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ANALYSIS OF CHANGES IN GROUNDWATER QUALITY IN AREAS OF MINERAL RESOURCE EXTRACTION IN WESTERN AND CENTRAL UKRAINE

Abstract. It is a well-known fact that the qualitative characteristics of the environment change during the extraction of mineral resources. Land resources and the water environment are most affected. The purpose of the study is to identify the factors that affect water quality changes in areas of mineral resource extraction. Based on long-term research into the chemical composition of quarry, recycled, and wastewater from industrial processes, groundwater and surface natural water, an analysis of changes in their quality has been conducted. The study utilized monitoring data of the water environment around sand, graphite, ilmenite, and iron ore deposits in Ukraine. It was found that the most significant changes in the water environment occur around iron ore deposits. The main factors that determine the scale of changes in water quality are the size of the quarry, the presence of external waste dumps and tailings ponds, and the discharge of wastewater into surface water bodies. According to monitoring data, a water quality change coefficient was determined as the average value of changes across all investigated parameters. An analysis was conducted of how this coefficient varies with quarry depth and area. The results indicate an exponential increase in water quality changes around quarries as their depth and area increase. Among other factors affecting water quality change is the presence of tailings ponds and dumps near the quarry, but this has not yet been sufficiently researched and will be determined in the future.

Pollution of surface and groundwater by specific elements is determined by the type of mineral resource being extracted and the types of overlying rocks: on iron ore deposits increases the chloride content, on graphite deposit - increase in magnesium, calcium, and nitrates, on ilmenite sands deposit - raises the levels of bicarbonates, calcium, nitrates, sodium, and potassium, on sand deposits - increased calcium and nitrate content in the surrounding surface and groundwater increases. Additionally, elevated concentrations of sulfates and dry residue were observed in the areas surrounding all the studied quarries.

It should be noted that for most of the objects studied, pollution of the surrounding aquatic environment is not critical, since most components do not exceed the maximum permissible concentrations. However, this article did not examine the time factor, which makes it impossible to predict when changes in water quality may become critical in the future.

Keywords: water quality, mining impact, groundwater contamination, surface water pollution, iron ore deposits, environmental monitoring

1. Introduction

Water and land are the most vital resources for humanity. The life and health of the population depend on their quality. It is believed that these resources are most affected by the extraction of mineral resources. While the impact on land resources can be observed visually, the impact on water resources is more complex and often difficult to quantify.

The impact on water resources consists of changes in the hydrodynamic and hydrogeochemical regimes of groundwater and surface water in the areas affected by mineral resource extraction.

It was previously found [1] that the volume of mine water discharged in Ukraine is excessively high, approximately equal to the natural flow volumes of the small rivers into which it is discharged.

In [2], the authors analyzed changes in groundwater quality in Ukraine since 1960

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and documented large-scale deterioration. The similar observation is made for surface waters, including rivers [3–5]. At the same time, [6] notes that under current management practices, the waters of Ukraine's rivers will not only become unusable but also dangerous.

According to [7], about 2 million tons of mineral salts are discharged annually into the hydrographic network along with mine water. The authors of the article [8] note that mine waters contain a high concentration of fine particles (50–70%), which, unlike larger impurities, do not settle but may dissolve.

Paper [9] notes that the impact of mining operations on water resources is expressed in the disruption of water exchange, loss of natural water reserves, and pollution due to the discharge of mine water into surface water bodies. The article [10] adds to this list the drainage of technogenic waters from tailings ponds.

The authors of [11] note that the greatest impact on water resources is caused by landscape disturbance during mining, which leads to an imbalance in the natural drainage system.

The article [12] states that the main factor affecting the quality of water resources is the discharge of mine water into the hydrographic network. At the same time, pollution occurs with sulfates, chlorides, nitrates, sodium, and potassium in most mining regions of the world [13].

The authors of [14] note that natural waters, both surface and groundwater, naturally contain trace elements. However, severe heavy metal pollution is most often linked to mining activities. The article [15] emphasizes that in the Lviv-Volyn Basin, wells located near waste rock dumps have detected concentrations of Group 1 toxic elements close to or slightly exceeding the maximum permissible concentrations (MPC).

The problem of water quality around mining excavations is widespread and has been studied not only in Ukraine but also in other countries.

In Romania, in regions of extraction of various mineral resources, increased concentrations of metals in natural waters are recorded [16–18], and in gold mining areas a significantly increased sulfate content is also observed [17], while river water downstream is classified as Class V (the most polluted). Pollutants accumulate in water and soil and, as a result, in vegetables [18], which poses a threat to public health.

In Nigeria, in areas of barite and coal mining, increased concentrations of heavy metals and toxic substances in natural waters are also recorded, exceeding reference doses [19–20].

The article [20] shows that even decommissioned coal mines have a negative impact on the water quality in the region. The authors show that the water quality continues to deteriorate, which may be associated with waste rock dumps located on the surface.

The authors of [21] also note a deterioration in the water quality in areas of decommissioned mines in the Maramureș region. An increased content of toxic elements in groundwater has been recorded and, as a result, in surface watercourses.

The authors of publication [22] show that in northern Chile the greatest impact on the water quality is caused by accumulated tailings.

In [23], it is noted that in Canada, in order to reduce the impact of mining activities on the environment, including water resources, the government introduced the wastewater quality regulations in 2002; therefore, most enterprises discharge mine waters into tailings storage facilities, which has had a positive effect on the quality of natural waters.

However, in article [24], the authors show that in the Upper Silesian Coal Basin (southern Poland), the cessation of mine water discharge into the Bytomka River will negatively affect its flow, since the share of natural waters in river flows is extremely low, because due to prolonged transformation the replenishment of the river occurs largely due to municipal and industrial (including mine) waters.

The aim of the study is to identify the factors influencing changes in water quality in areas of mineral resource extraction.

2. Methods

Several quarries on the territory of Ukraine were selected for the study, each extracting minerals using different technological schemes and equipment. A common feature among the selected objects of study is that they are located on the path of surface and groundwater to a river, which is located in close proximity.

The Zakrupetske sand deposit is being developed using a hydromechanical method with a dredger and hydraulic transportation of the mineral resource to reclamation ponds (hydrowaste dumps), where it is dewatered and then loaded into trucks by excavators. The dredger's water supply is provided through a reverse system, without supplementation. Water from the reclamation ponds is discharged into the quarry basin through constructed drainage ditches. The mining front is advancing to the south.

The quarry exposes a single non-pressure aquifer, which is associated with the alluvial sands of the Desnian stage of the Upper Neopleistocene on the first floodplain terrace of the Horyn River, flowing 70–160 meters to the south and west of the site. Water-bearing rocks are represented by medium- to fine-grained sands that are almost completely saturated with water. Sand mining at the Zakrupetske sand deposit is carried out without dewatering and uses a reverse water supply system.

The depth of the groundwater table ranges from 0.7 to 2.7 meters. The water-bearing rock layers are relatively horizontal. Water samples were taken from the quarry, the Horyn River, and from three points in the nearby built-up area (figure 1).

The Byrzulivske ilmenite deposit is being mined using mechanized excavators in blocks that are opened by semi-trenches. Different types of overburden rocks are excavated selectively. Clayey rocks are transported to an external dump, while sandy rocks are moved to an internal dump. Waste rocks generated during beneficiation are also placed in the quarry dumps. Dumps, tailings storage facilities, and sedimentation ponds are located in the mined-out areas. The enterprise employs a recirculating water supply system: water from the quarry is directed to a settling pond and, after sedimentation, is returned to the technological cycle at the beneficiation plant.

