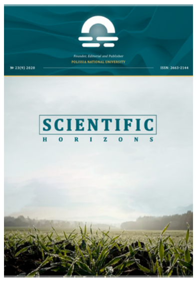
SCIENTIFIC HORIZONS

Journal homepage: https://sciencehorizon.com.ua
Scientific Horizons, 28(3), 104-116



UDC 626.8
DOI: 10.48077/scihor3.2025.104

Automation and intelligent water distribution control systems for optimising water use in agricultural irrigation systems

Ainura Batykova[*]
PhD in Technical Sciences, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0001-9173-3151

Victoria Sultanbaeva
PhD in Agriculture, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0002-8914-8778

Gulmira Shabikova
PhD in Technical Sciences, Associate Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
https://orcid.org/0009-0005-3016-393X

Oskon Osmonov
Doctor of History, Professor
Kyrgyz National Agrarian University named after K.I. Skryabin
720000, 68 Mederov Str., Bishkek, Kyrgyz Republic
https://orcid.org/0000-0003-0782-1584

Article's History:
Received: 09.09.2024
Revised: 02.01.2025
Accepted: 26.02.2025

Abstract. The purpose of this study was to analyse the methods of automation, intelligent distribution, and consumption of water in Central Asian irrigation systems using the example of the Kyrgyz Republic. The study considered the use of sensor networks for monitoring water data by Wzzard LRPv and John Deere Operations Centre. The study analysed the work of AquaCrop software for modelling water balance and irrigation optimisation and the use of drones for monitoring the state of water resources and land plots, including Da-Jiang Innovations Phantom 4 Real-Time Kinematic and P4 Multispectral drones. An analysis of the effectiveness of each method revealed considerable water conservation and improved water distribution performance. For the sensor networks, the level of water use in the irrigation system was 85% – with a supply of 1,000 m^3, losses amounted to 150 m^3. For the software,

Suggested Citation:
Batykova A., Sultanbaeva, V., Shabikova, G., & Osmonov, O. (2025). Automation and intelligent water distribution control systems for optimising water use in agricultural irrigation systems. *Scientific Horizons*, 28(3), 104-116. doi: 10.48077/scihor3.2025.104.

*Corresponding author

the water use efficiency was determined to be 70%, considering that the total volume of water supplied was 1,000 m^3 and the factual volume of water retained in the root zone of plants was 700 m^3. The efficiency of using drones reached 90%, which meant that out of 500 m^3 of water filled into the drones for spraying, 450 m^3 were evenly distributed, while losses due to evaporation and spraying inaccuracies amounted to 50 cubic metres. The study analysed the capabilities of the Demand Driven Distribution water distribution management system revealed a 25% reduction in pump energy consumption, a 15% reduction in water leaks and a 50% reduction in pipe damage. An analysis of the capabilities of the Siemens Water Leak Finder system revealed that artificial intelligence algorithms accurately detected even minor water leaks of 0.2 litres per second, reducing resource losses by up to 50%. The analysis of the performance characteristics of the Rain Bird controller and the CropX platform revealed an increase in water consumption efficiency and water conservation in Central Asia, which was a major step towards the sustainable development of the agricultural sector in the region

Keywords: data monitoring; sensor networks; software; use of drones; resource conservation; irrigation efficiency

INTRODUCTION

Agricultural irrigation systems play a key role in ensuring food security, especially in arid regions where natural moisture is insufficient for crop production. The efficiency of water use in such systems determines not only agricultural productivity but also the sustainability of ecosystems that depend on water resources. Irrigation systems involve a complex interaction of hydraulic structures, engineering networks, and management solutions that ensure the even and prompt distribution of water. With water scarcity exacerbated by climate change, population growth and agricultural intensification, special attention is being paid to the introduction of innovative approaches to water management. However, despite the significance of irrigation systems for agriculture, their efficiency often stays low due to outdated management practices, extensive water losses in networks, and uneven distribution of resources. This is especially true in Central Asia, where much of the infrastructure is outdated. The lack of modern monitoring systems, limited integration of automated solutions, and insufficient adaptation to changing climate conditions greatly complicate sustainable water use. The problem also lies in the lack of a comprehensive analysis of the effectiveness of available technologies and their adaptation to local conditions, which reduces the potential for introducing innovative approaches.

A. Batykova *et al*. (2023) investigated the issues of integrated management of land and water resources in Kyrgyzstan, which are key to sustainable agricultural development and environmental safety. The researchers noted the need to modernise the management of these resources, strengthen local land management institutions and rational use of water, considering the specifics of the mountainous and foothill regions of the country. K. Maatov (2024) analysed the use of economic and mathematical models and computer technologies to optimise resource management in agriculture. The researcher presented a model that allows determining the optimum sown areas and volumes of mineral fertilisers, considering financial capabilities, which contributes to the rational use of resources and increase the efficiency of agricultural production. N. Temirbaeva *et al*. (2024) investigated the prospects for the use of autonomous sources of renewable energy, particularly microelectric power plants, for the energy supply of agricultural enterprises. The researchers noted the significance of optimising the use of water resources in the Kyrgyz Republic for the development of such systems, which will help to improve the efficiency of irrigation and energy supply in the agricultural sector.

S. Ray and S. Majumder (2024) highlighted the significance of using innovative irrigation technologies, such as drip irrigation and automated water management systems, to improve water supply efficiency and conserve resources in agriculture. The study revealed that the use of such methods helps to reduce water and energy consumption and improve crop productivity. F. Behzadipour *et al*. (2024) demonstrated the effectiveness of an intelligent irrigation system for greenhouses, which reduced water consumption by 15.6% compared to conventional irrigation without reducing yields and product quality. The findings confirmed the feasibility of using smart technologies to optimise water distribution in conditions of limited water resources.

M. u Nisa *et al*. (2024) considered an ontological intelligent irrigation system that allows increasing water use efficiency and yields through accurate monitoring and control. The findings revealed that the use of sensors, actuators, and data processing algorithms contributes to the sustainable management of water resources in the agricultural sector, reducing water loss and adverse environmental impact. Moreover, L. Aiswarya *et al*. (2024) analysed the prospects for automating irrigation canals as a tool for improving the efficiency of water distribution and reliability of water supply. The study revealed that automatic flow control can minimise water losses, especially in arid regions, providing flexibility and accuracy in water management.

On the other hand, M. Pourgholam-Amiji *et al*. (2024) found that the introduction of drip irrigation for wheat cultivation in Iran reduced water consumption by 134.1 million m^3 and increased water productivity. The key advantages of the method are increased yields and reduced labour costs, although the high cost of implementation is still a considerable limitation. S. Zhao *et al.* (2024) developed an optimisation method for managing end canals and field irrigation, which reduced water losses and improved water use in irrigation areas of China. Improving water supply schedules reduced filtration losses by up to 4.6% and irrigation time by up to 14 hours, which demonstrated the prospects of the approach for improving water management efficiency. R. Pierre *et al.* (2024) proposed a methodology for estimating water consumption for irrigation at the catchment level, which allows identifying farms with high irrigation levels. The application of artificial intelligence (AI), machine learning (ML) and regression approaches helped to estimate the volume of irrigation water with a minimum error (14%), create water consumption maps, and identify areas with high water demand (Mamchur & Studinska, 2024).

