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WATER SUPPLY EFFICIENCY: METHODS FOR DETERMINING AND PREVENTING WATER LOSSES

СУМЕН ЖАБДЫҚТАУДЫҢ ТИІМДІЛІГІ: СУДЫҢ ШЫҒЫНДАРЫН АНЫҚТАУ ЖӘНЕ АЛДЫН АЛУ ӘДІСТЕРІ

ЭФФЕКТИВНОСТЬ ВОДОСНАБЖЕНИЯ: МЕТОДЫ ОБНАРУЖЕНИЯ И ПРЕДОТВРАЩЕНИЯ ПОТЕРЬ ВОДЫ

Abstract. *The article is devoted to the actual problem of water losses in water supply systems and methods of their detection and prevention. Various approaches to reducing losses, including technical and managerial aspects, are analyzed. Attention is paid to innovative technologies, such as intelligent sensors and remote monitoring systems, which make it possible to quickly detect leaks and optimize the allocation of water resources. The article proposes an integrated approach to water supply management aimed at improving its efficiency and sustainability.*

Keywords: *water supply, water losses, reduction, information technology, strategy, modernization, reconstruction, construction.*

Аңдатпа. *Мақала сумен жабдықтау жүйелеріндегі судың жоғалуының өзекті мәселесіне және оларды аңықтау мен алдын алу әдістеріне арналған. Шығындарды азайтудың әртүрлі тәсілдері, соның ішінде техникалық және басқару аспектілері талданады. Ағып кетуді тез аңықтауға және су ресурстарын бөлуді оңтайландыруға мүмкіндік беретін ақылды датчиктер мен қашықтықтан бақылау жүйелері сияқты инновациялық технологияларға назар аударылады. Мақала суды басқарудың тиімділігі мен тұрақтылығын арттыруға бағытталған кешенді тәсілді ұсынады.*

Түйін сөздер: *сумен жабдықтау, суды жоғалту, қысқарту, ақпараттық технологиялар, стратегия, жаңғырту, қайта құру, құрылыс.*

Аннотация. *Статья посвящена актуальной проблеме потерь воды в системах водоснабжения и методам их обнаружения и предотвращения. Анализируются различные подходы к уменьшению потерь, включая технические и управленческие аспекты. Внимание уделяется инновационным технологиям, таким как интеллектуальные датчики и системы дистанционного мониторинга, которые позволяют оперативно выявлять утечки и оптимизировать распределение водных ресурсов. Статья предлагает комплексный подход к управлению водоснабжением, направленный на повышение его эффективности и устойчивости.*

Ключевые слова: *водоснабжение, потери воды, сокращение, информационные технологии, стратегия, модернизация, реконструкция, строительство.*

Introduction. Water is a vital resource for sustaining life and infrastructure of any locality. An efficient water supply provides not only for the daily needs of the population, but also supports economic activity, health and social wellbeing. With urbanization and population growth, the reliability of water supply systems is becoming critical. Every year, the pressure of infrastructure increases, requiring not only the expansion of networks, but also the improvement of their efficiency. One of the key aspects of efficiency is minimizing water losses that can occur at various stages of water delivery from source to consumer. However, many urban systems face the problem of water loss, with significant financial and environmental consequences. Water losses in urban networks are not only a lost opportunity for municipalities, but also a threat to the sustainability of water resources. In the context of climate change and the increasing frequency of dry periods, conserving every drop becomes a priority for water security.

Detecting water losses is the first step to preventing them. Modern methods include the use of pressure transducers, acoustic sensors and remote monitoring systems, which allow for the rapid detection of leaks. Analyzing data from these devices helps to determine not only the location but also the possible causes of the problem.