The ilmenite-bearing deposits are continental alluvial sediments and coastal-marine sediments represented by sandy rocks (glauconite-quartz sands). The ore sands are 7 meters thick and covered by a layer of sands and secondary kaolins with silicon inclusions.

Figure 1 –Diagram of water sampling points in the Zakrupetske sand deposit

The section contains several aquifers; however, the quarry's water inflow occurs due to Neogene-Paleogene Lower Cretaceous deposits.

Water samples were taken from the quarry, the sedimentation pond, the Velyka Vys River, three wells, and three points in the nearby settlements (figure 2).

The Zavallivske graphite deposit is developed using a mechanized method with drilling and blasting operations for rock fragmentation. The waste rocks are transported to an external dump, and minerals to the warehouses by dump trucks.

The geological structure of the deposit consists of crystalline limestone and quartzite. Below the section, there are graphite-bearing gneisses (productive layer), with variable thickness: in the northern wing, it reaches up to 250 meters, while in the southern wing, it sharply decreases to 15 meters.

Tectonically, the *Zavallivske* graphite deposit is associated with the wings of the eponymous large fold structure of the second order. Transverse faults and dislocations divide the *Zavallivske* deposit into a series of blocks, which are characterized by horizontal displacements ranging from 10 to 150 meters.

The quarry exposes three aquifers: a weakly water-bearing horizon in the eluvial and eolian-deluviated sediments of the Middle and Upper Neopleistocene; in the sediments of the Baltic stage; and in the fractured zone of crystalline rocks. The quarry is watered by all three aquifers.

Water from the quarry is pumped out and discharged into the tailings storage facility, which is located to the east.

Water samples were taken from the quarry, the Pivdennyi Buh River (upstream and downstream), and from five points in the nearby settlement (figure 3).

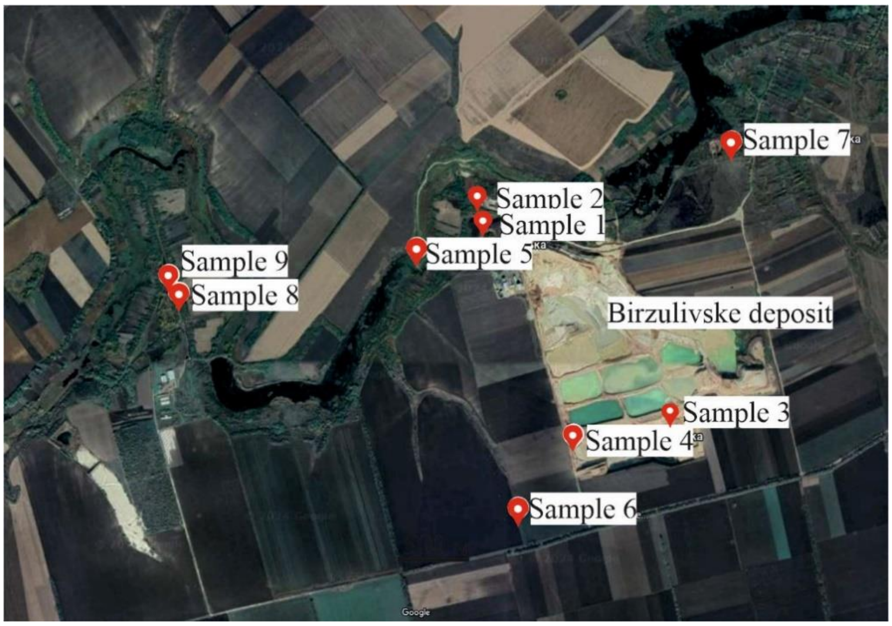

Figure 2–Diagram of water sampling points in the Byrzulivske deposit area

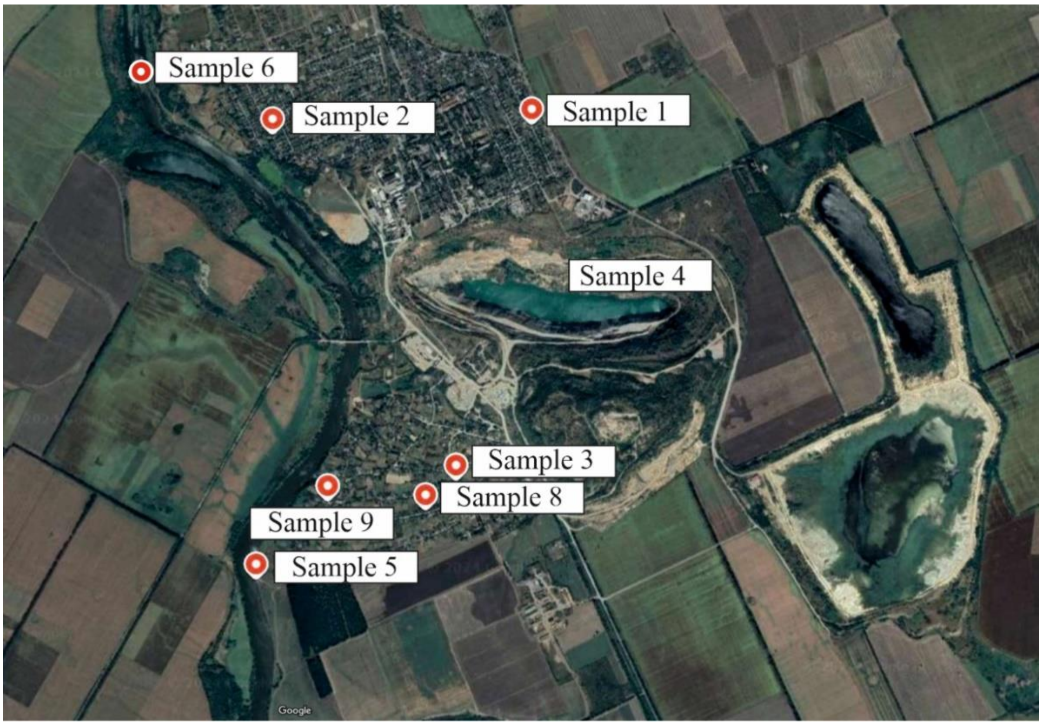

Figure 3 –Diagram of water sampling points in the Zavallivske deposit area

The iron ore deposit in Kryvyi Rih (name not disclosed due to the commercial confidentiality agreement) is being developed using a mechanized method with the application of drilling and blasting operations.

The deposit is formed by the rocks of the iron ore formation of the first, second, and fourth iron-bearing horizons. The Novokryvorizkyi formation is represented by a layer of amphibolites. The Skeliovatskyi formation is represented by metasandstones and quartzites, biotite-sericite (phyllites), biotite-chlorite-sericite (biotite mostly chloritized), talc, talc-chlorite, and carbonate-chlorite-talc schists. The Saksahanskyi formation is iron-bearing, represented by iron-rich and shale horizons.

The deposit is tectonically disrupted, has a large fault and small microfractures, cracks and cleavages.

The main aquifer that provides water for mine workings is the crystalline rock aquifer. The water-bearing and water-permeable properties of the rocks are determined by their fracturing, which exhibits an extremely uneven distribution.