These studies lack data on a comprehensive analysis of automation methods and an overview of intelligent water distribution control systems in irrigation systems in Central Asia, particularly in the Kyrgyz Republic, which determined the purpose of the present study. The objectives of the study were to analyse sensor networks, drones, and software, as well as automated and intelligent water distribution management tools.

MATERIALS AND METHODS

The study performed a comprehensive analysis of methods for automating water distribution control in agricultural irrigation systems, namely sensor networks for monitoring the irrigation process, software for planning and forecasting, drones for monitoring the state of water resources, irrigation and land plots. Schemes and architectures of these methods were presented. The study examined the sensors that monitor humidity, water levels in canals and water flow in the Wzzard LRPv and John Deere Operations Center™ sensor network systems (New Level of..., 2021; Smart Irrigation System, 2023).

The efficiency of each automation method was calculated, which helped to determine the best approaches to irrigation for the conditions of the Kyrgyz Republic. The level of water use in the irrigation system was defined as the ratio between the volume of water that was effectively used for irrigation and the total volume of water supplied (1):

$$\eta_u = \frac{W_u}{W_a} \times 100\%, W_u = W_a - W_l, \tag{1}$$

where η_u is the level of water use in the irrigation system, %; W_u is the volume of water used directly for irrigation, m^3 (cubic metres); W_a is the total volume of water supplied to the system, m^3; W_l is the water losses, m^3 (Ware, 2023).

Water balance modelling and optimisation of irrigation schedules were performed using AquaCrop software from the Food and Agriculture Organisation of the United Nations (Standard AquaCrop proogramme..., n.d.). The model of efficient water use in irrigation systems is based on an estimate of the amount of water that reached the root zone of plants compared to the amount of water supplied to the field. This approach was based on the calculation of irrigation efficiency (2):

$$\eta_a = \frac{W_z}{W_a} \times 100\%, \tag{2}$$

where η_a is the irrigation efficiency, %; W_z is the volume of water stored in the root zone of plants, m^3; W_a is the total volume of water supplied for irrigation, m^3 (Ware, 2023).

The study considered the technologies for the use of drones: Da-Jiang Innovations Phantom 4 Real-Time Kinematic (DJI Phantom 4 RTK mobile mapping station), Global Positioning System (GPS), and DJI P4 Multispectral, which contributed to more efficient water distribution management (Jingao Technology Co., n.d.). The efficiency was assessed by calculating the fluid application efficiency coefficient (3):

$$\eta_c = \frac{W_l}{W_r} \times 100\%, \tag{3}$$

where η_c is the efficiency of liquid application by drones, %; W_l is the volume of liquid that reached the crops, m^3; W_r is the total volume of liquid filled in drones, m^3 (Ware, 2023).

The study analysed intelligent and automated water distribution management systems, including examples of their use in the Central Asian region. Particular attention was paid to the study of the Kyrgyz Research Institute of Irrigation (KRII), namely, the creation of an automated system for irrigation control, water accounting, and water distribution. In this context, the possibilities of using the geospatial platform Geographic Information System (GIS) and ArcGIS (n.d.) software were explored (Bairamukova, 2024; What is GIS?, n.d.). The features of the Demand Driven Distribution (DDD) (n.d.) intelligent water distribution management system was analysed using the example of the Grundfos CU 354 pumping system: the operation scheme, methods of assessing efficiency in reducing water losses and increasing distribution accuracy. The study described the operation scheme, capabilities, and advantages of the Siemens Water (SIWA) Leak Finder application designed to intelligently reduce water losses associated with leaking pipes, the Rain Bird Electronic Smart Programming (ESP) controller, and the CropX platform (Siemens makes it..., 2024; Patil, 2024; ESP-Me Series Controllers, n.d.; Cropx platform overview, n.d.).

RESULTS

Methods of automation of water distribution control in irrigation systems. Automation of water distribution management in irrigation systems is a key area of hydromelioration aimed at ensuring the rational use of water resources. The approach allows optimising water consumption, increasing crop productivity, and minimising environmental impact, factoring in the regional climatic, hydrogeological, and agronomic conditions. The irrigation system is increasingly being integrated with a sensor network to improve the efficiency of water distribution management (Fig. 1). Such a network allows for continuous monitoring of soil, climatic conditions, and canal water levels, providing accurate data for real-time decision-making. This is particularly relevant for Central Asia, where uneven distribution of water resources and high evaporation make irrigation management challenging.

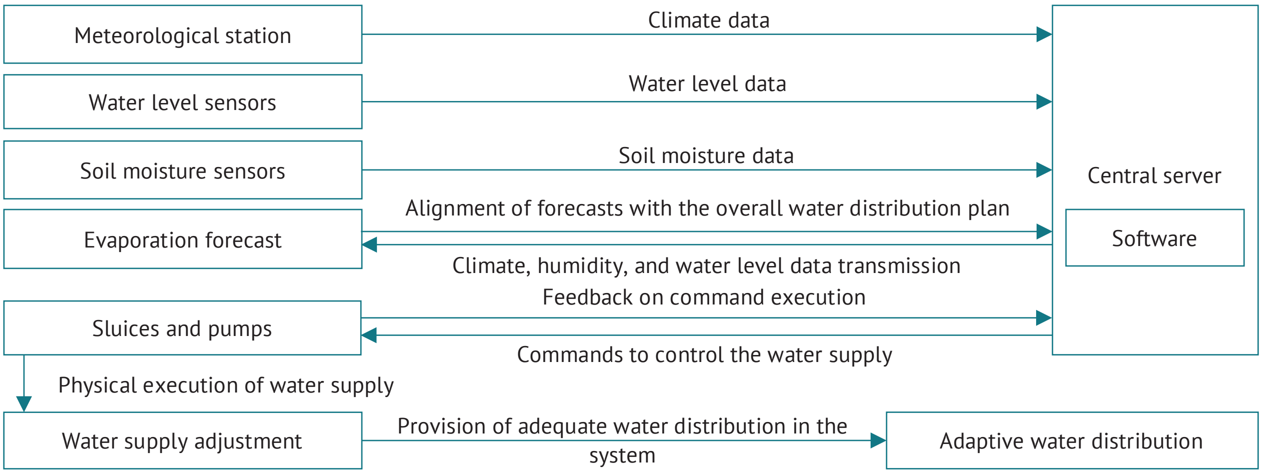


Figure 1. *Sensor network architecture for monitoring irrigation systems*
Source: *compiled by the authors*

The weather station of the sensor network collects temperature, humidity, and precipitation data and sends it to the central server, where it is processed by the software. Canal water level and soil moisture sensors record the relevant parameters and transmit them to the central server. Based on the results of the data analysis, the server predicts evaporation and generates an optimum water distribution plan. Based on the plan, the server sends commands to the gateways and pumps to regulate the water supply. Feedback on the execution of commands ensures constant monitoring and adaptation of the system to current conditions, which enables efficient and adaptive distribution of water resources in real time. Sensor networks automatically analyse the collected data using built-in processing algorithms (ML, neural networks, forecasting methods) and optimise water supply by adapting irrigation modes to current conditions. The Wzzard LRPv wireless sensor network for real-time soil and irrigation monitoring, with the ability to integrate data with weather forecasts, and the John Deere Operations Centre monitoring and control system for monitoring tillage equipment have been adapted to agricultural production conditions (New Level of..., 2021; Smart Irrigation System, 2023).

