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Original Empirical Research

Investigation of the Impact of Water Quality in Central Water Supply Systems on Human Health and the Environment

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Abstract

Introduction. Providing safe drinking water to the population is a crucial task for health protection and sustainable development, as its quality directly influences the level of morbidity and mortality. The UN and WHO have stated that insufficient efficiency of water treatment systems contribute to the emergence and spread of infectious diseases, causing up to 1.4 million deaths worldwide each year. At the same time, the issue of comprehensive comparative assessment of water treatment technologies in terms of the overall risk to public health remains underdeveloped, considering both chemical and microbiological hazards. This gap in scientific knowledge necessitates research that focuses not only on meeting water quality standards but also on an integrated assessment of the effects of various technological schemes on human health. In this study, we aim to conduct a comparative assessment of the effectiveness of drinking water treatment technologies used in centralized water supply systems in terms of the overall risk to public health. This will made it possible to choose the best solution for water treatment in practice.

Materials and Methods. The information base for the study consisted of current regulatory documents that establish requirements for drinking water quality and technological processes for its preparation, such as the "Methodology for developing a register of BAT for water supply and sanitation systems"[1]; Russian and international standards, and guidelines for assessing public health risks, scientific articles and monographs on filtration, coagulation, clarification, sorption, oxidation, and disinfection of water. The assessment of source water quality was conducted according to the main groups of indicators: organoleptic, generalized, sanitary-microbiological, parasitological, as well as sanitary-chemical. Mathematical modeling and statistical data processing methods were used to quantify and compare different water treatment schemes. The calculation was performed in accordance with the approaches described in MR 2.1.4.0289–22[2].

Based on the classification of water supply sources by water quality, we analyzed the recommended sets of technological operations:

– for the first class — pre-filtration with optional reagent treatment and mandatory disinfection;
– for the second class — filtration (in the presence of phytoplankton, microfiltration) with coagulation, settling and subsequent disinfection;
– for the third class — additional stage of purification including clarification, oxidation, sorption and repeated disinfection.

The study was performed using standard methods of laboratory analysis of water quality and specialized software for modeling and risk assessment.

[1] *"Methodology for developing a register of BAT for water supply and sanitation systems"*, Section 1 "Water supply", Contract No. 34/08/13 dated December 18, 2013, volume 1. (In Russ.) URL: http://nghp-sro.ru/files/news/news137/1_SRO_04-471.pdf (accessed: 01.04.2026)

[2] Methodological recommendations MR 2.1.4.0289-22 *"Comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems"* (approved by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare on June 1, 2022). (In Russ.) URL: https://cepportal.ru/upload/iblock/009/44r5ndj9le2pp2uhlas9txk6c35956dl.pdf?ysclid=mnfxyjeh4k339528214 (accessed: 01.04.2026)

Results. The effectiveness of the current treatment technology (mechanical purification, coagulation, and chlorination) and the proposed multistage scheme (including ultrafiltration, sorption, and combined disinfection) were evaluated. Mathematical modeling of changes in water quality parameters for three scenarios of water treatment was performed. Using special software, a model experiment and an assessment of quality changes were conducted for four groups of parameters (organoleptic, generalized, sanitary-microbiological and parasitological, and sanitary-chemical). According to MR 2.1.4.0289–22[3], the values of integrated risk and the effectiveness of its reduction as a result of water treatment were calculated. The results were statistically processed. Based on the data on sanitary and hygienic monitoring and calculation of the overall risk to public health, the source water was found to have excesses in several indicators. It was established that the proposed multi-stage method provided more thorough purification and significantly reduced the negative impact on health across all groups of parameters (organoleptic, generalized, sanitary-microbiological and sanitary-chemical).

Discussion. A comparative analysis of the effectiveness of the two water treatment methods revealed a significant advantage of the multi-stage purification process. The proposed integrated approach fully ensured that water quality met the regulatory requirements for maximum permissible values through a combination of ultrafiltration, sorption and combined disinfection. The multi-stage purification scheme ensured not only complete microbiological and chemical safety, but also high organoleptic water parameters, enhancing the overall reliability of the water supply system.

Conclusion. The paper provides a comparative assessment of the effectiveness of two water treatment technologies for the centralized water supply system in Penza. Based on the methodology for calculating the overall risk to public health, it was found that the source water from the Surskoye reservoir had a high risk level. The current purification method (coagulation and chlorination) has been shown to reduce the risk to an average level, leaving the water supply system vulnerable. In contrast, the proposed multi-stage method (ultrafiltration, sorption, UV disinfection, and chloroamination) demonstrated very high efficiency (82%) in reducing the cumulative risk to negligible value. These results support the advantages of a multi-stage approach and can serve as a foundation for upgrading water treatment systems to increase their reliability and safety for the public.