Quarry water is discharged into a recycling water supply pond.

Water samples were collected from wells and in the quarry from the sump and from 4 water points at different horizons (figure 4), as well as from the Inhulets River 500 meters above and 500 meters below the discharge point (not shown on the figure).

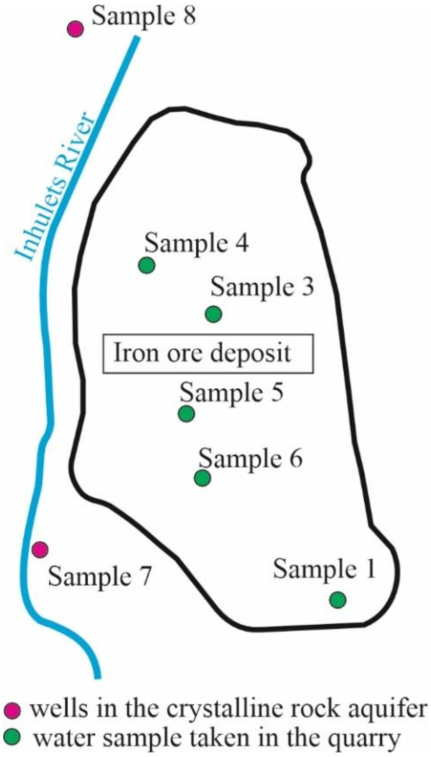

Figure 4– Diagram of water sampling points in the iron ore deposit area in Kryvyi Rih

The Pershotravneve deposit is developed using a mechanized method with drilling and blasting operations. It is composed of a metamorphic rock complex of the Kryvyi Rih series, represented by four formations: Novokryvorizkyi, Skeliovatskyi, Saksahanskyi, and Hdantsivskyi.

The Novokryvorizkyi formation in the deposit area is represented by amphibolites interbedded with quartz-biotite and, less frequently, quartz-chlorite schists. The rocks of the Skeliovatskyi formation lie on the eroded surface of the amphibolites and are represented by arkosic sandstones, quartz-mica schists, and talc-carbonate schists. The Saksahanskyi formation is iron-bearing and is divided into shale and iron-rich horizons. The productive layers are the iron-rich quartzites of the fifth and sixth iron-bearing horizons.

Faulting is widespread in the field. Most of the faults are tectonic zones formed by breccias.

Within the deposit, three aquifers are developed: in Quaternary deposits, Poltava-Kharkiv sediments, and crystalline rocks. The quarry is watered by all three aquifers.

Water accumulates in the quarry sump, from where it is pumped into a retention pond (located on the western side of the quarry).

Water samples were taken from wells (samples 4, 10–12), from the quarry sump (sample 7) and the ducker (sample 6), from the water body on the quarry's rim (swampy area – sample 2), from the retention pond (at two points – samples 1 and 3), from the drainage ditch (sample 5), from the Petrykivka ravine (sample 9), and from the Saksahan River (sample 8) (figure 5).

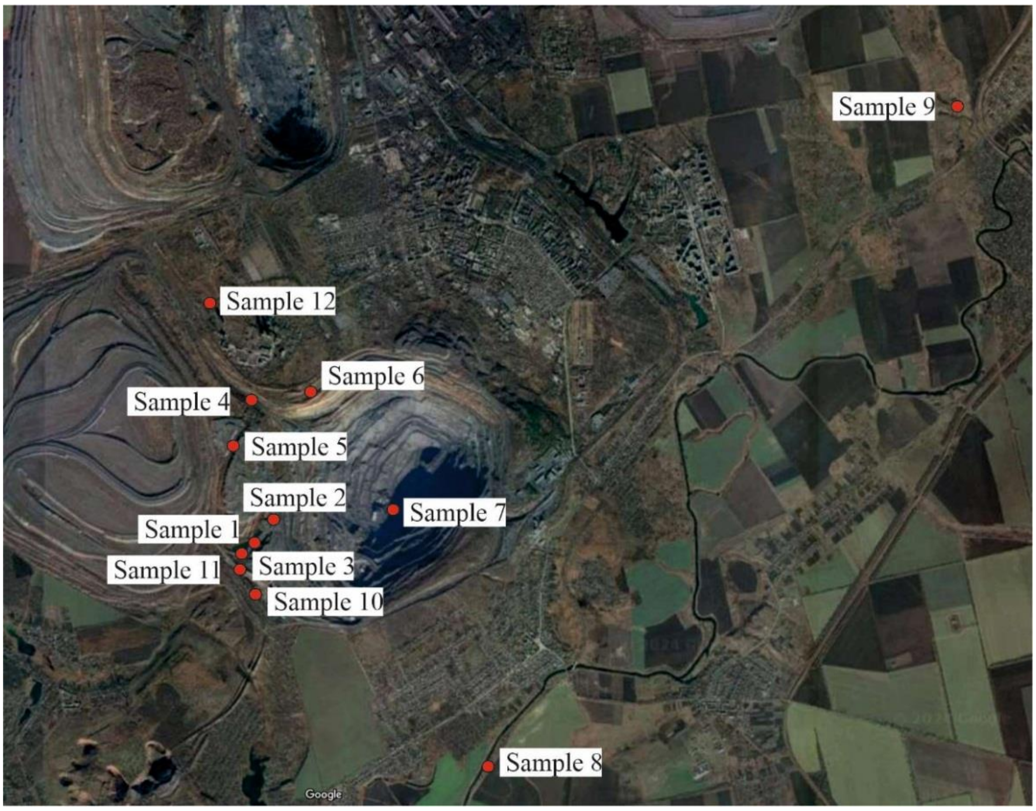

Figure 5– Diagram of water sampling points in the Pershotravneve deposit area

Thus, data on the quality of natural and technogenic waters in the quarry impact zone have been obtained from different regions of Ukraine. At the same time, all the quarries have different characteristics (size, depth, number of exposed aquifers, etc.) and extract various minerals using different technological schemes. The sampling points were located in such a way as to investigate the water quality upstream of the groundwater and surface water flow (before the source of impact) and downstream (after the source of impact).

To study the chemical composition of the water, photometric, gravimetric, colorimetric, electrometric, chromatographic, and complexometric methods were used.

All the water samples were analyzed for 13–27 indicators. To avoid the scale of comparison, only the main pollutants were considered. Observations were carried out over a long period, and 10-year averaged data were used for analysis.

To identify the impact of mining operations on the composition of groundwater and surface water in the mining area, the methods of analysis and synthesis of groundwater quality indicators, their comparison with regulatory values, classification and generalization were used. Data classification and statistical analysis were performed using Microsoft Excel.

3. Results and discussion

Figure 6 presents a comparison of the element content in samples from the Zakrupetskyi sand deposit area. The water analyses show the following:

- The composition of groundwater indicates that the quality of the groundwater in the quarry meets the standards for groundwater and even complies with drinking water quality standards.
- The quality of water in the Horyn River fully meets the standards for surface water quality.
- In samples 3–4, the water complies with the MPC for most indicators, but the nitrate content significantly exceeds the norm, making the water unsuitable for consumption.
- The water in sample 5 fully complies with the MPC for drinking water.