To evaluate the efficiency of the sensor network, the irrigation monitoring system uses a water use rate that reflects the ratio of water used to the total amount of water supplied (Formula 1). For instance, if the system shows = 85% on the central server monitor or the operator's mobile application, it means that 85% of the water is effectively used for irrigation, and losses are only 15%. This is calculated based on the fact that, for instance, the total volume of water supplied to the system is 1,000 m^3, and the volume of water lost through evaporation, filtration, and other processes is 150 m^3. Thus, the volume of water used for irrigation is 850 m^3, and the percentage of efficient water use is defined as the proportion of water saved to the total volume of water supplied, expressed as a percentage. This approach allows optimising water supply through prompt detection of losses.

For planning and forecasting, the study considered software with integrated algorithms that factor in the climatic, hydrogeological, and agrotechnical conditions of the region, as well as data obtained from sensor networks (Fig. 2). An example of such software was the AquaCrop crop growth model, which allowed assessing the effects of the environment and management practices on yields. It is particularly useful in environments where water is a limiting factor in crop production (Standard AquaCrop proogramme..., n.d.). The software integrated a variety of inputs that were employed to calculate the water balance. This includes modelling water reserves and demands, and forecasting changes in parameters associated with droughts and floods. The analysis results were used to formulate an optimum water distribution plan, considering irrigation schedules and priority zones, to ensure efficient and rational use of water resources.

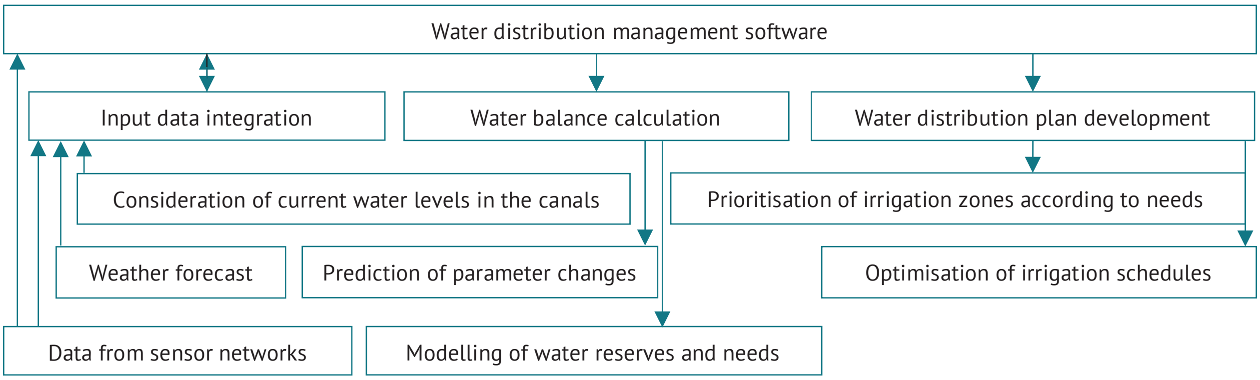


***Figure 2**. Scheme of software use in the automation of water distribution management*
***Source:** compiled by the authors*

This diagram illustrates the automation of water distribution management using software that worked in three stages: integration of input data, calculation of water balance, and generation of a water distribution plan. At the first stage, the system received data from sensor networks, factored in the weather forecast and current water levels in the canals. The system predicted the impact of weather conditions and evaporation and adjust the irrigation plan accordingly by integrating with data from meteorological stations. At the second stage, the data was used to model water reserves and needs, and to predict changes in parameters, which allowed estimating future water consumption. For this, the algorithms analysed data on the amount of water supplied and consumed, considering evaporation and filtration losses. The final stage involved prioritising irrigation zones according to needs and optimising irrigation schedules, which ensured efficient use of water resources, reduced water losses, and increased agricultural productivity. The software calculated the optimum time and volume of water supply according to crop needs and soil conditions.

The software also had to account for the irrigation efficiency, which is the ratio of the volume of water retained in the root zone of plants after irrigation to the total volume of water applied (2). For instance, the total volume of water applied is 1,000 m^3, and according to the analysis results of soil moisture sensors, the volume of water stored in the root zone of plants is 700 m^3. The water use efficiency is 70%, which means that 70% of the applied water was stored in the root zone of the plants for their use. The remaining 30% of the water is lost through evaporation, infiltration into deeper soil layers, or runoff. Additionally, the software should ensure accuracy in water distribution, reduce excessive losses, and increase crop yields (Yeraliyeva *et al.*, 2017). For instance, by adapting irrigation schedules to weather forecasts, waterlogging or water shortages can be avoided (Shuka *et al.*, 2011). Thus, this approach helps reduce water losses and ensures the stability of irrigation processes.

Another promising method of automating water distribution management in irrigation systems is the use of drones to monitor the state of water resources, land, and irrigation conditions (Fig. 3). In Central Asia, where fields and orchards are often located in remote or inaccessible areas, the use of such technologies can reduce the time and resources required to collect the necessary information. In Kyrgyzstan's agricultural sector, drones such as the DJI Phantom 4 RTK are commonly used to provide accurate mapping (Jingao Technology Co., n.d.). These devices are equipped with cameras and GPS technology, which contributes to the efficiency of irrigation management.

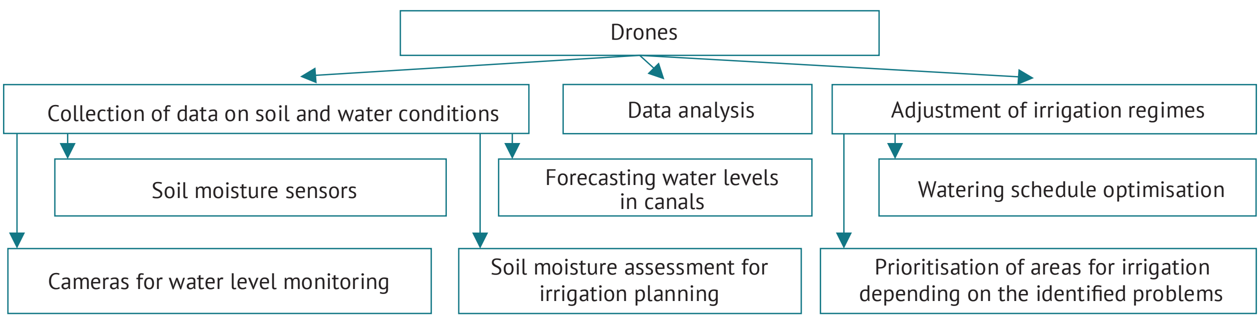


***Figure 3**. Scheme of using drones in water distribution management*
***Source:** compiled by the authors*

Figure 3 shows the key stages of data collection, analysis, and management of irrigation regimes. Overall, drones with high-sensitivity sensors can be used to assess soil conditions, monitor soil moisture and water levels in canals with high accuracy. A drone with built-in DJI P4 Multispectral sensors can be used to assess the condition of vegetation (Jingao Technology Co., n.d.). An essential criterion was to assess the effectiveness of using drones to distribute water during fine-dispersed (local) irrigation or the application of working solutions of fertilisers or biological products (Formula 3). For instance, if the volume of water evenly distributed by drones over crops was 450 m^3, and the total volume of water filled into the drones was 500 m^3, the process efficiency was 90%. This means that 90% of the water was effectively used for irrigation, while losses due to evaporation, spraying outside the plots or other factors amounted to 10%.

