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Energy efficiency monitoring system of operated irrigation pumping stations in Uzbekistan

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Abstract: This study addresses the challenges of online monitoring of water metering in irrigation systems in Central Asia, specifically in the Republic of Uzbekistan. The importance of this study lies in improving water management and energy efficiency in a region where water resources are critical for agriculture. Uzbekistan, with 2.3 mln ha of irrigated land – 53% of the total agricultural area – is dependent on 1,693 pumping stations that annually pump over 50 mln m^3 of water. These stations consume between 8 to 8.2 bln kWh of electricity each year, representing about 11% of the nation's total electricity generation.

Currently, energy consumption at these irrigation pumping stations is monitored manually, and most stations lack accurate water metering devices, which hinders the ability to account for sediment in the water and prevents real-time energy efficiency monitoring. Additionally, 1–3% of the electricity used by these stations is consumed by auxiliary systems, contributing to increased overall energy consumption.

The primary goal of this study is to scientifically substantiate, develop, and implement a system for monitoring the energy efficiency of irrigation pumping stations in real time. This includes providing real-time data on electricity consumption and supply, as well as integrating photovoltaic systems to meet the internal energy needs of the pumping stations. The implementation of such a monitoring system is expected to optimise energy use, reduce operational costs, and enhance sustainable water management practices in Uzbekistan.

Keywords: electricity consumption, monitoring system, operated stations, pumping station, smart device

INTRODUCTION

Global warming is negatively impacting water resources in Central Asia, leading to a decline in water availability and uneven distribution of precipitation over the past two decades (Aizebeokhai, 2009; Sorg *et al.*, 2012; Karthe, Chalov, and Borchardt, 2015). This trend has exacerbated water and energy shortages across the region, particularly in Uzbekistan (Li *et al.*, 2015). Concurrently, the population of Central Asia has surged from 51.2 mln to 78.7 mln over the past 30 years (a 53.7% increase), with Uzbekistan experiencing the most significant demographic growth, from 21.7 mln to 36.5 mln people (68%) (ICWC, 2024). This demographic increase necessitates a corresponding rise in water and energy resources. The region's primary water sources, the transboundary Amu Darya and Syr Darya rivers, have a long-term average annual flow of 116.4 bln m^3 (ICWC, 2024). Given this finite supply, per capita water availability is declining year by year, highlighting the urgent need for more efficient water use through advanced monitoring systems for water consumption in each country.

According to the International Institute for Sustainable Development, Uzbekistan annually consumes an average of 51–54 bln m^3 of water, approximately 90% of which is used in agriculture (Ministry of Ecology, Environmental Protection and

Climate Change of the Republic of Uzbekistan, 2023). This figure is derived from national water use statistics and reflects the central role of agriculture in the country's economy. There is, however, significant variation in water usage across different regions, depending on local agricultural practices and the type of crops cultivated. For over 30 y, the area of irrigated land in Uzbekistan has remained relatively stable at around 4.3 mln ha. This stability can be attributed to a combination of historical land allocation policies, limited availability of suitable land for expansion, and sustainable water management practices designed to prevent land degradation. Studies indicate that there is minimal scope for expanding irrigated areas without significant investments in infrastructure and changes in water allocation strategies (Ikramov *et al.*, 2021a).

Out of the total irrigated land, 2.3 mln ha rely on 1,693 irrigation pumping stations managed by the Ministry of Water Resources of Uzbekistan (Ikramov *et al.*, 2020). The distribution and density of these stations are critical factors affecting the efficiency of water delivery. Denser networks can ensure a more consistent water supply but also require more electricity and maintenance, particularly in areas with uneven terrain or where water must be lifted across multiple elevation levels. The cascading operation of pumping stations, which is often required to lift water to higher elevations, significantly impacts both the volume of water pumped and the electricity consumption. For instance, pumping stations operating in cascades can increase electricity consumption by 15–20% due to the additional energy required to overcome gravitational forces and maintain pressure in the system (Ikramov *et al.*, 2021b).

The annual operation of these pumping stations results in the pumping of approximately 52–56 bln m^3 of water, consuming 8–8.2 bln kWh of electricity, or roughly 11% of the total electricity generated in Uzbekistan. When compared to international benchmarks, Uzbekistan's energy consumption for irrigation is relatively high, primarily due to outdated equipment, lack of automation, and the need for energy-intensive water lifting in many regions. Efforts to improve energy efficiency have been limited but include pilot projects for equipment modernisation and the introduction of variable frequency drives (VFDs) to optimise pump operations (Ikramov *et al.*, 2019).

The Ministry of Water Resources is responsible for managing these pumping stations and has implemented various policies aimed at improving water use efficiency. These policies include guidelines for the modernisation of irrigation infrastructure, promotion of water-saving technologies, and training programs for operational personnel. However, the effectiveness of these policies is often limited by financial constraints, lack of technical expertise, and inadequate data for decision-making.

The primary data sources for water consumption and irrigation practices in Uzbekistan are national reports from the Ministry of Water Resources, scientific studies, and field surveys. However, there is a need for more precise and updated data collection methods, including the use of remote sensing and advanced telemetry systems, to better understand and manage water resources.

Given the current challenges, the main objectives of this study are to develop and implement an energy efficiency monitoring system for irrigation pumping stations in Uzbekistan. This involves the installation of smart devices to measure water flow and turbidity, monitor electricity consumption in real time, and develop a mobile photovoltaic installation to meet the energy needs of pumping stations.

MATERIALS AND METHODS

This study implemented several scientific and technical solutions to achieve its objectives, as detailed below.

Survey of pumping stations. A comprehensive survey was conducted on 29 large irrigation pumping stations strategically selected based on their economic and strategic importance in seven regions of Uzbekistan (Fig. 1).

The selection criteria included factors such as the volume of water pumped, energy consumption, and their role in regional agriculture. These stations were chosen to represent a diverse range of operating conditions and geographical locations, ensuring that the findings would be broadly applicable across different regions. The intelligent device for accounting water consumption was designed with several key considerations in mind, including accuracy, durability, and ease of integration with existing infrastructure. The device was subjected to a series of laboratory tests to assess its accuracy and reliability under various operating conditions before being implemented at the pumping stations.

