

Evaluation of the efficiency of local post-treatment and conditioning of tap water (on the example of water vending machines in Kokshetau city)

Natalya Grabovskaya^{1*}, Tatyana Karnaukhova¹, Tatyana Litau¹, Asel Agaidarova²

¹Sh. Ualikhanov Kokshetau University, Kokshetau, Kazakhstan;
NGrabovskaya@shokan.edu.kz, tatyanakarnaukhova@shokan.edu.kz,
TLitau@shokan.edu.kz

²K. Kulazhanov Kazakh University of Technology and Business, Astana, Kazakhstan; agaidarova.asel@kaztbu.edu.kz

*Correspondence: NGrabovskaya@shokan.edu.kz

Citation: Grabovskaya, N., Karnaukhova, T., Litau, T., Agaidarova, A. (2026). Evaluation of the efficiency of local post-treatment and conditioning of tap water (on the example of water vending machines in Kokshetau city). *Journal of Ecology and Sustainability*, 156(3), 43-60. <https://doi.org/10.32523/hf63s09>

Academic Editor:
A. Zandybay

Received: 16.07.2026
Revised: 03.09.2026
Accepted: 17.09.2026
Published: 30.09.2026



Copyright: © 2026 by the authors. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY NC) license (<https://creativecommons.org/licenses/by-nc/4.0/>)

Abstract. The study focuses on evaluating the efficiency of local post-treatment and conditioning of tap water using «Zhivaya Voda» stationary water vending machines in Kokshetau. The aim of the work was to conduct a comparative analysis of the properties of initial tap water and permeate obtained after filtration and reverse osmosis. «TURAN» bottled table water was adopted as a benchmark for comparing physicochemical parameters. Sampling for laboratory analysis was carried out in three districts of the city. The membrane elimination capacity was calculated using the classic formula for baromembrane separation. It was established that the cascade filtration system provides 100 % barrier efficiency against suspended solids, reducing turbidity to 0 NTU (Nephelometric Turbidity Units) and odor intensity by 1 point on the organoleptic scale. Spectrophotometric analysis demonstrated a high elimination rate of residual free chlorine (up to 96.0 %), total iron (up to 78.6 %), total chromium (up to 70.0 %), copper (25.0–40.0 %), manganese (up to 50.0%), and phosphate ions (up to 100 %), alongside characteristically lower selectivity toward low-molecular-weight singly charged nitrate anions. The results indicate a significant improvement in the overall physicochemical profile of the water. A directional downward shift in water pH was recorded in the samples, driven by the membrane's retention of the hydrocarbonate buffer and the concomitant carbonic acid equilibrium shift. Meanwhile, the stability of total hardness values confirmed the efficiency of water conditioning in the integrated mineralization unit, which completely prevents deep demineralization. The data obtained demonstrate that water vending machines effectively bring tap water quality closer to the natural benchmark parameters, which allows recommending them as an accessible method for decentralized drinking water safety enhancement at the consumer level.

Keywords: water quality; local post-treatment; water vending machines; water conditioning; reverse osmosis; remineralization; permeate; centralized water supply; drinking water.

1. Introduction

The Sustainable Development Goals (SDGs) represent a complex set of seventeen interconnected global targets aimed at improving human

quality of life. Goal 6, 'Clean Water and Sanitation,' focuses on ensuring the availability and sustainable management of water resources, guaranteeing not only public access to water but also compliance with sanitary and hygienic water quality standards. Safe and high-quality drinking water constitutes a fundamental cornerstone of modern healthcare and a pivotal prerequisite for the sustainable development of society (United Nations [UN], 2015; World Health Organization [WHO], 2024). Under conditions of increasing anthropogenic pressure, intensifying industrial production, and global climate change, a steady degradation in the state of natural water supply sources is being observed (Church, 2024; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2023). According to current statistical data, more than two billion people worldwide experience a deficit of clean drinking water (UN, 2024). The consumption of contaminated water coupled with poor sanitary and hygienic conditions leads to severe medical and environmental consequences, contributing to the spread of acute intestinal infections and somatic diseases (WHO, 2024). In this regard, a preventative approach focused on improving the quality of consumed water directly at the local level is recognized as the most cost-effective instrument for reducing public morbidity (UNESCO, 2023).

In the Republic of Kazakhstan, the water issue is of a strategic nature. The country is characterized by a pronounced deficit of its own water resources and a high dependence on transboundary hydrological systems, which significantly limits the self-purification potential of rivers and water bodies (Aben & Zholdasqyzy, 2026; Tursunova et al., 2022). Despite a formally high level of public coverage by centralized water supply (94 % in urban areas and 63 % in rural areas) (World Bank Group [WBG], 2022), the actual quality of the supplied water often raises justified concerns among end consumers. The primary reason for the degradation of drinking water quality characteristics on its path from treatment facilities to the consumer is the deterioration of communal distribution networks. As of 2025, the average wear and tear of water supply networks in the Akmola Region ranges from 51 % to 58 %, which represents an elevated indicator across the country (United Nations Economic Commission for Europe [UNECE], 2026). During transportation through old, corrosion-prone pipelines, the water undergoes secondary contamination by pipe degradation products, leading to an increase in total iron concentration, elevated turbidity, and deterioration of organoleptic properties (Li et al., 2016; Wang et al., 2025).

The traditional method of centralized disinfection—chlorination—effectively mitigates biological threats but gives rise to new risks. An excessive content of residual free chlorine imparts a specific unpleasant odor to the water and promotes the formation of halogenated compounds (Richardson & Postigo, 2012). Furthermore, in several industrial regions of Kazakhstan, including the Akmola Region and the city of Kokshetau, elevated concentrations of heavy metals (chromium, copper, manganese) are recorded in tap water, originating from surface water intakes due to anthropogenic pollution and rock leaching (Khripko & Baykenova, 2025; Salikova & Uralbayeva, 2016). Chronic consumption of such water is associated with the risk of cumulative toxicity and exerts a destructive impact on the liver, kidneys, and urogenital system (Balali-Mood et al., 2021; Chen et al., 2025; Teschke & Xuan, 2025).

Under these circumstances, standard domestic pitcher-type filters often prove ineffective due to their limited service life. Vending water purification machines (water vending machines) with integrated deep multi-stage treatment systems have emerged as an innovative and accessible alternative. Functioning on the basis of reverse osmosis technology, such localized units perform filtration under high pressure through semipermeable membranes with a pore size of up to $1 \cdot 10^{-4} \mu\text{m}$. A cascade of mechanical filters pre-cleans the water from insoluble impurities (sand, rust, suspended solids) up to 1 micron in size. Next, under high pressure, the water passes through a reverse osmosis membrane where the primary purification occurs: mainly water molecules and dissolved gases pass through the pore structure, whereas the salt concentrate is discharged into the drainage system (Dedele et al., 2022; Hazzazi et al., 2024; Kaepula et al., 2022; Yu et al., 2024). Subsequently, the water passes through a carbon post-filter and is disinfected by ultraviolet irradiation, which guarantees its microbiological safety.

In Kazakhstan, «Zhivaya Voda» water vending machines have been actively operated since 2015, offering clean water within walking distance at a socially oriented price. They are connected to the centralized water supply and can be installed both indoors and outdoors. The filters in the machines are replaced every two weeks, with the date of the last replacement displayed on the screen. Since reverse osmosis removes up to 99 % of all dissolved solids, leading to deep demineralization, a post-mineralization unit is integrated into the technological scheme of «Zhivaya Voda» vending machines. Passing through this cartridge, the purified water comes into contact with natural minerals (calcite and dolomite), becoming dosed and enriched with calcium ions, magnesium ions, and hydrocarbonates. This allows for the restoration of the physiological value and salt balance of the purified water, as well as the adjustment of its taste qualities. The manufacturer offers water at a price ranging from 10 to 15 KZT per liter (Alive Water Kazakhstan, 2026).

Despite the popularity of water vending machines, there is a pronounced deficit of independent comprehensive examinations in domestic science confirming the actual dynamics of improvement in the chemical composition and organoleptic qualities of water after its post-treatment under specific urban conditions. The present study is aimed at filling this gap.

Research Objective: An objective evaluation of the efficiency of mechanical post-treatment and conditioning of tap drinking water via «Zhivaya Voda» stationary units in the city of Kokshetau.

Relevance and Practical Significance: The findings will provide a scientific rationale for integrating local water vending machines into urban infrastructure as an effective tool for the decentralized enhancement of drinking water consumption safety.

