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Groundwater quality in coal mines of Ukraine: possibility of using it as drinking water

Iryna Shvets[1,2*], Yevgen Zbykovskyy[3], Olha Bohomaz[4]

[1] E.O. Paton Electric Welding Institute (PWI), 11, Kazymyr Malevych St., 03150, Kyiv, Ukraine
[2] Donetsk National Technical University, Shybankova Sq., 2, 85300, Pokrovsk, Ukraine
[3] Chemical Engineering Department, Donetsk National Technical University, Shybankova Sq., 2, 85300, Pokrovsk, Ukraine
[4] Technical University "Metinvest Polytechnic" LLC, 80, Pivdenne shose, 69008, Zaporizhzhya, Ukraine
* Corresponding author's e-mail: iryna.shvets@donntu.edu.ua

ABSTRACT

The article outlines the results of a study of groundwater in the mines of the Donetsk and Lviv-Volyn coal basins of Ukraine. Comparative analysis of groundwater in 9 mines of the Lviv-Volyn coal basin and 7 mines of the Donetsk coal basin confirmed the influence of the depth of mine workings on the quality of groundwater. It was established that there is a significant excess of standard values for water quality parameters: Hardness, content of chlorides, sulfates, calcium and magnesium. The use of groundwater from the "Centralna" mine is connected with the catastrophic deterioration of the situation with water supply to the population of Myrnohrad and Pokrovsk (Donetsk region) due to military actions. The study of groundwater in the "Centralna" mine was conducted using 122 parameters in the Chemical and Veterinary Inspection Offices of Stuttgart, Freiburg and Sigmaringen, Germany. Significant excesses of standard values were found for the following indicators: electrical conductivity, coloration, content of sulfate, sodium and chloride. The content of Trifluoroacetic acid was detected in groundwater, reaching 0.1360 μg/l. Analysis of groundwater after its preliminary treatment revealed no improvement in quality parameters. After treatment, the mine water contained Trifluoroacetic acid and Acesulfam-K E950. Their sources have not been identified.

Keywords: mine water, groundwater, chemicals, water quality standards, safety.

INTRODUCTION

Climate change, reduction of fresh water reserves, and ecological disasters lead to a sharp reduction of drinking water reserves. The shortage of fresh water on the planet requires the search for alternative sources of water supply. Groundwater is an extremely valuable resource of fresh water for drinking and agricultural use, and its value increases with the growth of the planet's population and the reduction of fresh water reserves in many parts of the world. In coal-mining countries, the use of groundwater from mines is an alternative source of water supply for the population and industrial consumption, especially for the countries and regions experiencing a shortage of drinking water. The problem of using mine water for drinking and technological purposes has already been widely discussed in scientific papers. Water from abandoned mines is the subject of research for various purposes, primarily as a source of drinking water [Medas et al., 2019]. Regardless of the exploitation method and the purpose of further use, it must be pumped to the surface and, as a rule, treated in accordance with environmental standards. At the same time, in most cases, it is discharged into rivers [Cień et al., 2024; Akpan et al., 2021].

It was proven that mining provides significant economic value while often impacting local water supplies and environment because of usage of treated mine [Miller et al., 2021]. The economic feasibility of treating mine water for use as drinking water is the main factor in deciding whether to use mine water [Dvořáček et al., 2022]. The quality of the water is a key factor governing the ability to sell the water after treatment but, in the case of polluted water, constructing a water purification plant of an appropriate nature is a simple engineering process [Clay et al., 2022].

One of the potential threats to the quality of underground and surface water sources is the drainage from abandoned mines [Tomiyama and Igarashi, 2022]. Long-term studies show that the impacts of mine water on all kinds of water sources continues to occur regardless of mining activities. It is noted that mine water rebound and flooding do not automatically reduce long-lasting impacts on surface waters [Janson, 2024]. At the same time, the discharge of mine water leads to salinization of the territories.

Taking into account the low quality of most mine waters, they are primarily considered as a source of technical water supply. Hydrogeological and hydrogeochemical studies of mine waters confirm the possibility of using them for individual space heating projects, district heating/cooling systems or for preheating air for mine ventilation. Examples of such applications are already known from Canada, US, Netherlands, UK, Spain, and Poland [Janson et al., 2016]. In Spain, the mine water from the abandoned and flooded Barredo-Santa Bárbara coal mine system is used as a source of low-potential energy for the heating and air conditioning system of a local hospital [Lara et al., 2017]. The possibility of using mine water as a geothermal energy source is being considered [Loredo et al., 2017]. The use of purified mine water in the cooling system of thermal power plants in China is a successful example [Gao et al., 2016]. In Indonesia, a system for treating acidic mine water is used to produce clean water, which is used for sanitary purposes and as technical water during coal mining [Islamudin et al., 2023]. The experience of Ukrainian mines shows that the use of forecasting hydrodynamic solutions allows minimizing environmental risks and justifying heat supply systems using mine water [Bazaluk et al., 2021; Sadovenko et al., 2020].

Coal mines are the sources of large volumes of mine wastewater. The amount of water pumped out of the mine workings depends on the location of the coal seams and the characteristics of the aquifer. On average, in the coal regions of Ukraine, about 10 m^3 of mine water is generated per ton of coal mined. This indicator is quite high, since, for example, in the coal regions of Poland, one ton of coal mined accounts for 3 m^3 [Mitko et al., 2024], and in China – 1.87 m^3 [Guo et al., 2023]. There are various technological schemes for the accumulation and storage of groundwater in underground reservoirs with purification for final consumption, also as drinking water [Guo et al., 2023].

The groundwater from coal deposits, penetrating into mine workings, interacts with rocks, metal fasteners and equipment [Bondarenko et al., 2024]. As a result of the interaction of groundwater with metal equipment in mine workings, the iron concentration in water increases [Zbykovskyy et al., 2025]. During wartime in the East of Ukraine, when mines are flooded, the equipment is not extracted to the surface, remaining in the flooded mine workings. Currently, there is a large amount of mining equipment remained in the flooded mines. It can be assumed that the saturation of mine waters with iron will occur over a long time in large quantities.

The chemical composition of mine waters directly depends on the physicochemical properties of the host rocks, cation exchange, mineral dissolution, pyrite oxidation, silicate weathering, and other processes occurring in the “mine water-rock system” [Xu et al., 2022; Zhang et al., 2019]. Detailed knowledge of the seasonal hydrochemical regime allows understanding the origin of mine waters. It is also indispensable for accurate assessment of the impact of mine water on surface water quality, as well as design of water treatment technologies [Bajtoš, 2022; Yang et al., 2024].