Software development for energy efficiency monitoring. A specialised software application was developed for the online energy efficiency monitoring of pumping stations. The software features real-time data collection, analysis, and reporting capabilities and integrates seamlessly with a mobile application designed for use by water management workers and farmers. This mobile application provides users with up-to-date information on water consumption in machine canals supplied by pumping stations, along with alerts for potential issues. The application was developed with user-friendliness in mind, incorporating feedback from initial users to enhance its usability and functionality.

Mobile application features. The mobile application offers comprehensive data on water flow rates, energy consumption, and real-time alerts for maintenance needs. The app was designed to be intuitive, with a straightforward user interface that allows easy access to critical information. Feedback from users has been overwhelmingly positive, highlighting the app's ease of use and the value of having real-time data at their fingertips.

Installation of intelligent metering devices. Intelligent metering devices were installed at the 29 large irrigation pumping stations to measure the flow and turbidity of pumped water. These devices employ ultrasonic technology to measure water flow with an accuracy of ±1% and optical sensors to detect turbidity. The devices were calibrated using a standardised process to ensure reliable data, including periodic checks against known standards and *in situ* adjustments.

Photovoltaic system installation. The mobile photovoltaic systems were designed to address the energy needs of the pumping stations, considering factors such as solar irradiance, installation angle, and energy storage requirements. These systems are expected to reduce the overall energy consumption of the pumping stations by providing a renewable energy source for their operational needs. The design was optimised to balance cost, efficiency, and durability under local environmental conditions.

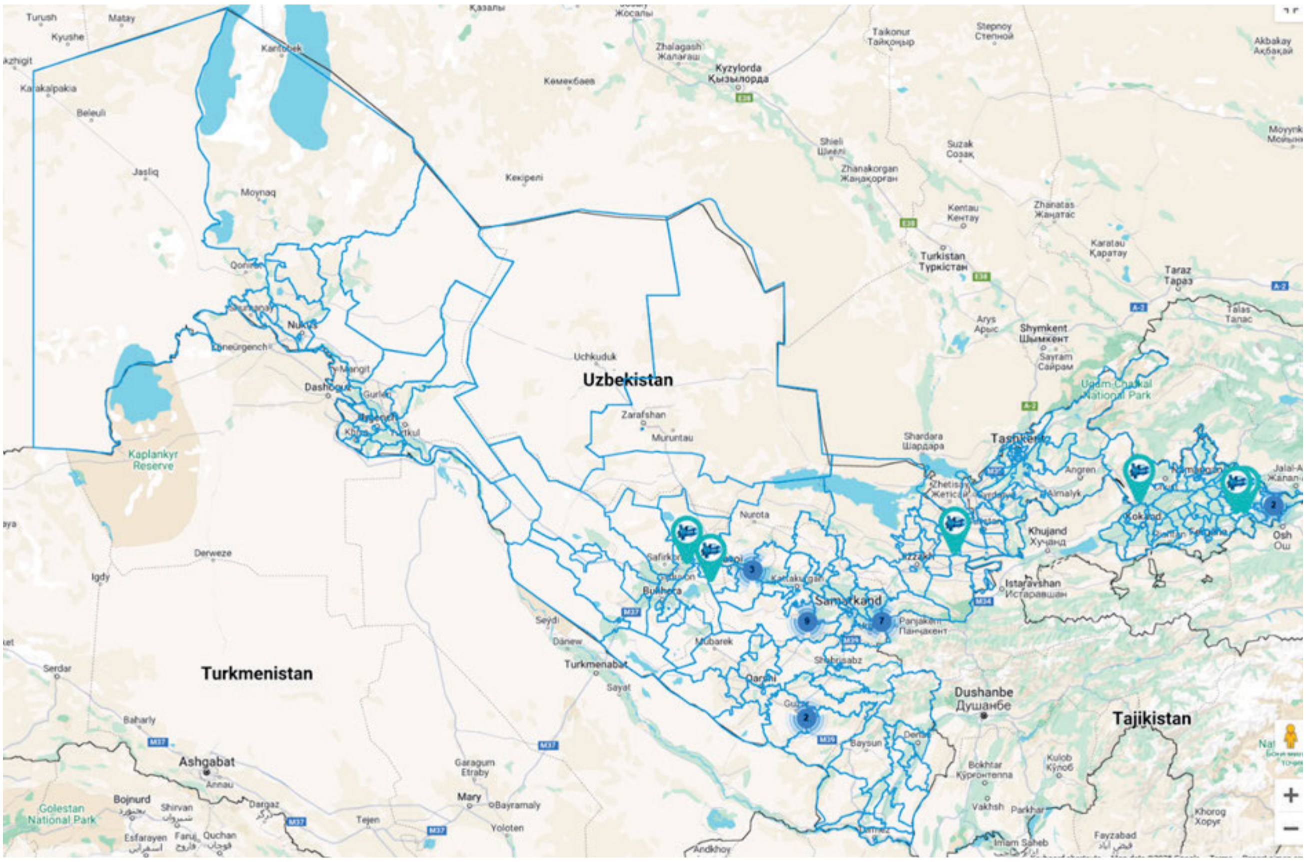


Fig. 1. Map of the location of the study area and the 29 pumping stations; source: own elaboration using Google Maps

Energy-efficient operating modes. Energy-efficient operating modes for the pumping stations were developed based on scientific principles, including hydraulic modelling and energy optimisation algorithms. These modes take into account regional variations in water demand and supply, ensuring their applicability across different areas and station types. The recommended operating modes were tested and validated in the field to ensure their effectiveness.

Geographical distribution of research. The study's findings are based on data from 29 pumping stations spread across seven regions, providing a broad geographical perspective. This distribution allows for the examination of regional variations in water management practices and energy consumption, thereby enhancing the generalisability of the results. Notable differences were observed in energy use efficiency and water delivery performance across regions, highlighting the need for region-specific strategies.