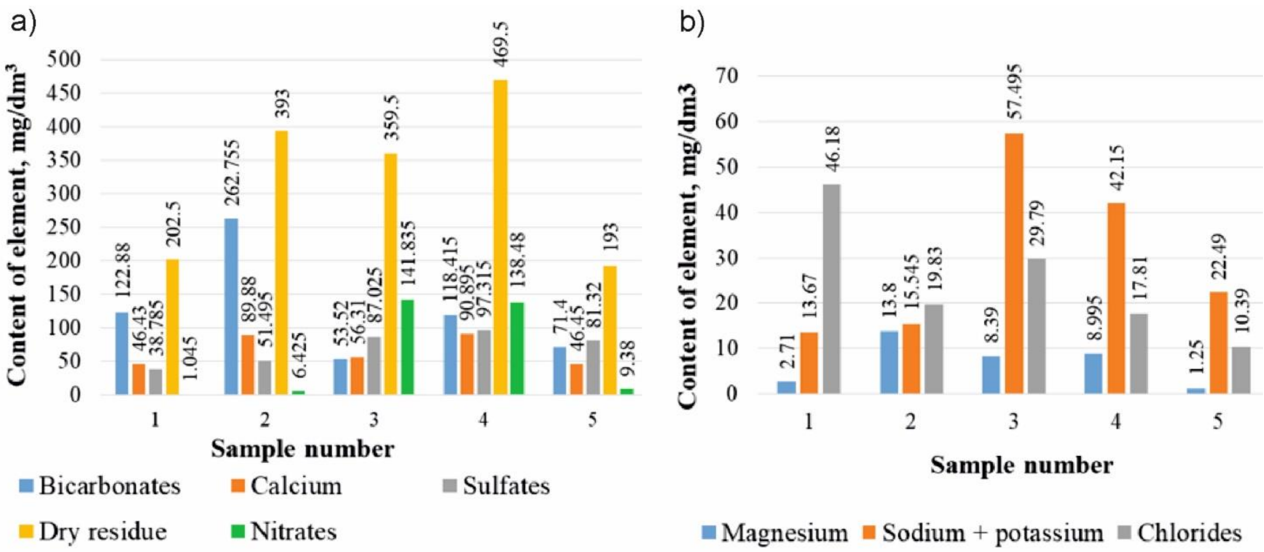

Figure 6– Content of microelements in water samples in the Zakrupetskyi deposit area

As seen from the graph in figure 6 (a), the river water, where the first aquifer discharges, contains significantly higher levels of bicarbonates, calcium, and total dissolved solids compared to the quarry water. These indicators are not regulated and, for the most part, their values are mostly formed by the activity of flora and fauna in the water body. According to figure 6 (b), the magnesium content in the river water is significantly higher than in the quarry water, indicating that this element enters the river water not through the discharge or filtration of quarry water, but through the dissolution of minerals underlying the riverbed.

Water samples 3–5 were taken from the same aquifer that discharges into the quarry, but they have different chemical compositions. Figures 6 (a) and (b) show that for all elements except chlorides, the water in samples 3–4 has worse indicators than the quarry water, while the water in sample 5 is almost identical to the quarry water in composition. Considering the direction of movement of the aquifer towards the Horyn River, wells 3–4 are not located within the quarry's impact zone. The only water body that may be affected by the quarry's mining activities is the Horyn River. However, its water quality is different.

Figure 7 presents a comparison of water quality in the area of the development of the Byrzulivskyi ilmenite deposit.

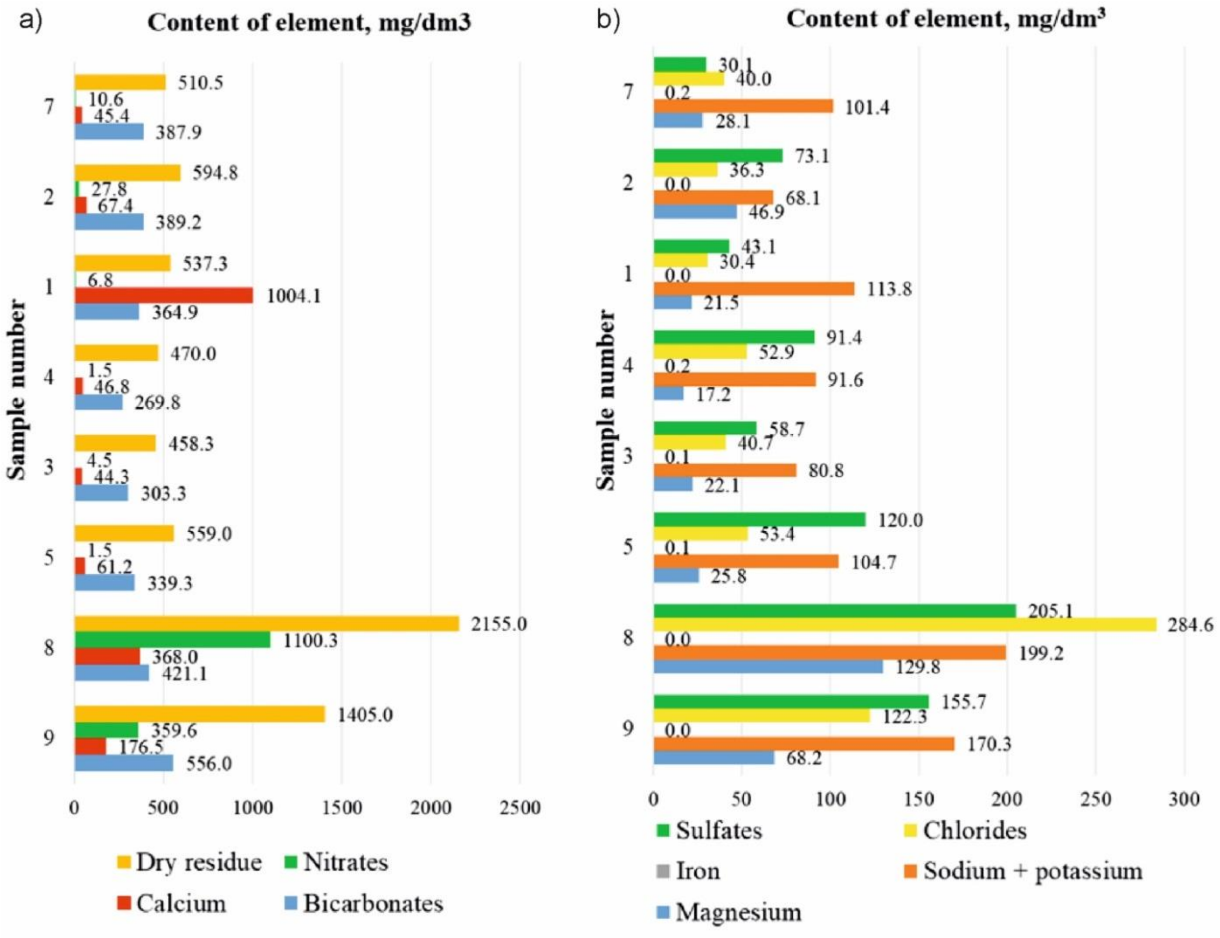

Figure 7 –Content of microelements in water samples in the Byrzulivske deposit area

The composition of groundwater, surface and quarry water in the Byrzulivskyi deposit area is as follows:

- The analysis of the cation-anion composition showed that the waters of sample 1, the quarry waters (from the settling pond), and the waters of sample 7 belong to the same aquifer. The waters of sample 2 belong to the second aquifer, while the waters from wells 8–9 belong to another aquifer. All these aquifers are exposed by the quarry.
- The composition of the groundwater indicates that the quality of the groundwater in the quarry meets the standards for groundwater and even meets the standards for drinking water quality.
- The water quality in wells 1 and 2 meets the standards for drinking water quality.
- The water quality in the River Velyka Vys fully meets the standards for surface

water quality and is suitable for drinking water supply.