The key processes that were automated included monitoring soil moisture levels, real-time control of water supply volumes, and management of water distribution between individual plots. Sensor networks allowed reading data on soil moisture, temperature, and evaporation levels, which were transmitted to a central server for processing. The software analysed this data and generated recommendations or automatically adjusted the operation of pumps and valves to ensure optimum irrigation. Drones were used to collect additional data on the condition of vegetation, water levels in canals, and potential leaks. The collected information was integrated into an automated control system, which enabled prompt decision-making on redirecting flows or regulating water flow. In 2023, the Kyiv Scientific Research Institute of Water Resources, Agriculture and Processing Industry implemented six research projects on hydromelioration topics at the request of the Ministry of Water Resources, Agriculture and Processing Industry. Among them is the development of an automated system for water metering, water distribution, and irrigation control to improve the efficiency of water use in irrigated agriculture in the Chui Valley (Bairamukova, 2024). This system includes the installation of 72 electronic water level sensors at gauging stations equipped with antennas for long-distance wireless data transmission. By 2023, the sensors had been installed on the Kegeti and Shamsi river systems (32 sensors), covering an area of about 15 thsd ha. A computer and telecommunication equipment were purchased for the Water Use Department of the District Water Management Department to organise communication with the gauging stations. It was planned to install the remaining 40 gauges to complete the system.

In another study on the creation of a reference and analytical database of indicators of the reclamation status of irrigated lands in the Chui Oblast, GIS technologies were employed to ensure accurate monitoring and adaptive management of water distribution, contributing to the rational use of water resources and increasing the productivity of irrigation systems (What is GIS?, n.d.). GIS provided monitoring of water supply and distribution through the integration of geographic data, software and hardware, and analysis methods. In other words, geographic data included spatial coordinates of objects and attribute information, which enabled accurate tracking of the condition of irrigated land. ArcGIS (n.d.) software provided the tools for processing this data, and hardware, such as GPS devices and drones, facilitated its collection. Furthermore, ArcGIS software enabled a comprehensive assessment of the water balance over large agricultural areas. Spatial and thematic analysis methods helped to optimise water distribution, increasing irrigation efficiency and rational use of water resources.

Intelligent water distribution management systems. The Demand Driven Distribution (n.d.) system for the Grundfos pumping system used self-learning algorithms to optimise the pressure in the water supply network (the algorithm is integrated in the Grundfos CU 354 pump controller), which reduced water losses, energy consumption and maintenance costs. It provided adaptive pressure control, adjusting to the real needs of consumers, which increased the efficiency of municipal water pumping stations and extended the service life of the pipeline network. According to the manufacturer, the reduction in overpressure in the DDD intelligent pumping system network could lead to a 25% reduction in pump energy consumption, while a 10% reduction in average pressure could reduce the cost of active water leakage management by 10%. Optimum pressure management could reduce water leakage by 15%, which reduced losses and increased water supply efficiency. Therewith, pressure stabilisation over 24 hours proved to be effective in reducing the number of pipe bursts, and a 16% reduction in night-time pressure could reduce the number of pipe bursts by 50% (Demand Driven Distribution, n.d.).

One of the leaders in the use of AI in water distribution management was Siemens with its SIWA Leak Finder, which analysed data from smart flow meters and enabled the detection of water leaks in pipelines with high accuracy, reducing water losses by up to 50% (Siemens makes it…, 2024). The system can detect leaks as small as 0.2 litres per second, which facilitates rapid response and reduces water losses. Integration of SIWA Leak Finder with Siemens Sitrans FM Mag8000 flow meters simplified the installation process and did not require specialised knowledge or additional services. The system could process and analyse operational data from smart sensors via a cloud connection, providing access to information within two hours of installation. The AI algorithms were automatically trained and adapted to the data from the moment of installation, which increased the efficiency of monitoring and management of the water distribution network. The implementation of SIWA Leak Finder contributed to the sustainability of water resources by reducing water losses and improving the efficiency of water supply systems. Thanks to the use of AI, the system ensured reliable monitoring and management, which was a major step towards the sustainable development of water infrastructure.

Siemens offered intelligent solutions for cybersecurity of water infrastructure, specifically through its Mendix platform (Siemens makes it..., 2024). Using Mendix, companies could create interfaces to integrate data from SIWA applications into Enterprise Resource Planning (ERP) systems, ensuring secure information exchange between distinct infrastructure components. This enabled efficient data management and increased cybersecurity of water systems. Siemens provided guidance and templates for creating secure network and system architectures, and offered certified cybersecurity solutions to help water infrastructure operators protect against cyber threats. These initiatives have contributed to improving the resilience and security of water resources.

Overall, the use of various tools and technologies for accurate measurement and control was an integral element in water distribution management systems. For instance, the amount of useful water that actually reached the root zone of plants was determined using soil moisture sensors. These were tensiometers or capacitive sensors that measured soil moisture in real time. Furthermore, usable water was estimated by direct soil sampling before and after irrigation and observing changes in moisture levels in the root zone. Evaporators or weather stations were used to measure evapotranspiration losses, which helped to calculate the evapotranspiration rate, the sum of evaporation from the soil and transpiration from plants. Water loss through infiltration into deep soil layers was estimated using soil permeability models or observations of water movement in the soil. Monitoring systems that measure the volume of water flowing over the field can be used to estimate losses due to runoff (Haleeva *et al.*, 2024).

The processes were automated by intelligent irrigation systems that integrated data from various sensor networks (e.g., soil moisture sensors, weather stations, water levels in canals) and analysed them to make decisions. Such intelligent systems comprised hardware and software, including controllers, data processing algorithms, applications, and online platforms. The controllers used were Rain Bird ESP series, which supported integration with various sensors (including those measuring soil moisture, atmospheric parameters, and water levels) and could adapt to changing conditions to ensure optimum irrigation. Rain Bird ESP-Me is a high-tech controller of the ESP series, designed for automation and integration of intelligent solutions into irrigation systems, supporting a variety of irrigation settings through flexible programming (ESP-Me Series Controllers, n.d.). It supported from 4 to 22 stations and could be equipped with the LNK™ module for Wi-Fi connection, which enabled monitoring and control via mobile applications on iPhone Operating System (iOS) and Android platforms. Thanks to this functionality, the ESP-Me controller could reduce water consumption by 30% by using data from online weather services to adjust irrigation schedules in real time. This enabled efficient application of adjustment seasons, as well as customisation of restrictions for each station to adapt irrigation to weather conditions.

One of the key advantages of the ESP-Me controller was the ability to control irrigation both automatically and manually and monitor water flow. The user could set a schedule for each station separately or start watering on demand. Furthermore, the ESP-Me supported the seasonal adjustment function, which allowed changing the watering intensity according to weather conditions. The controller was also equipped with a rain sensor that automatically stopped watering during precipitation, preventing unnecessary water consumption. A delayed watering function allowed pausing the system for a certain time, e.g., after heavy rain. For even more control, the number of stations could be expanded, making ESP-Me the best option for large areas. The ESP-Me controller could support a Wi-Fi connection (by connecting the LNK2 module). This allowed controlling irrigation remotely via a mobile application, which is especially convenient for people who are often on the move or manage several facilities at the same time.