Researchers at Indraprastha University (Indonesia) in their study (Harry Dhika, Achmad Daengs GS & Erlin Windia Ambarsari, 2018) note that water leaks in pipelines are a serious problem, as they cause financial losses for both the water supplier and customers. To further investigate this problem, the researchers analysed the monthly water losses over the course of a year. Prediction was done using ANFIS method and then the results were verified using back propagation method to assess the accuracy of the data. The results showed that the main cause of leakage was due to visible damages such as pipe cracks caused by complex soil composition (31.8% of losses with an error rate of 1%). Efforts are being made to replace leaking pipes and further research is being conducted on the materials used to manufacture the pipes, taking into account the specifics of the area where they are laid.

The paper (Ishido & Takahashi, 2014) notes the importance of early diagnosis and detection of pipeline leaks, as leaks can cause significant damage to the surrounding infrastructure.

Pipes that carry water are underground, thus, it is not easy to determine the exact location of a leak in the pipe wall. Without any preventative methods, leaks are usually detected whenever water comes out from underground in the event of a significant pipe rupture. Acoustic leak detection methods are a preventative approach. A qualified technician scans the suspected location, and the appearance of an unexpected sound indicates the presence of a leak. However, the accuracy and speed of the process depends solely on the skill of the expert (Hunaidi, 2000). A comprehensive review of leak detection methods is explored in (Liu & Kleiner, 2013), where the authors review new technologies for perform- ing water pipe condition assessments.

Preventing water loss requires a comprehensive approach that includes regular maintenance, modernization of outdated systems and the use of innovative materials and technologies. Network pressure management programs, for example, can significantly reduce the risk of bursts and leaks. In addition, staff training and public awareness-raising play an important role in timely detection and remediation. Outdated water supply systems in settlements pose a serious challenge to the provision of reliable water supply. Ageing infrastructure leads to an increased risk of accidents, leaks and consequent water losses. These systems are often built with materials that corrode and deteriorate over time, exacerbating the problem.

The technical decay of these systems not only increases the operational costs of maintenance and repair, but also reduces the quality of water delivered to consumers. Burst pipes can lead to water contamination, endangering public health. In addition, frequent the normal course of city life.

Modernization is a key solution to the problems of outdated systems. Replacing old pipes with new ones made of more durable and corrosion-resistant materials can significantly reduce the number of leaks and accidents. Introduction of modern monitoring and diagnostics technologies allows not only to detect problems in time, but also to prevent their occurrence.

Investing in the renewal of the water supply network is an investment in the future. Properly planned and executed modernization works can significantly reduce operating costs, improve the quality of water supply and improve the living standards of the population. It is also important to consider sustainability and environmental aspects when selecting materials and technologies for system upgrades.

The problem of outdated water supply network requires immediate attention and action. Joint ef- forts of the government, local authorities, professionals and the public can lead to more reliable, efficient and environmentally friendly water supply systems.

Water loss detection and prevention is an integral part of sustainable water resources management and requires active implementation of new technologies and methodologies, as well as cooperation between different levels of government and society. This will not only reduce water losses, but also ensure its availability for future generations.

This article is devoted to methods of detection and prevention of water losses in urban water supply systems. We will review existing technologies and strategies, and explore how innovation can improve the efficiency and reliability of water supply. Special attention will be paid not only to technical as- pects, but also to managerial, legislative and social factors that play a key role in addressing the prob- lem.

Materials and methods. Scope of the problem. Expert estimate that, on average, 20 to 30 percent of water is lost in urban systems due to leakage and unauthorized use (https://mk-kz.kz/economics/2022/07/14/poslednie-dvadcat-let-kazakhstan-pri/). In some cases, this figure can be as high as 50 percent. This means that a significant portion of water that should be used for domestic and industrial needs is lost before it reaches the end user (https://bizmedia.kz/2024-06-05-rk-teryaet-13-vody-ona- ne-dohodit-do-polej/).

Causes of losses. The main causes of water losses are:

- outdated infrastructure: many urban water supply networks were built decades ago and have not been updated since then;
- inadequate maintenance: lack of regular maintenance and monitoring of the networks leads to leaks;
- uncontrolled use: illegal connections to the network and water theft also contribute to losses (Kosygin, Khanin, Gosudarev & Fomina, 2010).

