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REVIEW ARTICLE

DEVELOPMENT OF TECHNOLOGICAL SCHEMES OF WATER SUPPLY FOR SMALL SETTLEMENTS

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Abstract. *This study examines the challenges associated with water supply in small settlements, using the village of Shatyrbai in the Zhetysu region of the Republic of Kazakhstan as a case study. Particular attention is given to the transition from surface water sources to groundwater, which generally exhibits a more stable chemical composition and lower susceptibility to contamination. The research focuses on assessing the benefits and limitations of groundwater use for drinking water supply and the necessity of employing advanced purification technologies. The methodological approach includes an analysis of the initial water quality, the selection of an appropriate technological scheme for water treatment, and an evaluation of the purification efficiency of a block-modular water treatment system (BMWTS). The proposed system integrates sequential treatment stages, including coarse (mechanical) filtration, aeration, clarification, fine filtration, demineralization, and ultraviolet disinfection. The findings indicate that groundwater in Shatyrbai contains elevated concentrations of iron, nitrates, and other contaminants, necessitating a multi-stage purification process. The implementation of the BMWTS system effectively reduces turbidity, removes excess salts and organic compounds, and ensures compliance with sanitary standards for potable water. The discussion evaluates the effectiveness of various water treatment methods and their adaptation for small settlements. Additionally, the study explores the technological and economic feasibility of BMWTS implementation and its role in ensuring a sustainable regional water supply. The conclusions emphasize that transitioning to groundwater, in conjunction with block-modular purification technologies, represents a viable strategy for providing high-quality drinking water in small settlements.*

Keywords: *small settlements, drinking water supply, groundwater, water purification, block-modular water treatment system*

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ШОЛУ МАҚАЛАСЫ

ШАҒЫН ЕЛДІ МЕКЕНДЕРДІ СУМЕН ЖАБДЫҚТАУДЫҢ ТЕХНОЛОГИЯЛЫҚ СХЕМАЛАРЫН ӘЗІРЛЕУ

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Аңдатпа. *Мақалада Қазақстан Республикасының Жетісу облысында орналасқан Шатырбай ауылының негізінде шағын елді мекендерді ауыз сумен қамтамасыз ету мәселелері қарастырылады. Жерүсті су көздерін пайдаланудан, әдетте, тұрақты химиялық құрамы бар және ластануға аз ұшырайтын жерасты көздеріне көшуге ерекше назар аударылады. Зерттеу ауыз сумен жабдықтау мақсатында жерасты суларын пайдаланудың артықшылықтары мен шектеулерін талдауға, сондай-ақ заманауи тазарту технологияларын қолдану қажеттілігін негіздеуге бағытталған. Әдіснамалық тәсілдеме судың бастапқы сапасын жан-жақты бағалауды, суды дайындаудың оңтайлы технологиялық схемасын таңдауды және блокты-модульдік су дайындау жүйесін (БМСДЖ) пайдалана отырып, тазалау тиімділігін талдауды қамтиды. Бұл жүйе өрескел (механикалық) тазалауды, аэрацияны, мөлдірлеуді, сүзуді, минералсыздандыруды және ультракүлгін сәулемен зарарсыздандыруды қамтитын суды көп сатылы өңдеуді қарастырады. Зерттеу нәтижелері Шатырбай ауылындағы жерасты көздерінен алынған судың құрамында темірдің, нитраттардың және басқа да ластаушы заттардың жоғары мөлшерін көрсетеді, бұл көп сатылы тазартуды қажет етеді. БМСДЖ қолдану лайлануды айтарлықтай төмендетуге, артық тұздар мен органикалық қосылыстарды кетіруге, сондай-ақ судың сапасын белгіленген санитарлық-гигиеналық стандарттарға жеткізуге мүмкіндік береді. Талқылау аясында суды тазартудың әртүрлі әдістерінің тиімділігі, оларды шағын елді мекендердің жағдайына бейімдеу, сондай-ақ суды дайындаудың блокты-модульдік жүйелерін енгізудің технологиялық және экономикалық орындылығы қарастырылады. Сонымен қатар, бұл технологиялардың аймақты тұрақты сумен қамтамасыз етуге ықпалы талданады. Қорытындыда блокты-модульдік тазарту технологияларын қолданумен ұштастыра отырып, жерасты суларын пайдалануға көшу шағын елді мекендерді заманауи санитарлық талаптарға сәйкес келетін сапалы ауыз сумен қамтамасыз ету мәселесінің перспективалық шешімі болып табылатыны атап көрсетілген.*

Түйін сөздер: *шағын елді мекендер, ауыз сумен жабдықтау, жерасты сулары, суды тазарту, суды дайындаудың блокты-модульдік жүйесі*