Keywords: environment, human health, central water supply, natural water purification methods

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Оригинальное эмпирическое исследование

Исследование воздействия на здоровье человека и окружающую среду качества воды, поступающей в центральные системы водоснабжения

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Аннотация

Введение. Обеспечение населения безопасной питьевой водой является одной из ключевых задач охраны здоровья и устойчивого развития, поскольку её качество напрямую влияет на уровень заболеваемости и смертности. По данным ООН и ВОЗ, недостаточная эффективность систем водоподготовки способствует возникновению и распространению инфекционных заболеваний, приводящих к гибели в мире до 1,4 миллиона человек ежегодно. Вместе с тем остаётся недостаточно разработанным вопрос комплексной сравнительной оценки технологий водоподготовки с точки зрения совокупного риска для здоровья населения, учитывающей одновременно химические и микробиологические факторы опасности. Указанный пробел в научном знании обусловливает необходимость исследований, ориентированных не только на достижение нормативных показателей качества воды, но и на интегральную оценку последствий применения различных технологических схем для здоровья человека. В связи с этим целью настоящего исследования является сравнительная оценка эффективности технологий водоподготовки питьевой воды централизованных систем водоснабжения по совокупному риску для здоровья населения, что позволит обосновать выбор оптимальных решений в практике водоподготовки.

[3] Methodological recommendations MR 2.1.4.0289-22 *"Comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems"* (approved by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare on June 1, 2022). (In Russ.) URL: https://cepportal.ru/upload/iblock/009/44r5ndj9le2pp2uhlas9txk6c35956dl.pdf?ysclid=mnfxyjeh4k339528214 (accessed:01.04.2026)

Материалы и методы. Информационную базу исследования составили действующие нормативные документы, устанавливающие требования к качеству питьевой воды и технологическим процессам ее подготовки; «Методика разработки реестра НДТ систем водоснабжения и водоотведения»; российские и международные стандарты и руководства по оценке риска для здоровья населения; научные статьи и монографии по технологиям фильтрования, коагулирования, осветления, сорбции, окисления и обеззараживания воды. Оценка качества исходной воды выполнялась по основным группам показателей: органолептическим, обобщенным, санитарно-микробиологическим, паразитологическим, а также санитарно-химическим. Для количественной оценки и сравнения различных схем водоподготовки применялись методы математического моделирования и статистической обработки данных. Расчет выполнялся в соответствии с подходами, изложенными в МР 2.1.4.0289–22.

На основе классификации источников водоснабжения по качеству воды анализировались рекомендуемые совокупности технологических операций:

– для первого класса — предварительное фильтрование с возможной реагентной обработкой и обязательным обеззараживанием;

– для второго класса — фильтрование (при наличии фитопланктона – микрофильтрование) с коагулированием, отстаиванием и последующим обеззараживанием;

– для третьего класса — добавление второй ступени очистки, включающей осветление, окисление, сорбцию и повторное обеззараживание.

Исследование выполнено с использованием стандартных методик лабораторного анализа качества воды и специализированного программного обеспечения для моделирования и оценки риска.

Результаты исследования. Проведена оценка эффективности действующей технологии (механическая очистка, коагуляция, хлорирование) и предложенной многоступенчатой схемы (включающей ультрафильтрацию, сорбцию и комбинированное обеззараживание). Выполнено математическое моделирование изменения параметров качества воды для трёх сценариев водоподготовки. С использованием специального программного обеспечения проведён модельный эксперимент и оценка изменения качества по четырём группам параметров (органолептические, обобщенные, санитарно-микробиологические и паразитологические, санитарно-химические). По МР 2.1.4.0289–22 рассчитаны значения совокупного риска и эффективность его снижения в результате водоподготовки; результаты статистически обработаны. На основе данных санитарно-гигиенического мониторинга и расчёта совокупного риска для здоровья населения показано, что исходная вода имеет превышения по ряду показателей. Установлено, что предложенный многоступенчатый метод обеспечивает более глубокую очистку и значительно эффективнее снижает негативное влияние на здоровье по всем группам параметров (органолептическим, обобщённым, санитарно-микробиологическим и санитарно-химическим).

Обсуждение. Проведенный сравнительный анализ эффективности двух методов водоподготовки показал значительное преимущество многоступенчатой схемы очистки. Предложенный комплексный подход полностью обеспечил соответствие качества воды нормативным требованиям по предельно-допустимым значениям за счет сочетания ультрафильтрации, сорбции и комбинированного обеззараживания. Метод многоступенчатой схемы очистки обеспечил не только полную микробиологическую и химическую безопасность, но и высокие органолептические показатели воды, повышая общую надежность системы водоснабжения.

Заключение. В работе проведена сравнительная оценка эффективности двух технологий водоподготовки для централизованной системы водоснабжения г. Пензы. На основе методики расчета совокупного риска для здоровья населения было установлено, что исходная вода из Сурского водохранилища обладает высоким уровнем риска. Показано, что существующий метод очистки (коагуляция и хлорирование) снижает риск до средней эффективности, оставляя систему водоснабжения уязвимой. В свою очередь, предложенный многоступенчатый метод (ультрафильтрация, сорбция, УФ-обеззараживание и хлораминирование) продемонстрировал очень высокую эффективность (82 %), снизив совокупный риск до пренебрежимо малого значения. Результаты доказывают преимущество многоступенчатого подхода и могут служить основанием для модернизации систем водоподготовки с целью повышения их надежности и безопасности для населения.

Ключевые слова: окружающая среда, здоровье человека, центральное водоснабжение, методы очистки природных вод

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Introduction. Providing the population with high-quality drinking water is a global challenge. This challenge is caused by a combination of factors, with access to clean water sources being a key one. However, due to the global anthropogenic impact on the environment, there are virtually no natural sources that provide water suitable for drinking without treatment. The qualitative and quantitative composition of water in natural sources of drinking water supply is an important factor determining the state of the environment and the sanitary and epidemiological well-being of the population. A study by the UN Special Committee found that human disease burden is largely determined by the quality of water from natural sources. With the development of urban areas and industrial agglomerations, the anthropogenic load on water bodies increases, which leads to their pollution [1]. In this regard, water treatment technologies come to the fore, the choice of which should be justified taking into account sanitary, hygienic, environmental, technological, and economic considerations.