2. Materials and methods

The object of the study was drinking water samples taken from the centralized water supply systems (urban water pipelines) in three districts of Kokshetau before and after treatment in «Zhivaya Voda» machines. The subject of the study was the quality of drinking water before and after mechanical post-treatment, as well as an evaluation of the efficiency of this method.

To ensure the integrity of the experiment, «TURAN» natural bottled table water was adopted as a comparative benchmark. Extracted from the underground sources of the Kokshetau Upland, it is positioned as high-quality natural water (Kokshetauskie Mineralnye Vody, n.d.). According to the manufacturer, it does not undergo reverse osmosis or artificial mineralization; it maintains the water-salt balance and is well absorbed by the body. «TURAN» water is extracted from the «Kuskol» deposit (Burabay region), which is recognized as one of only five unique sources of natural light water in the world. After filtration from rock particles and ozonation, it is bottled in its pristine form.

Sampling was performed in accordance with the regulatory requirements established by the Committee for Standardization, Metrology and Certification [CSMC] (2003). Sampling points were selected in residential buildings at the following addresses: 158B N. Nazarbayev Avenue (hereinafter referred to as 'Point 1'); 1/1 Osipenko Street (hereinafter referred to as 'Point 2'); and 198 Sh. Ualikhanov Street (hereinafter referred to as 'Point 3'). To ensure sample representativeness and eliminate the influence of stagnant plumbing fixtures, the initial tap water was allowed to run for 5–10 minutes at a constant flow rate before collection. Clean 500 mL glass containers were rinsed three times with the water being sampled, filled to the brim to prevent volatile component loss, and immediately sealed. All samples were meticulously labeled with the exact date, time, and specific location of collection.

2.1. Evaluation of organoleptic and physical parameters

Organoleptic and physical parameters of the water samples were evaluated using the following methodologies:

- 1) Odor intensity and color parameters were determined in accordance with the CSMC (2003) requirements;
- 2) Turbidity was determined using a PCE–TUM 20 Turbidity Meter (Direct Industry by Virtualexpo Group, n.d.);

3) Water pH was initially screened at the sampling sites using universal pH indicator paper 0–12 (Tautest, n.d.). To eliminate instrumental errors and obtain high-precision values for subsequent statistical analysis, the final pH measurements were verified photometrically using a HACH DR 1900 spectrophotometer (Ecoinstrument LLC, n.d.).

To ensure analytical quality control and data reproducibility, all instrumental measurements (turbidity and pH) were performed in quintuplicate for each water sample, and the average values were recorded. Prior to each analysis cycle, calibration protocols for the PCE–TUM 20 and HACH DR 1900 instruments were executed using verified standard baseline solutions.

2.2. Spectrophotometric chemical analysis

Chemical analysis of water samples was performed by spectrophotometry using the previously described HACH DR 1900 instrument. During the study, concentrations of total iron (Fe^{2+} , Fe^{3+}), nitrates (NO_3^-), phosphates (PO_4^{3-}), free chlorine (Cl_2), copper (Cu^{2+}), total chromium (Cr^{3+} , Cr^{6+}), and manganese (Mn^{2+}), as well as total hardness, were determined. Standard laboratory glassware, graduated cylinders, pipettes, and specialized HACH reagents were used during the analysis. Measurements for each parameter were performed according to the corresponding instrument program code (Table 1).

Table 1. Spectrophotometer program codes for determining chemical parameters of water

No.	Parameter	Program Code
1	Free chlorine	81
2	Total iron	90
3	Nitrates	73
4	Phosphates	60
5	Total hardness	85
6	Copper	65
7	Chromium	76
8	Manganese	45

Water samples of 10 mL were placed into cuvettes, mixed with the corresponding reagents, and kept on a timer until the completion of the chemical reaction. Before each measurement cycle, the specific program code was entered, and the instrument was calibrated using verified baseline solutions and control blanks. To ensure analytical quality control and eliminate random operational errors, all laboratory analyses were performed in five replicates (*in quintuplicate*) for each controlled parameter, and the arithmetic mean values were recorded.

The membrane rejection coefficient (purification efficiency), E , %, was determined using the classic formula for baromembrane separation (Dytnerskii, 1986):

$$E = \frac{C_f - C_p}{C_f} \times 100\% \quad (1)$$

where E is the purification efficiency, %; C_f is the concentration of substances in the *feed water*, mg/L; and C_p is the concentration of substances in the *permeate*, mg/L.

The compliance of the studied parameters with hygienic requirements was evaluated based on the drinking water safety standards of the Republic of Kazakhstan (Ministry of Healthcare of the Republic of Kazakhstan, 2022). Natural bottled water «TURAN» was utilized as a reference sample.

Statistical processing of the obtained results, including the calculation of mean values, standard deviations (SD), and standard errors (SE), was performed using the MS Excel software package.

3. Results

For an objective evaluation of the performance efficiency of «Zhivaya Voda» stationary local post-treatment systems, a comprehensive comparative analysis of the physicochemical and organoleptic parameters of the initial tap water and the permeate generated after passing through membrane filters and reverse osmosis processes with subsequent conditioning was conducted.

3.1. Organoleptic parameters and water pH

Organoleptic evaluation and pH monitoring serve as primary indicators of the sanitary and chemical condition of water. Summary measurement data are presented in Table 2.

Table 2. Changes in organoleptic properties and pH value during advanced *POU water treatment

Parameter	Standard (not more than) (Ministry of Healthcare, 2022)	«TURAN» Water (reference)	Point 1: N. Nazarbayev Ave, 158		Point 2: Osipenko St, 1/1		Point 3: Ualikhanov St, 198	
			Before	After	Before	After	Before	After
Turbidity, NTU	2,6	0 ± 0	0,5 ± 0,15	0 ± 0	1,2 ± 0,4	0 ± 0	1,05 ± 0,3	0 ± 0
Odor, points	2	0 ± 0	1 ± 0	0 ± 0	2 ± 1	1 ± 0	2 ± 1	1 ± 0
Color, degrees	20 (35)	15 ± 0	15 ± 1,5	15 ± 2	20 ± 2,5	20 ± 3,5	15 ± 1,5	15 ± 1,8
pH, units	6,5–7,5	7,5 ± 0	7,5 ± 1,5	6,5 ± 0,55	8,0 ± 0,5	6,0 ± 0,55	8,0 ± 0,5	7,5 ± 0,5

*POU - point-of-use

Analysis of the obtained data reveals that the barrier function of the membrane systems against suspended solids reaches 100 %, reducing turbidity to zero values (0 NTU) in all samples, which fully complies with the benchmark indicators (Figure 1; Table 2).

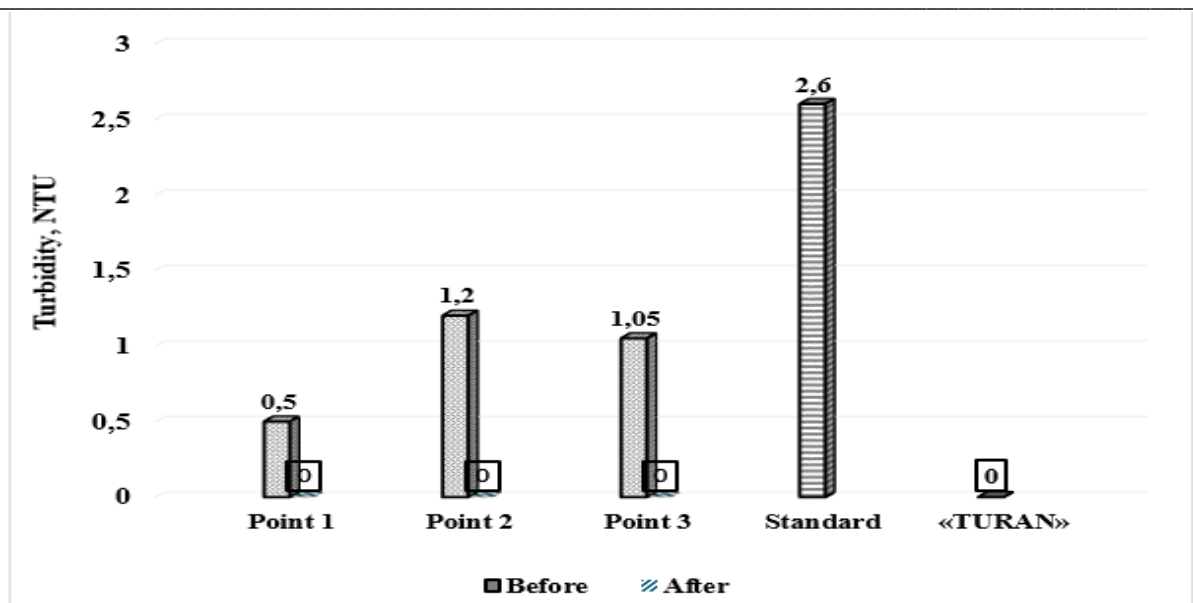


Figure 1. Dynamics of turbidity changes in the investigated water samples during advanced POU treatment

Deodorization of the purified water is observed: the odor intensity decreased by 1 point on the organoleptic scale in all studied water samples, except for the «TURAN» water sample, where this value was initially 0 (Table 2).