Consequences of losses. Water losses in urban systems lead to a number of negative consequences:

- economic losses: cities lose significant amounts of money due to the need for additional water treatment and pumping;
- environmental damage: leaks can lead to environmental pollution and depletion of water re- sources;
- social problems: water scarcity can exacerbate social inequalities, as the poor are more likely to suffer from water scarcity (Sakanov & Kaskirbaev, 2010).

In the Republic of Kazakhstan, as in many other countries, the problem of water losses in urban systems remains relevant. Only 9 regions in the country are 100% supplied with water (Stepancova, 2017). Water losses in cities of Kazakhstan vary depending on the state of infrastructure and efficiency of water supply systems. For example, in Almaty, water losses can reach up to 25%, while in Astana

this figure can be about 20%. In smaller cities, where water supply systems are older and less efficient, losses can be even higher.

Kazakhstan losses billions of cubic meters of water every year. The Ministry of Water

Resources and Irrigation (MWR&I) reported that in 2023, losses in transporting this resource totalled 3.37 billion cubic meters. of these, agriculture accounted for the largest share at 2.61 billion cubic meters/ In 2022, losses amounted to 3.4 billion cubic meters (in agriculture – 2.69 billion cubic meters).

At the same time, "Kazvodkhoz", which is the largest subject of natural monopolies and a structural subdivision of the Ministry, provides services on supply of about 11 billion cubic meters of resource through channels annually (6-6.5 billion cubic meters – for irrigation). Regulatory and technical losses from intake to sale to the end consumer are about 20%. There are also losses during transport, costs for filling and maintaining the working water horizon. In addition, during reconstruction and repair and rehabilitation works, bypass canals are constructed at some sections. Since they are temporary, there are unaccounted losses (https://www.lada.kz/kazakhstan-news/).

Most of the canals were put into operation in the 1950's. Due to this, their technical condition becomes unsatisfactory and leads to a decrease in the coefficient of performance (COP). Now, 77 per cent of facilities have low efficiency. Only to maintain the design indicators it is necessary to carry out annual current repairs, and capital repairs – once in 8-10 years.

Since gaining independence, Kazakhstan has not initiated a comprehensive overhaul of its irrigation systems. Repairs have only been made to the most urgent sections, which has not effectively reduced water loss. Currently, there are no areas from the main intake structure to the consumer that have undergone significant rehabilitation.

In 2023, state authorities received approximately 43,500 official complaints from the public concerning water supply issues. Many of these complaints highlight severe deterioration of the networks and frequent breakdowns. For example, a local emergency was declared last year due to the extensive wear of the Nura group water pipeline in the Akmola region. Additionally, in Atyrau, the project to modernize the pumping and filtering station, which is about 90% worn out, has experienced delays (https://kz.kursiv.media/2024-06-13/print1038-water/).

Last year, leakage and unaccounted water consumption amounted to 218 million cubic meters, and the total amount of losses due to deterioration of water supply networks reached T16billion. In terms of regions, Almaty was the leader in terms of leakage and unaccounted water consumption in 2023 – 33% (i.e. one third of water supplied to the network, more than 74 million cubic meters or over T4 billion). In Akmola region water losses amounted to 20%, in Zhambyl, Aktobe and Kostanay regions, as well as in the cities of Astana and Shymkent - from 13 to 16% (https://stat.gov.kz/ru/). The level of wear and tear of utility networks (water supply and sewerage) at the end of 2023 was 57%. At the same time, the level of their renewal is low and annually averages a little more than 5%. This is a huge standardized water losses.

Main canals have exhausted their resources, physical deterioration of some of them is 100%. It is necessary to carry out a full-fledged accounting to clarify the number and technical condition of water management facilities and structures. Since the independence of the Republic of Kazakhstan, full-scale passportization of water management facilities and structures has not been carried out.