Mine waters contain colloidal substances and impurities of organic and inorganic origin. The solid mineral part of mine waters is particles of sand, clay, coal and rock. The solutions also contain salts, alkalis, acids, petroleum products, and sometimes radioactive substances [Wysocka et al., 2019]. Chinese mine water with suspended solids accounts for 60% of all mine water. The study found the following characteristics of mine water: neutral, mostly gray-black color, and high amount of suspended matter and turbidity. According to the actual measurement statistics of the suspended solids content in mine water, the mines with suspended solids content of less than 300 mg/L account for approximately 80%, while the mines with suspended solids content of more than 500 mg/L account for less than 12% [Du et al., 2021]. Various bacteriological impurities and microorganisms, such as molds and intestinal microbes, are an essential part of mine waters. Common to most mine waters in coal-mining regions of the world is the presence of a significant number of suspended solids (coal and rock particles) and high salinity. The most typical inorganic components in mine water with high salinity are Ca^{2+}, Mg^{2+}, K^+, Na^+, SO_4^{2-}, Cl^-, HCO^{3-} [Gaoa et al., 2020].

The water extracted from mines as a result of mining activities often exhibits specific chemical and physical compositions, presenting both challenges and potential benefits for various economic sectors [Cień et al., 2024]. An assessment of the quality of mine water and its impact on the environment of surface and groundwater was carried out at 97 mines in France, Greece, Germany, Poland, Spain and the United Kingdom as part of the MANAGER research project of the European Commission's Coal and Steel Research Fund [Gombert et al., 2019]. The coal mine water quality evaluation notes a first group of pollutants, represented by SO_4 and Fe, which were shared by all countries. Most of the research is devoted to the investigation of the presence of heavy metals in groundwater and mine water. Studies of coal mine water in India have shown that the high levels of sulfates and heavy metals cause high concentrations of these chemicals in mine water, but also in surface water and river sediments around coalfields [Chabukdhara and Singh, 2016].

Currently, in coal-mining countries, studies are being actively conducted to determine the suitability of mine water as a source of drinking water supply. A hydrogeochemical study of surface water of the West Bokaro Coalfield (India) has been undertaken to assess its quality and suitability for drinking, domestic and irrigation purposes [Tiwari et al., 2016]. It was found that in majority of the samples, the analyzed parameters are well within the desirable limits and water is potable for drinking purposes. However, concentrations of TDS, TH, Ca^{2+}, Mg^{2+} and Fe exceeded the desirable limits in some water samples and needs treatment before utilization. A geochemical study of mine water in the Western Jharia Coalfield area (India) and water quality assessment indicated that total dissolved solids (TDS), total hardness (TH), magnesium and sulfate are the major parameters of concern in the study area and make it unsuitable for drinking and domestic purposes [Kumar and Singh, 2016]. The study of underground water samples in the mining areas of Jharia Coalfield found that pH of the samples were mildly acidic to alkaline (6.5 to 8.3) with varying total hardness (149 to 719 mg L^{-1}), total dissolved solids (341 to 953 mg L^{-1}), and electrical conductivity (568 to 1389 µS cm^{-1}), reflecting heterogeneity in underlying hydrosystems, variations in geological formations, as well as the influence of lithogenic and anthropogenic processes on the water chemistry of the region [Mazinder Baruah and Singh, 2022].

In general, each mine is characterized by its own specific composition of mine water. In mines in China, most mine waters have elevated fluoride levels, ranging from 0.05 to 11.65 mg/L with an average of 1.96 mg/L, compared to a drinking water standard of up to 1 mg/L [Zhang et al., 2021]. A characteristic feature of the Makum coal deposit, which is located in India, is the high sulfur content in the coal, which leads to the formation of acidic mine waters, with a pH value of 5.8 [Chandra and Ghosh, 2024]. Analysis of the mine water samples from the "Grot" Pb–Zn mine (Serbia) showed that the water has a neutral pH, and heavy metals as well as other hazardous compounds are absent. This suggests that the water in most of the selected samples meets the criteria for drinking, which opens up the possibility of its use for drinking needs [Kretic et al., 2024].

MATERIALS AND METHOD

Description of the study area

The quality and safety of groundwater differ depending on the biogeochemical zones, the concentration of industrial enterprises, and the state of treatment plants, creating problems in different regions of Ukraine [Shulyak et al., 2021]. The total forecast resources of groundwater are 22.5 × 10^6 million m^3/year. The explored operational reserves of underground drinking and technical water on January 1st, 2023 were 5.96 × 10^6 million m^3/year. In 2022, water withdrawal from groundwater sources, including mine and quarry sources, was 787 million m^3/year. Most of the groundwater (61.8%) extracted in Ukraine is used for domestic and drinking water (37.3%), industrial (17.5%), agricultural needs (6.6%), and land irrigation (0.4%). Part of the groundwater from mine workings during mineral extraction (38.2%) is discharged without use [National Report, 2023].

In recent years, the groundwater from coal mines has become a strategic, and in some cases the only, source of water for the population of the eastern part of the Donetsk region [Donbas environment, 2021]. In 2022, water withdrawal from groundwater sources in the Donetsk region was 63.3 million m^3/year (23.7% of total water withdrawal). Water use from groundwater sources is only 9.2 million m^3/year (14.6%). Much of the groundwater in the Donetsk region was used for industrial purposes (64.7%), domestic and drinking (27.4%). A small amount of groundwater was used for irrigation (0.4%) and other needs (7.6%). During mineral extraction, 54.1 million m^3/year (85.4%) of groundwater is discharged without use [National Report, 2023]. The low level of groundwater use in the Donetsk region is caused by active military operations.

The local study was conducted with groundwater from the "Centralna" mine, located in the city of Myrnohrad, Pokrovsk district of the Donetsk region, Ukraine (Figure 1). Pokrovsk district is an administrative-territorial unit in the west of the Donetsk region with a total area of 4004.1 km². The population of the Pokrovsk district before the full-scale Russian aggression was 413,000 people.

The landscape of the Pokrovsk district is predominantly steppe, typical for eastern Ukraine. The Pokrovsky district is characterized by a lack of surface water. There are only a few small rivers, which are not enough to completely supply the population with drinking water. Since 2014, the main source of drinking water in the Pokrovsk district of the Donetsk region has been the Karlivka Reservoir and groundwater from wells [Shvets et al., 2025; Zbykovskyy et al., 2024]. However, due to the destruction of the dam during military operations, water losses from the reservoir were 9.85 million cubic meters. As a result, the Pokrovsk district was left without a centralized water supply. Therefore, residents of the Pokrovsk district are faced with the catastrophic problem of shortage and quality of drinking water. In order to provide the residents of Pokrovsk and Myrnohrad with water, a decision was made to use the groundwater of the "Centralna" mine as a reserve source.