- In wells No. 8–9, the water meets the MPC for most indicators; however, the nitrate content is significantly exceeded, making the water unsuitable for consumption.
- The water in well No. 7 fully meets the MPC.

The analysis of the graphs in figure 7 (a) – (b) shows that the lowest content of elements is found in the quarry water, the water from the settling pond, the water from wells 1 and 2, and in well 7. Although the quarry water has the highest calcium content, the content of this element is significantly lower in all other water samples. Given the difficulty of calcium dissolution, it is considered that calcium precipitates out of the water.

Considering the direction of groundwater flow toward the Velyka Vys River, wells 8–9 are outside the influence of the quarry. However, the water quality in these wells does not meet the regulatory standards, and among all the samples taken, they have the highest concentration of all elements. This is likely due to the proximity of agricultural fields around the wells, where herbicides and various fertilizers are actively used.

Figure 8 shows a comparison of water sample quality in the Zavallivske graphite deposit area. As is shown in figures 8 (a) and (b), the water in the quarry (sample 4) contains the highest levels of contaminants. The water samples 1 and 2 are the cleanest and meet drinking water quality standards. The water from well 1 is located at the incoming flow. The quarry receives atmospheric water, surface runoff, and water from three aquifers, where the composition of these waters mixes and averages out. The water in the Pivdennyi Buh River upstream of the deposit development area is the cleanest and complies with the standards for surface and drinking water quality. However, downstream (on the outflow), the underground (samples 3, 8, 9) and surface (sample 6) waters show an increased content of elements, indicating the negative impact of mining activities. The water in well 3 is the most mineralized, with the dry residue in the sample nearly twice exceeding the MPC. Additionally, the sulfate levels exceed the MPC by 2.5 times, and the nitrate levels are 1.5 times higher, making it unsuitable for drinking. In samples from wells 8 and 9, there is an excessively high content of sodium, potassium, magnesium, and sulfates. A seasonal pollution factor is also observed (in the summer), which may be linked to both agricultural and mining (dusting) activities.

Figure 9 shows a comparison of the quality of water samples in the area of the iron ore deposit in Kryvyi Rih.

The results of the analysis indicate that the highest content of trace elements is found in the water from the quarry, sampled in the sump (sample 3) and at the 210 horizon (sample 5). At the same time, the iron content in the water samples is highest at the 75 and 195 horizons (sample 1 and sample 6, respectively). Moreover, water at different horizons of the quarry has varying chemical compositions and, consequently, different qualities. The cleanest water is observed in samples 1, 4, and 6. The water collected from wells on the downstream flow (sample 7) and the opposite bank of the river (sample 8) is similar in quality to the quarry water sampled from the 195 horizon.

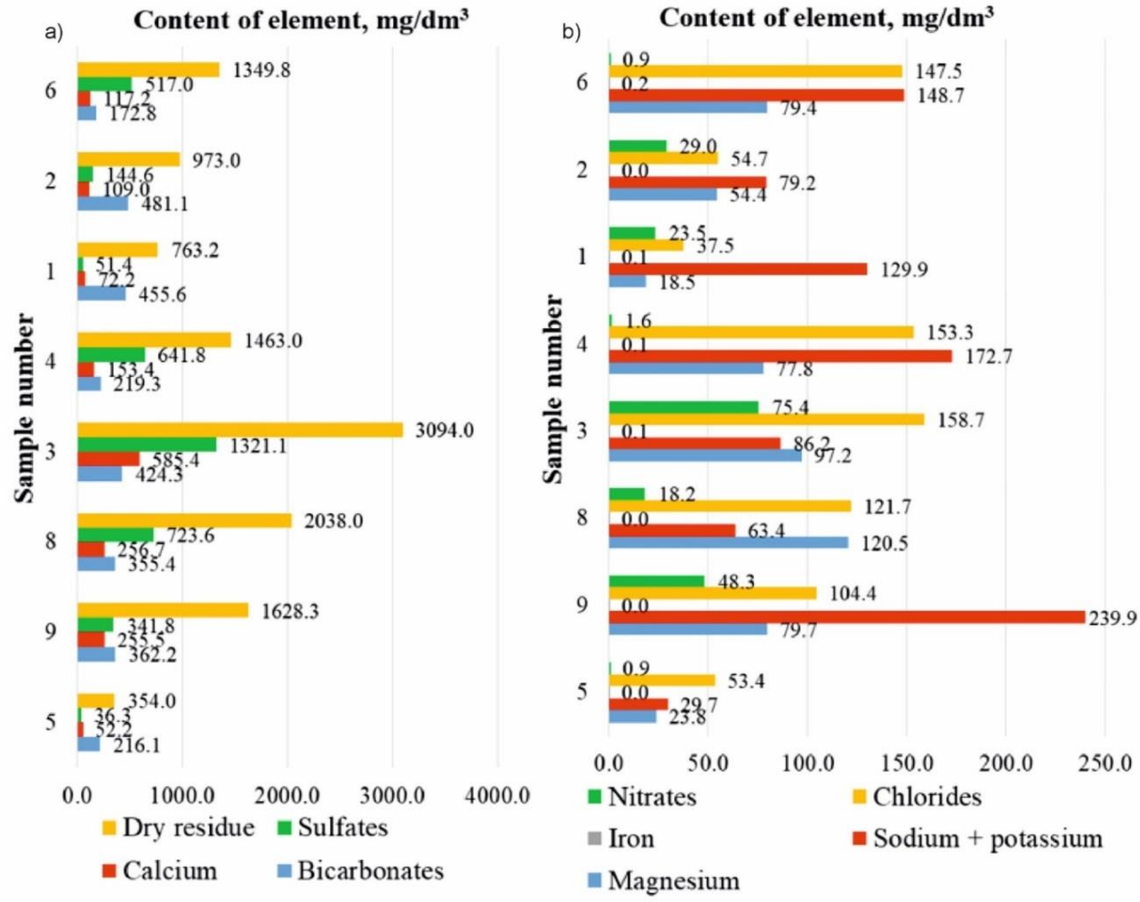

Figure 8 – Content of microelements in water samples in the Zavallivske deposit area