In 2021, water withdrawal for economic and population needs was 24.6 km^3, dropping slightly to 24.5 km^3 in 2022, and increasing to 24.9 km^3 in 2023 (The concept of development of the water resources management system of the Republic of Kazakhstan for 2024-2030). While this trend is relatively stable, an increase is anticipated due to rapid development in the oil and gas sector in Western Kazakhstan and the mining sector in Central Kazakhstan.

The issue of groundwater utilization is pressing. As of 2023, there are 4,416 deposits (5,384 sites) with approved exploitable groundwater reserves totaling 43,120.56 thousand m^3/day across the country.

Table 1. Indicators of water withdrawals and losses in agriculture, industry and municipal sector

Economic sectors	Years, abstraction and loss rates, (km^3)							
	2010-2020		2021		2022		2023	
	fence	losses	fence	losses	fence	losses	fence	losses
Utilities sector	0,94	0,18	0,95	0,15	1,0	0,17	1,3	0,2
Agriculture	15,17	2,94	15,5	3,1	14,7	3,0	14,2	2,7
Industry	5,59	0,189	5,8	0,15	5,9	0,2	5,9	0,2
Others	3,16	0,34	2,35	0,3	2,9	0,3	3,5	0,3
Total:	24,86	3,63	24,6	3,7	24,5	3,67	24,9	3,4
Note – compiled by the authors								

The issue of groundwater utilization is pressing. As of 2023, there are 4,416 deposits (5,384 sites) with approved exploitable groundwater reserves totaling 43,120.56 thousand m^3/day across the country (https://exclusive.kz/grozit-li-kazahstanu-deficzit-vody/):

A – 13428,23 thousand m^3/day;

B – 13481,26 thousand m^3/day;

C1 – 10675,31 thousand m^3/d;

C2 – 5535,75 thousand m^3/d.

Forecast reserves are about 40 km^3/year.

Methods of water loss detection. Water loss in municipal water supply systems is a serious problem that requires effective detection and remediation methods. There are various technologies and approaches to locate leaks and estimate the amount of water lost.

1. Acoustic methods.

One of the most common methods of leak detection is the use of acoustic technologies. Specialized devices such as hydrophones and correlators can detect the sounds produced by water flowing out of pressurised pipes (Kosygin, Khanin, Gosudarev & Fomina, 2010). These devices can be used for both spot inspection and monitoring over large sections of the network.

Water leaking directly from the point of a leak generates sounds that travel through the ground to the surface. Acoustic leak detectors capture these sounds using a ground microphone and display the intensity and frequency spectrum either graphically or digitally.

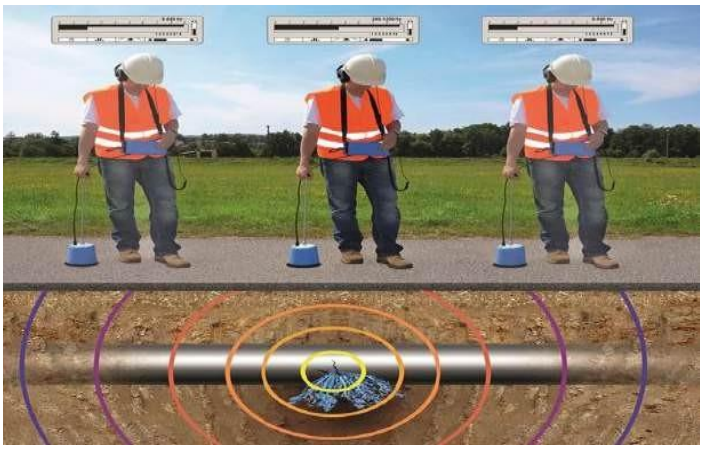

Figure 1. Method of acoustic leak detection in water pipes

Note – compiled by the authors based on photos from the Internet (https://yandex.kz/images/search?from=tabbar&img_)

2. Ground Penetrating Radar

Ground penetrating radar (GPR) is a portable technology that uses short electromagnetic pulses to investigate a land area. It can penetrate the ground and rock to depths of 15-20 meters, providing visual indications of rock layers and hidden objects.