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ОБЗОРНАЯ СТАТЬЯ

РАЗРАБОТКА ТЕХНОЛОГИЧЕСКИХ СХЕМ ВОДОСНАБЖЕНИЯ ДЛЯ МАЛЫХ НАСЕЛЕННЫХ ПУНКТОВ

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Аннотация. *В статье рассматриваются вопросы обеспечения питьевой водой малых населённых пунктов на примере села Шатырбай, расположенного в Жетысуской области Республики Казахстан. Особое внимание уделяется переходу от использования поверхностных водных источников к подземным, обладающим, как правило, более стабильным химическим составом и меньшей подверженностью загрязнению. Исследование направлено на анализ преимуществ и ограничений использования подземных вод для целей питьевого водоснабжения, а также на обоснование необходимости применения современных технологий очистки. Методологический подход включает всестороннюю оценку исходного качества воды, выбор оптимальной технологической схемы водоподготовки и анализ эффективности очистки с использованием блочно-модульной системы водоподготовки (БМСВ). Данная система предусматривает многоступенчатую обработку воды, включающую механическую очистку, аэрацию, осветление, фильтрацию, деминерализацию и ультрафиолетовое обеззараживание. Результаты исследования свидетельствуют о повышенном содержании в подземных водах села Шатырбай железа, нитратов и других загрязняющих веществ, что обуславливает необходимость комплексного подхода к очистке. Применение БМСВ позволяет эффективно снижать мутность воды, удалять избыточные соли и органические соединения, а также доводить её качество до установленных санитарно-гигиенических нормативов. В рамках обсуждения рассматривается эффективность различных методов очистки воды, их адаптация к условиям малых населённых пунктов, а также технологическая и экономическая целесообразность внедрения блочно-модульных систем водоподготовки. Кроме того, анализируется влияние данных технологий на обеспечение устойчивого водоснабжения региона. В заключении подчёркивается, что переход на использование подземных вод в сочетании с применением блочно-модульных технологий очистки представляет собой перспективное решение задачи обеспечения малых населённых пунктов качественной питьевой водой, соответствующей современным санитарным требованиям.*

Ключевые слова: *малые населенные пункты, питьевое водоснабжение, подземные воды, очистка воды, блочно-модульная система водоподготовки*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ / ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

Water is an essential resource for life and plays a crucial role in the development of humanity. For centuries, people have settled near water sources, which have consistently remained fundamental to life and well-being, often venerating them as sacred sources of sustenance.

At present, due to rapid population growth, economic expansion, environmental challenges, and other factors impacting natural resources, the issue of ensuring access to high-quality drinking water has become one of the most urgent global concerns. Goal 6 of the UN's "17 Goals for Sustainable Development" aims to provide safe drinking water to all people and, recognizing the significance of a favorable environment, places particular emphasis on the sustainable management of water resources, wastewater, and ecosystems.

The issue of supplying the population with environmentally safe drinking water is also pressing in our country. The primary water resources in the Republic consist of surface water, with an average annual volume of 101 km³. Of this volume, 56% is generated domestically, while the remaining 44% originates from transboundary rivers flowing from China, Uzbekistan, Russia, and Kyrgyzstan (**National report, 2022**).

According to data from the Bureau of National Statistics of the Republic of Kazakhstan (**Monitoring of Sustainable Development Goals. Goal 6.**), over the past five years, the proportion of the population utilizing organized water supply services that comply with safety standards has gradually increased. However, the issue of ensuring a reliable supply of high-quality water to small settlements remains unresolved: out of the 7.5 million people residing in rural areas, approximately 450,000 face shortages of clean water. The primary causes of this issue include the absence of water sources in small settlements or their contamination, deterioration of sanitary and epidemiological conditions, and the unsatisfactory technical state of water supply infrastructure. In nearly all small settlements, surface water sources serve as the primary means of meeting the population's needs. However, the quality of these waters remains suboptimal, particularly in the context of anthropogenic influences and climate change.

Given the challenges associated with the depletion and contamination of surface water, numerous experts advocate for transitioning to the use of groundwater, which is classified as a renewable mineral resource and exhibits relatively stable quality. Groundwater is less susceptible to seasonal fluctuations and anthropogenic impacts than surface water sources, and natural filtration through soil layers significantly reduces contamination levels.

Currently, more than four thousand artesian water sources have been studied in Kazakhstan. Experts estimate that the volume of available groundwater in the country exceeds 15.7 km³. To facilitate the study and efficient utilization of this natural resource, a specialized service has been established under the Ministry of Water Resources and Irrigation of the Republic of Kazakhstan, tasked with overseeing hydrogeological research, as well as monitoring and analyzing the condition of groundwater.