Strategic importance of pumping stations. The 29 selected pumping stations were identified based on their economic and strategic importance, which was determined by factors such as their contribution to regional agricultural productivity, water supply stability, and energy consumption levels. These criteria guided the prioritisation of stations for upgrades and implementation of the monitoring system.

Documentation and reporting. Throughout the study, a standardised process for documentation and reporting was maintained to ensure consistency and accuracy in data collection and analysis. This process included the use of structured data sheets, regular audits, and cross-verification to minimise errors and ensure the reliability of the results.

Technical challenges. Several technical challenges were encountered during the design, implementation, and testing phases, including issues related to device calibration, integration with existing infrastructure, and data transmission reliability. These challenges were addressed through iterative testing, stakeholder consultations, and technological adjustments. Key lessons learned include the importance of robust testing environments and the need for adaptive design approaches to accommodate varying field conditions.

Data analysis. The data collected from the intelligent metering devices and monitoring systems were analysed using a combination of statistical methods and analytical tools, such as regression analysis and time-series forecasting, to ensure the reliability and validity of the findings. Data quality was assessed continuously to identify and correct any anomalies or inconsistencies.

The implemented monitoring system was tested throughout the vegetation season, covering large pumping stations in regions such as Bukhara, Navoi, Surkhandarya, Jizzakh, Andijan, Namangan, and Fergana. The results from these stations have informed the gradual extension of the online monitoring system to other irrigation pumping stations across the country.

Based on the objectives of the research, the following tasks were set.

1. Development and implementation of the smart device for determining the water flow rate and its turbidity pumped by pumping stations.
2. Development software and its mobile application for the online system for monitoring the energy efficiency of pumping stations for water management workers and farmers to inform

about the water consumption supplied by pumping stations at the moment.
3. Installation of mobile photovoltaic systems developed by the research participants to meet the personal needs of each of the 29 large pumping stations.
4. Determination of scientifically based energy-efficient operating modes for each of the selected 29 pumping stations.
5. Implement the developed energy efficiency monitoring system at pumping stations.
6. Testing the implemented monitoring system during the operation of pumping stations in the vegetation season.

RESULTS AND DISCUSSION

SMART SYSTEM FOR MEASURING FLOW RATE AND WATER VOLUME IN PUMPING STATIONS

To address the critical challenges posed by declining water availability and rising energy demands in Uzbekistan, exacerbated by global warming and a growing population, we have developed a smart device that measures water flow rates in irrigation canals with high precision. This device, designed to improve water use efficiency, also transmits data online for extended periods, offering a reliable solution for optimising the performance of irrigation pumping stations (Ikramov *et al*., 2023). The proposed system integrates advanced components to ensure accurate monitoring and efficient resource management.

1. The MaxiBotix MB7580 ultrasonic range finder has been used as a sensitive element of a smart device (Photo 1). This meter has the ability to reduce the effects of condensation and freezing during continuous operation in a closed room or in a high-humidity environment, measures to the millimetre, detects short and long distances, and has a reading speed of 0.6 Hz. The output signal can be pulse width, analogue voltage, or transistor-transistor logic (TTL) series. In addition, this sensor has a compact and durable polyvinyl chloride (PVC) housing that meets the international protection (IP67) waterproof standard.
2. The integrated circuit MAX 485 converts the signal received from the meter based on the universal asynchronous receiver-transmitter (UART) protocol into the RS-485 protocol for the control controller. There are various options for the package of this microcircuit, and the choice of the most compact one for this project allows us to reduce the dimensions of the overall control unit (Flammini *et al*., 2002).
3. The LTC3105 converter is used as an uninterruptible power supply for continuous operation of the sensor as a charger for a solar battery (Bathre and Das, 2022; Hmamsy *et al*., 2022; Hoffart, 2023). A standard electrical circuit is proposed.
4. Mobile operators' services are used for remote transmission of the received information via the communication channel. Thus, the problem of reliable wireless reception of information over long distances is solved. To increase the reliability of communication, the subscriber identity module (SIM) 868 was used, which has the ability to connect to at least two companies (Nooruddin, Islam and Sharna, 2020). The SIM868 module is a full-fledged quad-band global system for mobile communications (GSM) / general packet radio service (GPRS) module, which also includes global navigation satellite system (GNSS) technology for satellite navigation. The compact design with leadless chip carrier (LCC) and land grid array (LGA) platforms saves a lot of time and money when developing GNSS-based applications.
5. Since some irrigation pumping stations in Uzbekistan are located far from residential areas, the signals of mobile operators in these areas are very weak or absent altogether. To solve this problem, long range (LoRa) technology was used, which provides continuous data exchange, albeit at a low speed (Sinha, Wei and Hwang, 2017; Kochhar and Kumar, 2019; Mroue *et al*., 2020).
6. The memory unit XTSD01G was used as a data storage device, it takes measurements offline and stores all data in its memory, prevents data loss when exchanging information with the server due to lack of communication. The advantage of the memory unit XTSD01G is its low cost, small size and sufficient reliability. The type of memory of this device with a capacity of 128 MB allows you to store long-term data.
7. The STM32L151RCT6 microcontroller is the preferred solution for combining all the elements and performing the control task (Fig. 2). This microcontroller is 32-bit and has 256 KB of flash memory. In addition, this microcontroller is efficient for battery life as it requires very little power.

It works completely independently of any power source as it contains a solar panel and a rechargeable battery. For the sensor to work correctly, you need to install it correctly and insert a SIM card that works with a 2G connection. The industrial sample of the device is shown in the Photo 2.