Color analysis revealed that the initial tap water at all sampling points was characterized by stable values at the level of 15–20 degrees, which strictly complies with the hygienic standard (no more than 20–35 degrees) (Table 2). In the course of mechanical filtration, the color indicators of the permeate remained practically unchanged, staying within a narrow range of 15–20 degrees across all three points (Table 2). Minor fluctuations in the mean values (for instance, at Point 1, the indicator was recorded at 15 degrees both before and after treatment) lie within the margin of statistical error for laboratory measurements. The obtained results are completely identical to the parameters of the «TURAN» natural benchmark (15 degrees), which indicates that the initial water of Kokshetau complies with hygienic standards for this parameter and that optical transparency is maintained after baromembrane separation (Table 2).

The hydrogen ion exponent (pH) of the initial water is characterized by a slightly alkaline and alkaline reaction of the medium (7.5–8.0) (Table 2). In the course of mechanical post-treatment, a shift in the pH of the resulting permeate into the slightly acidic region was recorded. This decrease in pH (down to 6.0–6.5 units at Points 1 and 2) can be explained by the nature of reverse osmosis: the membrane retains hydrocarbonate ions (HCO_3^-), thereby reducing the buffer capacity, while CO_2 penetrates through the pores, forming carbonic acid (Table 2). In turn, the higher pH value at Point 3 (7.5 units) presumably indicates a final alkalization of the solution due to the intensive dissolution of components within the integrated remineralization unit (Table 2).

3.2. Spectrophotometric analysis of chemical composition

The results of the quantitative determination of chemical components by spectrophotometry, as well as the calculated elimination efficiency (E, %) of individual impurities, are presented in Table 3.

Table 3. Chemical component concentrations and advanced POU treatment efficiency (E, %)

Parameter , mg/L	Standard (Ministry of Healthcare, 2022)	«TURAN» Water (reference)	Point 1: N. Nazarbayev Ave, 158		Point 2: Osipenko St, 1/1		Point 3: Ualikhanov St, 198	
			*C _f	**C _p	C _f	C _p	C _f	C _p
Total iron (Fe ²⁺ , Fe ³⁺)	0,3	0,03	0,07± 0,015	0,015± 0,0075	0,135± 0,05	0,08± 0,015	0,15± 0,06	0,1± 0,055
			E = 78,6 %		E = 40,7 %		E = 33,3 %	
Nitrates (NO ₃ ⁻)	45	5	1±0,25	1±0,2	1±0,25	1±0,3	5±1,55	3±1
			E = 0 %		E = 0 %		E = 40,0 %	
Total hardness, mEq/L	7	3,25	2,4 ±0,65	2,5±0,8	2,85±0,5	2,8±0,9	2,7± 0,8	2,8±0,75
			E = -4,2 %		E = +1,7 %		E = -3,7 %	
Phosphate s (PO ₄ ³⁻)	3,5	0,3	0	0	0,3±0,06	0	0,3±0,07	0,2±0,05 5
			E = 0 %		E = 100 %		E = 33,3 %	
Free chlorine (Cl ₂)	0,3 – 0,5	0,01	0,03± 0,0095	0,008± 0,002	0,05±0,0 1	0,002± 0,00085	0,035± 0,0075	0,025± 0,0095
			E = 73,3 %		E = 96,0 %		E = 28,6 %	
Copper (Cu ²⁺)	0,5	0,15	0,3± 0,075	0,2±0,06	0,4±0,1	0,3±0,08	0,5± 0,15	0,3±0,09 5
			E = 33,3 %		E = 25,0 %		E = 40,0 %	
Total chromium (Cr ³⁺ , Cr ⁶⁺)	0,05	0,04	0,05± 0,009	0,015± 0,0085	0,05±0,0 1	0,025± 0,0085	0,035±0, 1	0,03± 0,0095
			E = 70,0 %		E = 50,0 %		E = 14,3 %	
Manganese e (Mn ²⁺)	0,1	0,09	0,05± 0,01	0,045± 0,015	0,06± 0,02	0,035±0,0 1	0,02± 0,007	0,01± 0,0065
			E = 10,0 %		E = 41,7 %		E = 50,0 %	

*C_f - feed water concentration; **C_p - permeate concentration

3.2.1. Iron and copper removal

The initial concentrations of total iron (0.07–0.15 mg/L) and copper (0.3–0.5 mg/L) did not exceed the MPC (Maximum Permissible Concentration), yet they indicated probable secondary water contamination processes within the deteriorated distribution networks. Local treatment reduces the iron content with an efficiency of up to 78.6 %, bringing its level closer to the biogenic benchmark (Figure 2; Table 3).

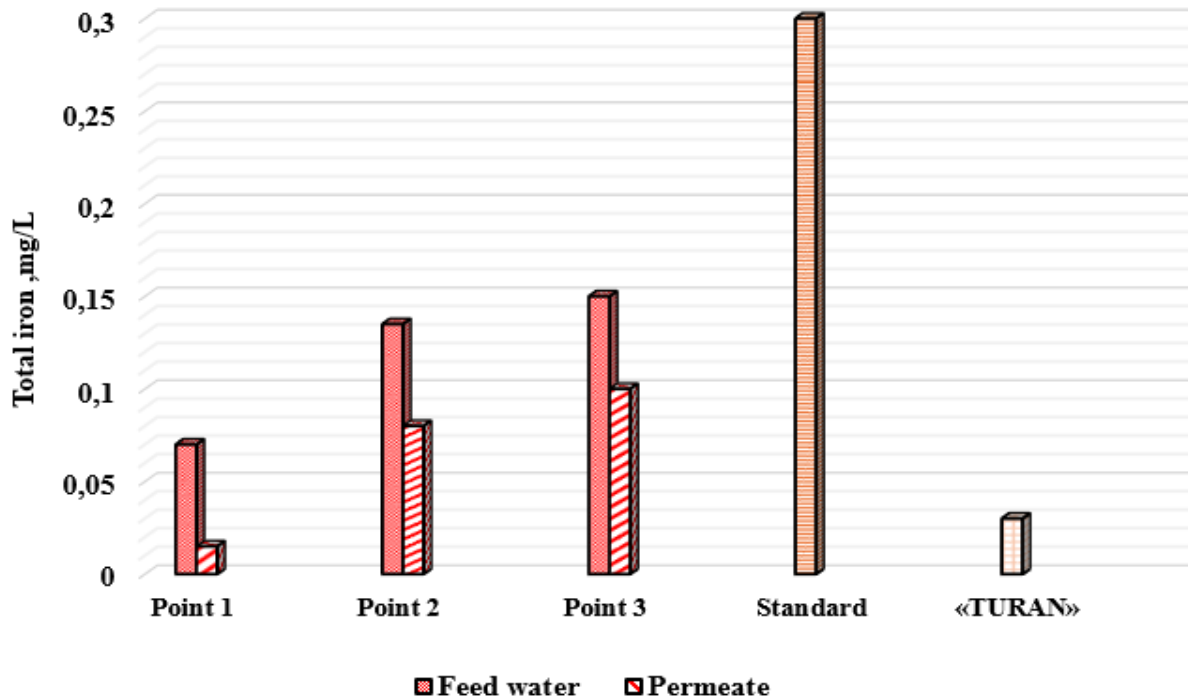


Figure 2. Total Iron (Fe^{2+} , Fe^{3+}) Removal efficiency by the barrier systems of water vending machines

The copper concentration stably decreases by 25.0–40.0 % (Table 3).

3.2.2. Toxic Chromium Removal

Chromium is a heavy metal with a pronounced cumulative toxic effect. In the initial water, its concentration was at a critical level near the upper limit of the normative standard (0.035–0.05 mg/L, with an MPC of 0.05 mg/L) (Figure 3; Table 3).