The documents of the World Health Organization (WHO) and the national regulatory documents of the Russian Federation establish drinking water quality standards aimed at ensuring safety and maintaining human health. According to WHO's recommendations, the quality of water treatment is assessed by the following groups of factors: microbiological, chemical, radiological, and sensory (or organoleptic in Russian terminology). WHO also emphasizes the importance of monitoring and regular verification of water quality at all stages of the supply chain, from source to end user. This approach guarantees timely identification of deviations and adoption of appropriate measures to reduce risks to public health and maintain public well-being.

Insufficient water treatment leads to the emergence and spread of infectious diseases (cholera, dysentery, typhoid fever, hepatitis A, poliomyelitis) [2], which cause deaths of up to 1.4 million people every year around the world [3]. Prolonged consumption of drinking water containing chemical pollutants in concentrations exceeding the maximum permissible limits leads to the development of pathologies of the digestive system [4], urinary [5], endocrine [6], and cardiovascular systems: disruption of the heart muscle [7], hypertension and high blood pressure [8], ischemic cardiomyopathy [9]. In addition, high nitrate content in the water leads to stomach cancer [10]. The presence of heavy metals causes neurological diseases in children: lead — damage to the brain and central nervous system [11], mercury — impaired concentration, memory loss, nerve damage [12], and skin cancer noted by domestic [13] and foreign [14] researchers. Increased water hardness contributes to the accumulation of salts in the human body, which causes joint diseases and kidney stone disease [15].

In this regard, the improvement of water treatment and water purification technologies, as well as systems for monitoring the parameters of natural and drinking water, is of paramount importance. This requires a reasonable choice of these technologies and the determination of a set of parameters for their comparative evaluation. Methodological recommendations MR 2.1.4.0289–22[4] propose a methodology for assessing the effectiveness of measures aimed at improving the quality of drinking water in centralized water supply systems. A comparative assessment is conducted based on such parameters as the potential risk to human health and the efficiency of water treatment.

Despite the availability of approved methods for assessing the risk to public health from drinking water quality, the existing studies focus on individual pollutants or evaluate the effectiveness of specific purification stages. A comprehensive assessment of various water treatment technologies based on total risk indicators to human health in Penza has not been conducted. This fragmented approach prevents us from fully determining which combination of purification methods is optimal for reducing the total number of diseases associated with water consumption from a specific source. The current research aims to address this gap by systematically analyzing and comparing alternative water treatment scenarios for Penza city conditions.

One of the natural sources of water for the central water supply in Penza is the Surskoye reservoir. According to the data from sanitary and hygienic monitoring, and classification of natural waters based on physical-chemical indicators of water quality, the Surskoye reservoir is classified as a first-class surface source [16]. The current method of water treatment for this source involves mechanical purification, followed by coagulation and flocculation, and disinfection through chlorination. Under this system, natural water from the source is filtered through a series of filtration grids and settled in special clarifying tanks to remove suspended particles. Coagulants are then added, which help to aggregate fine and colloidal particles into larger flocs, which can be filtered out. Finally, the water is chlorinated to ensure its safety from bacteria when it enters the central water supply systems.

The disadvantages of this process of water treatment before it enters the central water supply systems include:

– the formation of large amounts of sludge that must be disposed of, which can have a negative impact on the environment during storage;

– the potential risk to public health from residual aluminum content in the water if there is a possible dosage error, which can harm human health;

– the risk to public health from incomplete elimination of pathogenic viruses and bacteria, which also contributes to the deterioration of public health.

[4] Methodological recommendations MR 2.1.4.0289-22 *"Comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems"* (approved by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare on June 1, 2022). (In Russ.) URL: https://cepportal.ru/upload/iblock/009/44r5ndj9le2pp2uhlas9txk6c35956dl.pdf?ysclid=mnfxyjeh4k339528214 (accessed: 01.04.2026)

Modern water treatment technologies rely on an integrated approach implemented through a multi-step process where different purification methods work together to compensate for the limitations of each individual technique. One such technology involves pre-treatment designed to prepare water for further purification. The basic treatment step removes fine particles and dissolved contaminants. Disinfection ensures the microbial safety of water entering the central network. Pretreatment consists of mechanical filtration of surface water through drum screens, aggregation of the smallest particles into large flakes, followed by precipitation and physical removal of these agglomerates from the treated water. This step reduces turbidity and color, as well as removes up to 90% of suspended solids and colloidal impurities.

The main cleaning is carried out using ultrafiltration and sorption methods to remove pathogenic microorganisms, organic compounds, disinfection by-products, and substances that cause unpleasant taste and odor.

At the disinfection stage, water first passes through chambers with ultraviolet radiation to destroy the DNA and RNA of microorganisms. After that, a small amount of chloramine is added to ensure complete disinfection. The effect of this treatment lasts throughout the distribution network, ensuring that the water is safe from a microbiological and chemical point of view, has excellent organoleptic properties, and reaches the system with minimal risk to consumer health.

Figure 1 shows algorithms for purification methods for water supplied to the central water supply systems from the Surskoye reservoir.