The ESP-Me controller is designed for both irrigation of private gardens and programming of commercial irrigation systems, enabling efficient management of water supply to different areas (Zavertaliuk & Naumovska, 2024). Thanks to its flexible settings, it allows you to control the time, duration, and frequency of irrigation, which helps to save water and ensure optimum plant care. ML and forecasting algorithms were also employed to analyse the collected data, which helped to determine the best irrigation regimes depending on current conditions. These could be algorithms for predicting soil moisture based on weather data and historical indicators. There were also software solutions that enabled users to monitor and control irrigation systems in real time. For example, the CropX platform offered a mobile application that displayed sensor data, provided irrigation recommendations, and allowed remote control of equipment (Cropx platform overview, n.d.).

Overall, the efficiency of water distribution in an irrigation system depended on various factors: the type of irrigation system, soil characteristics, climatic conditions, and the technical condition of the equipment. Drip irrigation usually provided the least water loss compared to other methods, while conventional canal systems could have major losses due to evaporation and infiltration. Thus, the findings of the present study substantiated the significance of automation and implementation of intelligent water distribution management systems to optimise the use of water resources in the Kyrgyz Republic.

DISCUSSION

The findings of the study confirmed a considerable improvement in water consumption efficiency and water conservation through automation and intelligent water distribution management systems. The use of sensor networks helped to achieve a level of water use in the irrigation system of up to 85%, while reducing losses to 150 m^3 out of 1,000 m^3 of supplied water. The study by H. Ojaghlou *et al.* (2024) on alfalfa crops also reported water savings due to the adjustment of irrigation time, but three times higher, as the crop is not demanding on humidity. The introduction of intelligent water distribution management systems, such as DDD, reduced water leakage by an average of 15% and pipe damage by 50%. These findings are substantially better than the conventional irrigation methods mentioned by K.R. Choudhary (2024), including sprinkling, surface or drainage irrigation, and flooding, which also had limitations: they contributed to soil erosion and significant water losses.

The precision irrigation methods (drip, sub-surface drip, micro-irrigation) investigated by K.R. Choudhary (2024) provided high precision and resource savings by minimising water loss and precisely distributing water directly to the root zone of plants. Compared to these conventional methods, the DDD system demonstrated efficiency mainly in water conservation and reduction of energy consumption and infrastructure repair costs. The findings confirmed the need for the development and application of innovative technologies in irrigation, primarily for intelligent water distribution management. This is consistent with the findings of Y. Li (2023), who noted the significance of integrating IoT and sensor systems for water resources monitoring. However, the researchers did not pay attention to methods of reducing water losses and infrastructure damage.

J. Singh *et al.* (2024) investigated the use of ML algorithms to optimise irrigation and confirmed the significance of automation technologies. Sensor networks in the study by J. Singh *et al.* were integrated with intelligent systems to achieve high accuracy in predicting plant water needs. In contrast, the present study found that the integration of sensor networks with intelligent water distribution control systems reduced water losses to 150 m^3 when supplying 1,000 m^3 of water, which resulted in substantial resource savings and contributed to water management efficiency. The studies complemented each other as they demonstrated the potential of combining sensor technologies and intelligent systems to optimise irrigation and increase water use efficiency.

H. Liu and Q. Li (2021) developed an intelligent system for automated greenhouse irrigation based on a microcontroller that helped to control soil moisture and reduce water consumption. The researchers' study confirmed the findings of the present study, but it did not cover the possibility of integrating water monitoring and optimisation technologies, which enabled a reduction in infrastructure damage and a 15% reduction in water losses. The findings of the current study on the significance of using energy-efficient systems were also consistent with the findings of M. Tripathi (2022), who studied automatic micro-irrigation based on solar energy in remote areas. The findings obtained in both studies demonstrated the possibility of large-scale implementation of integrated solutions that combined automation, intelligent systems, and innovative monitoring technologies, which ensures integrated resource management and minimises energy supply costs.

Analogously to the study by B. Mason *et al.* (2019) on agriculture and its adaptation to different climatic conditions, the present study substantiated the effectiveness of smart irrigation systems and confirmed that smart irrigation systems could operate effectively in different conditions without loss of yield. The findings demonstrated the efficiency of using drones for spraying, which was estimated at 90%, enabling the uniform distribution of 450 m^3 of spray solution from an initial volume of 500 m^3, minimising losses of up to 50 m^3. On the other hand, A.R. Alex *et al.* (2025) confirmed the significance of automation for optimising irrigation and water conservation. This approach, which focused on continuous monitoring of soil moisture using soil moisture sensors and an Arduino Uno microcontroller, enabled localised irrigation automation. The present study, on the other hand, included a review of an automated system for water metering, water distribution, and irrigation control in Kyrgyzstan, which enabled the integration of automation into larger irrigation networks, improving water use efficiency at the macro level.

The study found that the integration of sensor networks, drones, and water distribution management software saved resources and increased irrigation efficiency. Y.K. Kushwaha *et al.* (2024) applied the Smart Irrigation Monitoring System (SIMS) system for real-time irrigation management, which uses IoT components to monitor soil moisture and forecast precipitation, which also helps to optimise water consumption. Both approaches included intelligent monitoring and control systems, although Y.K. Kushwaha's *et al.* study focused on the use of IoT for real-time monitoring and forecasting. At the same time, the present study focused on methods of automating water distribution, including not only monitoring but also active management using drones and integrated software for irrigation networks.

D.M.C.D. Le Veut *et al.* (2024) explored an autonomous solar pumping system with a controller for local irrigation. In the present study, on the contrary, solar panels were not included in the automation system, which may reduce its efficiency. Still, both studies were aimed at saving water and, accordingly, sustainable agricultural development, and therefore contributed to optimising water consumption in various climatic zones. The study also confirmed the effectiveness of integrating intelligent water distribution management systems, which is consistent with the findings of

M.C. Lallawmkimi *et al.* (2024), who noted the significant potential of nanotechnology to improve water and irrigation management through the use of nanomaterials for water purification and real-time nanosensors for water quality and soil moisture. The integration of such technologies helped to save water, increase yields, and ensure sustainable agricultural development.

B. Askaraliev *et al.* (2024) confirmed the effectiveness of drip irrigation and automatic IoT-based systems in reducing water consumption by 50% while increasing yields by 30%. As in the present study, the introduction of agrodrones for monitoring and precise irrigation control in this study confirmed the significance of innovative technologies in reducing water costs and increasing productivity. Therewith, the findings of the present study revealed that the data collected by drones can be integrated into the automation system by automatically reading and transmitting them to the central server or the operator's mobile application.

The findings of the present study demonstrated a considerable improvement in the efficiency of water consumption and water conservation through the introduction of automated systems. K.V. Joshi *et al.* (2024) confirmed the significance of such irrigation systems for optimising water use. N. Patel *et al.* (2024) investigated the improvement of irrigation efficiency in horticulture, specifically through the strategy of deficit irrigation and the use of hydrogels. The findings of the present study, which included technologies for precise monitoring and management of water resources, complemented this approach, confirming the effectiveness of integrated solutions for water conservation and irrigation optimisation. The study also found that SIWA's intelligent Leak Finder system detects water leaks with an accuracy of 0.2 litres per second, reducing water losses by up to 50%, while the DDD system reduces pump energy consumption by 25%, water leaks by 15% and pipe damage by 50%. At the same time, a study by M.C.A. Diallo *et al.* (2024) highlighted that smart irrigation technologies can reduce water consumption by 30% and increase productivity by up to 125%, with maximum savings of up to 78% in arid regions. Notably, the present study focused on an integrated approach to reducing water loss, energy consumption, and infrastructure damage, while M.C.A. Diallo *et al.* focused more on optimising water consumption and increasing productivity in drought conditions.

