Kazakhstan to benefit from the experience of other countries and implement best practices.

For the long-term development of the Kazakh agricultural sector, it is necessary to apply an agroecological approach, which includes methods of protecting water resources, improving soil quality and enhancing biodiversity. This will not only increase the resilience of agriculture to climate change but also ensure a balance between economic interests and ecosystem conservation. There is a need to adopt agroforestry practices that will help conserve water resources and use sustainability-oriented land and water management practices. To effectively manage water resources in the agricultural sector, a unified data and monitoring system needs to be established to track changes in water supplies, water use levels, and soil health and yields. Data from such systems will contribute to optimising irrigation scheduling and rational water allocation between different agricultural sectors. This will ensure more equitable and efficient use of water resources.

DISCUSSION

Key aspects affecting the efficiency of water resources use and the costs associated with their use were identified in the analysis of the economics of water use in the agricultural sector of Kazakhstan. The assessment of the status of water resources has shown that water supply in certain regions of the country is limited due to natural conditions and insufficient infrastructure for efficient water distribution. As a result, many agricultural enterprises face a shortage of water resources, which requires careful consideration of irrigation methods and rational water use. This problem was also investigated by Y. Zhao *et al.* (2021), confirming that analysing the status of water resources in the agricultural sector is key to ensuring agricultural sustainability and efficient use of water resources. In the face of climate change and increasing water consumption, especially in arid regions, the availability of water sources for agricultural production needs to be carefully assessed. An important aspect is an analysis of seasonal variations, as well as geographical and infrastructural water availability, which directly affects agricultural development (Mustafayeva & Tagiyev, 2023).

X. Liu *et al.* (2022) also demonstrated that the assessment of water allocation in the agricultural sector requires consideration of various factors such as the spatial location of water bodies, the density of water withdrawals and the degree of utilisation. Uneven water distribution can cause deficits in some areas and surpluses in others, creating additional challenges for the agricultural sector. It is necessary to develop strategies aimed at optimising the distribution of water resources, including the improvement of infrastructure and the introduction of water-saving technologies. It is worth noting that effective management of water resources in the agricultural sector requires not only analysing their availability but also addressing various external factors such as climate change and demographic growth. These factors can significantly change the water needs of agricultural regions, which poses a challenge for public and private structures to adapt to new conditions. Therefore, it is necessary to develop monitoring and forecasting systems that will help to identify possible water problems on time and take measures to address them, such as the introduction of innovative irrigation and water conservation methods.

One of the main factors affecting the economic efficiency of the agricultural sector is the choice of irrigation methods. A study of different irrigation systems established those traditional methods, such as surface irrigation, cause substantial water losses. Modern technologies such as drip and sprinkler irrigation can significantly reduce water consumption and increase crop yields (Pichura *et al.*, 2023). The application of these technologies in Kazakhstan has already shown positive results, especially in water-scarce areas. S.Z. Safoevna and M.N. Juraevna (2021) concluded that modern irrigation methods, such as drip and sprinkler irrigation, significantly affect agricultural economics by increasing productivity and reducing water costs. Drip irrigation, for instance, minimises water loss by spot irrigating the root zone of plants, thereby improving crop growth and yield. This is particularly relevant in the context of limited water resources and increased concern for the resilience of agro-systems to climate change.

D. Bhavsar *et al.* (2023) highlighted that a comparison of the efficiency of drip and sprinkler irrigation with traditional methods shows that modern irrigation systems provide higher economic efficiency. Drip irrigation reduces water and energy consumption, leading to lower operating costs in the long term. Sprinkler systems, on the other hand, have greater versatility as they can be used on different soil types and for a wider range of crops, but they also require more water and energy compared to drip irrigation. These results support the above study as they show that modern irrigation systems, such as drip and sprinkler irrigation, significantly reduce overall water consumption and provide a more precise distribution of moisture flow based on plant needs. This not only improves crop yields but also reduces the operational costs of water management. In the face of climate change and uncertain water availability, the use of such technologies can be key to ensuring food security and agricultural sustainability in the long term. Data collected on the deployment of water use monitoring technologies has demonstrated the high efficiency of intelligent control systems, which allow farmers to monitor water consumption in real-time and optimise resource use. Sensor systems integrated with information technology provide more accurate water distribution depending on crop needs, which reduces water costs and minimises losses. The use of such solutions in Kazakhstan has already been implemented in some large agricultural enterprises, allowing them to improve their economic sustainability.