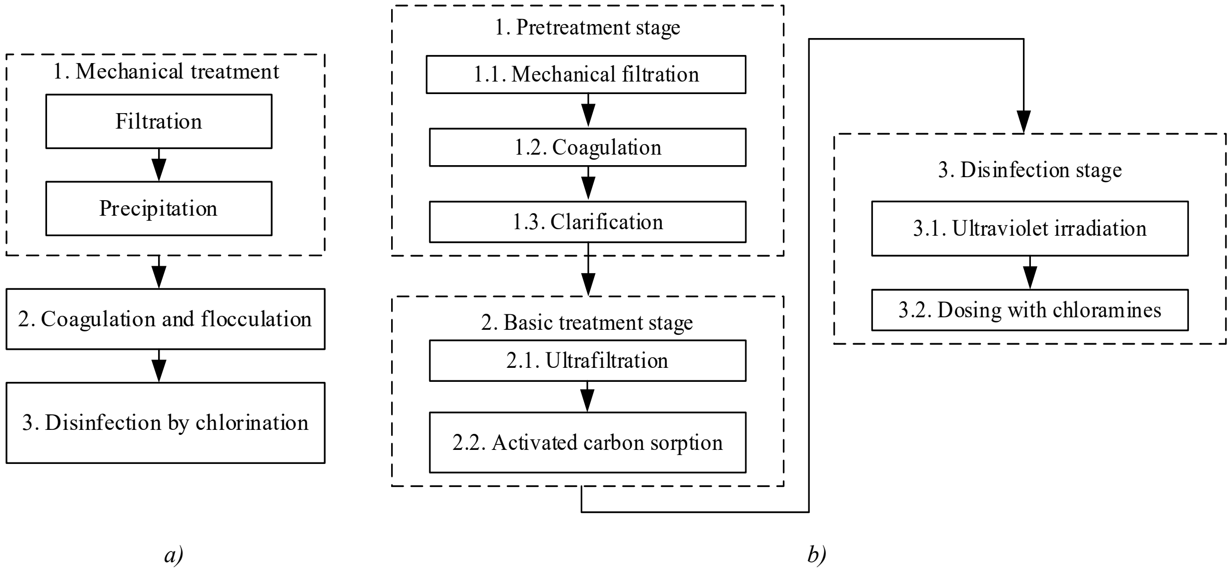

Fig. 1. Algorithm for water purification methods used in central water supply systems: *a* — water purification method No. 1 [17]; *b* — water purification method No. 2 [18]

To compare the cleaning efficiency of the presented methods, we conducted an assessment of the overall risk to public health and the degree of effectiveness in accordance with MR 2.1.4.0289-22[5]. We selected the controlled parameters that had a negative impact on human health, and in the analyzed water body they were in excess of maximum permissible values (MPV), according to GOST[6] and SanPiN[7]. We examined water samples before and after purification using two methods.

The primary aim of this study was a comparative assessment of the effectiveness of drinking water treatment technologies of centralized water supply systems in terms of the overall risk to human health.

[5] Methodological recommendations MR 2.1.4.0289-22 *"Comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems"* (approved by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare on June 1, 2022). (In Russ.) URL: https://cepportal.ru/upload/iblock/009/44r5ndj9le2pp2uhlas9txk6c35956dl.pdf?ysclid=mnfxyjeh4k339528214 (accessed: 01.04.2026)

[6] GOST 31952–2012. *"Water treatment for units. General requirements and methods of efficiency determination"*. (In Russ.) URL: https://files.stroyinf.ru/Data2/1/4293785/4293785990.pdf?ysclid=mnfyc28qpx343642988 (accessed: 01.04.2026)

7 SanPiN 1.2.3685-21 *"Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans"*. (In Russ.) URL: https://nagut6.gosuslugi.ru/netcat_files/174/2801/SP123685_21.pdf?ysclid=mnfyfca8xz794025561 (accessed: 01.04.2026)

To achieve this goal, the following tasks were expected to be solved:

– to analyze physical-chemical and biological composition of water from natural water supply sources in Penza in order to identify the most significant pollutants;

– to calculate the cumulative risk of disease burden for different scenarios of water treatment;

– to assess the effectiveness of water treatment provided to centralized water supply systems.

The novelty of this work lies in the application of an integrated approach, which allows you not only to determine compliance or non-compliance with standards, but also to quantify and compare the final effects of introducing various technologies in terms of preventing potential harm to public health.

Materials and Methods. During the research, we analyzed scientific publications, patents, and regulatory documents containing information on the composition, indicators and methods of water treatment. Mathematical modeling was used with subsequent statistical processing of its results. We studied the influence of the composition of drinking water on human health and environmental quality.

The assessment of the drinking water composition was carried out based on the following groups of indicators, which were regulated by Russian and international regulatory documents: organoleptic, generalized, sanitary-microbiological, parasitological, and sanitary-chemical parameters.

The maximum permissible values (MPV), which were established by Russian regulatory documents, were used as criteria for assessing the quality of drinking water. The study was conducted on the basis of Penza State University.