D. Mukhamedieva *et al.* (2024) explored the creation of an intelligent irrigation system based on fuzzy Sugeno logic that optimises water use and increases yields. The software proposed by the researchers can make decisions on the need for irrigation and the optimised amount of water supply based on the collected data on soil moisture. In terms of the findings of the present study, the software (AquaCrop and ArcGIS) considered in this study was more focused on water balance and irrigation optimisation based on geospatial data and agronomy models, but did not provide the flexibility to make decisions in the presence of uncertainty as the Sugeno model does. However, it had the advantage of providing a comprehensive assessment of water balance over large agricultural areas, considering various agronomic and geographic factors (Fedoniuk & Skydan, 2023).

This study analysed the effectiveness of using automated water distribution management systems to conserve water and improve irrigation efficiency. In the study by W. Patel *et al.* (2024), an IoT system for irrigation optimisation collected data on soil and plant health and used neural networks to provide recommendations to farmers, resulting in improved water conservation efficiency and productivity. This study confirmed the findings of the present study, as both approaches used intelligent systems to monitor and manage irrigation. However, the present study focused on the integration of sensor networks, drones, and software to automate water distribution in agricultural areas, allowing for integrated water management at the macro level.

I. Abd-Elaty *et al.* (2024) showed that the use of modern irrigation systems in the Nile Delta can save significant amounts of water (2.15×10^9 m^3), but there are problems with increased salinity and lower groundwater levels. The conclusions of the present study also pointed to the significance of an integrated approach to water management, where the introduction of innovative technologies can greatly increase efficiency without harming the environment. Additionally, the findings obtained were consistent with the study by P. Kumar *et al.* (2023), who focused on the automation of drip irrigation using wireless sensor networks and IoT, which ensured an increase in water use efficiency. However, the current study concentrated not only on improving water use efficiency, but also on predicting water balance and using various technologies.

Z. Yang *et al.* (2024) proposed a method for optimising irrigation profits, considering climate risks, which complements current approaches to water balance modelling and irrigation optimisation. Overall, the findings obtained in this study confirmed the efficiency of automated systems for improving water supply and optimising agricultural production. Thus, compared to other studies, the present study demonstrated a more comprehensive approach to water management, including monitoring, optimisation of water balance, and the use of intelligent systems that significantly reduce water leakage and pipe damage.

CONCLUSIONS

The use of sensor networks to monitor soil moisture, canal water levels, and water flow in the Wzzard LRPv and John Deere Operations Centre systems was found to be highly effective. Their implementation enabled the irrigation system to achieve a water use efficiency of up to 85%, which corresponded to losses of 150 m^3

when supplying 1,000 m^3. AquaCrop and ArcGIS water balance modelling and irrigation optimisation software helped to reduce water losses and improve water management efficiency, ensuring water use efficiency of 70%. This was achieved when the total volume of water applied was 1,000 m^3, and the volume of water retained in the root zone of plants was 700 m^3. The use of drones for water and land monitoring, such as the DJI Phantom 4 RTK and P4 Multispectral, demonstrated the advantage of collecting data with high precision and speed. The efficiency of liquid distribution using drones was estimated at 90%, which allowed for an even spraying of 450 m^3 out of a total volume of 500 m^3, accounting for losses due to evaporation and other factors (e.g., dosing inaccuracy, battery wear, wind, and uneven surface coverage). Overall, the findings revealed improved water distribution performance and reduced water consumption, which is essential for the sustainable use of water resources in the agricultural sector.

The introduction of intelligent systems and their improvement with GIS allowed increasing the accuracy and efficiency of water management. The DDD intelligent system reduced pump energy consumption by 25%, water leakage by 15%, and pipe damage by 50%. The SIWA Leak Finder system could detect minor water leaks, reducing resource losses by up to 50%. Thus, the findings of the present study confirmed the significance of integrating intelligent and automated systems into agriculture in Central Asia, where water resources are limited. The use of such technologies has helped to conserve water and reduce energy consumption, which is significant for the development of sustainable agriculture in the region. Additionally, the Rain Bird ESP controller enabled efficient irrigation automation, while the CropX platform provided monitoring and remote control of the process. Limitations of the study included the integration of the latest technologies into existing irrigation systems, which would require extensive investment and time, as well as dependence on specific climatic conditions that could vary from region to region. Areas for future research could include the development of common standards for integrating various technologies, ML-based water balance forecasting algorithms, and improving infrastructure to support the latest solutions in remote areas.

ACKNOWLEDGEMENTS

The research in the HWCA project was funded by the Education, Audio-visual and Culture Executive Agency, Erasmus+, ref. 101082976 – HWCA – ERASMUS-EDU-2022-CBHE. The authors are also grateful to all partners of the HWCA team with their valuable contributions to discussions and verification of the developed procedures. The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Abd-Elaty, I., Ramadan, E.M., Elbagory, I.A., Nosair, A.M., Kuriqi, A., Garrote, L., & Ahmed, A.A. (2024). Optimizing irrigation systems for water efficiency and groundwater sustainability in the coastal Nile Delta. *Agricultural Water Management*, 304, article number 109064. doi: 10.1016/j.agwat.2024.109064.

[2] Aiswarya, L., Siddharam, Gaddikeri, V., Jatav, M.S., Dimple, & Rajput, J. (2024). Canal automation and management system to improve water use efficiency. In Yasheshwar, A.K. Mishra & M. Kumar (Eds.), *Recent advancements in sustainable agricultural practices: Harnessing technology for water resources, irrigation and environmental management* (pp. 267-282). Singapore: Springer. doi: 10.1007/978-981-97-2155-9_14.

[3] Alex, A.R., Mahdi, M., & Fezzani, W.E. (2025). Optimizing water usage in agriculture: A study on automated irrigation systems using humidity sensors and Arduino Uno. In E. AlDhaen, A. Braganza, A. Hamdan & W. Chen (Eds.), *Business sustainability with artificial intelligence (AI): Challenges and opportunities* (pp. 119-128). Cham: Springer. doi: 10.1007/978-3-031-71318-7_11.

[4] ArcGIS. (n.d.). *How ArcGIS works*. Retrieved from https://surl.li/gptfpe.

[5] Askaraliev, B., Musabaeva, K., Koshmatov, B., Omurzakov, K., & Dzhakshylykova, Z. (2024). Development of modern irrigation systems for improving efficiency, reducing water consumption and increasing yields. *Machinery & Energetics*, 15(3), 47-59. doi: 10.31548/machinery/3.2024.47.

[6] Bairamukova, I. (2024). *Doctor of Economics U. T. Chortombaev told how scientific developments of the Kyrgyz Research Institute of Irrigation in 2023 are being implemented in production*. Retrieved from https://surl.li/wycgie.

[7] Batykova, A., Tuleev, T., Tuleev, B., Asanaliev, A., Denisov, V., Hegay, S., Sultanbaeva, V., & Babajanov, A. (2023). Integrated management of water and land resources of the Kyrgyz Republic and characteristics of their use at the present stage. *E3S Web of Conferences*, 386, article number 05001. doi: 10.1051/e3sconf/202338605001.

