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JUSTIFICATION OF DECISIONS REGARDING THE WATER SUPPLY TO THE POPULATION IN THE MINING REGIONS IN THE CONDITIONS OF LOCAL RESOURCES INSUFFICIENCY

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Abstract. The issue of the possibility of providing the population with water through the available resources of mine/quarry water formed during the extraction of minerals is considered. The authors show that there is an insufficient level of local water resources in Ukraine. The situation is especially negative in industrialized regions with high water consumption. However, in these regions, the mining industry is widely developed, and their activity is accompanied by a different level of mine workings watering. Today, mine/quarry waters are pumped out and, after sedimentation, discharged into the hydrographic network, polluting it. It is shown that the most rational is to collect, purify and use mine water.

The methods of mathematical statistics were used in this work: correlation-regression and dispersion analyses, which were used to analyze data from 10 mines in the city of Kryvyi Rih over a five-year period. The annual level of water inflows, the depth of deposit development, volumes of ore extraction, areas of license areas, geological characteristics of ore deposits, etc. were analyzed. A noticeable correlation was established only between the levels of water inflows and the depth of deposit development and volumes of ore extraction. Therefore, further the multifactorial analysis of these factors was performed. During the preliminary analysis, it was established that there is a powerful dyke between the Frunze and Pokrovska mines, and the mines located on different sides of this dyke often differ in terms of water inflows. Because of this, the northern and southern groups of mines were chosen, the data for which were processed separately. The relationship between water inflows, the depth of deposit development and production volumes was analyzed according to linear and various non-linear dependencies. The exponential dependence of water inflows on the depth of deposit development and the logarithmic dependence on the volumes of extraction show the highest correlation coefficient (0.83–0.86). According to the dependencies given in the article, it is recommended to determine forecasting water inflows for the design of mine water treatment systems for drinking water supply.

In the article, a general technological scheme with separate collection, sedimentation and treatment of mine waters is proposed. For the conditions of Kryvyi Rih, this will cover almost half of the population's water consumption.

Keywords: water resources, mine waters, discharge, regularities, water supply, treatment.

1. Introduction

The total amount of fresh water resources of Ukraine is approximately 94 billion m^3 [1], which is insufficient in terms per a unit of population.

According to the UNESCO World Program for the Assessment of Water Resources, the water supply per person in Ukraine is approximately 3,000 m^3/year (external and internal resources) [2]. According to FAO Aquastat estimates [3], the supply of the population of Ukraine with general water resources is 3,964 thousand m^3/1 person/year, and with internal water resources – 1,246 thousand m^3/1 person/year. The National Institute of Strategic Studies also notes that in Ukraine water supply by river runoff is only 1 thousand m^3/1 person/year. At the same time, according to the assessment of the UN European Economic Commission, a state is considered water insecure when water resources are less than 1.7 thousand m^3/1 person/year. Water supply by region is shown in fig. 1.

In some regions, water supply is lower than the national average: AR of Crimea and Dnipropetrovsk, Donetsk, Zaporizhzhia, Mykolaiv, Odesa, Kherson regions.

The actual water consumption for 2023 is plotted on the graph (Fig. 1), according to the State Agency of Water Resources of Ukraine.