The purpose of this research article is to substantiate the transition to the use of groundwater to ensure the supply of high-quality drinking water to small settlements, such as the village of Shatyrbay. Groundwater is characterized by stable quality indicators and lower levels of contamination compared to surface sources, which is particularly significant in the context of environmental instability and increasing river pollution.

The study involves an analysis of the physical and chemical properties of groundwater in the village of Shatyrbay, with the identification of key pollutants that exceed the maximum permissible concentration (MPC). It also provides a rationale for the implementation of a block-modular water treatment system (BMWTS) as an effective method for purifying groundwater to meet sanitary standards. The research describes the stages of the water treatment process, including mechanical filtration, aeration, clarification, demineralization, and sterilization, and evaluates their effectiveness in reducing pollutant concentrations. Additionally, an assessment of the economic feasibility of utilizing a block-modular system in remote settlements is conducted, highlighting its potential for ensuring a sustainable water supply.

2 LITERATURE REVIEW

There is no clear and universal definition of the concept of a "small settlement", as its meaning may vary depending on the context and country. Common characteristics that allow distinguishing small settlements include population size, economic structure, functional characteristics, infrastructure, and type of settlement.

The law «On the Administrative-Territorial Structure of the Republic of Kazakhstan» states: «A settlement is a part of the territory of the Republic of Kazakhstan with a population of at least 50 people, formed as a result of economic and other public activities of citizens, registered in accordance with the procedure established by the laws of the Republic of Kazakhstan, and managed by local representative and executive bodies. Settlements are divided into urban and rural» **(Law of the Republic of Kazakhstan, 1993)**.

By comparing other definitions specified in this document, the category of «small settlement» includes a city of district significance and a village. Therefore, the settlement of Shatyrbay in the Zhetysu district, which is being considered in this study, is classified as a village, as according to the aforementioned document: «A village is a settlement with a population of at least 50 people. »

The population of Shatyrbay village is 520 people. The village has a secondary school with a capacity of 620 students, where 96 students are currently enrolled, as well as one post office, one medical center, one cultural center, and more than 20 economic entities operating within the village.

Characterizing a small settlement based on the aforementioned common features, Shatyrbay village is a regional rural settlement with a small population, an economy primarily based on agriculture and small businesses, specialized functions in a specific sector, and a low level of infrastructure development.

In any locality, several key factors contribute to the safety, comfort, health, and development of human life:

1) Physical safety – the absence of threats to human life and health from external factors (crime, natural disasters) and the social environment.

2) Sanitary and epidemiological safety – environmental cleanliness, access to water supply systems, compliance with hygiene and sanitation standards.

3) Provision of clean and high-quality drinking water.

4) Food security – access to food that ensures proper nutrition and satisfies the body's need for essential nutrients.

5) High-quality and safe housing – availability of necessary living conditions (water, heating, electricity).

6) Environmental well-being – air, water, and soil quality.

7) Educational and cultural development – access to educational institutions, sports, and recreational facilities that foster intellectual and cultural growth.

8) Access to medical care – availability of hospitals, clinics, pharmacies, and other healthcare facilities.

9) Economic stability and employment – access to jobs that fulfill economic needs and provide material well-being.

10) Social integration and support – availability of social benefits (pensions, allowances, assistance centers) to aid people in difficult circumstances and opportunities to participate in public life.

11) Infrastructure – roads, public transportation, utilities (electricity, gas, sewerage), internet access, and other facilities necessary for the normal functioning of the settlement.

An analysis of these factors reveals that more than half of them are directly linked to water. The quality of drinking water is determined based on a comprehensive evaluation of physical, chemical, biological, and microbiological parameters, which assess its suitability for human consumption. These parameters are established by sanitary standards and are regulated by both international and national regulations.

Currently, many countries adhere to international guidelines established by the World Health Organization (WHO), such as SanPiN 2.1.4.1074-01, when determining drinking water quality standards. Additionally, in Kazakhstan, the quality control of drinking water in terms of sanitary and epidemiological well-being is conducted in accordance with the «Sanitary and Epidemiological Requirements for Water Sources, Catchment Areas for Economic and Drinking Purposes, Economic and Drinking Water Supply, and Cultural and Domestic Use of Water and Safety of Water Bodies», as approved by Order No. 26 of the Ministry of Health of the Republic of Kazakhstan, dated February 20, 2023 (**Sanitary rules, 2023**).

The hygienic requirements and quality standards for drinking water outlined in these documents are presented in Table 1.