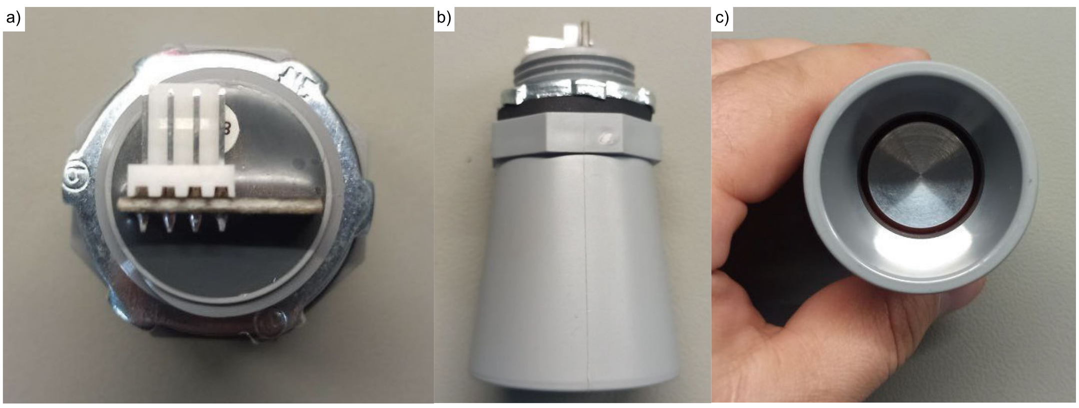


Photo 1. Ultrasonic rangefinder MB7580: a) top view, b) side view, c) bottom view (phot.: *N. Ikramov*)

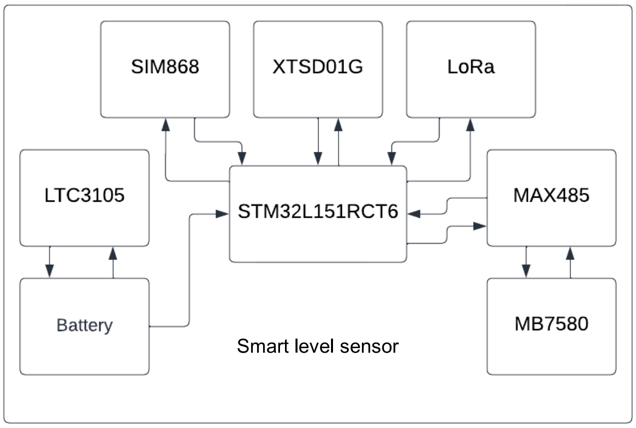


Fig. 2. Structure of the smart device for determining water flow; LoRa = long range; source: own elaboration

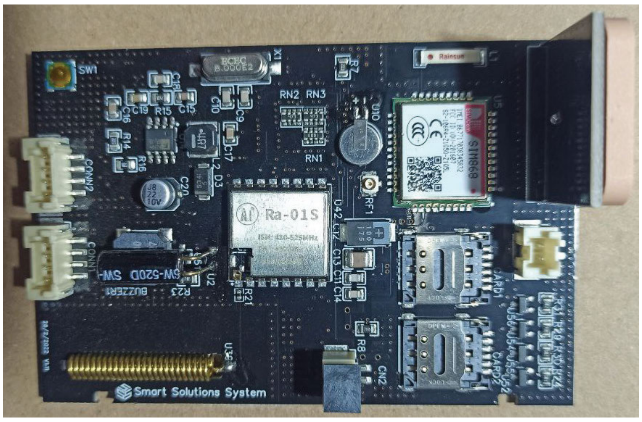


Photo 2. The industrial sample of the smart device for determining water flow (phot.: *N. Ikramov*)

8. The industrial sample of the smart device for determining water flow was created and successfully passed laboratory tests (Photo 3).
9. At the same time, according to the Law of the Republic of Uzbekistan "On Inventions, Utility Models, and Industrial Designs", the developed utility model of the water level control system was patented by the Ministry of Justice of the Republic of Uzbekistan, and copyright was protected by law (Ahmadjonov *et al.*, 2020b). For the operation of this smart device, a unique program was developed, for which a certificate was obtained from the Intellectual Property Agency under the Ministry of Justice of the Republic of Uzbekistan (Ahmadjonov *et al.*, 2020a). The smart device was tested and certified by the National Certification Centre of the Republic of Uzbekistan (Sertifikat, 2021), and permission was obtained for its mass production. At present, smart devices for determining water flow have been installed in more than 3,000 irrigation canals in the territory of Uzbekistan (Photo 4).

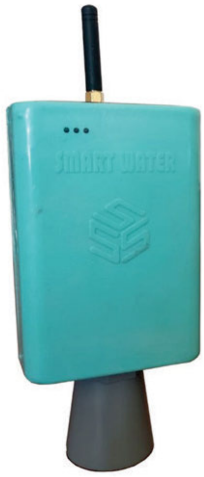


Photo 3. Industrial example of the smart device for determining water flow (phot.: *N. Ikramov*)

These devices have been operating for the last three years in real conditions with a given accuracy within their technical specifications. This, in turn, allows you to determine the parameters necessary to monitor pumping stations and evaluate their efficiency in real time. In addition, these devices from domestic manufacturers have advantages over their imported counterparts due to their low cost, the availability of customisation options, and their easy adaptation to difficult conditions. At the same time, all the problems identified during the operation of the devices are studied from a scientific and technical point of view.

The graphs below show the processes of intelligent filtering of noisy signals, in which the selection of the optimal filtering algorithm is performed automatically based on the program included in the smart device. The signal shown in blue in the

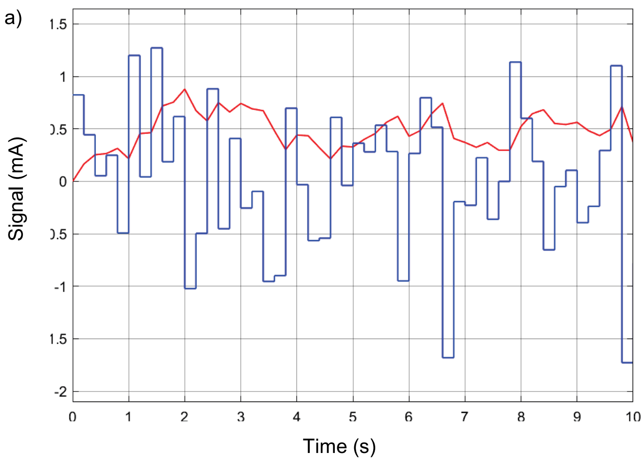
Photo 4. Smart devices for determining water flow installed on the irrigation canals (phot.: *N. Ikramov*)