The purpose of this study was to monitor the quality of groundwater from the "Centralna" mine in the city of Myrnohrad, which is used as a backup water supply for the population of the Pokrovsk district of the Donetsk region.

MATERIALS AND METHODOLOGY

The article is based on the data obtained as a result of the analysis of groundwater quality parameters from the coal mine, located in the city of Myrnohrad, Donetsk region (Ukraine). The object of the study was the samples of groundwater from the "Centralna" mine. Water samples were taken from a common ground reservoir, where water was supplied from two horizons of the "Centralna" mine: 300 and 600 m. Taking into account the possibility of further use of groundwater from the "Centralna" mine as drinking water, the study was conducted according to European standards for the food quality, including drinking water.

The investigations of groundwater samples were carried out in the Chemical and Veterinary Inspection Office Stuttgart, Chemical and Veterinary Inspection Office Freiburg, as well as Chemical and Veterinary Investigation Office Sigmaringen, Germany. The study of groundwater of the "Centralna" mine was carried out according to 11 groups of parameters. The total number of studied parameters was 122. The content of chemicals and other substances in groundwater was determined using the methods given in Table 1.

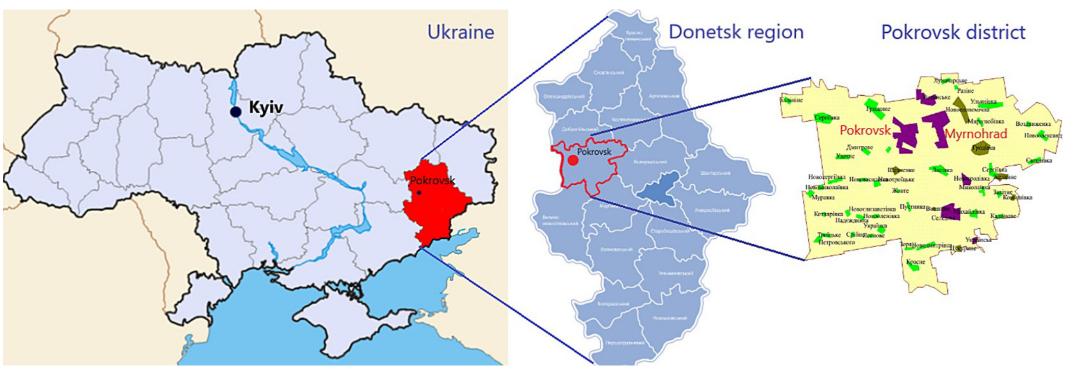

Figure 1. Geographical localization of Myrnohrad city, Pokrovsk district in the east of Ukraine

Drinking water samples were analyzed chemically and analytically. The parameters were determined in accordance with European water quality standards adapted in Germany, as well as standards for determining individual water quality parameters. Research methods and assessment of water quality parameters differ in Germany and Ukraine. For example, German standards do not include such parameters as total mineralization and total hardness. Instead, they define electrical conductivity, which characterizes the total amount of chemical compounds dissolved in water.

RESULT AND DISCUSSION

Mine water quality in eastern and western Ukraine

Mining and geological conditions and the tectonic structure of mine workings, as well as climatic conditions, determine the chemical composition and characteristics of mine waters in Ukraine [Vergelska and Verkhovtsev, 2023]. The mining, geological and hydrodynamic conditions of Ukrainian mines in different coal basins differ significantly. These differences are especially typical for the mines of the Donetsk and Lviv-Volyn coal basins which are located in the East and West of Ukraine. This article provides a comparative analysis of groundwater in 9 mines of the Lviv-Volyn coal basin and 7 mines of the Donetsk coal basin (Figure 2).

The peculiarity of mine waters is the great diversity of their chemical composition, which can change with the depth of extraction [Wolkersdorfera and Mugova, 2022]. One of the main differences between the Ukrainian mines of different coal basins is their depth (Figure 3).

Unlike Donetsk coal basin, the mines of the Lviv-Volyn basin have a smaller depth, simpler geological and hydrogeological conditions. In the Donetsk coal basin, there are more powerful aquifers, water exchange is more developed and water inflows into the mines are more intense. The depth of coal seams in this basin ranges from 300 to 650 meters. This circumstance is reflected in the difference in the chemical composition of

Table 1. Laboratory methods used to determine chemicals and other substances in groundwater

Research method/equipment	Groups of parameters	Number of parameters		
		Measured	Compliant with water quality standards	%
High-performance liquid chromatography (HPLC) coupled with tandem mass spectrometry (MS/MS), HPLC-MS/MS	Pesticide	39	-[*]	-
	Non-relevant pesticide metabolites, degradation and reaction products	19	-	-
	Drugs and drug degradation products[*]	9	-	-
	Artificial sweeteners	3	-	-
	Other industrial chemicals	3	-	-
	Other parameters	3	-	-
Inductively coupled plasma mass spectrometry, ICP-MS	Chemical elements: B, Al, Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Sb, Ba, Ti, Pb, U, V	17	17	100
Photometry, electrometry; ion chromatography (IC) with conductivity detection	Physical and physic-chemical parameters	16	11	69
Gamma Spectrometry	Radioactive isotopes	7	-	-
Ion chromatography coupled with tandem mass spectrometry, IC-MS/MS, direct measurement	Per- and polyfluorinated alkyl substances (PFAS)	1	1	100
Atomic fluorescence spectroscopy (AFS) and the cold vapor technique	Hg	1	1	100
Gas chromatography–mass spectrometry (acetonitrile extract, liquid injection); Liquid chromatography (LC) with orbitrap mass spectrometry (MS)	Foreign substances/ xenobiotic	4	-	-

Note: [*] There is no standard value for each parameter.