Table 1
Requirements for controlled indicators of drinking water

Indicator	Unit of measurement	Standards (MPC), no more
Organoleptic indications		
Taste	score	2
Smell	score	2
Color	degrees	20
Turbidity	mg/dm^3 (on kaolin)	1,5
Chemical indicators		
Hydrogen index (pH)	-	6-9
Total mineralization (dry residue)	mg / l	1000 (1500)
Total hardness	mg-eq/l	7,0 (10)
Permanganate oxidation capacity	mg / l	5
Petroleum products, total	mg / l	0,1
Surface-active substances (EPZ, anionic)	mg / l	0,5
Chlorides	mg / l	350
Sulfates	mg / l	500
Total iron	mg / l	0,3
Manganese	mg / l	0,1
Fluorine	mg / l	1,5
Aluminum	mg / l	0,5
Copper	mg / l	1
Zinc	mg / l	5
Nitrates (by NO_3)	mg / l	45
Nitrites (by NO_2)	mg / l	3

As shown in **Table 1**, organoleptic indicators such as odor and taste of drinking water should not exceed 2 points, turbidity should not exceed 2 mg/L, and hardness should be within the range of 7-100 mmol. A low concentration of calcium and magnesium salts, which determine the hardness of drinking water, can lead to increased bone fragility in humans. Therefore, according to sanitary standards and regulations, drinking water should be chemically safe. Additionally, the quantity of reagents used for disinfection and the concentration of natural substances that pollute water must comply with established standards.

To address the challenges of water resource conservation and rational utilization for ensuring access to high-quality drinking water, the «Concept for the Development of the Water Resources Management System of the Republic of Kazakhstan for 2024-2030» was adopted. Based on a comprehensive analysis of the current state of water resources and international best practices, the document outlines seven key strategies for effectively tackling these issues. It emphasizes that «The study, protection, and sustainable use of groundwater are essential for adapting to climate change and meeting the needs of a growing population» (**Concept, 2024**).

The challenges associated with groundwater use for industrial purposes and public water supply have been extensively examined by scientists and hydrogeologists. **Giordano (2009)** provides a comprehensive analysis of global groundwater issues and solutions, exploring the formation, movement, and utilization of groundwater for various purposes. His research highlights the fundamental role of groundwater in ensuring a sustainable water supply, particularly in regions experiencing surface water shortages. Furthermore, Giordano discusses management strategies aimed at optimizing groundwater use while mitigating the risks of overextraction and contamination. His findings remain highly relevant today and continue to be refined through ongoing advancements in hydrogeology and water resource management.

Foster, Chilton, Nijsten, and Richts (2013) emphasize the necessity of transitioning from surface water sources to groundwater, highlighting its strategic significance for water security. The authors argue that groundwater serves as a vital local resource with global implications, providing a more stable and resilient supply compared to surface water, which is highly susceptible to seasonal fluctuations and anthropogenic influences. Their study underscores the importance of sustainable groundwater management, particularly in regions where surface water sources are unreliable or insufficient. Moreover, they present case studies demonstrating that groundwater utilization has proven to be an effective long-term solution for addressing water supply challenges in both rural and urban areas.

Dillon (2005) investigates advanced groundwater treatment methods, including aquifer recharge, aeration, and biochemical filtration, as approaches to improving water quality. His research demonstrates that these techniques significantly reduce the concentration of contaminants in groundwater, ensuring compliance with sanitary drinking water standards. Furthermore, the author highlights that managed aquifer recharge can serve as an effective tool for enhancing groundwater sustainability.

Carrard, Foster, and Willetts (2019) conducted a multi-country analysis on the use of groundwater as a drinking water source in Southeast Asia and the Pacific, emphasizing the necessity of a comprehensive approach to resource management. The authors highlight that excessive groundwater extraction and pollution pose significant threats to water security, reinforcing the need for robust management and regulatory frameworks to ensure the long-term sustainability of these resources.

Howard (2015) examines the governance challenges associated with groundwater and its role in ensuring sustainable urban and rural water supply. His research highlights the significance of decentralized water supply systems, particularly in small settlements, where modular treatment facilities offer an efficient solution for improving groundwater access. The author also emphasizes the necessity of well-developed infrastructure and continuous monitoring of well conditions to maintain water quality and reduce operational costs. His findings suggest that well-managed groundwater resources can enhance water security and serve as a cost-effective solution for remote communities, aligning with modern principles of sustainable water management.

The issue of groundwater availability and its sustainable use has been widely studied in the context of climatic and geographical challenges. **Famiglietti (2014)** highlights the global groundwater crisis, focusing on the depletion of groundwater reserves due to overextraction and inefficient management practices. His research emphasizes regional disparities in groundwater availability and the necessity of adaptive strategies to ensure long-term sustainability. Additionally, Famiglietti underscores the importance of scientific assessments of slightly mineralized groundwater reserves, particularly in arid and semi-arid regions, where groundwater serves as a crucial resource for drinking water supply. His findings provide valuable insights into the rational use of groundwater and the development of policies aimed at improving water security in vulnerable regions.