Acoustic leak detector A10 Correlation leak detector K10-3M

Figure 2. Devices for detecting damage on water mains

Note – compiled by the authors based on photos from the Internet (https://ekb.ruskransnab.ru/sites/default/files/Articles/termo-akusticheskiy-techeiskatel-10t-19336.jpg, https://image.jimcdn.com/app/cms/image/transf/dimension=970x10000:format=jpg/path/sbe025e17a3cd8012/image/i37fab05d711d6dfb/version/1391377054/image.jpg)

Figure 3. Portable GPR for water leak detection

Note – compiled by the authors based on photos from the Internet (https://avatars.mds.yan- dex.net/i?id=88a3219d08d2919438dd5ff2004ec03b_l-5299402-images-thumbs&n=13)

In damp areas, there is a noticeable increase in relative dielectric permittivity, which is clearly displayed on the radar image (Timoshkin, 2001) This method enables reliable leak detection even when the precise location of the pipeline is unknown, thanks to GPR's high efficiency in surveying large areas quickly.

3. Gas tracers.

This method entails injecting a harmless gas into the water mains, which can be easily detected using specialized detectors. If a leak occurs, the gas escapes from the system and can be identified above ground, indicating the location of the issue. Although this approach has some limitations and may not be the most convenient, it is highly accurate and can detect smaller leaks more effectively than other methods for locating hidden leaks.

4. Hydraulic monitoring.

Hydraulic monitoring systems analyze the pressure and flow of water at various points in the water supply system. Anomalies in this data may indicate the presence of leaks.

Figure 4. Water leak detection device using indicator gas

Note – compiled by the authors based on photos from the Internet (https://a3-ng.com/assets/cache_image/products/2271/untitled3016_0x0_d34.webp)

5. Intelligent monitoring systems.

Results. With advancements in technology, intelligent systems are now being developed that lever- age machine learning algorithms to analyze water consumption data and detect unusual patterns that could signify losses. This equipment offers round-the-clock remote access to data. Additionally, wire- less telemetry systems and data services are being designed specifically for remote monitoring, includ- ing long-term observations of underground water pipes.

Loss Prevention Strategies and Technologies. In the Republic of Kazakhstan, as in many other countries, addressing water losses is an urgent issue that requires immediate action. Water losses in supply systems not only drive up operational costs but also have detrimental effects on environmental sustainability and social welfare (Kublanovskyii, 2019). As illustrated in Figure 5, there were 1,900 incidents in the water supply system in 2021. Over 19,000 kilometers of networks need to be replaced, accounting for 22% of the total length. This includes 6,200 kilometers of water conduits, 9,700 kilometers of street networks, and 3,500 kilometers of intra-block and intra-courtyard networks (https://forbes.kz/news/newsid_290908/).

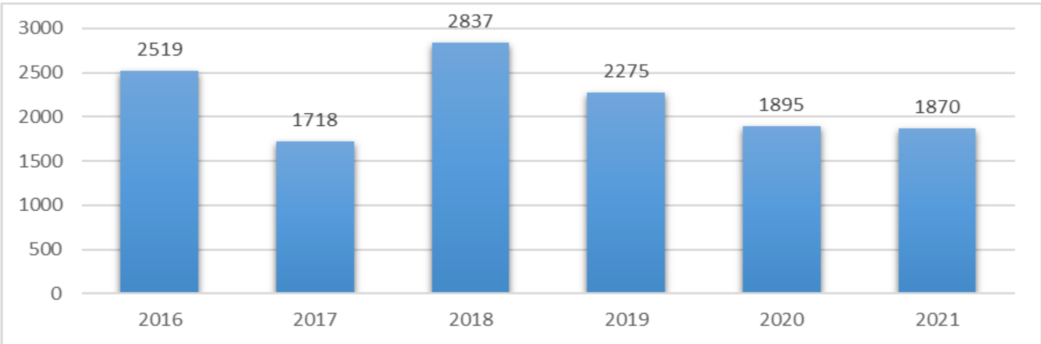

Figure 5. Number of accidents of water supply facilities (units)