According to MR 2.1.4.0289–22[8], in order to assess the effectiveness of measures to improve the quality of water treatment, it was necessary to calculate the average values for all sets of actual values of the controlled parameters before ($\overline{P}_{i,\text{before}}$) and after ($\overline{P}_{i,\text{after}}$) water treatment:

$$\overline{P}_{i,\text{before}} = \sum_{i=1}^{n} \frac{P_{i,\text{before}}}{n}, \quad (1)$$

$$\overline{P}_{i,\text{after}} = \sum_{i=1}^{n} \frac{P_{i,\text{after}}}{n}, \quad (2)$$

where $P_{i,\text{before}}$, $P_{i,\text{after}}$ — actual values of the controlled parameters before and after water treatment; n — number of samples taken.

Having obtained the average values for all sets of actual values of the controlled parameters before and after water treatment, the multiplicity of exceeding the maximum permissible concentration was determined by the formula:

$$x_i = \frac{\overline{P}_{i,\text{before(after)}}}{MPV_i}. \quad (3)$$

Dividing the range of changes in values in accordance with Table 1 for each of the values calculated by formula (3), the membership function to the range μ(x) was determined:

$$\mu(x) = \begin{cases} 0, \text{ if } x_{LB1} \le x_i < x_{UB1} \\ \dfrac{x_i - x_{LB2}}{x_{UB2} - x_{LB2}}, \text{ if } x_{LB2} \le x < x_{UB2} \\ 1, \text{ if } x_{LB3} \le x < x_{UB3} \\ \dfrac{x_i - x_{LB4}}{x_{UB4} - x_{LB4}}, \text{ if } x_{LB4} \le x < x_{UB4} \\ 0, \text{ if } x \ge x_{LB5} \end{cases}. \quad (4)$$

[8] Methodological recommendations MR 2.1.4.0289-22 *"Comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems"* (approved by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare on June 1, 2022). (In Russ.) URL: https://cepportal.ru/upload/iblock/009/44r5ndj9le2pp2uhlas9txk6c35956dl.pdf?ysclid=mnfxyjeh4k339528214 (accessed: 01.04.2026)

Table 1

Categories of risk to public health, $\mu(x)$

Characteristic		Categories of risk to public health				
		1	2	3	4	5
Range of multiplicity exceeding the MPV	x_{LBi}	0	0.5	1	2	5
	x_{UBi}	0.5	1	2	5	+∞
Rank, *k*		1	2	3	4	5
Health risk category		Negligibly small	Low	Average	High	Very high
Public health risk		$(0; 1 \cdot 10^{-8}]$	$(1 \cdot 10^{-8};1 \cdot 10^{-6}]$	$(1 \cdot 10^{-6};1 \cdot 10^{-4}]$	$(1 \cdot 10^{-4};1 \cdot 10^{-3}]$	$(1 \cdot 10^{-3};1]$

Note: LB — lower bound of the interval; UB — upper bound of the interval; «) » — means that the value does not belong to this interval; «] » — means that the value belongs to this interval.

After that, an assessment of the risk to public health was conducted for all controlled parameters, which were grouped into categories (sanitary and chemical). Based on the estimates obtained, a weighting factor was calculated for each controlled parameter, which established the relationship between the parameter and the class of diseases caused by pollutants present in the water. At the next stage of the research, we used the Fishburne principle to determine how common each class of disease was when assessing the magnitude of risk to public health using weight coefficients (W). At the same time, health risk rank (k) and disease class rank by degree (l) were taken into account:

$$W = \frac{2 \cdot (k - l + 1)}{(k+1) \cdot k}, \tag{5}$$

where k — health risk rank (Table 1); l — disease class rank by severity (Appendix 2 to MR 2.1.4.0289-22 Table P2)[9]).

Next, weighting coefficients (G_i) were determined for each *i-th* controlled parameter in each group:

$$G_i = \frac{1}{m}, \tag{6}$$

where m — number of all considered parameters in the group: for organoleptic parameters — 3, for generalized parameters — 5, for sanitary-microbiological and parasitological parameters — 6, for sanitary-chemical parameters — 9.

This was followed by the calculation of the cumulative contribution of each of the five groups of the controlled parameters (w_k) to the total amount of risk to public health:

$$w_k = \sum_i G_i \cdot \mu_{k,i}. \tag{7}$$

We used the formula to determine the risk to public health from exposure to each group of the controlled parameters:

$$R_g = \sum_{k=1}^{5} \overline{R_k} \cdot w_k, \tag{8}$$

where R_g — public health from exposure to each group of the controlled parameters; $\overline{R_k}$ — average value of the variation range of risk value to public health resulting from exposure to the *k-th* group of the controlled parameters.

Overall risk was calculated for all controlled parameters for two situations — before and after water treatment:

$$R = \frac{1}{\overline{V_g}} \sum_{p=1}^{5} R_g \cdot V_g, \tag{9}$$

where R — overall risk to public health; R_g — value of risk to public health for each group of the controlled parameters; V_g — total weighting factor of the *k-th* group of the controlled parameters in determining the overall risk to public health; $\overline{V_g}$ — average weighting coefficient of the *k-th* group of the controlled parameters in determining the overall risk to public health (Fig. 2).