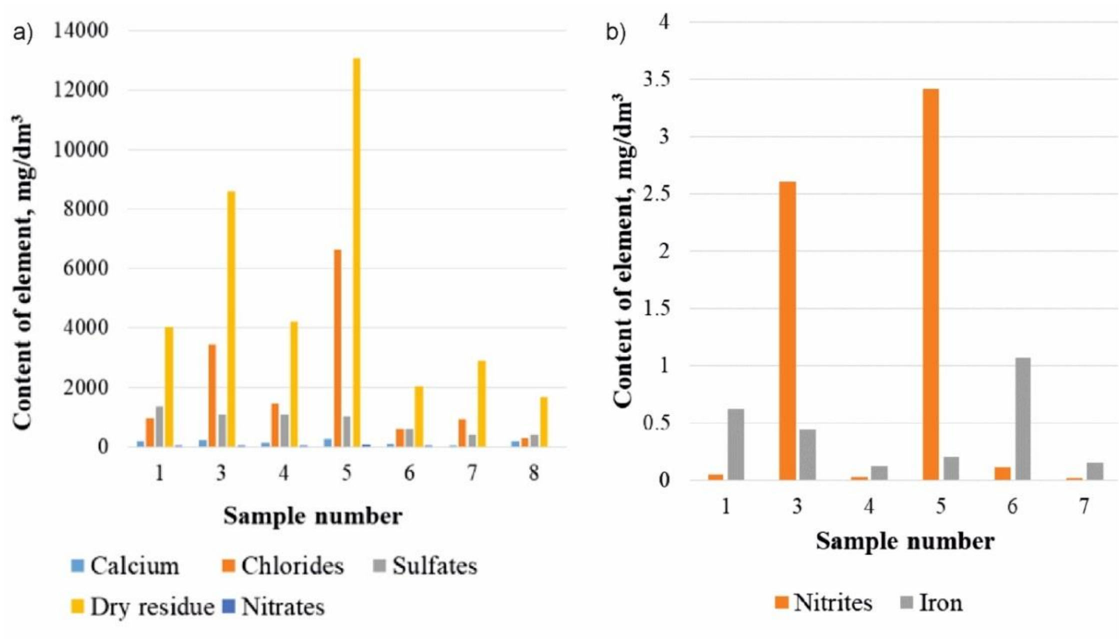

Figure 9– Content of microelements in water samples in the iron ore deposit area

This indicates that the water flowing through the quarry is saturated with various elements, and when it reaches the sump (the lowest point), it is mixed and has the worst quality. At the same time, no significant impact on the groundwater in the quarry area has been observed.

To study the impact of mining on surface waters, the water quality in the quarry (from the sump – sample 3) was compared to the water sampled 500 meters upstream (sample 9) and 500 meters downstream (sample 10) from the discharge point of return water from the settling pond into the Inhulets River, as visually represented in figure 10.

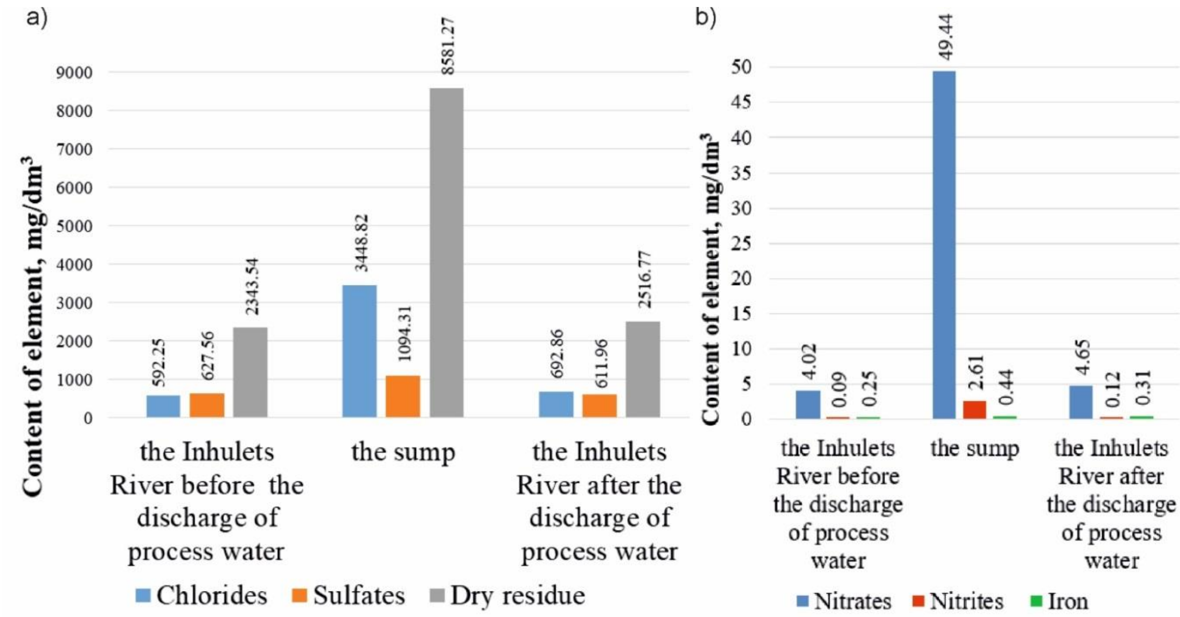

Figure 10– Comparison of microelement content in water samples from the quarry and the Inhulets River before and after the discharge of process water

As shown in figure 10, the water in the Inhulets River upstream from the enterprise's discharge point is already polluted beyond permissible limits, specifically: chloride content is 1.7 MPC, sulfate content is 1.25 MPC, nitrite content is 1.2 MPC, and dry residue is 2.3 MPC. According to the enterprise's technological scheme, water from the quarry sump is pumped into a settling pond, from which it is discharged after settling (the quality of water in the settling pond was not studied).

Therefore, when discharged, the water has a slightly improved quality compared to the water from the quarry. After water discharge, the water quality in the Inhulets River deteriorates (see figure 10) by all indicators. This indicates the evident impact of mining activities on the region's surface water.

Figure 10 shows a comparison of water quality in the Pershotravneve field area.

The data in figure 11 show that the most polluted waters are those in the drainage channel around the foot of the Pershotravnevy's dumps, which is polluted by runoff from the dumps.

The water from the quarry sump (sample 7) is more polluted than the water taken from the quarry's culvert (sample 6).

The water from the wells located upstream of the groundwater flow (samples 12 and 4) is already contaminated. Sample 12 shows elevated chloride levels (1.8 MPC), while sample 4 has increased sulfate concentrations (3.8 MPC). The dry residue ranges from 1.5 MPC in sample 12 to 3.45 MPC in sample 4. This is due to the fact that these wells are located on the downstream flow of groundwater relative to the Hanyvskyi quarry and waste dumps. The water in well 11, which is also on the downstream flow, is even more polluted, with the concentrations of all elements increased by 1.3 to 8 times. This indicates a significant impact of mineral extraction on groundwater quality.