[8] Behzadipour, F., Ghasemi-Nejad-Raeini, M., Mehdizadeh, S.A., Taki, M., Moghadam, B.K., & Bavani, M.R.Z. (2024). Optimizing water use efficiency in greenhouse cucumber cultivation: A comparative study of intelligent irrigation systems. *PLoS ONE*, 19(10), article number e0311699. doi: 10.1371/journal.pone.0311699.

[9] Choudhary, K.R. (2024). Advancements in water management for agriculture: Innovative strategies for efficient irrigation systems – with Reference to Sirohi District. *RESEARCH REVIEW International Journal of Multidisciplinary,* 9(11), 62-70. doi: 10.31305/rrijm.2024.v09.n11.011.
[10] Cropx platform overview: Hardware and software capabilities. (n.d.). Retrieved from https://cropx.com/cropx-system/.
[11] Demand Driven Distribution. (n.d.). Retrieved from https://www.grundfos.com/solutions/learn/ecademy/all-courses/water-distribution/demand-driven-distribution.
[12] Diallo, M.C.A., Santos, R.C., Gomes, E.P., Machado, C.A.C., Dias, C.R.A., Santos, E.C.D., Padilha, G.A.C., Belarmino, M.D., Galiaso, M., Riffel, A.S., Da Silva, E.A.S., & Lovatto, J. (2024). Challenges of smart irrigation implementation in water optimization and agricultural sustainability. *Contributions to the Social Sciences,* 17(13), article number e13723. doi: 10.55905/revconv.17n.13-270.
[13] ESP-Me Series Controllers. A flexible irrigation controller solution, supporting from 4 – 22 stations and a WiFi upgrade. (n.d.). Retrieved from https://www.rainbird.com/products/esp-me-series-controllers.
[14] Fedoniuk, T.P., & Skydan, O.V. (2023). Incorporating geographic information technologies into a framework for biological diversity conservation and preventing biological threats to landscapes. *Space Science and Technology*, 29(2), 10-21. doi: 10.15407/knit2023.02.010.
[15] Haleeva, A., Hruban, V., Horbunov, M., & Ruzhniak, M. (2024). Improving the process of plant protection mechanisation in grape growing. *Ukrainian Black Sea Region Agrarian Science*, 28(4), 85-95. doi: 10.56407/bs.agrarian/4.2024.85.
[16] Jingao Technology Co., Ltd. (n.d.). Retrieved from https://www.jauav.com/p-about.html.
[17] Joshi, K.V., Rathi, R.D., Raskar, A.R., Bhansali, R.R., Rathi, G.M., Rathi, N.A., & Rathi, P.P. (2024). Wireless automated irrigation system. *International Journal for Research in Applied Science and Engineering Technology*, 12(6), 867-872. doi: 10.22214/ijraset.2024.63224.
[18] Kumar, P., Didawat, R.K., Kumar, S. (2023). Automation in drip irrigation: An approach for increasing the water productivity in cereal based system in India. *Indian Council of Agricultural Research,* 73(9), 29-32.
[19] Kushwaha, Y.K., Joshi, A., Panigrahi, R.K., & Pandey, A. (2024). Development of a smart irrigation monitoring system employing the wireless sensor network for agricultural water management. *Journal of Hydroinformatics,* 26(12), 3224-3243. doi: 10.2166/hydro.2024.241.
[20] Lallawmkimi, M.C., Ashaq, M., veer Singh, B., & Pandey, S.K. (2024). Nanotechnology applications in water management and irrigation systems. In *Nanotechnology for sustainable agriculture and food security* (pp. 153-163). Springfield: DvS Scientific Publication. doi: 10.5281/zenodo.14489138.
[21] Le Veut, D.M.C.D., Wan, S., & Zhang, B. (2024). Optimization of Solar water pumping systems for agricultural irrigation: Comparative analysis and design of an ideal solution. *Saudi Journal of Engineering and Technology,* 9(7), 274-279. doi: 10.36348/sjet.2024.v09i07.001.
[22] Li, Y. (2023). Application of intelligent water conservancy information system in agricultural water-saving irrigation. In M.A. Jan & F. Khan (Eds.), *Second EAI international conference: Application of big data, blockchain, and internet of things for education informatization* (pp. 316-325). Cham: Springer. doi: 10.1007/978-3-031-23950-2_34.
[23] Liu, H., & Li, Q. (2021). Construction and application of intelligent agricultural greenhouse irrigation system. *Journal of Physics Conference Series*, 2005, article number 012089. doi: 10.1088/1742-6596/2005/1/012089.
[24] Maatov, K. (2024). Mathematical modeling of growing agricultural crops on the area of the enterprise. *Journal of Osh State University. Mathematics. Physics. Technical Sciences*, 1(4), 131-135. doi: 10.52754/16948645_2024_1(4)_26.
[25] Mamchur, V., & Studinska, G. (2024). Effectiveness assessment of technical innovations in the implementation of the modern model of the agricultural sector of Ukraine. *Ekonomika APK*, 31(2), 32-40. doi: 10.32317/2221-1055.202402032.
[26] Mason, B., Rufí-Salís, M., Parada, F., Gabarrell, X., & Gruden, C. (2019). Intelligent urban irrigation systems: Saving water and maintaining crop yields. *Agricultural Water Management*, 226, article number 105812. doi: 10.1016/j.agwat.2019.105812.
[27] Mukhamedieva, D., Alimbaev, K., Bakhtiyorov, S., & Normirzaev, S. (2024). Creation of an intelligent irrigation system based on the fuzzy Sugeno model. *Scientific Collection "InterConf+",* 43(193), 487-493. doi: 10.51582/interconf.19-20.03.2024.047.
[28] New Level of Integration from John Deere Operations Center and Soft.Farm System. (2021). Retrieved from https://soft.farm/en/blog/new-level-of-integration-from-john-deere-operations-center-and-softfarm-system-188.
[29] Ojaghlou, H., Oiaghlou, F., Jafari, M.M., Misaghi, F., Nazari, B., & Denkordi, E.K. (2024). Effect of irrigation management on water productivity indicators of Alfalfa. *Journal Management System,* 37(2), 165-185. doi: 10.22067/jsw.2023.79145.1211.