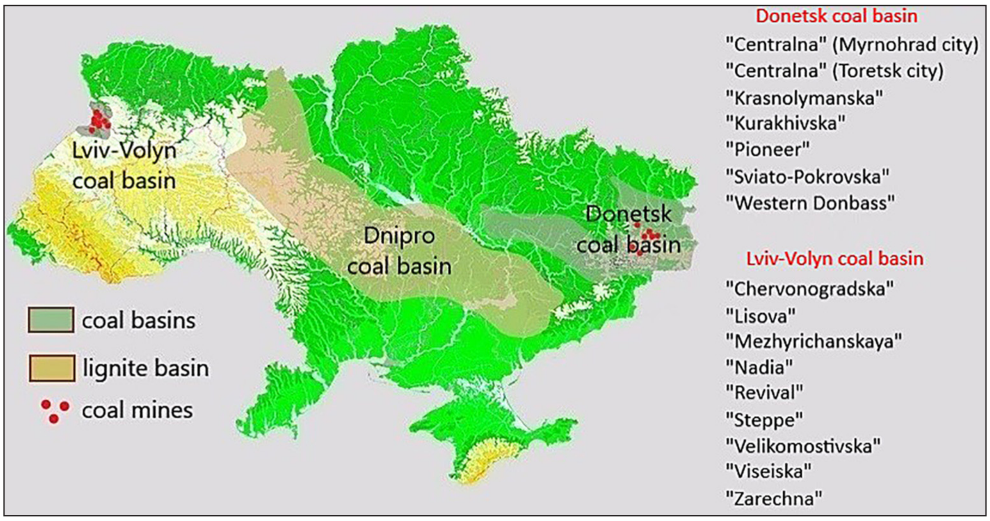

Figure 2. Geographical location of Ukrainian coal basins

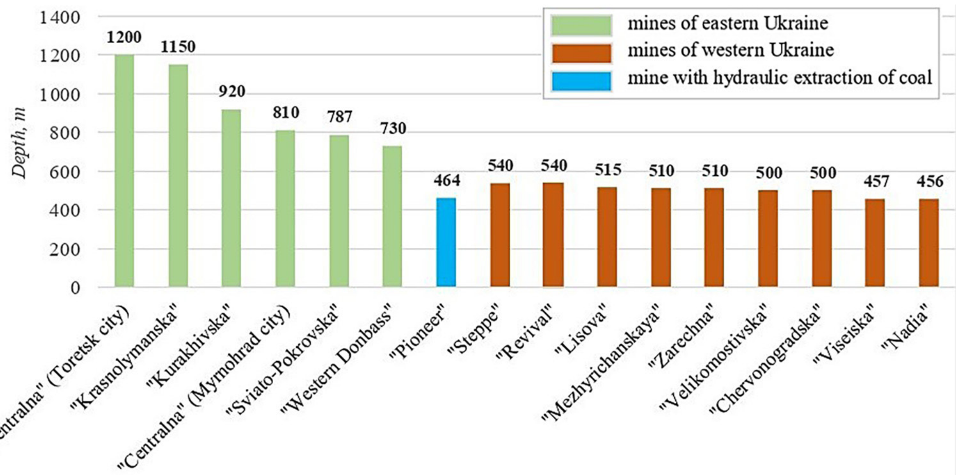

Figure 3. Depth of mines in the eastern and western Ukraine

mine waters which have a neutral pH, moderate mineralization and specific ionic composition.

The coal mines of Donetsk coal basin are characterized by significant depth and complex geological conditions. The depth of coal mines varies from 300 to 1,500 meters or more. The deep occurrence of coal seams contributes to the intensive interaction of mine waters with various geological layers. This fact leads to the saturation of groundwater with mineral salts, metals and other chemical elements, which increases its mineralization and changes its chemical composition. Unlike the Lviv-Volyn coal basin, the mine water of the Donetsk coal basin often contains heavy metals in high concentrations. Hydrodynamic parameters of mine fields, such as rock permeability and the presence of fractures, determine the volume and rate of groundwater inflow into mines.

The quality of mine water depends significantly on the quality of groundwater entering the mine workings. In the Pokrovsk district of the Donetsk coal basin, groundwater is located close to the surface, which also significantly affects its composition. A significant contribution to the pollution of groundwater and surface areas of the Pokrovsk district is made by the results of the economic activities of numerous industrial enterprises, primarily mining and metallurgical plants, storage facilities of industrial and household waste, mineral fertilizers and pesticides, as well as wastewater from livestock farms [Starovoit et al., 2021]. Effluents from industrial plants that use or process substances with high iron concentrations can be sources of iron in groundwater and mine waters [Pyshyev et al., 2023; Turchanina–Rybak et al., 2021]. Surface water and melt water, as well as sewage water from damaged storage sites, reach the mine workings [Donbas environment, 2021].

The groundwater from the mines of the Donetsk and Lviv-Volyn coal basins differs significantly in many quality parameters. In the mines of the Donetsk coal basin, chloride-sodium waters predominate. In the mines of the Lviv-Volyn coal basin, the situation is different: hydrocarbonate-calcium or sulfate-calcium waters predominate. In the deep mines of the Donetsk coal basin, the hardness of groundwater reaches 100 mg/l, compared to mine water of the Lviv-Volyn coal basin, where this figure is less than 10 mg/l. The same significant excess is observed in other water quality parameters: the content of Chlorides, Sulfates, Calcium and Magnesium (Figure 4).

On the basis of the comparative analysis of mine waters of two coal basins, a conclusion can be made about the possible further use of mine waters. Mine water in the East of Ukraine requires multi-stage purification, while for mine water in the West of Ukraine, simple mechanical and biological treatment will be sufficient. The content of chlorides and sulfates in mine water shows that this water cannot be discharged into water bodies or open areas without prior treatment.

Analysis of the groundwater quality from the "Centralna" mine

Despite the availability of studies on the groundwater quality in coal mines in Ukraine, there is still no unified systemic approach and a common set of parameters of mine water quality. This circumstance does not allow determining the possible directions of its further use, as well as the optimal technological scheme of its treatment. It is also impossible to compare the quality of groundwater from different mines with a different set of parameters. The study of groundwater in the "Centralna" mine made it possible to conduct a comprehensive analysis of water quality to assess the possibility of its further use as drinking water. This study is unique in the number of quality parameters of groundwater from a coal mine in Ukraine. It is especially necessary to highlight such groups of parameters that have never been studied in Ukraine and are not provided for by the Ukrainian standard for the quality of drinking water [DSTU, 2014]. These include non-relevant pesticide metabolites, degradation and reaction products; artificial sweeteners; drugs and drug degradation products; xenobiotics; per- and polyfluorinated alkyl substances (PFAS), foreign substances, and other chemicals of industrial origin.

Group of physical and physico-chemical parameters of groundwater of the "Centralna" mine make it possible to assess the suitability of water for human consumption as drinking water, as well as monitor the state of aquatic ecosystems. Five parameters out of sixteen in this group were significantly higher than the standard values (Table 2).