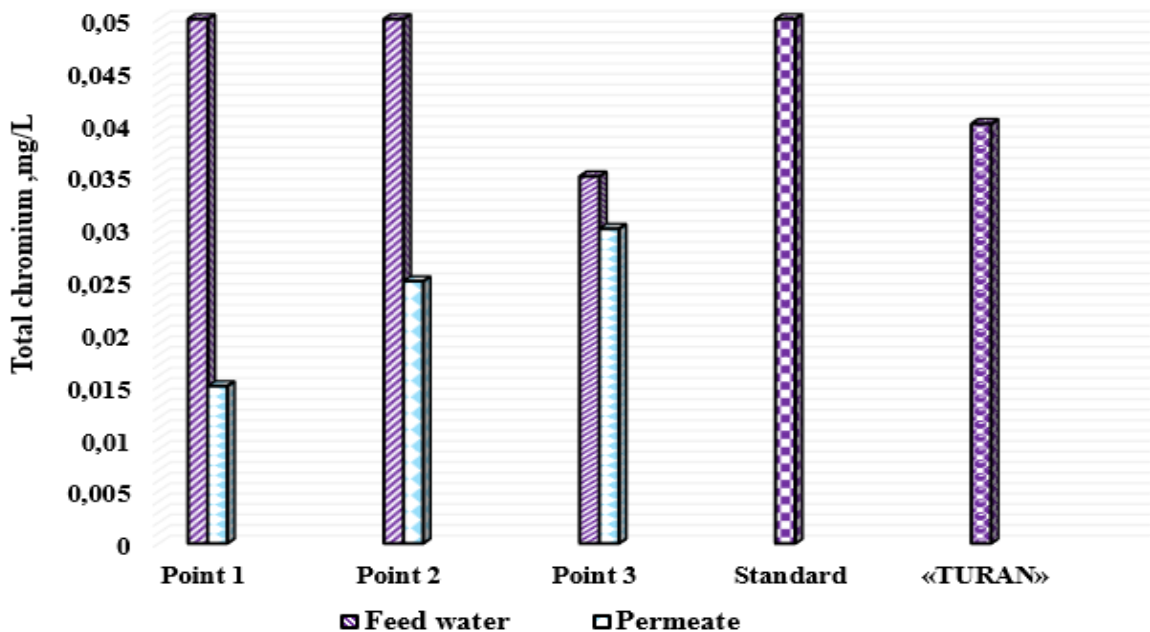


Figure 3. Comparative analysis of total chromium (Cr^{3+} , Cr^{6+}) content in raw and purified water

Mechanical filtration provides deep chromium extraction with an efficiency ranging from 14.3% to 70.0 %. Notably, in the «TURAN» natural water, the chromium content was also quite high (0.04 mg/L) but did not exceed the MPC.

3.2.3. Free chlorine elimination

Despite the low residual concentrations of free chlorine within the centralized network (0.03–0.05 mg/L) (Figure 4; Table 3), the sorption blocks of the water vending machines exhibit a high efficiency in capturing the disinfectant - up to 96.0 % (at Point 2).

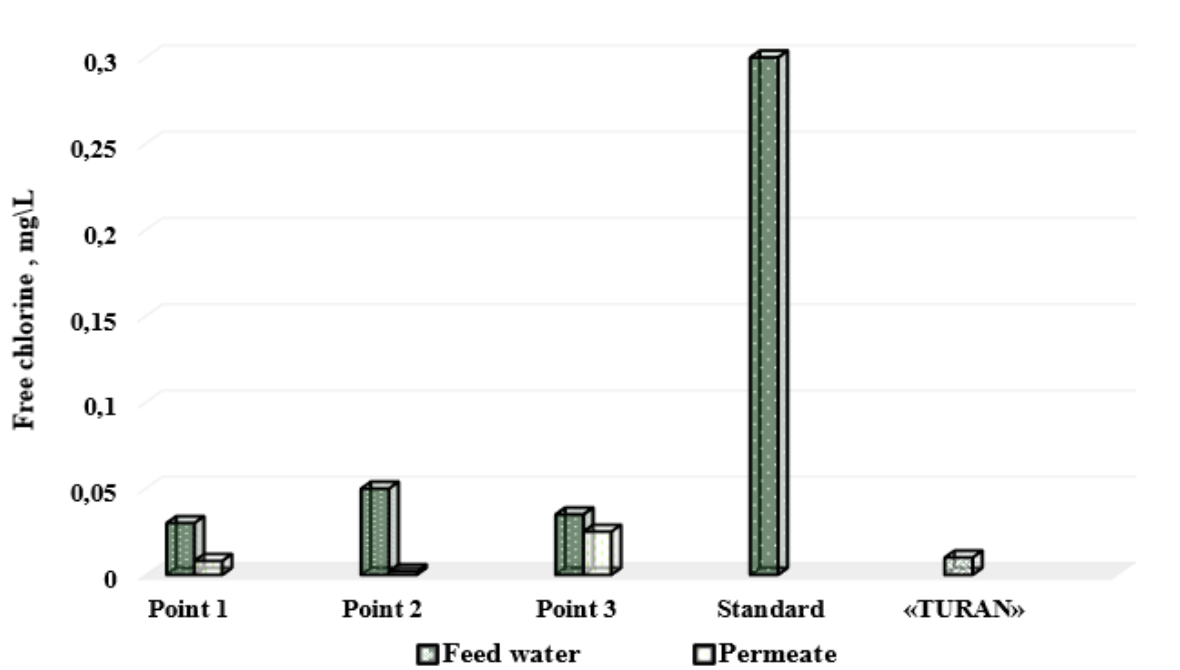


Figure 4. Changes in residual free chlorine (Cl_2) concentration following sorption-membrane filtration)

This allows for the complete neutralization of the risks associated with the formation of carcinogenic halogenated compounds.

3.2.4. Stability of total hardness

The total hardness value fluctuations across all points remain within a narrow range (2.4–2.85 mEq/L) and exhibit virtually no change after decentralized filtration (variations from -4.2 % to +1.7%, which fall within the margin of measurement error) (Table 3). A slight increase in total hardness ($E = -4.2\%$) at sampling Point 1 may be attributed to the permissible instrumental error of the HACH DR 1900 spectrophotometer when measuring low concentrations, or to the specific operating conditions of the remineralization unit in this particular system (Table 3). The obtained values are physiologically valuable and comparable to the mineralization of «TURAN» natural water (3.25 mEq/L). The high stability of this parameter against the background of deep reverse osmosis demineralization is presumably explained by the efficient performance of the integrated final correction unit - the mineralizer. Passing through a cartridge with natural minerals (calcite/dolomite), the deeply purified permeate becomes dosed and enriched with calcium and magnesium ions (conditioned), which prevents its demineralization and artificially restores the physiological value of the drinking water to the level of the benchmark.

3.2.5. Dynamics of nitrate and phosphate content

Analysis of the nutrient concentration revealed varying selectivity of the barrier systems towards nitrate and phosphate ions. The initial nitrate (NO_3^-) concentration within the Kokshetau tap water network was at a minimum level (1–5 mg/L), well below the regulatory limit of 45 mg/L (Table 3). At Points 1 and 2, the baromembrane purification demonstrated zero efficiency ($E = 0\%$), confirming the reduced selectivity of standard domestic reverse osmosis membranes towards low-molecular-weight singly charged anions under low operating pressures (Gomelya et al., 2022; Table 3). At Point 3, where the initial nitrate level was higher (5 mg/L), a decrease to 3 mg/L was recorded ($E = 40.0\%$) (Table 3). The observed discrepancy in efficiency requires a more detailed analysis. While this phenomenon is widely documented, the reason for such a sharp transition from zero to 40% efficiency within this experiment remains unclear. Possible factors influencing the observed difference include (Muhammad et al., 2020; Rojas-Ramos et al., 2023):

1) *operational parameter fluctuations*: variations in operating pressure, flow rate, or temperature among Points 1, 2, and 3 could significantly affect membrane selectivity;

2) *concentration polarization effect*: at low flow rates or insufficient pressure, concentration polarization could occur, causing contaminants to accumulate on the membrane surface, which hinders their passage but does not ensure complete retention - the extent of this effect could vary across the studied points;

3) *initial water composition specificities*: potentially, the presence of other dissolved solids in the water at Point 3, besides nitrates, influenced their interaction with the membrane.