Ensuring access to safe drinking water in rural areas remains a critical challenge, necessitating effective management of local groundwater resources. **Wada, Van Beek, and Bierkens (2012)** examine the challenges associated with groundwater use in agricultural and rural regions, emphasizing the risks of unsustainable extraction and its long-term consequences. Their research highlights the importance of localized water management strategies, particularly in areas where groundwater salinity poses difficulties for drinking water supply. The authors explore modern desalination techniques, such as electrodialysis, as viable solutions for improving groundwater quality in remote and water-scarce regions. Their findings suggest that integrated water resource management approaches can significantly enhance the sustainability of groundwater use, ensuring a stable and reliable drinking water supply for rural populations.

Based on an analysis of studies focused on the use of groundwater as a drinking water source, several key advantages of its use as an alternative for providing the population with high-quality water have been identified. Groundwater naturally undergoes filtration as it percolates through layers of soil, sand, and clay, which serve as natural purification barriers. These layers remove suspended particles and numerous contaminants, making groundwater often cleaner than surface water from rivers and lakes. Unlike surface water, groundwater is less exposed to anthropogenic pollution, such as industrial emissions, sewage, and agricultural runoff, thereby reducing the risks associated with chemical pollutants, including pesticides and heavy metals.

In remote and arid regions, groundwater frequently represents the only permanent water source, particularly in areas where precipitation levels are insufficient to sustain surface water bodies. Unlike rivers and lakes, which are subject to seasonal fluctuations, underground aquifers provide a consistent water supply, making them a more reliable resource. Additionally, geological formations surrounding deep aquifers protect groundwater from most pollutants present at the surface, reducing the risk of contamination by microorganisms, chemicals, and heavy metals. These natural protective mechanisms make groundwater less vulnerable to climate-related threats such as droughts and floods, ensuring long-term water security.

Groundwater often requires minimal treatment compared to surface water, making it a cost-effective solution for many rural communities. In most cases, simple purification methods such as disinfection, aeration, or sedimentation are sufficient to meet sanitary standards, reducing the need for complex and expensive treatment technologies. With proper management, groundwater reserves can provide a stable and sustainable water supply, as aquifer recharge, though slow, ensures long-term availability. The use of groundwater also minimizes environmental impact on surface ecosystems, as it does not require modifications to natural rivers and lakes, thereby preserving biodiversity and ecological balance.

Despite its numerous advantages, groundwater use is associated with certain risks, including aquifer depletion, ecosystem degradation, and landscape alterations. Addressing these challenges requires the development of efficient water use systems and monitoring programs to track groundwater levels and quality. For the present study, particular attention is given to the challenges associated with the purification of groundwater with high mineralization and the presence of natural pollutants.

In recent years, block-modular water treatment technology has emerged as a promising solution for improving water supply in remote and sparsely populated areas where centralized water distribution is impractical. This modern approach is based on modular blocks, each designed to perform specific purification functions, ranging from coarse mechanical filtration and aeration to advanced filtration and disinfection. The modular nature of this system allows for adaptability to different water sources, ease of transportation, installation, and maintenance, making it particularly suitable for use in rural and hard-to-reach regions.

Block-modular treatment systems provide flexible and efficient solutions for both surface and groundwater purification. Their scalability, ease of operation, and adaptability to local conditions make them an optimal choice for ensuring safe drinking water access in rural settlements such as Shatyrbay. The ability to implement such systems with minimal infrastructure investment further supports their potential for addressing water supply challenges in remote areas, reinforcing the viability of groundwater as a sustainable source of high-quality drinking water.

3 MATERIALS AND METHODS

On the first task of the study, first of all, we conducted a survey among the population of the village of Shatyrbay. The questionnaire lists the main conditions that ensure the health and safety of a person, comfort of life, and it is proposed to assess their level established in the village as «high», «medium», «low». As a result, out of 200 people who participated in the empirical study, 141 (70,5%) rated «low» on the indicator of «clean and high-quality drinking water». Then, through an interview, we tried to find out the reasons for this situation. The results of a survey of rural residents are shown in **Figure 2**.