The electrical conductivity parameter, which characterizes the amount of dissolved salts, is 1.3 times higher than the standard value. Drinking such highly mineralized water may place an additional strain on the heart and kidneys. The sulfate content in mine water is 4.1 times higher than the standard value, the sodium content is 3.1 times higher, and the chloride content is 1.1 times higher. Their excess may be caused either by natural mineralization load or by anthropogenic pollution. Excess sodium is especially dangerous as it is harmful to people with cardiovascular or kidney diseases due to water retention in the body. The Coloration parameter, which indicates the presence of organic substances or contaminants, exceeds the standard value almost twice. The results of the parameter analysis indicate the need for mandatory preliminary purification of mine water from hardness, sulfates, chlorides, sodium, and suspended solids before its use as drinking water. The purification system can be a multistage system using ultrafiltration to capture particles < 1 μm, reverse osmosis to remove chemical and other contaminants, as well as activated carbon filters to purify water from Chlorine and other chemical compounds.

The study of the content of chemical elements in mine water was carried out using 18 parameters, including heavy metals: lead, mercury, cadmium, arsenic, chromium, nickel, copper, zinc, antimony, vanadium, thallium, and uranium (Table 3). Heavy metals are dangerous because they have a mutagenic effect and sharply reduce the intensity of biochemical processes in water bodies. The presence of most chemical elements was detected, but their content did not exceed standard values. However, it is necessary to take into account the long period of time between sampling, transportation and analysis. This fact can have a significant impact on the final results of the analysis, for example on the iron content in water [Bohomaz et al., 2025; Zbykovskyy et al., 2025].

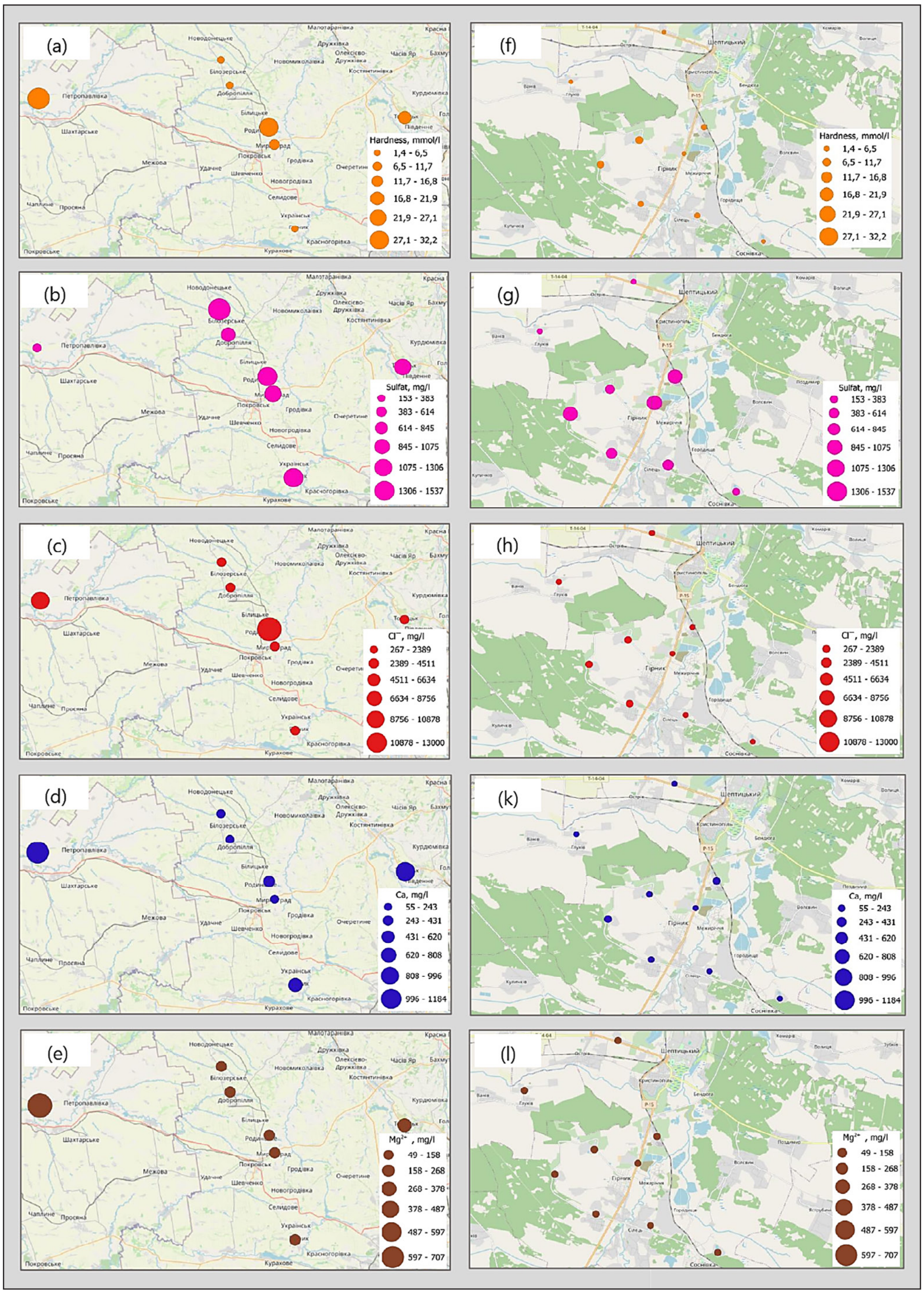

Figure 4. Geographical localization of Donetsk coal basin mines (a); (b); (c); (d); (e) and Lviv-Volyn coal basin mines (f); (g); (h); (k); (l) and the corresponding parameter values

Water pollution by pesticides is one of the serious problematic aspects of ecosystems. Pesticides and their metabolites can enter groundwater either after agricultural use or through the wastewater from pesticide manufacturing plants. The content of pesticides in groundwater in the eastern and western regions of Ukraine is significantly lower than in the traditionally agricultural southern and central ones [Osokina, 2021]. However, the studies on the presence of pesticides in mine waters in the Pokrovsky district have never been conducted before.