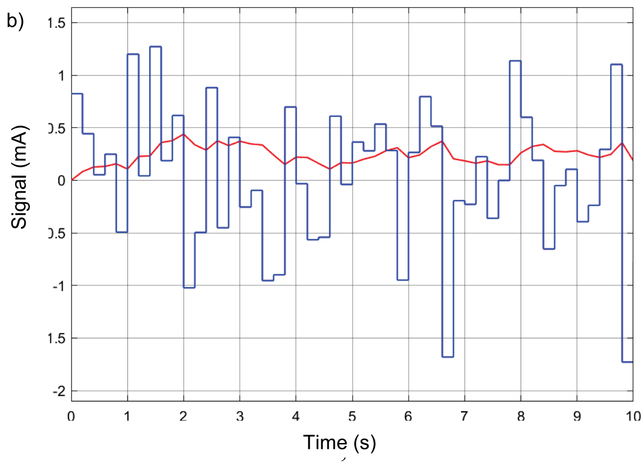
graphs represents the noise being generated. The red line shows the filtering result. Information is received by measuring five times per second. The received information is passed through various filtering algorithms. For this process, the device found the structure of three consecutive filtering blocks to be optimal, and the information filtering processes in it were carried out in the following order: Figure 3a – the signal obtained from the primary filtering unit, Figure 3b – the signal obtained from the secondary filtering unit, Figure 3c – the signal is received from the tertiary filtering unit.

The results show that the stabilisation of received signals is improved by 74.2% due to the use of intelligent filtering algorithms in a smart device. The reliability of information decreased by 8.2% in total.

usage, and turbidity levels of pumped water, enabling a comprehensive approach to managing energy efficiency.

The monitoring system integrates all key operational parameters of reclamation pumping stations managed by the Ministry of Water Resources of Uzbekistan. It is designed to receive, process, and transmit data on water flow rate, volume, turbidity, electricity consumption, and energy limits. Additionally, it tracks changes in these parameters over time and presents specific energy consumption curves, such as the electricity used to pump 1000 m^3 of water per meter of lifting height. By analysing these data, both the operational personnel and regional management of pumping stations can make informed decisions to optimise energy use, directly impacting the quality and efficiency of water delivery to agricultural consumers.





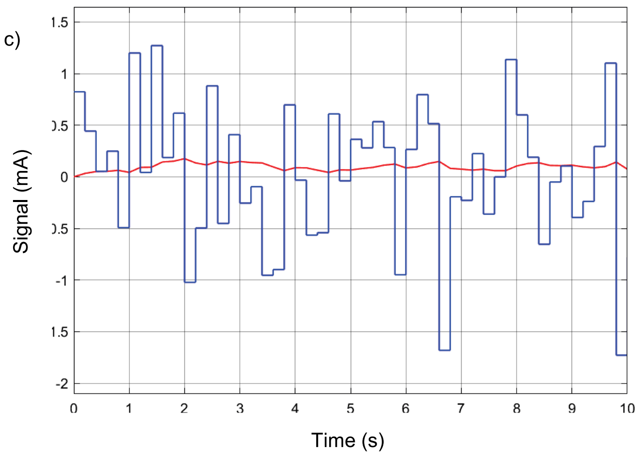


Fig. 3. Filtering result: a) primary, b) secondary, c) tertiary; source: own study

SOFTWARE AND MOBILE APPLICATION FOR ONLINE ENERGY EFFICIENCY MONITORING OF PUMPING STATIONS

Real-time energy and water efficiency monitoring in irrigation systems

In the arid landscapes of Uzbekistan, where water is a vital resource for agriculture, optimising the energy efficiency of irrigation pumping stations is crucial for sustainable farming. To address this need, an advanced monitoring system has been developed to track, analyse, and improve the energy efficiency of these stations across the country. This system provides real-time data on essential parameters such as water flow rate, electricity

Daily monitoring

The daily monitoring feature provides users with real-time data that allows for immediate detection and response to any irregularities or inefficiencies in pumping station operations. This daily data collection focuses on short-term adjustments and rapid decision-making to maintain optimal performance. The monitoring system employs smart devices installed at each pumping station, which continuously measure parameters such as water flow, electricity consumption, and turbidity levels. The data from these devices are sent to a centralised system that can be accessed remotely via desktops or mobile devices, offering crucial flexibility for operators, engineers, and decision-makers to monitor and manage operations without being physically present at the site.

Daily monitoring plays a critical role in energy efficiency by providing early warning signs of potential inefficiencies, such as unusual increases in electricity usage or drops in water flow rates. By addressing these issues promptly, operators can minimise energy wastage and reduce operational costs. The intuitive user interface of the monitoring system includes dashboards with colour-coded indicators, charts, and graphs that visualise trends and status, making it easier to identify and rectify any operational anomalies swiftly.

Monthly monitoring

Monthly monitoring aggregates daily data to provide a broader view of the pumping station's performance over time. This function is vital for identifying trends and patterns in water flow, electricity consumption, and water quality that may not be apparent through daily data alone. By examining these monthly trends, users can detect recurring inefficiencies or manage operational issues, such as consistent overuse of energy or fluctuating water quality, which could indicate equipment wear or environmental factors affecting the stations.

The monthly data analysis helps to refine energy efficiency strategies by highlighting periods of higher-than-average consumption or irregular water flow rates, allowing for targeted maintenance and operational adjustments. By understanding these longer-term trends, the monitoring system supports a proactive approach to energy management, ensuring that corrective actions are based on comprehensive data analysis rather than isolated incidents.

Annual monitoring

Annual monitoring offers a macroscopic view of the irrigation pumping stations' performance over an extended period. This long-term data analysis is crucial for assessing the overall effectiveness of energy efficiency measures and identifying areas where further improvements are needed. By comparing annual data, stakeholders can evaluate the impact of implemented strategies and make data-driven decisions for future enhancements in system design or operation.

The annual data also support strategic planning by providing insights into the performance of the pumping stations throughout different seasons and varying environmental conditions. This information is essential for developing sustainable agricultural practices and ensuring the long-term viability of water resources in Uzbekistan.