Nevertheless, despite the questions regarding the attainment of full purification efficiency at individual points, the nitrate content in the purified product (1–3 mg/L) is completely comparable to the indicator of the «TURAN» natural benchmark (5 mg/L) (Table 3).

Regarding phosphate ions, the sorption-membrane cascade demonstrated high efficiency: at Point 2, a 100 % elimination was recorded (a decrease from 0.3 mg/L to zero), while at Point 3, the phosphate content decreased by 33.3 % (from 0.3 to 0.2 mg/L) (Table 3). In all cases, the final concentrations are kept well within the regulatory hygienic limit (3.5 mg/L) (Table 3).

3.2.6. Manganese removal efficiency

Manganese compounds (Mn^{2+}) possess a pronounced cumulative effect and are capable of deteriorating the organoleptic properties of water (U.S. Environmental Protection Agency, 2004; World Health Organization, 2022). The initial manganese level at the studied points of the distribution network fluctuated within the range of 0.02–0.06 mg/L, without exceeding the MPC (0.1 mg/L) (Table 3). After passing through the «Zhivaya Voda» units, a stable positive dynamic in the removal of this metal was recorded: the purification efficiency ranged from 10.0 % (Point 1) to 41.7 % (Point 2) and 50.0 % (Point 3) (Table 3). At the final stage of post-treatment, the manganese concentration decreased to 0.01–0.045 mg/L, which is substantially below the regulatory limits (Table 3).

4. Discussion

The data obtained in the course of the study allow for a detailed evaluation of the filtration capacity and selectivity of the semipermeable reverse osmosis membranes utilized in «Zhivaya Voda» local post-treatment vending machines. The observed changes in the physicochemical and organoleptic profile of the tap water are governed by the fundamental laws of mass transfer and phase separation at the solution–polymer matrix interface.

The reduction of water turbidity to 0 NTU across all monitored sampling sites serves as a clear indicator of the efficiency of the cascade filtration blocks (Figure 1; Table 2). Similar results regarding turbidity and color parameters were documented in a study by Thuadaij and Duangkham (2024) evaluating 101 water vending machines in Thailand, which also demonstrated 100 % compliance with regulatory standards. This effect is achieved through mechanical size exclusion on ultra- and nanofiltration pre-filters, combined with a polishing reverse osmosis membrane featuring a pore size of less than 0.0001 μm . This process completely prevents the passage of colloidal particles, hydrated oxides of iron and silicon, and high-molecular-weight organic matter. Specifically, the

removal of total iron (up to 78.6 %) is ensured by the combined action of this mechanical filter cascade and the selective reverse osmosis membrane (Al Sayed et al., 2012; Figure 2; Table 3). Furthermore, the deodorization effect observed in both studies is attributed to the operation of pre-sorption units based on activated carbon; the recorded deep elimination of residual free chlorine (up to 96.0 %) is directly driven by the high sorption capacity of this pre-treatment unit (Altekrety & Al-Fatlawy, 2017; Figure 4; Table 3), which efficiently adsorbs dissolved volatile organic compounds and active chlorine residues.

A process of directional reduction in the hydrogen ion exponent (pH) was recorded (Table 2). At Points 1 and 2, the pH of the initial alkaline water decreased to slightly acidic values (6.0–6.5 units); at Point 3, the reduction was less pronounced, shifting from 8.0 down to 7.5 units (Table 2). Permeate acidification is a typical manifestation of baromembrane separation (Dytterskii, 1986). Highly selective reverse osmosis membranes retain up to 98–99 % of multicharged anions, including hydrocarbonate ions (HCO_3^-), which form the buffering capacity of the initial solution. As a result of the alkaline buffer removal, dissolved carbon dioxide (CO_2), which freely penetrates through the membrane pores, reacts with water, shifting the carbonic acid equilibrium toward the formation of weak carbonic acid (H_2CO_3). A study by Thuadaij and Duangkham (2024) also revealed a widespread drop in pH below regulatory limits, where 81.19 % of the examined vending machines exhibited pH values between 3.24 and 6.40. This demonstrates the universality of the physicochemical process of permeate acidification during reverse osmosis application without subsequent correction (Adams et al., 2022; Table 2).

Notably, in our study, the total water hardness across all points remained stable (Table 3). This indicates the occurrence of artificial remineralization processes, which were most pronounced at Point 3 (Table 2; Table 3). From a physiological and organoleptic standpoint, the preservation of total hardness is a critical factor preventing an aggressive or 'flat' taste typical of raw reverse osmosis permeate. As the deeply purified water passes through the remineralization bed containing natural crushed calcite (CaCO_3) and dolomite ($\text{CaMg}(\text{CO}_3)_2$), a controlled dissolution process takes place. The unreacted dissolved free (CO_2) acts as a primary driving agent, reacting with the carbonate matrix of the minerals to form soluble calcium and magnesium bicarbonates via a classic leaching mechanism. This interaction enriches the water with vital divalent cations while functioning as a natural chemical buffer. The differences in the final pH values among the points are attributed to varying depletion levels or flow rates of water through the mineralizing cartridges, where the final alkalization of the solution occurs due to the intensive dissolution of components within the integrated remineralization unit, which aligns with the operating principles of local solution conditioning systems (Vingerhoeds et al., 2016; Table 2; Table 3). Specifically, lower volumetric flow rates or lower depletion levels prolong the hydraulic retention time within the mineralizer, maximizing mineral leaching and successfully shifting the carbonic acid equilibrium toward complete neutralization.

The membranes demonstrated virtually zero selectivity toward nitrate ions NO_3^- : at Points 1 and 2, the retention efficiency was 0 % (Table 3). This is explained by their small hydrated radius and high mobility, which hinder their rejection by the polymer matrix under the standard operating pressures of domestic systems (Gomelya et al., 2022; Table 3). Under these low operating pressures typical for point-of-use (POU) systems (approximately 2–4 bar), the convective transport of solvent through the polymer matrix often overrides the diffusive rejection component for low-molecular-weight monovalent species. Due to their low hydration energy, nitrates exhibit higher mobility within the concentration polarization layer, which substantially reduces the effective electrostatic repulsion forces - known as the Donnan potential - thereby allowing unhindered passage of monovalent anions into the permeate stream at low initial concentrations. At Point 3, where the initial nitrate level was the highest, a 40.0 % reduction in their concentration was recorded (Table 3). Such a discrepancy in efficiency within this experiment remains unclear, yet it suggests a concentration-dependent threshold effect related to competitive ion transport and membrane fouling dynamics. According to Muhammad et al. (2020) and Rojas-Ramos et al. (2023), the barrier function of membranes can be influenced by

external factors (operating parameters of water vending machines, the concentration polarization effect, initial water composition specificities, etc.) that were not accounted for during this study. For instance, a localized drop in the feed flow rate or micro-fluctuations in operating pressure within the vending unit at Point 3 could have facilitated a localized transformation of the concentration polarization profile, shifting mass transfer toward a diffusion-dominated regime where the physical sieve-retention properties of the polymeric dense structure became more pronounced. Nevertheless, given that the initial nitrate concentrations were extremely low (1 mg/L against an MPC of 45 mg/L), the resulting product remains safe regarding this parameter (Table 3). At the same time, the deep removal of phosphate ions (up to 100 % at Point 2) is explained by their large hydrated radius and multicharged nature. Under baromembrane separation conditions, such ions are effectively repelled by the Donnan potential of the membrane, which guarantees the protection of the finished permeate from the presence of phosphates that can alter the organoleptic properties of water (Aydogan Gokturk et al., 2022; Gomelya et al., 2023; Pleshakov et al., 2023; Table 3).