The study of the groundwater of the "Centralna" mine for pesticide content is especially relevant, since it can be used as drinking water by the local population. The water contaminated

Table 2. Physical and physico-chemical parameters of groundwater of the “Centralna” mine

Parameter	Unit	Standard value	Result
Turbidity	NTU	1.0	0.24
Spectral absorption coefficient at 254 nm	1/m	-	5.0
Coloration, spectral absorption coefficient at 436 nm	1/m	0.5	0.96
Ammonium NH_4^+	mg/l	0.50	0.064
Sodium Na	mg/l	200	620
Chlorid	mg/l	250	267
Sulfate	mg/l	250	1030
Potassium K	mg/l	-	7.03
PH value	-	≥6.5 and ≤9.5	7.7 (at 16.0 °C)
Calcium Ca	mg/l	-	121
Electrical conductivity	µS/cm	2790	3610 (below 25 °C)
Magnesium Mg	mg/l	-	78.5
Fluorid-Ion F^-	mg/l	1.05	0.510
Nitrat	mg/l	50	1.47
Ortho-phosphate (as phosphate)	mg/l	-	n.d.* (<0.0260)
Nitrite	mg/l	0.05	n.d.** (<0.010)

Note: n.d.* – not detectable (< limit of detection); n.d.** – not determinable (< limit of quantification).

Table 3. Content of chemical elements in groundwater of the “Centralna” mine

Parameter/ chemical element	Result, mg/l	Parameter/ chemical element	Result, mg/l	Parameter/ chemical element	Result, mg/l
Boron B	0.260	Copper Cu	<0.005	Barium Ba	0.035
Aluminum Al	0.005	Zinc Zn	<0.010	Thallium Tl	<0.0002
Chromium Cr	<0.005	Arsenic As	<0.001	Lead Pb	<0.001
Manganese Mn	0.032	Selenium Se	<0.001	Uranium U	0.006
Iron Fe	0.130	Cadmium Cd	<0.0005	Vanadium V	<0.0004
Nickel Ni	<0.005	Antimony Sb	<0.001	Mercury Hg	<0.0002

with pesticides can cause a variety of diseases, including allergies, metabolic disorders, respiratory diseases, cardiovascular diseases and cancer. Therefore, mine water samples were tested for the content of the most common 39 types of pesticides. Among the pesticides analyzed, there are those that are very dangerous to human health and are prohibited for use in EU countries. For example, Atrazine is often found as a water pollutant and is an endocrine disruptor. Linuron can be present in water in trace amounts. It causes hormonal system disorders. Even low concentrations of these in water are dangerous to humans.

The pesticides analyzed in the groundwater of the “Centralna” mine are either completely absent or present in quantities below the measurement accuracy level. The absence of pesticides in the groundwater of the “Centralna” mine can be explained by the depth of the mine workings, which is about 600 m. It is practically impossible for pesticides and metabolites to penetrate to a greater depth from the surface of agricultural lands. However, they may subsequently appear in mine water when they mix with groundwater flows located at a depth of 50–80 m. Therefore, monitoring of groundwater pollution by pesticides should be carried out regularly.

The groundwater of the “Centralna” mine was tested for the content of 19 non-relevant pesticide metabolites, degradation and reaction products. Although they are considered to be of low toxicity or safe, there are some potential risks. For example, chloridazone-desphenyl (a metabolite of the pesticide chloridazone) is often found in groundwater, especially in the areas with intensive chloridazone use. Because of its persistence and ability to penetrate water sources, it poses a threat to ecosystems as well as humans, under certain conditions.

The main risk factors are related to its presence in drinking water, persistence, and toxicity when accumulated. The European Food Safety Authority (EFSA) notes that chloridazone-desphenyl has a toxicity comparable to chloridazone itself. Therefore, its presence in the environment is considered hazardous. A similar conclusion can be made for all metabolites analyzed. Therefore, regular monitoring of their presence in water is required and, if necessary, the measures to limit the spread of such pesticides are taken.

The groundwater of the "Centralna" mine was also tested for the content of three of artificial sweeteners. Sweeteners E950 (Acesulfame K), E952 (Cyclohexylsulfamic acid; Cyclamate) and E954 (Saccharin) are not considered acutely toxic, but their presence in drinking water is undesirable. This is due to their persistence, interaction with the aquatic ecosystem and the risk of chronic human exposure when consumed through drinking water. Even at low concentrations, constant consumption can have negative long-term effects. E952 is prohibited in some countries, including the United States, due to its carcinogenicity. Sweeteners can enter groundwater with pharmaceutical waste or sewage. However, standard water purification methods do not always effectively remove artificial sweeteners. In this study, the accuracy of artificial sweeteners determination was 0.025 µg/l. At these and lower concentrations, artificial sweeteners E950, E952 and E954 were not detected in mine water.

The presence of drugs and drug degradation products in drinking water is a growing environmental and sanitary problem. Even at low concentrations, their regular consumption can cause accumulation and negative impact on the human body. For example, Carbamazepine is very resistant to purification, causes neurotoxicity. Metoprolol causes changes in heart rhythm. Medicines are included in the list of priority substances, the content of which in drinking water is monitored in the EU countries and by the World Health Organization. The groundwater of the "Centralna" mine was also tested for the content of nine of drugs and drug degradation products (Candesartan, Carbamazepin, Gabapentin, Metoprolol, Sotalol, Sulfadimidin, Sulfamethoxazol, Trimethoprim, Valsartan). These substances were not detected at a determination accuracy of 0.025 µg/l.

The study of groundwater in the "Centralna" mine for radioactive isotopes was conducted due to the presence of facilities in the Donetsk region associated with the storage of radioactive waste. These facilities pose a threat to the environment and public health. These facilities include the Yunkom mine (Yenakiyevo city), where an underground nuclear explosion was carried out at a depth of about 900 meters in 1979. Radioactive waste has been stored in the Alexander-Zapad (Yenakiyevo city), Uglegorskaya (Uglegorsk city) and Kalinina (Donetsk city) mines since 1963. There was also a radioactive waste storage facility on the territory of the Donetsk Chemical Products Plant. Currently, the above-mentioned mines are flooded and the storage facilities are destroyed. Taking into account the complex hydrogeology and massive uncontrolled flooding of mines in the Donetsk region, there is a real threat of radioactive substances entering aquifers. Studies of radiation levels in coal mines indicate the presence of radium in mine water [Wysocka et al., 2019; McDevitt et al., 2024].

Groundwater analysis was carried out for the content of seven radioactive isotopes and did not reveal their presence (Table 4). In this study, the analytical method of gamma spectrometry was used. Increased Hardness of mine water reduces the sensitivity of the method, since excess salts cause signal weakening and interfere with obtaining pure concentrates for measurements. High Hardness of the groundwater of the "Centralna" mine due to the increased content of Calcium and Magnesium Carbonates did not allow determining the exact content of radioactive isotopes in it. At the same time, Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) ions could precipitate together with radionuclides, creating poorly soluble compounds.