The monitoring system is capable of generating comprehensive reports in electronic and printed formats, summarising daily, monthly, and annual data. This feature ensures that all stakeholders, including farmers, engineers, and policymakers, have access to the necessary information to make informed decisions regarding energy efficiency and water management.

To ensure broad accessibility, especially for users in remote areas with limited internet access, the monitoring system is optimised for mobile devices. This mobile compatibility empowers farmers and station operators to receive real-time updates, access detailed reports, and make timely decisions directly from their fields, thereby enhancing their ability to manage energy use effectively and contribute to sustainable farming practices.

INSTALLATION OF MOBILE PHOTOVOLTAIC SYSTEMS FOR PUMPING STATIONS' ENERGY NEEDS

To address the energy needs of irrigation pumping stations, research participants developed mobile photovoltaic systems tailored to the specific requirements of each station. These systems help reduce the reliance on the main power grid, especially in cases of power outages, which can lead to operational disruptions and potential flooding due to a lack of power for auxiliary systems.

Each mobile photovoltaic system includes four 500 W solar panels, providing a total power output of 2000 W, and is equipped with four 200 Ah helium batteries, a 3 kW inverter, and an air-cooling system for optimal performance. The design includes a mobile platform, allowing the system to be easily moved around the pumping station's premises to optimise energy collection. Additionally, solar panels can be adjusted to various angles to maximise sunlight exposure throughout the day.

For each of the 29 pumping stations, one photovoltaic system was installed along with a submersible centrifugal pump designed for the drainage system. These pumps, powered by the photovoltaic system, operate automatically based on the water level in the drainage wells.

During the vegetation season, 75–80% of the generated electricity is used to power the submersible pumps, while the remainder is used for lighting. In the winter months, when the main pumping units are not in use, 72–77% of the generated electricity is allocated to lighting and other personal needs of the station personnel.

ENERGY-EFFICIENT OPERATING MODES FOR 29 PUMPING STATIONS

The energy-efficient mode of pumping station operation is understood as the mode of operation in which the power consumption (for the rotation of electric motors and pumps, for overcoming hydraulic resistances of pipelines, for the correct organisation of operation and repair), including for own needs, will be relatively minimal. The energy-efficient operation of pumping stations is influenced by design (type of pump and pumping station, design (shaped parts) of the pressure pipeline, the degree of opening of the gates, etc.) and operational (hydrology of the source and supply canals, the presence of floating debris, bottom and suspended sediments in the water, the technical condition of the pumping station node structures, the condition of the discharge canals, etc.) factors. The greatest changes in power consumption are observed at those pumping stations where several pumping units are connected in parallel to a common pressure pipeline.

Studies have shown that at large pumping stations "Amu-Bukhara-I" of the Bukhara Region and "Namangan" of the Namangan Region, with an increase in the number of parallel pumping units, the power consumption coming to one unit increases by 0.72–6.53%, and at pumping stations "Amu-Bukhara-2" of the Bukhara Region and "Amu-Zang-2" of Surkhandarya Region, on the contrary, decreases by 0.32–1.67% (Aizebeokhai, 2009). Based on design and technical, regulatory and cadastral data, as well as data from field surveys, the research team members have developed and recommended energy-efficient operating modes for all 29 large pumping stations for implementation. The effectiveness of the recommended regime has been proved by the monitoring system of pumping stations during the vegetative season. Comparative data have shown the main advantages and possible disadvantages of the implemented monitoring system, as well as improved operating modes of pumping stations.

IMPLEMENTATION OF THE DEVELOPED ENERGY EFFICIENCY MONITORING SYSTEM AT PUMPING STATIONS

The implementation of the monitoring system was carried out alternately from the moment the devices were installed at pumping stations. Signals from all installed smart devices at 29 large pumping stations were received and processed using a developed program. The information interaction scheme of the main components of the monitoring system for pumping stations of the Ministry of Water Resources (MWR) of the Republic of Uzbekistan is illustrated in Figure 4.

The implementation of the developed monitoring system has significantly reduced labour costs at various operational levels of pumping stations.

At the pumping stations:

- 100% on the removal of indicators of metering devices for electricity consumption, registration in logs, and transmission to the pumping station database (PSD), because these functions have been fully automated;
- 100% on the preparation of the document "Permission to change the limit", because the function has been fully automated;
- 100% on the compilation of daily, monthly and for any period reports on the consumed electricity.

In the pumping station database:

- 100% on the preparation of daily summary data on electricity consumed by the PSD and transmission to the Central Office of the Ministry of Water Resources (CO MWR), because the function has been fully automated;
- 100% on the compilation of summary reports of daily, monthly and for any period on the electricity consumed;
- by 80% for setting the task to turn on/off the pumping units.

In the CO MWR:

- 100% on the compilation of summary reports of daily, monthly and for any period on the electricity consumed;
- by 80% for the installation to allow the change of the electricity limit.

In addition, the installation of water flow metering devices makes it possible to receive real-time information about the flow rate of pumped water by pumping stations, taking into account the flow turbidity, promptly responding to and adjusting their operation.

TESTING THE IMPLEMENTED MONITORING SYSTEM DURING THE OPERATION OF PUMPING STATIONS IN THE VEGETATION SEASON

In addition to some large irrigation pumping stations operated year-round, such as Amu-Zang-1, Amu-Zang-2, Jizzakh Head Pumping Station (Uz.: Jizzax bosh nasos stansiyasi) and others, most pumping stations are operated mainly during the growing season. Therefore, tests of the monitoring system were carried out during the growing season with simultaneous operation of all pumping stations. The monitoring was carried out by specialists from the research group and the Pumping Stations Department of the Ministry of Water Resources. Operation monitoring of each pumping station was carried out in the usual operating modes used by the service personnel.