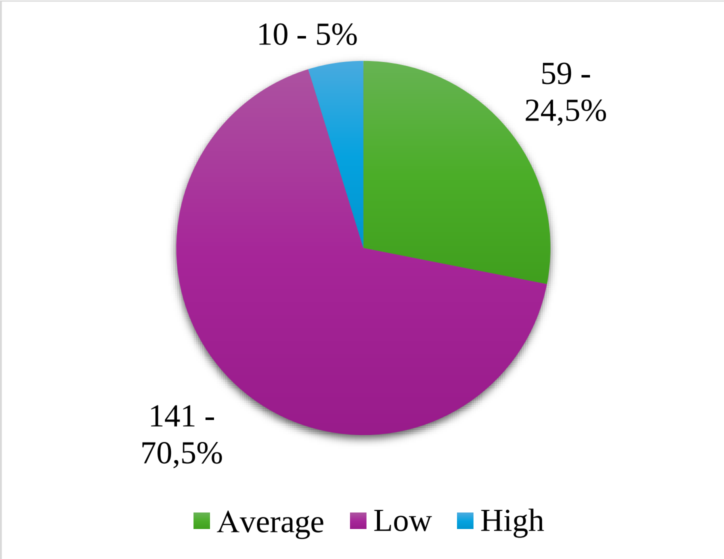

Figure 1 – The results of a survey of rural residents

The analysis of the responses of the villagers made it possible to draw the following conclusions: the Terekty River is used as a source of water supply in the village; although the village is provided with centralized water supply, the water quality is low in terms of visible physical indicators (transparency, smell, taste, temperature). «ALIMA AGRO» LLP, a large enterprise engaged in mixed agriculture in the village, uses groundwater to meet its needs.

Comparative indicators obtained as a result of laboratory analysis of samples from the two listed types of water used as drinking water are shown in **Table 2**.

Table 2
Comparative indicators of surface and underground water

№ s/n	Indications	Unit of measurement	MPC	Determined concentration	Type of water
1	Turbidity	mg/l	1,5 (2,0)	2,5 – MPC 1,67 times more	surface
				1,78 – MPC 1,2 times more	underground
2	Nitrate nitrogen	mg/l	45	75,5 – MPC 1,68 times more	surface
				69,65 – MPC 1,55 times more	underground
3	Total hardness	mg-eq/l	7 (10)	12 – MPC 1,2 times more	surface
				33 – MPC 4,7 times more	underground

4	Dry residue	mg/l	1000 (1500)	4100– MPC ,1 times more	surface
				3870 – MPC 3,87 times more	underground
5	Chlorides	mg/l	350	1400 – MPC 4 times more	surface
				1270 – MPC 3,63 times more	underground
6	Total iron	mg/l	0,3	0,65 – MPC 2,17 times more	surface
				0,45 – MPC 1,5 times more	underground

As can be seen from the table, the main pollutants of surface and underground water exceeding the maximum permissible concentration (MPC) are: water turbidity, hardness, nitrate nitrogen in the water, chlorides, iron, dry waste. A comparative analysis of these indicators showed that the quality of surface water is much lower than that of underground water. This circumstance confirms our assumption about the effectiveness of groundwater use.

However, groundwater also requires purification in terms of its physical and chemical indicators. To bring the water in line with sanitary standards, a block-modular water treatment system was used, the plan of which is presented in **Figure 2**.

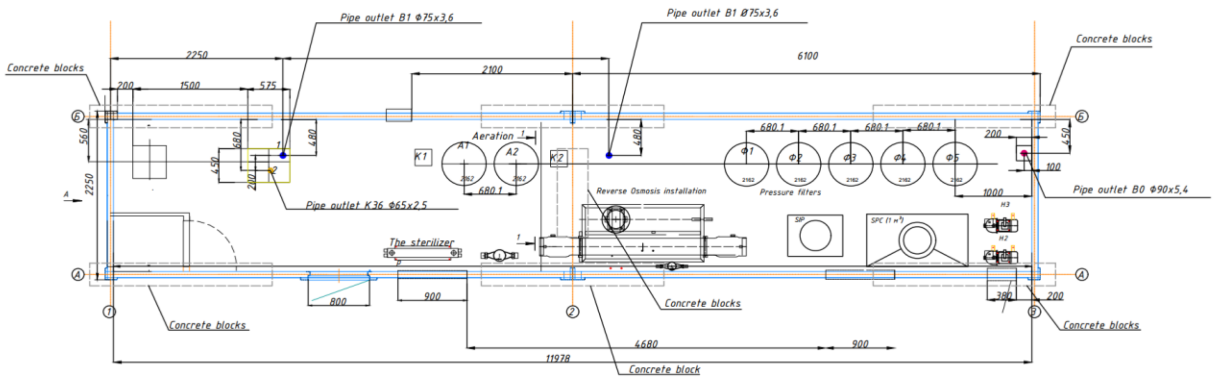

Figure 2 – Plan of a block modular water treatment system

The scheme of water purification in a block-modular system is given in **Figure 3**.