Analysis of mine water for the content of per- and polyfluoroalkyl substances (PFAS) showed the presence of Trifluoroacetic acid in the water (Table 5). Trifluoroacetic acid is an organic

Table 4. Content of radioactive isotopes* in groundwater of the "Centralna" mine

Parameter	Result, µg/l
Potassium-40 K-40	<0.70
Cobalt-60 Co-60	<0.05
Ruthenium-103 Ru-103	<0.05
Iodine-131 I-131	<0.06
Caesium-134 Cs-134	<0.05
Caesium-137 Cs-137	<0.05
Cerium-144 Ce-144	<0.28

Note: there is no standard value for each parameter.

fluorine-containing compound, has high chemical stability, does not decompose under natural conditions, therefore, is resistant to biodegradation, photolysis and hydrolysis. If Trifluoroacetic acid enters the human body with water, it may disrupt metabolism, liver and kidney function. Monitoring of Trifluoroacetic acid in water, especially near chemical plants, is carried out in EU countries and United States. The content of Trifluoroacetic acid in mine water is 0.1360 μg/l, which is within the permissible standard value.

Analysis of mine water for Chlorate, Perchlorate and Bromate showed their absence in the water due to their insignificant amounts, which are below the limit of detection (<0.001 mg/l). Other industrial chemicals, including 1H-benzotriazole, 4-Methyl-1H-benzotriazole and 5-Methyl-1H-benzotriazole could not be determined because their amounts are below the limit of quantification (<0.03 μg/l). Analysis of mine water for xenobiotics, including explosives (Trinitrotoluene, Dinitrotoluene, Hexogen, Octogen) was negative.

Experience of using groundwater from the "Centralna" mine for water supply

The use of groundwater from the "Centralna" mine is connected with the catastrophic deterioration of the situation with water supply to the population of Myrnohrad and Pokrovsk due to military actions. In this situation, the use of full purification of mine water was impossible. Therefore, it was decided to use simplified preparation of mine water before its supply to the existing water supply system. The treatment included filtration of suspended particles and disinfection from bacteria using Sodium Hypochlorite. Such treatment of groundwater did not bring the quality of mine water to the quality of drinking water. Analysis of water after disinfection showed that the quality of groundwater for some physical and physicochemical parameters had deteriorated (Table 6).

The water quality parameters have worsened: Chlorides from 267 to 269 mg/l, Electrical Conductivity – from 3610 to 3630 μS/cm, Spectral Absorption Coefficient at 436 nm – from 0.96 to 1.42 1/m. The deterioration of these water quality parameters may be due to several reasons. Industrial Sodium Hypochlorite (NaOCl) tablets, which may contain Chloride impurities, were used for disinfection. In addition, Sodium Hypochlorite decomposes to form Chlorides according to the following chemical reaction: $3NaOCl \rightarrow 2NaCl + NaClO_3$. As a result, this process leads to an increase in the concentration of Chlorides in the water. Hypochlorite may oxidize organic matter, forming colored compounds (e.g. quinones, humic acids), which increases the Coloration of the water. If pre-filtration is insufficient, oxidation of Iron or Manganese is also possible, which leads to the formation of colored oxides in the water and an increase the Coloration. The existing pre-treatment plant used conventional mechanical filters, which do not reduce water Electrical Conductivity.

Table 5. Content of per- and polyfluoroalkyl substances (PFAS), other parameters, other industrial chemicals, and xenobiotics in groundwater of the "Centralna" mine

Parameter	Unit	Standard value	Result
Per- and Polyfluoroalkyl substances (PFAS)			
Trifluoroacetic acid	μg/l	60	0,136
Other parameters			
Chlorate	mg/l	0.070	n.d.* (<0.001)
Perchlorate	mg/l	-	n.d.* (<0.001)
Bromate	mg/l	0.010	n.d.* (<0.001)
Other industrial chemicals			
1H-benzotriazole	μg/l	-	n.d.** (<0.03)
4-Methyl-1H-benzotriazole	μg/l	-	n.d.** (<0.03)
5-Methyl-1H-benzotriazole	μg/l	-	n.d.** (<0.03)
Xenobiotic screening			
Xenobiotics	Qualitative evidence	-	Negative. No organic foreign substances detected (including explosives such as TNT, DNT, RDX, or HMX)

Note: n.d.* – not detectable (< limit of detection); n.d.** – not determinable (< limit of quantification).

Table 6. Physical and physic-chemical parameters of groundwater of the "Centralna" mine after treatment

Parameter	Unit	Standard value	Result
Turbidity	NTU	1.0	0.14
Spectral absorption coefficient at 254 nm	1/m	-	4.54
Coloration, spectral absorption coefficient at 436 nm	1/m	0.5	1.42
Ammonium NH_4^+	mg/l	0.50	n.d.** (<0.015)
Sodium Na	mg/l	200	615
Chlorid	mg/l	250	269
Sulfate	mg/l	250	1020
Potassium K	mg/l	-	7.05
pH value	-	≥6.5 and ≤9.5	7.8 (at 16.0 °C)
Calcium Ca	mg/l	-	123
Electrical conductivity	µS/cm	2790	3630 (below 25 °C)
Magnesium Mg	mg/l	-	78.3
Fluorid-Ion F^-	mg/l	1.05	0.530
Nitrat	mg/l	50	1.50
Ortho-phosphate (as phosphate)	mg/l	-	n.d.* (<0.0260)
Nitrite	mg/l	0.05	n.d.** (<0.010)

Note: n.d.* – not detectable (< limit of detection); n.d.** – not determinable (< limit of quantification).

After adding NaOCl, an increase in water pH was observed, which enhances the side reactions of releasing Hardness salts from sediments in pipelines or filters. These phenomena lead to a deterioration in the Electrical Conductivity after treatment, which was observed in the operating installation. For other parameters that exceed the standard, the parameters have remained virtually unchanged: the Sulfate content before/after purification was 1030/1020 mg/l, Sodium content – 620/615 mg/l. The greatest excess of the water quality standard was recorded for the content of Sulfates in water which amounted to 312%, the smallest – 7% for the content of Chlorides (Figure 5).