Note – compiled by the authors based on photos from the Internet (https://img.forbes.kz/forbes-photobank/media/2024-05- 17/6a2f313f-55d6-43a2-8b5e-288af199464c.webp)

The primary emphasis in combating water losses is on repairing and modernizing outdated water supply infrastructure. This involves replacing old, deteriorated pipes, installing modern shutoff and regulating devices, and utilizing new materials and technologies that resist corrosion and mechanical damage.

For 2024, the national budget has allocated 218 billion tenge for the execution of 324 projects aimed at constructing and reconstructing water supply and wastewater disposal systems. Of this total, 106 billion tenge is designated for urban projects, while 112 billion tenge is earmarked for rural initiatives (https://bizmedia.kz/2024-06-11-218-mlrd-tenge-pojdut-na-stroitelstvo/).

Digitalization and innovation are crucial for modern water resource management. They enhance the efficiency of water supply systems while ensuring their sustainability and reliability.

Intelligent water supply systems consist of integrated solutions that feature automated data collection, analysis, and realtime decision-making (Piskunov, 2019). This is accomplished through the use of sensors, controllers, and software that monitor and manage all aspects of system operations, including pipe pressure and water quality.

Data collection and analysis are essential components of digitalization (see Figure 6). With the help of modern data collection technologies like IoT devices, it is possible to acquire precise information about the water system's status at any moment. This data can be utilized to optimize system performance, prevent accidents and leaks, and facilitate longterm infrastructure planning.

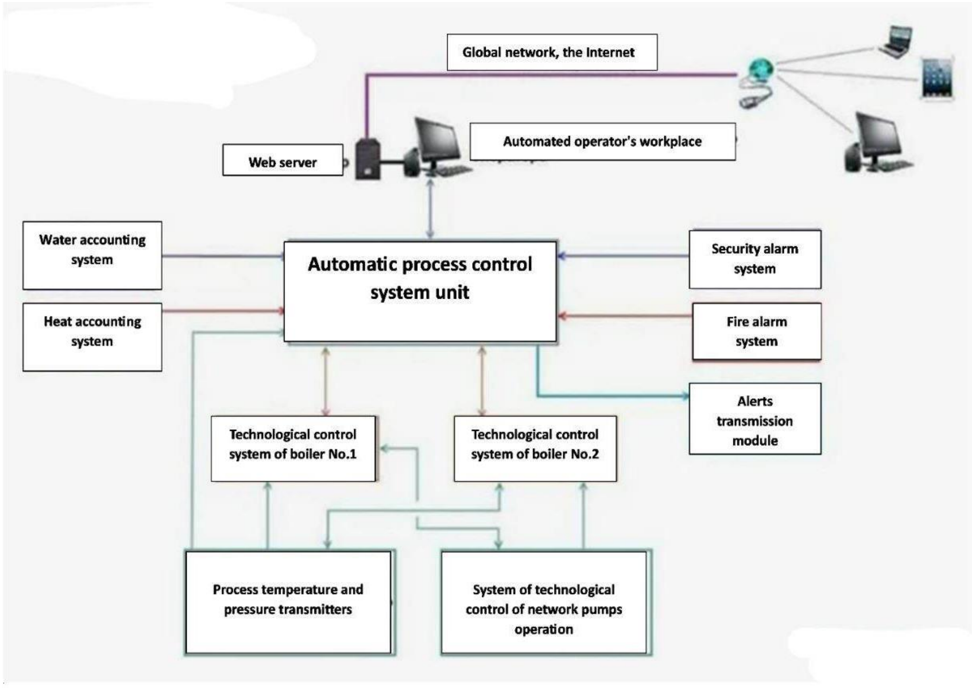

Figure 6. Structural Diagram of Automation for an Automated Control System

Note – compiled by the authors based on photos from the Internet (https://bts.net.ua/wa-data/public/site/btsnetu-aimg/acy_tp_kotelna_block-sxema.jpg)