Unlike nitrate ions, reverse osmosis systems effectively retain heavy metal cations. Membranes demonstrate a consistently high rejection capacity (exceeding 95–99 %) towards many metals, which is attributed to their significant hydrated radius, high valence, and the action of Donnan electrostatic repulsion forces on the surface of the polymer matrix (Azmi et al., 2025; Thaçi & Gashi, 2018). In our samples, the removal efficiency varied from 14.3 % up to 70.0 % for total chromium and up to 78.6 % for total iron (Figure 2; Figure 3; Table 3). Chromium, present in the initial tap water at the upper limit of the MPC (0.05 mg/L), was reduced to safe values (0.015–0.03 mg/L) (Figure 3; Table 3). Similarly, a stable reduction was observed for copper (Cu^{2+}) ions, with an elimination efficiency ranging from 25.0 % to 40.0 % (Table 3). This process successfully lowered copper concentrations across all points down to 0.2–0.3 mg/L, remaining well below the regulatory limit of 0.5 mg/L and closely matching the biogenic benchmark of the «TURAN» reference water (0.15 mg/L) (Table 3). Although the chromium content in the «TURAN» natural benchmark (0.04 mg/L) is also within the normal range, decentralized mechanical post-treatment yields water that may surpass certain natural underground sources of the region in terms of toxicological safety, as the latter can be prone to natural or anthropogenic metal enrichment (Imbulana et al., 2020; Figure 3; Table 3). The removal efficiency of manganese ions (Mn^{2+}) was slightly lower than that of chromium and iron, ranging from 10.0 % to 50.0 % (Table 3). Despite the fact that the initial manganese concentrations did not exceed the MPC, its elimination is considered important from a sanitary and hygienic perspective (Table 3). This is attributed to the ability of manganese compounds to cause cumulative neurotoxicity, as well as their tendency to degrade the organoleptic parameters of water (taste, color) even at minimal concentrations due to the formation of a dark precipitate of hydrated oxides (U.S. Environmental Protection Agency, 2004; World Health Organization, 2022; Table 3).

Overall, the conducted study demonstrates that the multi-stage mechanical purification in «Zhivaya Voda» stationary vending machines effectively corrects the organoleptic and chemical composition of tap drinking water, which consistently aligns with existing global research on point-of-use (POU) water post-treatment systems.

5. Conclusion

The conducted study has provided a comprehensive evaluation of the barrier role and performance efficiency of «Zhivaya Voda» stationary local post-treatment vending machines in relation to the conditions of the centralized drinking water supply in the city of Kokshetau. Based on the data obtained, the following key conclusions have been formulated:

1. The cascade filtration system, based on sorption processes and baromembrane separation, ensures absolute 100 % efficiency against suspended solids, reducing the initial tap water turbidity to 0 NTU. Concurrently, the integrated technology achieves substantial sample deodorization, consistently lowering the odor intensity by 1–2 points on the organoleptic scale.

2. Spectrophotometric analysis confirmed the high barrier efficiency of the multi-stage system against key inorganic and organic pollutants. The cascade configuration ensured deep elimination of

residual free chlorine, total iron, total chromium, manganese, and phosphate ions, while providing a moderate, stable reduction of copper ions (up to 40.0 %). Concurrently, the system exhibited characteristically lower selectivity toward low-molecular-weight singly charged nitrate anions. Despite variations in ion-selective retention, the reduction of the cumulative impurity load successfully brought the physicochemical profile of the purified permeate closer to the natural benchmark parameters of «TURAN» bottled water.

3. A directional trend in hydrogen ion exponent changes was established: the reduction to slightly acidic values (6.0–6.5 units at Points 1 and 2) and the shift toward neutral values at Point 3 are driven by the membrane's retention of the hydrocarbonate buffer and the concomitant shift in the carbonic acid equilibrium. Concurrently, the maintenance of stable and physiologically valuable total hardness values in the purified water experimentally proves the performance efficiency of the integrated artificial mineralization units, which completely eliminate the risks of deep demineralization of the finished product.

In conclusion, under stable technological operating regimes, «Zhivaya Voda» vending machines serve as an effective instrument for the hygienic correction of tap water composition, ensuring the enhancement of its organoleptic and physicochemical characteristics at the consumer level. Further research into optimizing the performance of membrane elements in relation to high-load systems will expand the application scope of this technology.

6. Supplementary Materials: No supplementary material.

7. Author Contributions

Conceptualization - N.G.; methodology - N.G.; software - N.G.; validation - N.G., T.K., T.L., A.A.; formal analysis - N.G.; investigation - N.G.; resources - T.K., T.L.; data curation - N.G.; writing - original draft preparation - N.G.; writing - review and editing - N.G., T.K., T.L., A.A.; visualization - N.G.; supervision - A.A.; project administration - T.K.; funding acquisition - T.K., T.L., A.A. All authors have read and agreed to the published version of the manuscript.

8. Author Information

Grabovskaya, Natalya – M.Sc., senior lecturer, Sh. Ualikhanov Kokshetau University, Abay st., 76, Kokshetau, Kazakhstan, 020000; NGrabovskaya@shokan.edu.kz, <https://orcid.org/0000-0001-7826-1161>

Karnaukhova, Tatyana – M.Sc., senior lecturer, Sh. Ualikhanov Kokshetau University, Abay st., 76, Kokshetau, Kazakhstan, 020000; tatyanakarnauhova@shokan.edu.kz, <https://orcid.org/0000-0003-2597-682X>

Litau, Tatyana – M.Sc., senior lecturer, Sh. Ualikhanov Kokshetau University, Abay st., 76, Kokshetau, Kazakhstan, 020000; TLitau@shokan.edu.kz, <https://orcid.org/0009-0005-3581-7429>

Agaidarova, Asel – M.Sc., senior lecturer, Kazakh University of Technology and Business named after K. Kulazhanov, K. Mukhamedzhanov st., 37A, Astana, Kazakhstan, 010000; agaidarova.asel@kaztbu.edu.kz, <https://orcid.org/0009-0002-3107-9834>

9. Funding: This research received no external funding.

10. Acknowledgements: The authors express their gratitude to Yulia Khrustaleva for her technical assistance in water sampling and laboratory analysis conducted during her study period at Sh. Ualikhanov Kokshetau University.

11. Conflicts of Interest: The authors declare no conflicts of interest.

12. References

1. Aben, A., & Zholdasqyzy, Z. (2026). *Kazakhstan's Water Security: Current Challenges and Future Alternatives: Analytical Report*. Kazakhstan Institute for Strategic Studies under the President of the Republic of Kazakhstan. <https://kisi.kz/wp-content/uploads/2026/04/eng-water-security-in-kz-2026-poln-1.pdf>
2. Adams, H., Burlingame, G., Ikehata, K., Furatian, L., & Suffet, I. H. (2022). The effect of pH on taste and odor production and control of drinking water. *AQUA - Water Infrastructure Ecosystems and Society*, 71(11), 1278–1290. <https://doi.org/10.2166/aqua.2022.133>
3. Al Sayed, M. A., Kamel, M. K., Hamdy, A., Mohammed, K. Z., & Abbas, M. A. (2012). Reverse osmosis (RO) pretreatment: removal of iron in groundwater desalination plant in Shupramant-Giza – a case study. *Current World Environment*, 7(1), 23–32. <http://dx.doi.org/10.12944/CWE.7.1.04>
4. Alive Water Kazakhstan. (2026). Vending machines for purification and sale of drinking water for bottling - Alive Water (Vendingovyye apparaty po ochistke i prodazhe pit'yevoy vody dlya rozliva v taru - Zhivaya voda in Russian). <https://alivewater.kz/>
5. Altekrety, A. A., & Al-Fatlawy, Y. F. (2017). The study of the efficiency of household reverse osmosis system to remove the pollutants from different water sources. *International Journal of Scientific & Nature*, 8(4), 674–680. [https://www.scienceandnature.org/IJSN/IJSN_Vol8\(4\)D2017/IJSN-VOL8\(4\)17-10.pdf](https://www.scienceandnature.org/IJSN/IJSN_Vol8(4)D2017/IJSN-VOL8(4)17-10.pdf)
6. Aydogan Gokturk, P., Sujanani, R., Qian, J., Wang, Y., Katz, L. E., Freeman, B. D., & Crumlin, E. J. (2022). The Donnan potential revealed. *Nature Communications*, 13(1), 5880. <https://doi.org/10.1038/s41467-022-33592-3>
7. Azmi, L. S., Jabit, N. A., Ismail, S., Ku Ishak, K. E. H., & Abdullah, T. K. (2025). Membrane filtration technologies for sustainable industrial wastewater treatment: a review of heavy metal removal. *Desalination and Water Treatment*, 323, 101321. <https://doi.org/10.1016/j.dwt.2025.101321>
8. Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. *Frontiers in Pharmacology*, 12, 643972. <https://doi.org/10.3389/fphar.2021.643972>
9. Chen, J., Wang, X., & Liu, Y. (2025). The association between low-concentration heavy metal exposure and chronic kidney disease risk through α -klotho. *Scientific Reports*, 15(1), 9601. <https://doi.org/10.1038/s41598-025-96016-4>
10. Church, J. M. (2024). *UN Initiatives on Water Management in Central Asia and Potential Entry Points*. Issue-Based Coalition on Environment and Climate Change; United Nations Economic Commission for Europe. https://unece.org/sites/default/files/2025-01/IBC%20Central%20Asia%20Water%20Paper%202024_Final.pdf
11. Committee for Standardization, Metrology and Certification of the Ministry of Industry and Trade of the Republic of Kazakhstan. (2003). Drinking water. General requirements for organization and quality control methods: ST RK GOST R 51232 – 2003 (Voda pitevaya. Obshchie trebovaniya k organizatsii i metodam kontrolya kachestva: ST RK GOST R 51232 – 2003 in Russian). Gosstandart <https://waterservice.kz/downloads/rd/gst7.pdf?ysclid=ld3fpwacho899490449>
12. Dedele, A., Nikiforov, N., Madiyeva, A. N., & Miškinytė, A. (2022). Potential of water vending machine to remove trihalomethanes and heavy metals during high and low water seasons in Petropavlovsk. *Polish Journal of Environmental Studies*, 31(2), 1667–1674. <https://doi.org/10.15244/pjoes/143255>
13. Direct Industry by Virtualexpo Group. (n.d.). *Turbidity Meter PCE-TUM 20* (Turbidity Meter PCE-TUM 20 in Russian). Retrieved January 5, 2023, from <https://www.directindustry.com.ru/prod/pce-deutschland-gmbh/product-37414-1616695.html>
14. Dytnerskii, Yu. I. (1986). Baromembrane processes. Theory and calculation (Baromembrannye protsessy. Teoriya i raschet in Russian). Khimiya. https://www.studmed.ru/dytnerskiy-yu-i-baromembrannye-processy-teoriya-i-raschet_4aea33d5c50.html