[9] Methodological recommendations MR 2.1.4.0289-22 *"Comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems"* (approved by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare on June 1, 2022). (In Russ.) URL: https://cepportal.ru/upload/iblock/009/44r5ndj9le2pp2uhlas9txk6c35956dl.pdf?ysclid=mnfxyjeh4k339528214 (accessed: 01.04.2026)

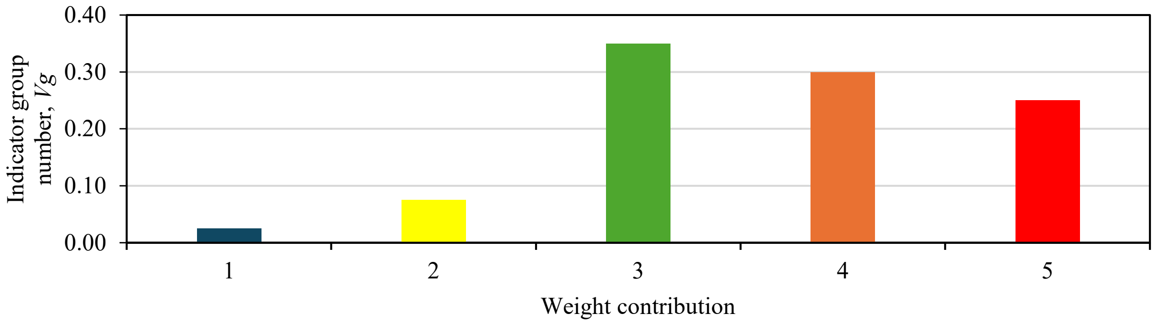

Fig. 2. Weighting coefficients V_g for different groups of parameters: 1 — organoleptic; 2 — generalized; 3 — sanitary, microbiological and parasitological; 4 — radiation; 5 — sanitary and chemical

When calculating the effectiveness of reducing the risk to public health by means of water treatment (Э) the value of cumulative risks before ($\overline{R}_{\text{before}}$) and after ($\overline{R}_{\text{after}}$) water treatment was taken into account:

$$Э = \frac{\overline{R}_{\text{before}} - \overline{R}_{\text{after}}}{\overline{R}_{\text{before}}} \cdot 100\%. \quad (10)$$

Based on the obtained value of Э (%) qualitative value of the degree of effectiveness of the measures taken was determined (Fig. 3).

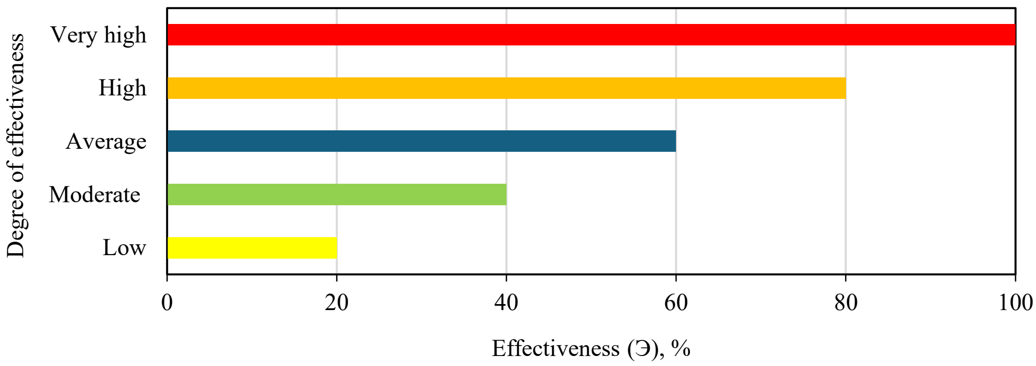

Fig. 3. Water treatment effectiveness, %

A comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems was conducted using the program implementing MR 2.1.4.0289–22[10]. Table 2 provides the initial data.

Table 2

Data from sanitary and hygienic monitoring of water from the central water supply systems

No.	Name of the controlled parameter	Group of parameters	Units of measurement	MPV	Value of the parameters before treatment	Value of the parameters after treatment by method No. 1	Value of the parameters after treatment by method No. 2
1	Odor	Organoleptic parameters	score	2	3	1	1
2	Colour		degrees	20	25	16	10
3	Formazine turbidity		FTU	2.6	5	2.0	0.5
4	Сухой остаток	Generalized parameters	g/m^3	1	1.5	0.15	0.11
5	Hardness		mg·equ/l	7	20	10	6
6	Petroleum products		mg/l	0.1	0.2	0	0
7	Anionic surfactants		mg/l	0.5	0.5	0	0
8	Hydrogen value		units	6—9	8	7	7

[10] Methodological recommendations MR 2.1.4.0289-22 *"Comprehensive assessment of the effectiveness of measures to improve the quality of drinking water in centralized water supply systems"* (approved by the Federal Service for Supervision of Consumer Rights Protection and Human Welfare on June 1, 2022). (In Russ.) URL: https://cepportal.ru/upload/iblock/009/44r5ndj9le2pp2uhlas9txk6c35956dl.pdf?ysclid=mnfxyjeh4k339528214 (accessed: 01.04.2026)

9	Total microbial count	Sanitary, microbiological, and parasitological parameters	CFU/cm^3	50	60	45	35
10	Escherichiacoli (E.coli)		CFU/100 cm^3	yes / no	yes	no	no
11	Enterococci		CFU/100 cm^3	yes / no	no	no	no
12	Coliphages		CFU/100 cm^3	yes / no	no	no	no
13	Cysts and oocysts of pathogenic protozoa		In 50 l	yes / no	no	no	no
14	Pathogens of intestinal infections		In 10 l	yes / no	no	no	no
15	Ammonia and ammonium ion	Sanitary and chemical parameters	mg/l	2	4.2	1.8	1.1
16	Copper		mg/l	0.5	1.5	0.25	0.05
17	Cadmium		mg/l	0.001	0.0012	0	0
18	Sulfates (SO_4^{2-})		mg/l	500	528	385.0	250.0
19	Nitrates (by NO^{3-})		mg/l	45	90	40.0	25.0
20	Nitrites (by NO^{2-})		mg/l	3	4.8	3.0	1.2
21	Iron		mg/l	0.3	0.6	0.3	0.1
22	Chlorides (by Cl)		mg/l	350	375	345.0	263.0
23	Zinc		mg/l	5	5.5	4.0	2.5

Results. Table 3 provides the results of calculating the parameters for evaluating the effectiveness of water treatment. Three options were considered: before treatment, after treatment by treatment No. 1, after treatment by method No. 2.