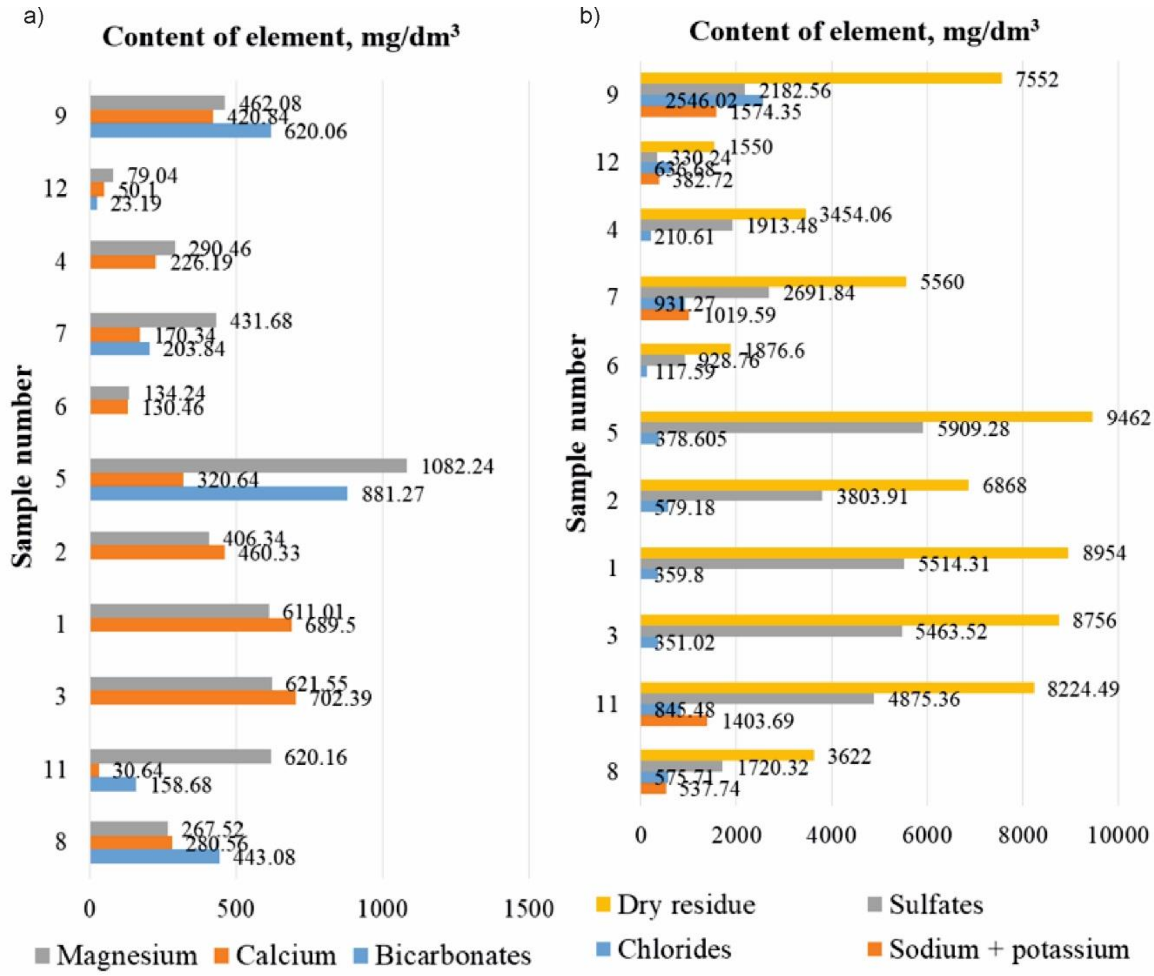

Figure 11– Content of microelements in water samples in the Pershotravneve deposit area

According to the technological scheme, the water from the quarry is pumped into a settling pond and after settling is discharged into the Saksahan River. Samples were taken from the settling pond in the tank (sample 3) and near the pumping station (sample 1). As shown by the data in figure 11, the water quality is almost the same, but worse than that of the quarry water. The water sample was taken from a natural-technogenic swampy area on the western side of the quarry near the settling reservoir, and it has a lower quality than the quarry water. The pollution of the water in the settling pond and the swampy area is explained by the location of these objects, which are affected by runoff from the waste heaps. The water in the Saksahan River, downstream of the discharge point of the quarry wastewater, has lower concentrations of chlorides, sulfates, nitrates, nitrites, iron, and total dissolved solids compared to the water in the quarry and the settling pond, but it is more polluted than the water in the wells at the inlet flow. The water quality in the Saksahan River is influenced by the discharge of quarry water, process water (such as from the Petrykivska stream – sample 9), and natural runoff from technogenic objects (waste heaps). Accordingly, it is possible to note the existing impact of mining on surface water quality, but it is not possible to isolate the impact of the actual extraction of minerals.

The surface water quality in Ukraine was previously assessed using the Water Pollution Index (WPI), later the Specific Combinatorial Water Pollution Index (SCWPI) [25], and since 2024 according to Environmental Standards [26]. However, no such assessment exists for groundwater; therefore, it is classified based on pollutants. It should be noted that all existing water pollution index models allow only classification, leaving uncertainties regarding the impact of pollutants [27].

To assess the impact of mining activities on the quality of groundwater and surface water, this study uses an algorithm for comparing the content of each pollutant at different sampling locations. Specifically, the contents of substances in groundwater upstream of the quarry and within the quarry are compared, as well as those within the quarry and downstream of it. This algorithm is similar to the calculation of the WPI, except that instead of maximum permissible concentrations, the content of the *i*-th substance at the sampling point upstream of the groundwater flow is used.

$$k = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i^{sump}}{C_i^{to}}, \tag{1}$$

$$k' = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i^{af}}{C_i^{sump}}, \tag{2}$$

where *k, k'* are the coefficients of water quality change in the quarry and downstream of the quarry, respectively; *n* is the number of investigated water quality parameters; C_i^{to}, C_i^{af}, C_i^{sump} are the contents of the *i*-th substance in water samples upstream of the quarry, downstream of the quarry, and in the sump, respectively.

To assess changes in river water quality, the water quality change coefficient was calculated by averaging the comparison of substance contents before and after the discharge of industrial waters (in the case of such discharge).

$$k_r = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i^{after}}{C_i^{t}}, \tag{3}$$

where k_r is the coefficient of water quality change after discharge; *n* is the number of investigated water quality parameters; C_i^{t}, C_i^{after} are the contents of the *i*-th substance in water samples before and after the discharge of industrial waters into the river, respectively.

The results of the calculations are presented in Table 1.

Table 1 – Results of the study of changes in water quality around mining excavations

Name of the deposit developed by an open pit	*k*	*k'*	k_r
The Zakrupetske sand deposit	-	1.0	-
The Byrzulivske ilmenite deposit	1.1	1.1	-
The Zavallivske graphite deposit	3.1	1.2	1.01
The iron ore deposit	-	2.5	1.15
The Pershotravneve deposit	7.0	4.3	1.02

As the study showed, river water quality changes only slightly, since there is no direct discharge of quarry waters (only after settling). However, groundwater quality changes significantly.

The presented data indicate that the quality of groundwater and surface water around the quarries is influenced by the following factors:

- The size and depth of the quarry; the larger and deeper the quarry, the greater the impact.
- The number of exposed aquifer layers.
- The presence of tectonic disturbances.
- The discharge of quarry water into surface water bodies after settling.
- The presence of external waste heaps and tailings ponds.

To determine the numerical values of the influence of the specified factors on changes in the water quality for each of the investigated sites, graphs were constructed, which are presented in Fig. 12.