The implementation of the monitoring system has provided the following advantages:

- eliminated discrepancies in data on the water flow rate in canals between the data of pumping stations and local irrigation system administrations, since before the implementation of the system, each organisation determined the water flow rate in canals independently and there were always disagreements between them in its quantity;
- made it possible for all interested parties to receive information about the flow rate, volume and turbidity of pumped water by pumping stations online;

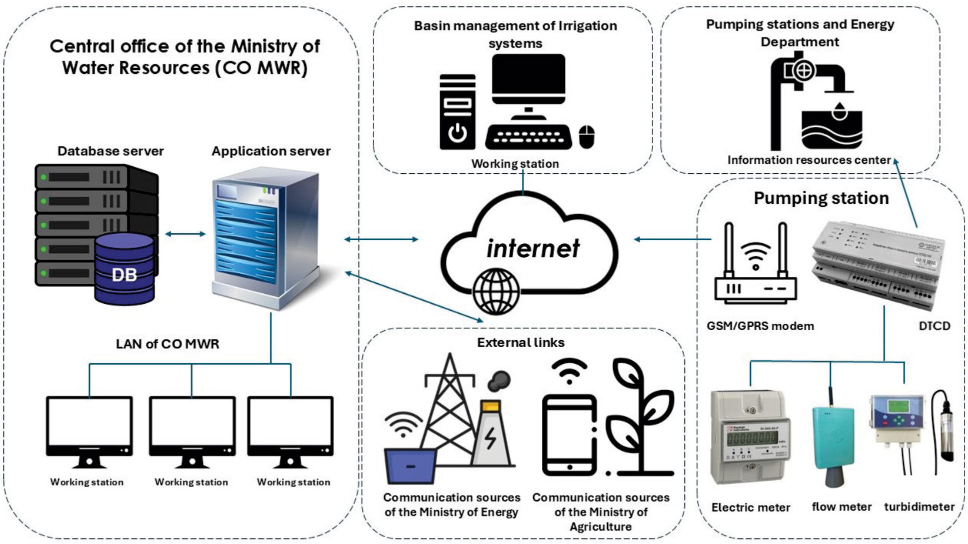


Fig. 4. The scheme of information interaction of the system main components; LAN = local area network, DTCD = data transmission and control device, GSM/GPRS modem = modem supporting protocols of global system for mobile communications / general packet radio service; source: own elaboration

- reduced the routine work of the pumping station's operating personnel on taking meter readings, calculating data, preparing and transmitting reporting data;
- increased the reliability and efficiency of decision-making on the management of pumping stations;
- eliminated unplanned switching on of pumping units;
- increased the reliability and timeliness of water supply to consumers;
- reduced annual electricity consumption by pumping stations by an average of 2.1%;
- made it possible to analyse the energy efficiency level of each operated pumping station.

The monitoring system is aimed at covering all 1,693 pumping stations that are on the balance sheet of the Ministry of Water Resources. In the future, as measuring instruments are installed at pumping stations and installations owned by water user societies, clusters and farmers, they can also be connected to the developed system.

CONCLUSIONS

The scientifically experimental studies conducted have led to several significant findings:

The smart device for determining water flow rate was specifically designed to function effectively in harsh continental climates, including both extremely hot and cold conditions. To ensure its reliability, the device was equipped with high-precision sensors, features for remote data transmission, and an in-memory archive system that stores data when transmission is not possible due to external conditions. This design helps prevent data loss and ensures continuous operation despite climatic challenges.

The industrial prototype of the smart device underwent rigorous testing and certification under both laboratory and field conditions at the national certification centre of the Republic of Uzbekistan. The successful certification process led to approval for mass production, ensuring that the device meets national standards for performance and reliability.

By producing the smart device domestically, the cost was reduced by 42.7% compared to imported alternatives. This cost reduction makes the technology more accessible and affordable for widespread adoption across Uzbekistan's irrigation network.

A significant scientific innovation of this study is the development of an intelligent filter algorithm for processing data measured by the smart device. This algorithm improves the stabilisation of received signals by 74.2% and reduces the information reliability error by 8.2%, which is below the target error rate of 9.5%. This enhancement ensures more accurate and reliable water flow measurements.

The developed monitoring system, along with its mobile application, provides real-time information on water flow rates, volume, turbidity, and energy consumption. This information is accessible to water management workers, farmers, and other stakeholders, facilitating better decision-making and more efficient water resource management.

The automation of data collection and transmission through the monitoring system reduced the labour costs associated with maintenance tasks by 14%. This reduction was quantified by analysing the time saved on activities such as taking meter readings, logging data, and transferring information to relevant departments. Consequently, the overall operating costs of irrigation pumping stations in Uzbekistan decreased by 9.8%, while the reliability of water supply to irrigated lands improved.

The installed mobile photovoltaic systems at the pumping stations demonstrated considerable energy savings. During the growing season, 75–80% of the electricity generated was used for submersible pumps, while 20–25% was used for lighting the pumping station buildings at night. In the non-growing season, when the main pumping units were off, 72–77% of the electricity output was allocated for lighting and the personal needs of maintenance personnel. This indicates that the photovoltaic systems significantly offset the electricity consumption from the grid.

The implementation of the monitoring system resulted in a reduction of the annual electricity consumption of pumping stations by an average of 2.1%. This improvement demonstrates the potential for energy efficiency gains through better monitoring and management practices.

The study concludes that the introduction of intelligent devices and systems for monitoring water flow and energy consumption in irrigation pumping stations has significantly enhanced operational efficiency, reduced costs, and improved water management in Uzbekistan. These results are highly relevant for other regions or countries facing similar irrigation challenges, particularly those with harsh climatic conditions. However, local factors such as climate, infrastructure, and economic conditions would need to be considered when adapting these solutions to different contexts.

The next steps will involve scaling up the deployment of the monitoring system across all pumping stations in Uzbekistan and exploring further enhancements to the smart device's capabilities, such as integrating more advanced sensors and predictive analytics for proactive water management.

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CONFLICT OF INTERESTS

The authors declare that they have no conflicts of interest.

REFERENCES

Ahmadjonov, V.M. *et al.* (2020a) *Suv satxini nazorat qilish tizimi [Water level control system]*. O'zbekiston Respublikasi Adliya Vazirligi. Patent specification FAP 01982. Appl. no. FAP 2020 0325. Date of filing 22.12.2020. Date of publ. 25.05.2022. Available at: https://my.ima.uz/cert-v1/default/check-patent?check_id=93dc1c3663571cec888c5d4f76661fa3 (Accessed: February 03, 2025).