Table 3

Contribution of each parameter group

No.	Group of parameters (indicators)	Risk groups				
		Before treatment	After treatment by method No. 1	Reduction of negative impact after treatment by method No 1	After treatment by method No. 2	Reduction of negative impact after treatment by method No. 2
1	Organoleptic	0.42	0	0.42	0	0.42
2	Generalized	0.31	0.21	0.10	0.19	0.12
3	Sanitary, microbiological, and parasitological	0.04	0.03	0.01	0	0.04
4	Sanitary and chemical	0.09	0.03	0.06	0	0.09

According to Table 1, it can be seen that in the source water (before treatment), almost all controlled parameters exceeded the maximum permissible concentration. The greatest cumulative risk in this case was formed by organoleptic (0.42) and generalized indicators (0.31), which was due to a significant excess of standards for turbidity, color, hardness and dry residue. Sanitary and chemical indicators also made a significant contribution (0.09) due to increased concentrations of copper, nitrates, nitrites, and ammonia.

The results obtained demonstrated a different level of treatment of the two methods under consideration. Based on the calculations, we determined the degree of treatment efficiency for each method (Table 4).

Table 4

Overall risk to public health for each water treatment scenario

Scenario	Overall risk, R	Effectiveness, %	Degree of effectiveness
Before treatment	0.36	–	–
After treatment by method No. 1	0.16	55	average
After treatment by method No. 2	0.007	82	very high

It was found that the use of water purification method No. 1 showed average purification efficiency, since the risk to public health was reduced from 0.36 to 0.16. At the same time, physical fine impurities, chemical pollutants (nitrates, nitrites), ions of certain metals (for example, aluminum), and disinfection byproducts (chlorine compounds) remained in the water. Method No. 2 reduced the overall risk to 0.007, which indicated a high efficiency of water treatment.

Figure 4 demonstrates the dynamics of public health risk for each group of the controlled parameters. The histogram shows the exclusion of the risk to public health in terms of organoleptic and sanitary-chemical indicators of water quality as a result of the application of treatment method No. 2.

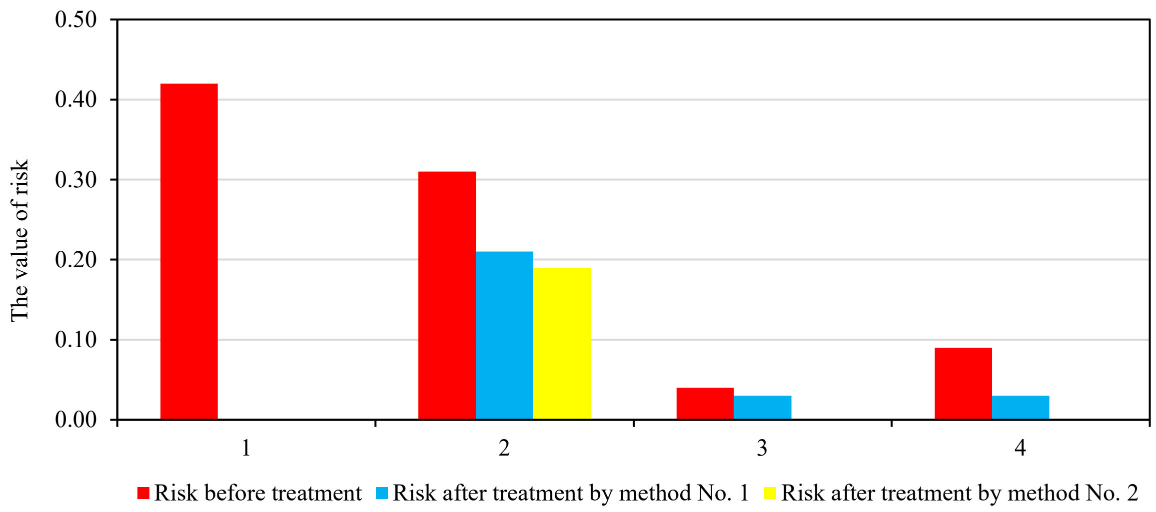

Fig. 4. Risk value for each group of controlled parameters: 1 — organoleptic parameters; 2 — generalized parameters; 3 — sanitary, microbiological and parasitological parameters; 4 — sanitary and chemical parameters

Figures 5 and 6 show a graphical representation of the calculation results.