15. Ecoinstrument LLC. (n.d.). *DR 1900 Portable spectrophotometer* (DR 1900 Portativnii spectrophotometer in Russian). Retrieved January 5, 2023, from https://www.ecoinstrument.ru/catalog/fiziko_khimicheskii_analiz/spektrofotometri/dr1900/
16. Gomelya, M., Shabliy, T., Makarenko, I., & Vakulenko, A. (2022). Efficiency of reverse osmosis and ion exchange in water purification from nitrates. *Journal of Ecological Engineering*, 23(10), 172–180. <https://doi.org/10.12911/22998993/152457>
17. Gomelya, M., Vakulenko, A., Trus, I., & Taranenko, A. (2023). Determining the efficiency of reverse osmosis in the purification of water from phosphates. *Journal of Ecological Engineering*, 24(4), 104–111. <https://doi.org/10.12911/22998993/157023>
18. Hazzazi, L. W., Soto-Rojas, A. E., & Martínez-Mier, E. A. (2024). The effect of water filter pitchers on the mineral concentration of tap water. *Journal of Public Health Dentistry*. Advance online publication. <https://doi.org/10.1111/jphd.12649>
19. Imbulana, S., Oguma, K., & Takizawa, S. (2020). Evaluation of groundwater quality and reverse osmosis water treatment plants in the endemic areas of chronic kidney disease of Unknown Etiology (CKDu) in Sri Lanka. *Science of The Total Environment*, 745, 140716. <https://doi.org/10.1016/j.scitotenv.2020.140716>
20. Khripko, E. N., & Baykenova, G. E. (2025). Ecological assessment of drinking water in Akmola region (Ekologicheskaya otsenka pitievoy vody Akmolinskoy oblasti in Russian). *Vestnik Nauki*, 1(4), 541–546. <https://cyberleninka.ru/article/n/ekologicheskaya-otsenka-pitievoy-vody-akmolinskoy-oblasti>
21. Kokshetau Mineral Waters. (n.d.). *TURAN natural still drinking water in a PET bottle, volume 1.0 L*. Export.gov.kz; Ministry of Trade and Integration of the Republic of Kazakhstan. <https://export.bgov.kz/ru/agricultural/30/turan-natural-still-drinking-water-in-a-pet-bottle-volume-1-0-l/>
22. Li, M., Liu, Z., Chen, Y., & Hai, Y. (2016). Characteristics of iron corrosion scales and water quality variations in drinking water distribution systems of different pipe materials. *Water Research*, 106, 593–603. <https://doi.org/10.1016/j.waters.2016.10.044>
23. Lumami Kapepula, V., García Alvarez, M., Sang Sefidi, V., Buleng Njoyim Tamungang, E., Ndikumana, T., Musibono, D.-D., Van Der Bruggen, B., & Luis, P. (2022). Evaluation of commercial reverse osmosis and nanofiltration membranes for the removal of heavy metals from surface water in the Democratic Republic of Congo. *Clean Technologies*, 4(4), 1300–1316. <https://doi.org/10.3390/cleantechnol4040080>
24. Ministry of Healthcare of the Republic of Kazakhstan. (2022). On approval of Hygienic standards for safety indicators of domestic and drinking and cultural and community water use: Order of the Minister of Healthcare of the Republic of Kazakhstan dated November 24, 2022, No. KR DSM-138 (Ob utverzhdenii Gigienicheskikh normativov pokazatelei bezopasnosti khozyaistvenno-pitevogo i kulturno-bitovogo vodopolzovaniya in Russian). Information and Legal System of Normative Legal Acts of the Republic of Kazakhstan "Adilet". <https://adilet.zan.kz/rus/docs/V2200030713>
25. Muhammad, M.S., Abdul-Wahab, M. F., Saidin, M. A. R., Asraf, M. H., & Nik Malek, N. A. N. (2020). Microbiological analysis of drinking water from water vending machines. *Malaysian Journal of Fundamental and Applied Sciences*, 16(2), 186–189. <https://doi.org/10.11113/mjfas.v16n2.1486>
26. Pleshakov, N. A., Belikov, M. L., & Safaryan, S. A. (2023). Water purification from phosphate ions using different reagents (Ochistka vody ot fosfat-ionov s primeneniem razlichnykh reagentov in Russian). *Trudy Kol'skogo Nauchnogo Centra RAN. Seriya: Tehnicheskie Nauki*, 14(5), 60–66. <https://doi.org/10.37614/2949-1215.2023.14.5.011>
27. Richardson, S. D., & Postigo, C. (2012). Drinking water disinfection by-products. In D. Barceló (Ed.), *Emerging Organic Contaminants and Human Health* (pp. 93–137). Springer. https://doi.org/10.1007/698_2011_125