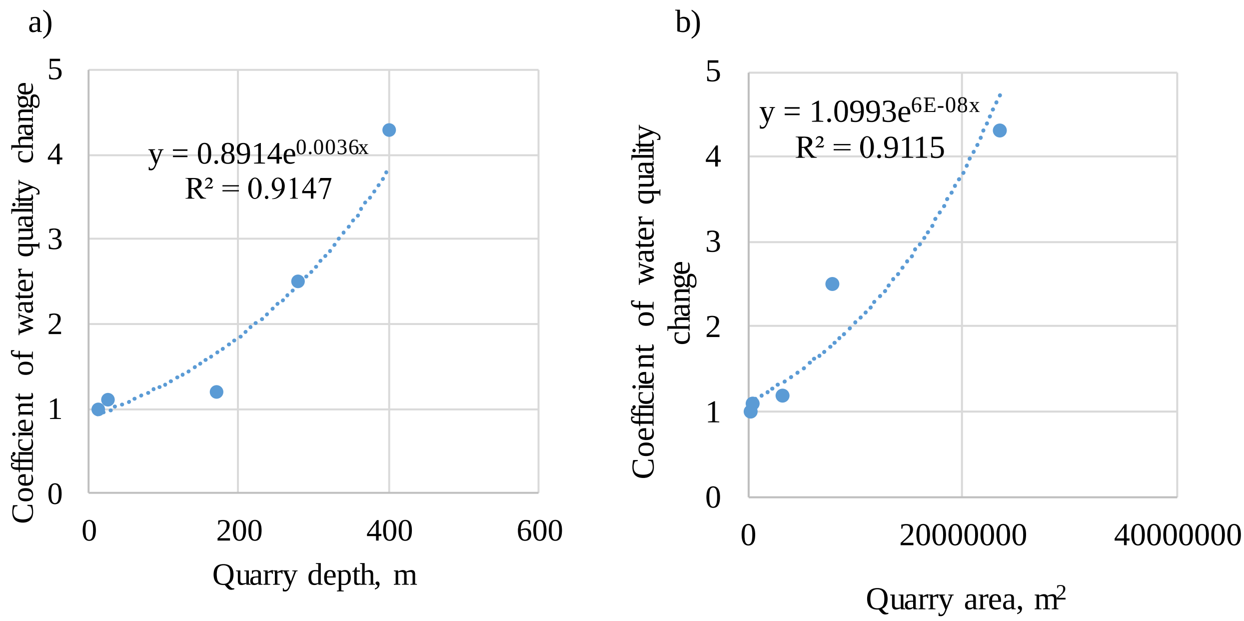

Figure 12 – Dependence of water quality changes on the depth and area of quarries

As can be seen in Fig. 12, the greater the depth and area of the quarry, the greater the change in water quality, with the dependencies having a similar exponential nature with a high correlation coefficient. However, there is no discernible pattern of pollution due to the presence of dumps and tailings ponds, which will be investigated further.

Pollution of surface and groundwater by specific elements is determined by the type of mineral being extracted and the types of overlying rocks. During the extraction of all the studied minerals, the content of total dissolved solids and sulfates increased around the quarries. In addition, the development of iron ore deposits significantly increases the chloride content in both groundwater and surface water. The extraction of graphite also leads to an increase in magnesium, calcium, and nitrates. The extraction of ilmenite sands raises the levels of bicarbonates, calcium, nitrates, sodium, and potassium. The extraction of sand deposits leads to an increased calcium and nitrate content in the surrounding surface and groundwater increases.

The most effective solution to prevent the pollution of groundwater and surface water is to intercept the water before it enters the quarry [28]. If such solutions are not feasible, it is recommended to collect quarry water separately from different aquifer layers [2] and treat it according to the content of elements [16]. This technological solution has another advantage: it will significantly improve the geomechanical condition of the sides [29].

External dumps have a significant impact on groundwater and surface water [30]. Therefore, it is recommended to capture and treat leaks from under the dumps separately.

The water generated during the beneficiation of mineral resources and the clearing of tailings ponds [31–33] should not be mixed with quarry water, which has better quality.

4. Conclusions

Based on the analysis of long-term monitoring data on the quality of quarry, surface and groundwater in the areas of mineral extraction, the article reveals changes in the quality characteristics of water around the deposits. The main factors determining the impact on changes in the quality of groundwater and surface water are the depth of the quarry, the presence of external waste heaps, and the discharge of processed water into water bodies. Around all the deposits, the content of sulfates and total dissolved solids has increased in both groundwater and surface water. Nitrates and calcium levels increase around graphite, ilmenite, and sand deposits. Around iron ore deposits, the chloride content in the water significantly rises, which is due to the exposure of the relevant rocks in the quarry and the presence of tectonic disturbances.

Using an algorithm similar to the determination of the Water Pollution Index for surface waters, changes in groundwater quality within the quarry were assessed relative to upstream waters, and downstream of the quarry relative to water in the sump. In addition, for two deposits, changes in river water quality were investigated, which showed only minor changes, which is associated with the absence of direct discharge of quarry waters.

It has been established that as the depth and area of the quarry increase, pollution of the surrounding aquatic environment also increases.

It should be noted that in some deposits, the increase in the content of certain elements in groundwater and surface water is not critical and does not exceed the regulatory limits. Also, the study did not consider the time factor, so it is impossible to assert that, in the future, changes will not occur that could cause the concentration of certain elements to exceed the maximum permissible concentration.

Conflict of interest

Authors state no conflict of interest.

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АНАЛІЗ ЗМІНИ ЯКОСТІ ПІДЗЕМНИХ ВОД В РАЙОНАХ ВИДОБУТКУ КОРИСНИХ КОПАЛИН У ЗАХІДНІЙ ТА ЦЕНТРАЛЬНІЙ УКРАЇНІ

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Анотація. Загальновідомою є зміна якісних характеристик довкілля при розробці корисних копалин. Найбільший вплив зазнають земельні ресурси та водне середовище. Метою дослідження є виявлення факторів, що впливають на зміну якості води в районах видобутку корисних копалин. На підставі багаторічних досліджень хімічного складу кар'єрних, оборотних, зворотних промислових вод, підземних та поверхневих природних вод виконано аналіз зміни їх якості. Для досліджень використано дані моніторингу водного середовища навколо піщаного, графітового, ільменітового, залізорудних родовищ в Україні. Виявлено, що найбільших змін водне середовище зазнає навколо залізорудних родовищ. Серед головних факторів, що визначають масштаб змін якості вод є розміри кар'єру, наявність зовнішніх відвалів та хвостосховищ, скидання зворотних вод в поверхневі водні об'єкти.

За даними моніторингу встановлено коефіцієнт змін якості води, як середнє значення зміни всіх досліджуваних показників. Виконано аналіз зміни коефіцієнта якості води від глибини кар'єру та його площі. Встановлено експоненціальний характер зростання змін якості води навколо кар'єрів при збільшені їх глибини та площі. Серед інших факторів, що впливають на зміну якості води є наявність хвостосховищ та відвалів біля кар'єру, проте це поки недостатньо досліджено та буде встановлено в подальшому.

Забруднення окремими елементами поверхневих та підземних вод зумовлюється типом корисної копалини, що видобувається, та видами покривних гірських порід: на залізорудних родовищах підвищується вміст хлоридів, на графітових - магній, кальцій і нітрати, ільменітових пісків - вміст бікарбонатів, кальцію, нітратів, натрію і калію, піщаного родовища - вміст кальцію та нітратів. Окрім того, навколо всіх досліджених кар'єрів підвищився вміст сульфатів та розчинених речовин.

Слід зазначити, що для більшості досліджених об'єктів, забруднення навколишнього водного середовища не носить критичний характер, оскільки більшість компонентів не перевищують ГДК. Проте в цій статті не досліджувався фактор часу, що не дає можливості здійснити прогноз на майбутнє – коли зміни якості води можуть стати критичними.

Ключові слова: якість води, вплив гірничодобувних підприємств, забруднення ґрунтових вод - забруднення поверхневих вод, родовища залізної руди, моніторинг навколишнього середовища.