After disinfection, the content of Acesulfam-K E950 in the water was detected in an amount of 0.097 µg/l. This is an artificial sugar substitute, its content in drinking water is not regulated, since it should not be there. The mine water after treatment also contained Trifluoroacetic acid, it was detected in an amount of 0.1250 µg/l. The sources of Acesulfam-K E950 and Trifluoroacetic

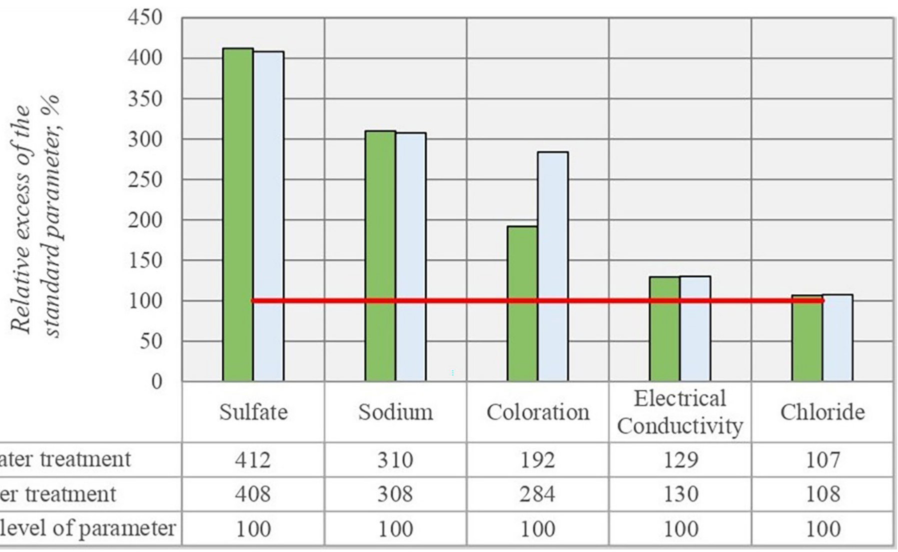

Figure 5. Relative excess of groundwater quality parameters compared to the standard level of parameters for drinking water

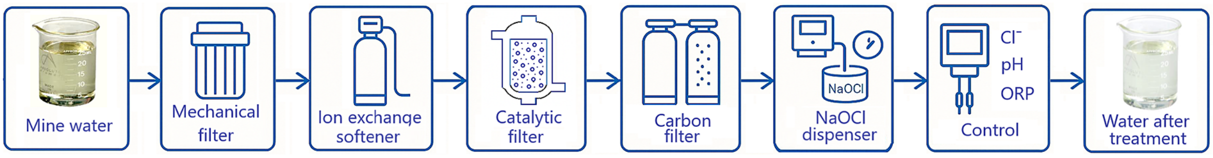

Figure 6. Simplified scheme of the groundwater treatment at the "Centralna" mine

acid entering the mine water have not been established, as this requires special additional studies. These studies did not reveal any other excesses of quality standards in mine water.

To improve the process of preparing mine waters, it is recommended to use additional purification stages taking into account the extreme operating conditions in the frontline zone. The proposed simplified scheme of the groundwater treatment at the "Centralna" mine is shown in Figure 6.

This scheme contains a stage of preliminary clarification or softening of mine water. For example, an ion exchange filter or a catalytic filter for Iron and Manganese. It is also recommended to adjust the Hypochlorite dosage, install pH and ORP control sensors before and after filtration to prevent overchlorination. To reduce Coloration and adsorb organics and Chlorides, it is recommended to use a filter with activated carbon. Water after preliminary purification can be used as technical water in exceptional situations.

CONCLUSIONS

The groundwater from coal mines has become a strategic source of water supply in Ukraine. The mining, geological and hydrodynamic conditions of Ukrainian mines in the Donetsk and Lviv-Volyn coal basins differ significantly. Comparative analysis of groundwater in 9 mines of the Lviv-Volyn coal basin and 7 mines of the Donetsk coal basin shows that the depth of mines is a determining factor in the quality of groundwater. The volume and quality of mine water are also determined by the hydrodynamic parameters of mine fields. In the deep mines of the Donetsk coal basin, the Hardness of groundwater reaches 100 mg/l, compared to mine water of the Lviv-Volyn coal basin, where this figure is less than 10 mg/l. The same significant excess is observed in other water quality parameters: the content of Chlorides, Sulfates, Calcium and Magnesium. A significant contribution to the pollution of groundwater in the Donetsk region is made by the economic activities of numerous industrial enterprises. In the western part of the Donetsk region groundwater from coal mines has become the only water source of water supply for the population. Therefore, before using mine water as drinking water, it requires multistage treatment.

The study of groundwater in the "Centralna" mine was carried out according to 11 groups of parameters. The total number of studied parameters was 122. Water quality parameters that have never been studied in Ukraine and are not provided for by the Ukrainian standard for drinking water quality were specially studied to determine the influence of anthropogenic factors. These include non-relevant pesticide metabolites, degradation and reaction products; artificial sweeteners; drugs and drug degradation products; xenobiotics; PFAS and other chemicals of industrial origin. The group of physical and physicochemical indicators of underground waters of the Central mine allows assessing the suitability of water for human consumption as drinking water, as well as to monitor the state of aquatic ecosystems. Five parameters of mine water quality out of sixteen in the group of physical and physicochemical parameters were significantly higher than the standard values. The Electrical Conductivity parameter is 1.3 times higher than the standard value. The Sulfate content in mine water is 4.1 times higher than the standard value, the Sodium content is 3.1 times higher, and the Chloride content is 1.1 times higher. The Coloration parameter, which indicates the presence of organic substances or contaminants, exceeds the standard value almost twice. The content of Trifluoroacetic acid was detected in groundwater, which is 0.1360 μg/l.

The water treatment system at the "Centralna" mine has not improved the quality of groundwater. Water quality parameters have worsened: Chlorides from 267 to 269 mg/l, Electrical Conductivity – from 3610 to 3630 μS/cm, Spectral Absorption Coefficient at 436 nm – from 0.96 to 1.42 1/m. For other parameters that exceed the standard, the parameters have remained virtually unchanged: the Sulfate content before/after purification was 1030/1020 mg/l, Sodium content – 620/615 mg/l. After treatment, mine water contains Trifluoroacetic acid in the amount of 0.1250 μg/l and Acesulfam-K E950 in the amount of 0.097 μg/l. The sources of Acesulfam-K E950 and Trifluoroacetic acid entering the mine water have not been established.

To improve the process of preparing mine waters, it is recommended to use additional purification stages taking into account the extreme operating conditions in the frontline zone. It is proposed to supplement the treatment of mine water with a stage of its preliminary clarification or softening using an ion exchange filter or a catalytic filter for Iron and Manganese. It is also recommended to adjust the hypochlorite dosage, install pH and ORP control sensors before and after filtration. To reduce Coloration, it is recommended to use a filter with activated carbon. Water after preliminary treatment can be used as technical water.

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