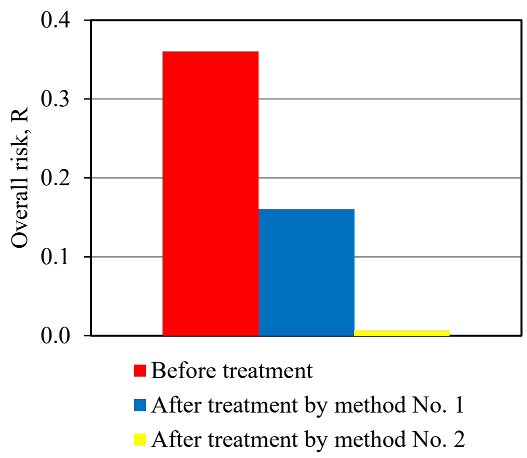

Fig. 5. Overall risk for each treatment scenario

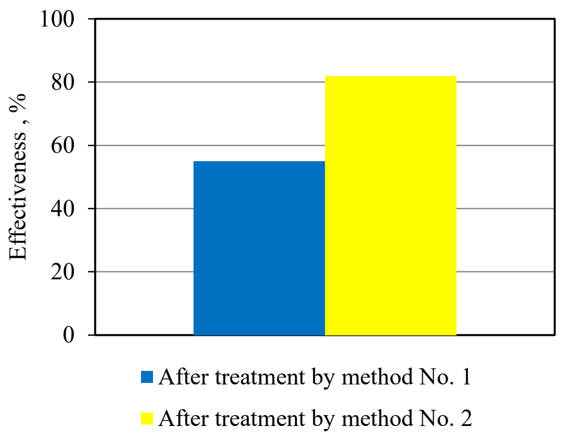

Fig. 6. Treatment effectiveness of the treatment methods under consideration

Discussion. The conducted research clearly demonstrated significant differences in the effectiveness of the two considered approaches to water treatment of the Surskoye reservoir. The data analysis presented in Table 2 and Figure 4 showed that the source water did not meet sanitary standards in many key parameters (odor, color, turbidity, hardness, ammonia, nitrates, etc.), which confirmed high initial overall risk to public health (Table 3).

The existing technology No. 1, based on coagulation and chlorination, really brought most of the parameters within the limits of the maximum permissible values. However, its effectiveness could be described as insufficient. For a number of critically important indicators, such as nitrites (3.0 mg/l with a MPV of 3 mg/l) and iron (0.3 mg/l with a MPV of 0.3 mg/l), water treatment was only up to the upper limit of the standard. This did not create the necessary "safety margin" and left the system vulnerable to seasonal deterioration in the water source quality. As a result, after the application of technology No. 1, a significant residual risk remained for the groups of generalized (0.21) and sanitary-chemical (0.03) parameters (Fig. 5), which was associated with incomplete removal of fine impurities, dissolved chemicals and the formation of chlorination by-products.

In turn, the proposed multi-stage method No. 2 demonstrated a radically higher level of water treatment. It not only adjusted the parameters to the maximum permissible concentration, but also significantly reduced their concentration. For example, turbidity decreased to 0.5 FTU (at the rate of 2.6), sulfate concentration decreased to 250 mg/l (at the rate of 500 mg/l), and ammonium ion decreased to 1.1 mg/l (at the rate of 2 mg/l). Such deep cleaning was a direct consequence of technological features of this approach: ultrafiltration and sorption effectively removed both suspended particles and dissolved organic and chemical compounds. Two-stage disinfection (UV radiation + chloramine) ensured complete microbiological safety while minimizing by-products.

The key result was the reduction in overall risk, as shown in Figure 5. Method No. 2 eliminated the risks associated with organoleptic, sanitary-microbiological, and sanitary-chemical parameters completely (to zero). The total overall risk was reduced to a negligible value of 0.007, indicating that this technology enabled the production of not only formally safe drinking water, but also water with excellent organoleptic qualities, thereby increasing the reliability and safety of the centralized water supply system.

Conclusion. Within the framework of this research, we successfully achieved our goal. We conducted a comparative assessment of the effectiveness of two drinking water treatment technologies based on the indicator of the overall risk to human health.

During the work, we performed the following tasks:

– the analysis of the water composition from the Surskoye reservoir revealed an excess of maximum permissible concentrations in several organoleptic, generalized, and sanitary-chemical parameters. This caused high initial cumulative risk to public health at the level of 0.36;

– we calculated the cumulative risk for three scenarios: before water treatment, after applying the existing technology No. 1, and after applying the proposed technology No. 2;

– the assessment of the effectiveness was conducted, which revealed that the current technology No. 1 had an average level of effectiveness (55%), whereas the proposed technology No. 2 had a very high level (82%).

The research showed that the existing water treatment technology, which was based on coagulation and chlorination, was not effective enough. This technology reduced the overall risk by only 0.16, leaving residual risks for general and sanitary-chemical indicators, and did not provide the necessary margin of safety, as the concentrations of certain pollutants remained at the upper limits of the standards.

At the same time, it was clearly demonstrated that the proposed multi-stage method No. 2, including ultrafiltration, sorption and two-stage disinfection, allowed for a radically higher level of water treatment. This technology reduced the overall risk to a negligible value of 0.007, completely eliminating the risks of organoleptic, sanitary-microbiological and sanitary-chemical indicators.

Thus, the work shows that the use of modern multi-stage water treatment technologies makes it possible not only to formally comply with regulations, but also to obtain drinking water of significantly higher quality. This ensures the creation of a "safety margin" for the water supply system in case of seasonal and emergency deterioration of the source water quality. The results obtained can be used as a scientific justification for making decisions on the modernization of existing water treatment plants and the introduction of the best available technologies to provide the population with high-quality and safe drinking water.

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