Ahmadjonov, V.M. *et al.* (2020b) *Guvohnoma elektron hisoblash mashinalari uchun yaratilgan dasturning rasmiy ro'yxatdan o'tkazilganligi to'g'risidagi "Smart Water" [Certificate of official registration of the computer program "Smart Water"]*. Toshkent: O'zbekiston respublikasi adliya vazirligi huzuridagi intellektual mulk agentligi, DGU 10262. Available at: https://im.adliya.uz/register/PROGRAM (Accessed: February 03, 2025).

Aizebeokhai, A.P. (2009) "Global warming and climate change: Realities, uncertainties and measures," *International Journal of Physical Sciences*, 4(13), pp. 868–879.

Bathre, M. and Das, P.K. (2022) "Water supply monitoring system with self-powered LoRa based wireless sensor system powered by solar and hydroelectric energy harvester," *Computer Standards & Interfaces*, 82, 103630. Available at: https://doi.org/10.1016/j.csi.2022.103630.

Flammini, A. *et al.* (2002) "Sensor interfaces: From field-bus to Ethernet and Internet," *Sensors and Actuators A: Physical*, 101(1–2), pp. 194–202. Available at: https://doi.org/10.1016/s0924-4247(02)00201-7.

Hmamsy, Y.E. *et al.* (2022) "Optimized piezoelectric energy harvesting circuit using DC/DC converter," *Materials Today: Proceedings*, 66, pp. 473–478. Available at: https://doi.org/10.1016/j.matpr.2022.07.219.

Hoffart, F. (2015) "Tiny 2-cell solar panel charges batteries in compact, off-grid devices," in B. Dobkin and J. Hamburger (eds.) *Analog Circuit Design*. Amsterdam: Elsevier, pp. 477–478. Available at: https://doi.org/10.1016/B978-0-12-800001-4.00225-8 (Accessed: February 03, 2025).

ICWC (2024) *Bulletin*, 1(100). Tashkent: The Interstate Commission for Water Coordination. Available at: http://www.icwc-aral.uz/content/100_en.htm (Accessed: May 22, 2024).

Ikramov, N. *et al.* (2019) "Effect of parallel connection of pumping units on operating costs of pumping station," *E3S Web of Conferences*, 97, 05014. Available at: https://doi.org/10.1051/e3sconf/20199705014.

Ikramov, N. *et al.* (2020) "Monitoring system for electricity consumption at pumping stations," *IOP Conference Series: Materials Science and Engineering*, 883(1), 012101. Available at: https://doi.org/10.1088/1757-899x/883/1/012101.

Ikramov, N. *et al.* (2021a) "Hydro-abrasive wear reduction of irrigation pumping units," *E3S Web of Conferences*, 264, 03019. Available at: https://doi.org/10.1051/e3sconf/202126403019.

Ikramov, N. *et al.* (2021b) "The height of the pumping unit suction pipe inlet relative to the riverbed bottom," *IOP Conference Series: Materials Science and Engineering*, 1030(1), 012125. Available at: https://doi.org/10.1088/1757-899x/1030/1/012125.

Ikramov, N. *et al.* (2023) "Intelligent device for measuring water level in irrigation channels of constant section," *E3S Web of Conferences*, 401, 01012. Available at: https://doi.org/10.1051/e3sconf/202340101012.

Karthe, D., Chalov, S. and Borchardt, D. (2015) "Water resources and their management in central Asia in the early twenty first century: Status, challenges and future prospects," *Environmental Earth Sciences*, 73(2), pp. 487–499. Available at: https://doi.org/10.1007/s12665-014-3789-1.

Kochhar, A. and Kumar, N. (2019) "Wireless sensor networks for greenhouses: An end-to-end review," *Computers and Electronics in Agriculture*, 163, 104877. Available at: https://doi.org/10.1016/j.compag.2019.104877.

Li, Z. *et al.* (2015) "Potential impacts of climate change on vegetation dynamics in Central Asia," *Journal of Geophysical Research: Atmospheres*, 120(24), pp. 12345–12356. Available at: https://doi.org/10.1002/2015jd023618.

Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan (2023) *National state of the environment report: Uzbekistan*. Tashkent: International Institute for Sustainable Development. Available at: https://www.iisd.org/system/files/2024-02/uzbekistan-state-of-the-environment-en.pdf (Accessed: May 22, 2024).

Mroue, H. *et al.* (2020) "LoRa+: An extension of LoRaWAN protocol to reduce infrastructure costs by improving the Quality of Service," *Internet of Things*, 9, 100176. Available at: https://doi.org/10.1016/j.iot.2020.100176.

Nooruddin, S., Islam, Md.M. and Sharna, F.A. (2020) "An IoT based device-type invariant fall detection system," *Internet of Things*, 9, 100130. Available at: https://doi.org/10.1016/j.iot.2019.100130.

Sertifikat (2021) *Sertifikat utverzhdeniya tipa sredstv izmereniy №O'T 0000577, Ts 29243261-01:2021: Urovnemery ul'trazvukovyye "Smart-Water" [Type approval certificate of measuring instruments №O'T 0000577, Ts 29243261-01:2021: Ultrasonic level gauges "Smart-Water"]*. Tashkent: Uzbekskoye agentstvo standartizatsii, metrologii i sertifikatsii (Agentstvo "Uzstandart"). Available at: http://sert2.standart.uz/ (Accessed: February 03, 2025).

Sinha, R.S., Wei, Y. and Hwang, S.-H. (2017) "A survey on LPWA technology: LoRa and NB-IoT," *ICT Express*, 3(1), pp. 14–21. Available at: https://doi.org/10.1016/j.icte.2017.03.004.

Sorg A. *et al.* (2012) "Climate change impacts on glaciers and runoff in Tien Shan (Central Asia)," *Nature Climate Change*, 2, pp. 725–731. Available at: https://doi.org/10.1038/nclimate1592.