28. Rojas-Ramos, M., de la Cruz, M. B., del Rosario-Sosa, M., & de la Cruz, K. S. (2023). Evaluation of concentration polarization due to the effect of feed flow rate on reverse osmosis membranes using CFD. *Membranes*, 13(1), 3. <https://doi.org/10.3390/membranes13010003>
29. Salikova, N. S., & Uralbayeva, A. A. (2016). Monitoring of hydrochemical indicators of surface reservoirs of Akmol region (*Monitoring gidrokhimicheskikh pokazateley poverkhnostnykh vodoyemov Akmolinskoy oblasti* (in Russian)). *Actual Problems of Humanities and Natural Sciences (Aktual'nyye Problemy Gumanitarnykh i Yestestvennykh Nauk)*, (2-4), 185–188. <https://cyberleninka.ru/article/n/monitoring-gidrokhimicheskikh-pokazateley-poverkhnostnykh-vodoemov-akmolinskoy-oblasti>
30. Tautest. (n.d.). Universal pH indicator paper 0–12 (*Indikatornaya bumaga universal'naya pH 0–12*). Tautest.kz. <https://tautest.kz/product-category/ph-metry/indikatornaya-bumaga-universalnaya-ph-0-12/>
31. Teschke, R., & Xuan, T. D. (2025). Heavy metals like aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc polluting the drinking water: their individual health hazards. *International Journal of Molecular Sciences*, 26(23), 11656. <https://doi.org/10.3390/ijms262311656>
32. Thaçi, B. S., & Gashi, S. T. (2018). Reverse osmosis removal of heavy metals from wastewater effluents using biowaste materials pretreatment. *Polish Journal of Environmental Studies*, 27(3), 1105–1113. <https://doi.org/10.15244/pjoes/81268>
33. Thuadaij, P., & Duangkham, S. (2024). Quality Assessment of Drinking Water from Vending Machines for a Healthier Life. *South East European Journal of Public Health (SEEJPH)*, 24, 252–262. <https://doi.org/10.70135/seejph.vi.579>
34. Tursunova, A., Medeu, A., Alimkulov, S., Saparova, A., & Baspakova, G. (2022). Water resources of Kazakhstan in conditions of uncertainty. *Journal of Water and Land Development*, (54), 138–149. <https://doi.org/10.24425/jwld.2022.141565>
35. U.S. Environmental Protection Agency. (2004). *Drinking water health advisory for manganese*. EPA Office of Water. <https://nepis.epa.gov/Exe/ZyPDF.cgi/P100537R.PDF?Dockey=P100537R.PDF>
36. United Nations Economic Commission for Europe. (2026). *Project of Revised National Target Indicators of the Republic of Kazakhstan under the UNECE - WHO/Europe Protocol on Water and Health* (Proekt peresmotrennykh natsionalnykh tselevykh pokazateley Respubliki Kazakhstan po Protokolu po problemam vody i zdorovya EEK OON – VOZ/Evropa in Russian). UNECE. <https://unece.org/environment/documents/2026/05/revised-national-targets-republic-kazakhstan-under-unece-who-europe>
37. United Nations Educational, Scientific and Cultural Organization. (2023). *The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water*. UNESCO. <https://doi.org/10.54679/QQJG4824>
38. United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. <https://sdgs.un.org/2030agenda>
39. United Nations. (2024). *The United Nations World Water Development Report 2024: Water for Prosperity and Peace*. UNESCO. <https://digitallibrary.un.org/record/4042870?v=pdf>
40. Vingerhoeds, M. H., Nijenhuis-de Vries, M. A., Ruepert, N., van der Laan, H., Bredie, W. L. P., & Kremer, S. (2016). Sensory quality of drinking water produced by reverse osmosis membrane filtration followed by remineralisation. *Water Research*, 94, 42–51. <https://doi.org/10.1016/j.watres.2016.02.043>
41. Wang, Z., Yang, X., Fu, L., & Li, M. (2025). A review of secondary contamination of drinking water quality in distribution systems: sources, mechanisms, and prospects. *AQUA - Water Infrastructure, Ecosystems and Society*, 74(1), 118–141. <https://doi.org/10.2166/aqua.2024.284>
42. World Bank Group. (2022). *Kazakhstan Country Climate and Development Report*. World Bank. <https://doi.org/10.1596/38215>

43. World Health Organization. (2022). *Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda*. World Health Organization. <https://iris.who.int/server/api/core/bitstreams/69c17edd-ee26-425b-9d34-33799377e886/content>
44. World Health Organization. (2024). *Guidelines for Drinking-Water Quality: Small Water Supplies – Global Update 2024*. WHO Publishing. <https://www.who.int/publications/i/item/9789240088740>
45. Yu, H.-Y., Gupta, S., & Zhou, Z. (2024). Removal of metals and assimilable organic carbon by activated carbon and reverse osmosis point-of-use water filtration systems. *Chemosphere*, 365, 143251. <https://doi.org/10.1016/j.chemosphere.2024.143251>

Құбыр суын жергілікті қосымша тазарту мен кондициялаудың тиімділігін бағалау (Көкшетау қаласындағы су автоматтары мысалында)

Наталья Грабовская, Татьяна Карнаухова, Татьяна Литая, Асель Агайдарова

Аңдатпа. Зерттеу Көкшетау қаласындағы «Живая вода» маркалы стационарлық су тазарту автоматтарының (суматтардың) көмегімен құбыр суын жергілікті қосымша тазарту мен кондициялаудың тиімділігін бағалауға арналған. Жұмыстың мақсаты - бастапқы құбыр суы мен сүзу және кері осмос процестерінен кейін алынған пермеат қасиеттерін салыстырмалы түрде талдау. Физика-химиялық параметрлерді салыстыруға арналған эталон ретінде «TURAN» бөтелкедегі ас суы қабылданды. Зертханалық талдау үшін сынамалар қаланың үш ауданында іріктеліп алынды. Мембраналардың элиминациялау қабілетін есептеу баромембраналық бөлудің классикалық формуласы бойынша жүргізілді. Каскадты сүзу жүйесі өлшенген заттарға қатысты абсолютті 100 %-дық тосқауылдық тиімділікті қамтамасыз етіп, лайлылықты 0 NTU (Nephelometric Turbidity Units) деңгейіне дейін төмендететіні анықталды. Бұл ретте құбыр суының иіс қарқындылығы органолептикалық шкала бойынша 1 балға төмендеп, терең дезодорациялануы тіркелді. Спектрофотометриялық талдау қалдық бос хлорды (96,0 %-ға дейін), жалпы темірді (78,6 %-ға дейін), жалпы хромды (70,0 %-ға дейін), мысты (25,0-40,0 %), марганецті (50,0 %-ға дейін) және фосфат-иондарды (100 %-ға дейін) жоюдың жоғары дәрежесін көрсетті, бұл ретте төмен молекулалы бір зарядты нитрат-аниондарға қатысты селективтіліктің тән төмендігі байқалды. Алынған нәтижелер судың жалпы физика-химиялық профилінің айтарлықтай жақсарғанын және қоспалардың жиынтық жүктемесінің азайғанын айғақтайды. Гидрокарбонатты буфердің мембранада ұсталып қалуына және көмірқышқыл тепе-теңдігінің соған байланысты ығысуына негізделген су рН көрсеткішінің төмендеу үрдісі тіркелді. Бұл ретте жалпы кермектік көрсеткіштерінің тұрақтылығы интеграцияланған минерализация блогында суды кондициялаудың тиімділігін растады, бұл дайын өнімнің терең деминерализациялануын толықтай болдырмайды. Алынған мәліметтер суматтардың құбыр суының сапасын табиғи эталон параметрлеріне тиімді жақындататынын көрсетеді, бұл оларды тұтынушылық деңгейде ауыз суды тұтыну қауіпсіздігін орталықсыздандырылған түрде арттырудың қолжетімді әдісі ретінде ұсынуға мүмкіндік береді.

Түйін сөздер: су сапасы; жергілікті қосымша тазарту; су автоматтары; суды кондициялау; кері осмос; реминерализация; пермеат; орталықтандырылған сумен жабдықтау; ауыз су.

Оценка эффективности локальной доочистки и кондиционирования водопроводной воды (на примере водоматов в городе Кокшетау)

Наталья Грабовская, Татьяна Карнаухова, Татьяна Литая, Асель Агайдарова

Аннотация. Исследование посвящено оценке эффективности локальной доочистки и кондиционирования водопроводной воды с помощью стационарных автоматов очистки воды (водоматов) марки «Живая вода» в городе Кокшетау. Целью работы являлся сравнительный анализ свойств исходной водопроводной воды и пермеата, полученного после фильтрации и обратного осмоса. В качестве эталона для сравнения физико-химических параметров принята бутилированная столовая вода «TURAN». Отбор проб для лабораторного анализа выполнялся в трёх районах города. Расчёт элиминирующей способности мембран проводился по классической формуле баромембранного разделения. Установлено, что каскадная система фильтрации обеспечивает абсолютную 100 %-ю барьерную эффективность по отношению к взвешенным веществам, снижая мутность до 0 NTU (Nephelometric Turbidity Units). При этом зафиксирована глубокая дезодорация водопроводной воды со снижением интенсивности её запаха на 1 балл по органолептической шкале. Спектрофотометрический анализ показал высокую степень элиминации остаточного свободного хлора (до 96,0 %), общего железа (до 78,6 %), общего хрома (до 70,0 %), меди (25,0-40,0 %), марганца (до 50,0 %) и фосфат-ионов (до 100 %) при характерно более низкой селективности к низкомолекулярным однозарядным нитрат-анионам. Полученные результаты свидетельствуют о значительном улучшении общего физико-химического профиля воды и снижении совокупной нагрузки примесей. Зафиксировано направленное изменение pH воды в сторону снижения, обусловленное удержанием гидрокарбонатного буфера мембраной и сопутствующим сдвигом углекислотного равновесия. При этом стабильность показателей общей жёсткости подтвердила эффективность кондиционирования воды в интегрированном блоке минерализации, что полностью предотвращает глубокое деминерализованное готового продукта. Полученные данные демонстрируют, что водоматы эффективно приближают качество водопроводной воды к параметрам природного эталона, что позволяет рекомендовать их как доступный способ децентрализованного повышения безопасности питьевого водопотребления на потребительском уровне.

Ключевые слова: качество воды; локальная доочистка; водоматы; кондиционирование воды; обратный осмос; реминерализация; пермеат; централизованное водоснабжение; питьевая вода.