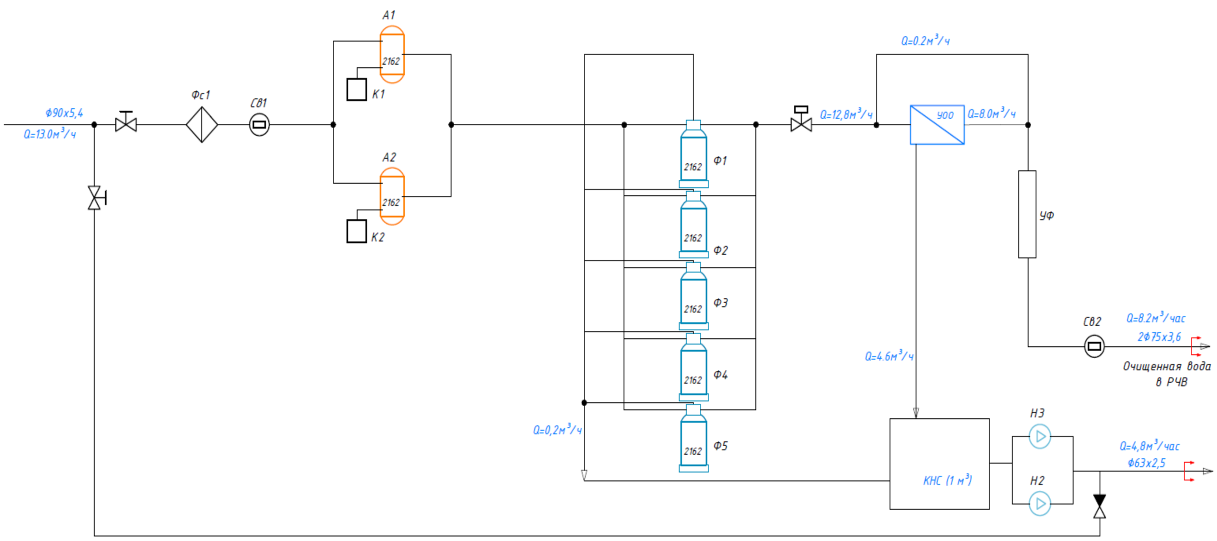

Figure 3 – Scheme of water purification in a block-modular system: ***Фс 1****-mechanical (coarse) cleaning filter;* ***Св*** *-water meter flow meter;* ***A1, A2*** *– aeration columns;* ***K1, K2*** *– compressors;* ***Ф1-Ф5*** *– pressure filters;* ***УФ*** *– sterilizer;* ***УОО*** *– reverse osmosis unit;* ***КНС*** *– brine collection tank with pumps.*

The water obtained in accordance with the technology was treated with the following stages of water preparation, as shown in **Figure 3**:

1) Coarse (mechanical) cleaning – removal of coarse particles and water surfaces (sand, silt, clay) using a mesh corner filter (Фс 1 in **Figure 3**).

2) Water aeration – the process of oxygenating water to remove hydrogen sulfide, excess carbon dioxide, as well as dissolved metals, such as iron and manganese (A1; A2 in **Figure 3**).

3) Water purification, removal of oxidized precipitates (iron, manganese) in pressure filters. (Ф1-Ф5 in **Figure 3**)

The pressure filter has a three-layer load:

- Filter-AG® top filter load («AG»). Large impurities, oxidized organic impurities precipitate;
- Medium load «Birm». In the chemical analysis of well water, special requirements for determining the exact content of iron and manganese are often not considered. If the iron content is higher than 0.1 mg/L, it negatively affects the operation of reverse osmotic membranes. In this well, the iron content is higher than MPC. Therefore, loading «Birm» is included in the composition of filter fillers;
- lower load (25%) - crushed stone with grain sizes of 3-10 mm.

4) desalination (demineralization) of water, reduction of hardness, removal of excess chlorides in the reverse osmosis unit. (УОО in **Figure 3**).

The essence of the reverse osmosis method is to filter water under the influence of osmotic pressure through semiconductor reverse osmotic membranes created as roller elements. Reverse osmosis is usually purified by homogenized (homogeneous) systems - true solutions, which imposes certain requirements on the quality of water for a reverse osmosis unit.

5) disinfection of purified water. (УФ in **Figure 3**) disinfection of purified water is carried out with the help of ultraviolet lamps before transferring it to a clean water tank.

4 RESULTS AND DISCUSSION

The integrated approach to water treatment implemented in the block-modular water treatment system has significantly improved the quality of primary underground water in the village of Shatyrbay. The water quality indicators following all treatment stages within the block-modular system are presented in **Table 3**.

Table 3. Results of underground water purification through a block-modular system

№ s/n	Indications	Unit of measurement	MPC	Initial values	After cleaning
1	Turbidity	mg/l	1,5 (2,0)	1,78	1,0
2	Nitrogen nitrate	mg/l	45	69,65	35
3	Nitrate nitrogen	mg/l	7 (10)	33	5
4	Dry residue	mg/l	1000 (1500)	3870	850
5	Total hardness	mg-eq/l	350	1270	320
6	Total iron	mg/l	0,3	0,45	0,15

The initial and post-treatment data provided in the table demonstrate a substantial improvement in water quality, ensuring compliance with relevant sanitary and epidemiological standards. The effectiveness of the purification process within the block-modular system was confirmed through water quality analyses conducted after each stage of treatment.