[30] Patel, N., Kiran, Y.D., Kalita, R., Kumar, A., Bagul, H., & Kendra, V. (2024). Optimizing water use in horticultural systems. In S. Pathakakula, V. Ramadevi, Parkavi, A. Karthika, P. Ragul & S.W. Haokip (Eds.), *Frontiers in horticulture sustainability* (pp. 9-16). Ghaziabad: Ninetales Publishings.
[31] Patel, W., Sangeetha, Y., Gopagoni, D.R., Mallik, D.M.A., Agrawal, R., Mishra, S., Sunil, M. P., & Kolandaisamy, R. (2024). An empirical intelligent water irrigation system using soft computing and IoT. *International Journal of Information Technology*, 16, 3983-3989. doi: 10.1007/s41870-024-01920-z.
[32] Patil, N. (2024). *Siemens launches SIWA ai-based analytics applications for water, wastewater industry*. Retrieved from https://dailycadcam.com/siemens-launches-siwa-ai-based-analytics-applications-for-water-wastewater-industry/.
[33] Pierre, R., Dominique, C., Fabrice, F., & Debolini, M. (2024). *Unravelling the heterogeneity of farms irrigation practices on Mediterranean perennial agricultural systems for the optimization of water resource management*. doi: 10.21203/rs.3.rs-4580425/v1.
[34] Pourgholam-Amiji, M., Hajirad, I., Nayebi, J., Alavi, S.R., Nozari, F., & Akbarpour, M. (2024). Improving wheat irrigation productivity in Iran (Part one: From the view point of irrigation system and water management). *Water and Soil Management and Modeling,* 4(1), 171-193. doi: 10.22098/mmws.2023.11937.1189.
[35] Ray, S., & Majumder, S. (2024). Water management in agriculture: Innovations for efficient irrigation. In P. Sil, P. Chhetri, S. Majumder & D.T. Satosh (Eds.), *Modern agronomy* (pp. 169-185). Delhi: Satish Serial Publishing House.
[36] Shuka, L., Çullaj, A., Shumka, S., Miho, A., Duka, S., & Bachofen, R. (2011). The spatial and temporal variability of limnological properties of Bovilla Reservoir (Albania). *Water Resources Management*, 25(12), 3027-3039. doi: 10.1007/s11269-011-9788-z.
[37] Siemens makes it easier for water utilities to benefit from artificial intelligence. (2024). Retrieved from https://assets.new.siemens.com/siemens/assets/api/uuid:26fce6bb-2b3c-4eaf-b621-04fb309992eb/HQDIPR202405106928EN.pdf.
[38] Singh, J., Shelke, N.A., Hasan, D.S., Sajid, M., Alsahlanee, A.T.R., & Upreti, K. (2024). Enhanced learning in IoT-based intelligent plant irrigation system for optimal growth and water management. In A. Abraham, A. Bajaj, T. Hanne, P. Siarry & K. Ma (Eds.), *Real world applications: International conference on intelligent systems design and applications (pp. 231-240).* Cham: Springer. doi: 10.1007/978-3-031-64847-2_21.
[39] Smart Irrigation System. (2023). Retrieved from https://www.proxis.ua/en/solution/smart-irrigation-system/.
[40] Standard AquaCrop proogramme with users' interface and database – version 7.1. (n.d.). Retrieved from https://www.fao.org/aquacrop/software/aquacropstandardwindowsprogramme/en/#c522959.
[41] Temirbaeva, N., Sadykov, M., Osmonov, Z., Osmonov, Y., & Karasartov, U. (2024). Renewable energy sources in Kyrgyzstan and energy supply to rural consumers. *Machinery & Energetics,* 15(3), 22-32. doi: 10.31548/machinery/3.2024.22.
[42] Tripathi, M. (2022). Componets of automatic irrigation system. In M. Nemichandrappa & R.R. Halidoddi (Eds.), *Advanced innovative technologies in agricultural engineering for sustainable agriculture* (pp. 1-13). New Delhi: AkiNik Publications. doi: 10.22271/ed.book.1810.
[43] u Nisa, M., Azam, M., Rafiq, T., Sattar, M., Zahra, A., & Zafar, S. (2024). Ontology-based smart irrigation system: Enhancing agricultural water management: Ontology-based smart irrigation system. *Asian Bulletin of Big Data Management,* 4(1), 286-312. doi: 10.62019/abbdm.v4i1.131.
[44] Ware, T. (2023). *Irrigation efficiency – definition, types, importance & formula*. Retrieved from https://www.twl-irrigation.com/irrigation-efficiency/.
[45] What is GIS? Geographic Information System (GIS). (n.d.). Retrieved from https://www.esri.com/en-us/what-is-gis/overview.
[46] Yang, Z., Chen, Y., Wang, S., Zhou, C., Niu, L., Wang, W., Huang, Q., & Yu, H. (2024). Optimized evaluations of irrigation profits and balance of irrigation water demand and supply under climate change. *Water*, 16(23), article number 3525. doi: 10.3390/w16233525.
[47] Yeraliyeva, Z.M., Kurmanbayeva, M.S., Makhmudova, K.K., Kolev, T.P., & Kenesbayev, S.M. (2017). Comparative characteristic of two cultivars of winter common wheat (*Triticum aestivum* L.) cultivated in the southeast of Kazakhstan using the drip irrigation technology. *OnLine Journal of Biological Sciences*, 17(2), 41-49. doi: 10.3844/ojbsci.2017.40.49.
[48] Zavertaliuk, O., & Naumovska, O. (2024). A comprehensive overview of modern environmental management software. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 20(3), 1-17. doi: 10.31548/dopovidi.3(109).2024.004.
[49] Zhao, S., Chen, J., Chen, D., Luo, Z., Bi, B., Lin, L., Du, X., Liu, Y., & Xia, Q. (2024). Optimizing terminal water management in irrigation district using water balance and genetic algorithm. *Agronomy*, 14(12), article number 2987. doi: 10.3390/agronomy14122987.

Автоматизація та інтелектуальні системи управління водорозподілом для оптимізації використання води в сільськогосподарських зрошувальних системах

Айнура Батикова
Кандидат технічних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0001-9173-3151
Вікторія Султанбаєва
Кандидат сільськогосподарських наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0002-8914-8778
Гульміра Шабікова
Кандидат технічних наук, доцент
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0009-0005-3016-393X
Оскон Осмонов
Доктор історичних наук, професор
Киргизький національний аграрний університет імені К.І. Скрябіна
720000, вул. Медерова, 68, м. Бішкек, Киргизька Республіка
https://orcid.org/0000-0003-0782-1584

Анотація. Метою цього дослідження був аналіз методів автоматизації, інтелектуального розподілу та споживання води в іригаційних системах Центральної Азії на прикладі Киргизької Республіки. У дослідженні розглянуто використання сенсорних мереж для моніторингу водних даних компанією Wzzard LRPv та John Deere Operations Centre. Проаналізовано роботу програмного забезпечення AquaCrop для моделювання водного балансу та оптимізації зрошення, а також використання дронів для моніторингу стану водних ресурсів та земельних ділянок, зокрема дронів Da-Jiang Innovations Phantom 4 Real-Time Kinematic та P4 Multispectral. Аналіз ефективності кожного методу показав значну економію води та покращення показників водорозподілу. Для сенсорних мереж рівень використання води в зрошувальній системі склав 85 % – при подачі 1,000 м^3 втрати склали 150 м^3. Для програмного забезпечення ефективність використання води була визначена на рівні 70 %, враховуючи, що загальний обсяг поданої води становив 1,000 м^3, а фактичний обсяг води, що утримується в кореневій зоні рослин, – 700 м^3. Ефективність використання дронів досягла 90 %, що означає, що з 500 м^3 води, заправленої в дрони для обприскування, 450 м^3 було рівномірно розподілено, а втрати через випаровування і неточності обприскування склали 50 кубічних метрів. Аналіз можливостей системи управління розподілом води Demand Driven Distribution показав зниження енергоспоживання насосів на 25 %, витоків води – на 15 % і пошкоджень труб – на 50 %. Аналіз можливостей системи Siemens Water Leak Finder показав, що алгоритми штучного інтелекту точно виявляють навіть незначні витоки води в 0,2 літра на секунду, скорочуючи втрати ресурсів до 50 %. Аналіз робочих характеристик контролера Rain Bird і платформи CropX показав підвищення ефективності водоспоживання та водозбереження в Центральній Азії, що стало важливим кроком на шляху до сталого розвитку сільськогосподарського сектору регіону

Ключові слова: моніторинг даних; сенсорні мережі; програмне забезпечення; використання дронів; ресурсозбереження; ефективність зрошення