The study by M. Lowe *et al.* (2022), which also determined that monitoring technologies are significant in optimising water use by enabling more precise water management at all levels of agricultural production, is noteworthy. Modern intelligent systems such as moisture sensors, automated irrigation control systems and satellite technology can be used to monitor the condition of soil and vegetation in real time. These technologies make it possible not only to improve the efficiency of water use but also to minimise the risks associated with its excessive or insufficient application. X. Xiang *et al.* (2021) concluded that the use of intelligent systems to control and distribute water resources can improve the accuracy of water distribution between different sites and crops. Such systems can automatically adjust the amount of water supplied depending on soil moisture data, plant needs and weather forecasts. This significantly reduces water losses and improves crop quality, as well as lowering the financial costs of water and energy, making agriculture more sustainable and cost-effective. These findings are consistent with the thesis in the previous section, as they confirm that the use of intelligent monitoring systems significantly improves water use efficiency. Real-time technologies provide accurate information on water requirements, thus avoiding surpluses and shortages of water in agricultural processes. This, in turn, improves not only the sustainability of agricultural systems but also contributes to long-term cost savings and environmental efficiency in agriculture.

Economic analysis demonstrated that optimisation of water use through the introduction of new technologies reduces irrigation costs and, in turn, increases the profitability of agriculture. While traditional irrigation methods require significant water costs, modern technologies significantly reduce these costs, while improving product quality and increasing yields (Zhovtonog *et al.*, 2022). The effectiveness of such methods was confirmed by several Kazakhstani farms, which managed to significantly improve their financial results. H. Quon and S. Jiang (2023) also conducted a study, the results of which confirmed that the introduction of new water-use technologies, such as drip irrigation and intelligent management systems, can significantly reduce irrigation costs. These technologies minimise water losses and provide a more accurate distribution of resources, which reduces the need for energy costs and equipment maintenance. As a result, agricultural businesses can significantly reduce operating costs, which sets the stage for improved economic performance. T. Zhang *et al.* (2021) also identified that reduction in irrigation costs directly affects yield and profitability improvements because it allows farmers to use water more efficiently, a resource that is often limited. Better management of water flows promotes optimal plant growth, increasing yields and product quality. This, in turn, improves financial performance, as agricultural enterprises can significantly reduce costs while increasing production and profits.

Comparing the data obtained during research, it is possible to assert that the introduction of modern water-use technologies leads to a significant reduction in irrigation costs. These technologies improve the precision of the amount of water required for different crops, which reduces unnecessary expenditure and improves overall resource efficiency. As a result, farmers can use the freed-up funds for other needs, such as improving soil conditions or purchasing more efficient technologies, which contributes to the overall profitability of farms.

The study also revealed the importance of external factors such as climate change and lack of investment in water supply infrastructures. For sustainable development of the agricultural sector in Kazakhstan, it is necessary not only to improve irrigation technologies but also to invest in the modernisation of water supply systems and water conservation developments. Without these changes, the long-term economic efficiency of water use in agriculture may be limited. S. Skendžić *et al.* (2021) concluded that climatic changes and external factors such as increased frequency of droughts or floods have a major impact on agricultural water use. These changes require continuous adaptation of irrigation and water supply systems, as traditional water supply systems often cannot effectively cope with the new challenges. Therefore, there is a need to modernise infrastructure so that it can provide a more stable and reliable water supply despite unstable climatic conditions. A. Adeniran *et al.* (2021) revealed that modernisation of water supply systems and investment in infrastructure is becoming key to ensure the sustainability of water supply in agriculture. Modern water supply systems require flexibility, and resilience to climate change and are equipped with the latest monitoring and management technologies. Investing in such projects will not only improve the quality of water supply but also significantly reduce water losses, which in the context of global climate change is becoming particularly relevant for food security and agricultural sustainability.

Climate change is significantly increasing the pressure on existing water supply systems, requiring them to be modernised to respond effectively to new challenges (Kravchenko & Tkachenko, 2024). Water supply systems that were designed with more stable climatic conditions in mind cannot cope with increases in extreme weather events such as droughts and floods. As a result, to maintain sustainable water use, investments need to be directed towards infrastructure improvements as well as innovative technologies to optimise water flows and minimise losses. Thus, the results of the analysis confirm the importance of further implementation of technologies aimed at rational use of water resources, as well as the need to create government support for innovation in the agricultural sector. The application of modern water management practices can be a key factor in improving the sustainability of agricultural production and reducing costs, which will improve the economic situation in rural areas of Kazakhstan.