Coarse (mechanical) filtration, implemented at the initial stage, effectively removes suspended particles, including sand and floating debris. This preliminary treatment minimizes the pollutant load on subsequent filtration stages, thereby enhancing the overall efficiency of the system and extending the service life of filtration equipment.

Aeration, which involves the addition of oxygen to the water, facilitates the oxidation of dissolved iron and manganese compounds, transforming them into insoluble forms that subsequently precipitate in the filtration units. At this stage, the removal of carbon dioxide and hydrogen sulfide enhances the taste and odor of the water while also protecting reverse osmosis membranes from excessive contamination in the later treatment stages.

Clarification (sedimentation) and pressure filtration, carried out using a three-layer filtration media, ensure the effective removal of oxidized sediments and organic substances. The upper layer of Filter-Ag® captures coarse impurities, while the middle layer of Birm® selectively retains iron and manganese ions. This multi-stage filtration process enhances water transparency and improves organoleptic properties, making it suitable for consumption.

Demineralization via reverse osmosis membranes has proven to be effective in reducing water hardness and overall mineralization, which is particularly critical in regions with elevated levels of dissolved salts. The reverse osmosis process efficiently removes excess chlorides and nitrates, thereby improving overall water quality and ensuring its safety for drinking.

Ultraviolet sterilization provides a high level of bacteriological safety, effectively eliminating the risk of microbiological contamination. As an environmentally friendly disinfection technology, ultraviolet (UV) treatment does not require the addition of chemical reagents, making it particularly advantageous for small settlements where reducing operational costs and minimizing potential side effects is essential.

Thus, the combined application of mechanical filtration, aeration, sedimentation, demineralization, and sterilization has successfully removed the primary pollutants characteristic of groundwater in this region.

The implementation of a block-modular water treatment system for water supply in small settlements, such as Shatyrbay, not only ensures high treatment efficiency but also provides notable economic advantages. A key benefit of this system is its modular structure, which allows adaptation to specific operational requirements and local conditions. This flexibility results in reduced capital expenditures and optimized operational costs, as modules can be added or replaced as needed, facilitating system upgrades with minimal investment.

The system is also characterized by low energy consumption and minimal use of chemical reagents, primarily due to the incorporation of mechanical and physical treatment methods such as aeration and UV sterilization. These factors contribute to environmental sustainability, making the system particularly suitable for application in remote and rural areas.

Additionally, the block-modular system offers operational flexibility and requires minimal maintenance personnel. The ability to adapt treatment modules to local water conditions and to incorporate technological upgrades ensures that this water purification technology remains viable for long-term use. As a result, it provides a reliable and stable water supply, meeting all necessary sanitary and drinking water standards while maintaining cost efficiency and environmental sustainability.

5 CONCLUSIONS

Surface water sources, such as the Terekty River, have historically been utilized for water supply in many rural areas of Kazakhstan. However, research indicates that surface waters are highly vulnerable to contamination due to agricultural runoff, wastewater discharge, and precipitation-related pollutants. For instance, a study conducted by the Kazakh Research Institute of Water Management revealed that river waters contain elevated concentrations of nitrates, iron, and other contaminants, necessitating the use of complex multi-stage treatment systems to ensure water safety.

In contrast, the quality indicators of underground water sources, such as artesian wells, demonstrate greater stability. These sources are significantly less susceptible to biological and organic contamination, thereby reducing the treatment burden on water purification systems. Research in the field of Kazakhstan’s hydrogeology, along with numerous studies conducted by domestic and international scientists, confirms the high efficiency of groundwater sources in providing safe drinking water to remote settlements.

To explore effective solutions for ensuring drinking water accessibility in small settlements, groundwater in the village of Shatyrbay, located in the Sarkan District of Zhetysu Region, was treated using a block-modular purification technology. As a result, water quality was significantly improved through a comprehensive treatment process, including mechanical filtration, aeration, pressure filtration, clarification, demineralization, and ultraviolet sterilization. Notably, the turbidity of the water decreased from 1.78 mg/L to 1.0 mg/L; nitrate nitrogen levels were reduced from 69.65 mg/L to 35 mg/L; chlorides from 1270 mg/L to 320 mg/L; iron concentrations from 0.45 mg/L to 0.15 mg/L; and total dissolved solids (TDS) were reduced from 3870 mg/L to 850 mg/L, significantly softening the water.

Thus, based on the comparative analysis of primary and treated water, the implementation of the block-modular water treatment system effectively reduced pollutant concentrations to meet sanitary and epidemiological standards. This purification technology ensures the safety of drinking water and improves water quality for domestic use, making it a suitable and efficient solution for rural water supply systems.

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