Modern remote monitoring and control technologies enable the rapid detection and resolution of leaks, as well as the optimization of the entire water supply system's operation. The implementation of smart grids and the Internet of Things (IoT) enhances the accuracy of monitoring water consumption and quality.

A key aspect of modernization is the training and qualification of personnel involved with the water network. Specialists must be well versed in new technologies and working methods to manage resources more effectively and prevent losses (Sultanbekova, 2024).

The Government of Kazakhstan approved the Concept for the Development of the Water Resources Management System for 2024-2030 in a resolution dated February 5, 2024. This Concept aims to establish a comprehensive water resources management system that addresses conservation and rational usage for the health and well-being of the country's citizens, while balancing the needs of various economic sectors with environmental considerations. This year, 218 billion tenge has been allocated from the national budget for the implementation of 324 projects focused on the construction and reconstruction of water supply and wastewater disposal systems. Of this amount, 106 billion tenge will be allocated to urban areas, while 112 billion tenge will be directed to rural areas.

In 2025, the goal is to provide 100 percent coverage for the population of 19 cities. To achieve this, 83 projects for the construction of water supply networks in these cities are planned. Of these, 27 projects are expected to be completed by the end of this year, while 28 will be finished in 2025.

The Ministry of Water Resources and Irrigation of the Republic of Kazakhstan has initiated 28 projects focused on the construction and reconstruction of water pipelines. The intended outcome is to enhance the quality of drinking water supply in 426 settlements, serving a population of 1.1 million people. The total length of the water pipelines scheduled for construction and reconstruction exceeds 2,000 kilometers, with completion planned within two years.

In the North Kazakhstan Region, 10 projects are underway, along with 6 in the Kyzylorda region, 4 in Akmola, 2 each in Almaty and Ulytau, and one project each in Atyrau, Mangistau, Turkestan, and West Kazakhstan (https://zhaikpress.kz/ru/news/v-426-naselennyx-punktax-postroyat/).

Conclusion. Strategies and technologies to prevent water losses in the Republic of Kazakhstan should be aimed at comprehensive improvement of the water supply network. Repair and modernization of infrastructure, application of modern technologies and staff training are key elements of a successful water management strategy (Chaadaev & Chaadaeva, 2021).

To solve the problem of water loss, a comprehensive approach is needed, including:

- modernization of infrastructure: replacement of old pipes and equipment with more modern and reliable ones;
- improved monitoring: introduction of remote monitoring and control systems for timely detection of leaks;
- raising awareness: educational programs for the public on the importance of water conservation and combating illegal water use.

The issue of water loss in supply systems demands attention and proactive action from government agencies, utilities, and the public. Collaborative efforts can lead to sustainable water management and ensure access to clean water for all segments of the population.

Digitalization and innovation in water supply present new opportunities to enhance the efficiency and reliability of systems. The implementation of intelligent systems and data-driven decision-making contributes to the development of smart cities and promotes sustainable growth.

To effectively detect and eliminate water losses, a comprehensive approach utilizing various methods is essential. By applying modern technologies and innovative solutions, it is possible to significantly reduce losses and achieve more sustainable water management.

Conflict of interest. The author(s) declare that there is no conflict of interest.

Notice of Use of Generative AI and AIassisted technologies during the writing of the manuscript. When preparing this work, the authors did not use AI tools

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