CONCLUSIONS

The study determined that water resources in Kazakhstan, especially in arid regions, are limited, which creates additional difficulties for farmers. Traditional irrigation methods, such as surface irrigation, lead to significant water losses, which increase the cost of water use and reduce overall economic efficiency. However, the introduction of more modern irrigation technologies, such as drip and sprinkler irrigation, can significantly reduce water consumption, improve the distribution of moisture across fields and, as a result, increase crop yields.

Drip irrigation is the most efficient method, reducing water consumption by up to 40% and saving 10,000 tenge per hectare. Sprinkler irrigation is less efficient, but still reduces water consumption compared to traditional methods. Automated water use control systems can achieve water savings of up to 20% and improve the accuracy of resource utilisation. To maximise savings and efficiency, it is recommended to use drip irrigation in combination with automated control systems. In addition, the introduction of modern drip irrigation technologies in agrarian farms in Kazakhstan, such as Baiserke-Agro, has reduced water consumption by 30%, saving approximately 500,000 cubic metres of water per year, with grain and vegetable crop yields increasing by 15-20%. In Israel, Netafim has achieved a 50% reduction in water use in some regions, contributing to a 30% increase in yields for some crops. In Spain, automated water management systems implemented by Citrus Valley reduced water costs by 25% and saved 1 million litres of water annually, while increasing citrus yields by 20%. In China, Shandong Green Agriculture reduced water consumption by 40% and increased productivity by 25%, improving agricultural sustainability and water optimisation.

The introduction of monitoring technologies and intelligent systems to control water use has demonstrated its effectiveness. The use of sensors and automated control systems makes it possible to accurately monitor water consumption and promptly adjust it depending on plant needs. This minimises water losses and reduces overall irrigation costs, which contributes to the economic sustainability of farms. In addition, the study showed that the introduction of innovative technologies in the agricultural sector leads to lower costs and increased profitability. Such technologies allow farmers to use water resources more efficiently, which becomes especially important against the background of climate change and decreasing water availability. The implementation of such solutions also contributes to increasing the resilience of agriculture to unfavourable climatic changes.

The study concluded that additional consideration should be devoted to the modernisation of water supply infrastructure, as old systems are often unable to cope with the demands of modern technologies. Investments in modernisation of water supply networks, creation of efficient irrigation systems and water management will be key to the long-term sustainability of the agricultural sector. Thus, the optimisation of water use in the agricultural sector of Kazakhstan is the most important task for improving the economic efficiency of agriculture. The introduction of innovative technologies and improved water management can ensure sustainable development of the agricultural sector and increase its productivity and resilience in a changing climate. A limitation of the study is the lack of data on the long-term economic results of the introduction of innovative technologies in different regions of Kazakhstan, which impedes a more in-depth analysis. In addition, it is necessary to study the impact of various climatic factors on the efficiency of water-use technologies in the agricultural sector of Kazakhstan, as well as to assess the possibility of adapting irrigation methods to changes in weather conditions.

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CONFLICT OF INTEREST

None.

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Ефективні методи раціонального використання водних ресурсів в аграрному секторі Казахстану

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Анотація. Метою дослідження було визначення ефективних методів раціонального використання водних ресурсів в аграрному секторі Казахстану. Проаналізовано вплив сучасних технологій зрошення, таких як крапельне та дощувальне зрошення, а також автоматизованих систем моніторингу на продуктивність сільськогосподарських культур, стан ґрунтів та адаптивність господарств до зміни клімату. Було відзначено, що крапельне зрошення зменшує втрати води до 40%, тоді як дощувальні системи забезпечують рівномірне покриття великих площ, оптимізуючи використання водних ресурсів. Автоматизовані системи моніторингу з використанням датчиків вологості ґрунту та прогнозування погоди зменшили споживання води на 25-50% та підвищили врожайність на 15-30 %. Дослідження також визначило, що впровадження таких систем покращило якість ґрунту, зменшивши його виснаження та забезпечивши довгострокову продуктивність. Аналіз досвіду фермерських господарств Казахстану, Ізраїлю, Іспанії та Китаю підтвердив економічну доцільність таких підходів за рахунок зменшення операційних витрат, а також залежності від зовнішнього фінансування та підвищення стійкості до кліматичних стресів. Зокрема, автоматизація водопостачання знизила витрати на воду, енергію та обслуговування системи, що забезпечило довгострокову стабільність фермерських господарств. Практична цінність роботи полягає у формуванні науково обґрунтованих рекомендацій щодо впровадження інноваційних технологій зрошення для підвищення ефективності аграрного сектору Казахстану, зменшення впливу зміни клімату та забезпечення сталого розвитку

Ключові слова: зрошення; продуктивність ґрунту; автоматизовані системи; урожайність; оптимізація