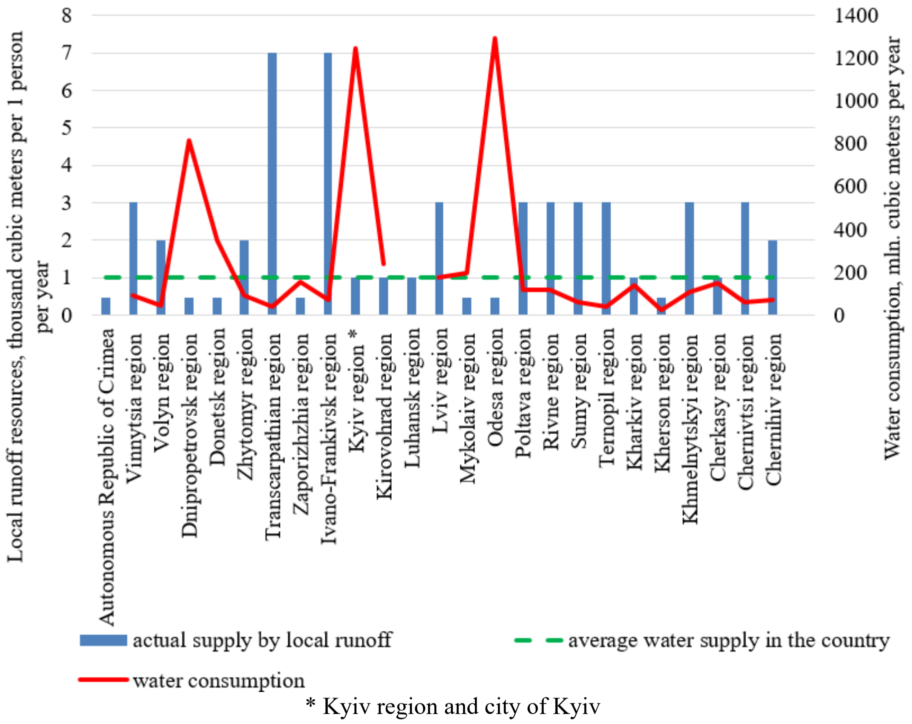


Figure 1 – Water supply and water consumption by regions of Ukraine

Taking into account the water supply in the regions of Ukraine and the concentration of the largest water consumers, it can be noted that the areas with the least water supply have the highest level of water consumption (Dnipropetrovsk, Donetsk, Zaporizhzhia, Odesa regions). At the same time, as noted in [4], groundwater withdrawal in the Donetsk, Mykolaiv and Dnipropetrovsk regions exceeds 63% of operational reserves. Therefore, the involvement of additional volumes of groundwater in the water supply system is impossible. Thus, in the areas with the largest water consumption, it is necessary to ensure the comprehensive use of available water resources and the high level of circulating water supply.

According to Ukrstat Agency, the greatest consumer of water is industry (43%), slightly less is consumed by agriculture (31%) and for communal needs (26%).

In the Donetsk and Dnipropetrovsk regions, the greatest consumers of water are mining enterprises. Despite the insufficient water supply in these regions, the majority of mine/quarry water is discharged into the hydrographic network (Fig. 2).

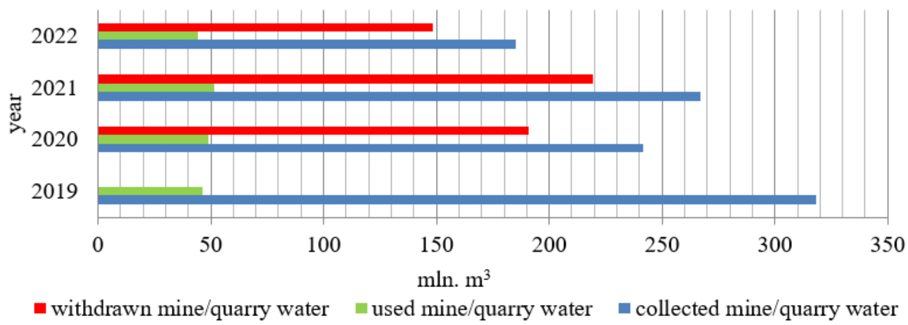


Figure 2 – Volumes of withdrawal, use and discharge of mine and quarry waters in Ukraine

This leads to a number of problems: salinization of surface water, depletion of groundwater, costs of water pumping out and transmission.

Therefore, the most rational is the implementation of complex development of deposits with the extraction of groundwater as a concomitant mineral with the mandatory introduction of a system for its treatment.

The purpose of the work is to determine the possible resources of mine water for substantiating this water supply to the population in mining regions in conditions of fresh water shortage.

Analysis of publications. The problem of the use of mine and quarry waters is considered by researchers all over the world. In work [5], it is shown that all over the world, minerals are mined in regions with a shortage of water. To solve the problem of fresh water shortage in mining regions, the authors of the article [6] recommend collecting and purifying all mine/quarry water, process water, rainwater, and waste water in sedimentation tanks. The authors of the work [7] also propose to arrange the recirculation of water with its purification and further use, instead of its withdrawal, which will lead to less fresh water extraction and pollution.

It should be mentioned that in world practice, mine waters are actively used in various directions, including for drinking water supply [8–13]. In Ukraine, this direction is just in the process. However, mine waters are actively used in our country for other needs [14–15]. In order to use mine water, many methods of its purification were developed, including treatment in the mine by cavitation [16–17], or in sedimentation tanks by biological methods [18–20], physical and chemical methods [21–23], etc. The relevant ministry developed a standard [24] for the conditions of the coal mines development regarding the use of mine water for drinking water supply.

Many scientific studies were carried out on the analysis of mine and quarry waters of the Kryvyi Rih iron ore basin. In work [25], the territory of the Left Bank dumps of the «YUZHNIY GOK» Mining and Processing Plant is considered. Eleven sources of water filtration are installed along the perimeter of the dumps, which are divided by chemical composition and hydrogeological conditions of origin. It was proven that hydrogeological features are determined by geological and tectonic structure, climatic and geomorphological factors, man-made influence. More detailed studies of the influence of geomorphological factors are given in articles [26–28]. The method of comparative statistical analysis of previously obtained and modern data (hydrogeological, hydrological, engineering-geological and geophysical) of the studies of the territory was applied to identify the degree and nature of man-made changes in the state of the hydrogeological structure of the earth's crust in the area of the deposit development.

However, according to the conducted analysis, there are no valid regulatory documents for the conditions of ore mines, which would specify any decisions on the use of mine and quarry waters for water supply to the population. Therefore, this problem is still relevant.

2. Research methods

Correlation-regression linear and non-linear analysis, including multifactorial, was used in this work to estimate the forecasting resources of mine water.

3. Theoretical and experimental part

From the point of view of water supply, the most problematic area in the Dnipropetrovsk region is Kryvorizhzhia.

Mining operations have been carried out in this region for more than 200 years, with different intensity. At present, 8 quarries, 9 mines and 3 mines are operating in hydroprotection mode. Mining enterprises are located in a belt from north to south along the Western Ingulets marginal raise, which separates the Kirovohrad and Middle-Pridnipro megablocks (Fig. 3).

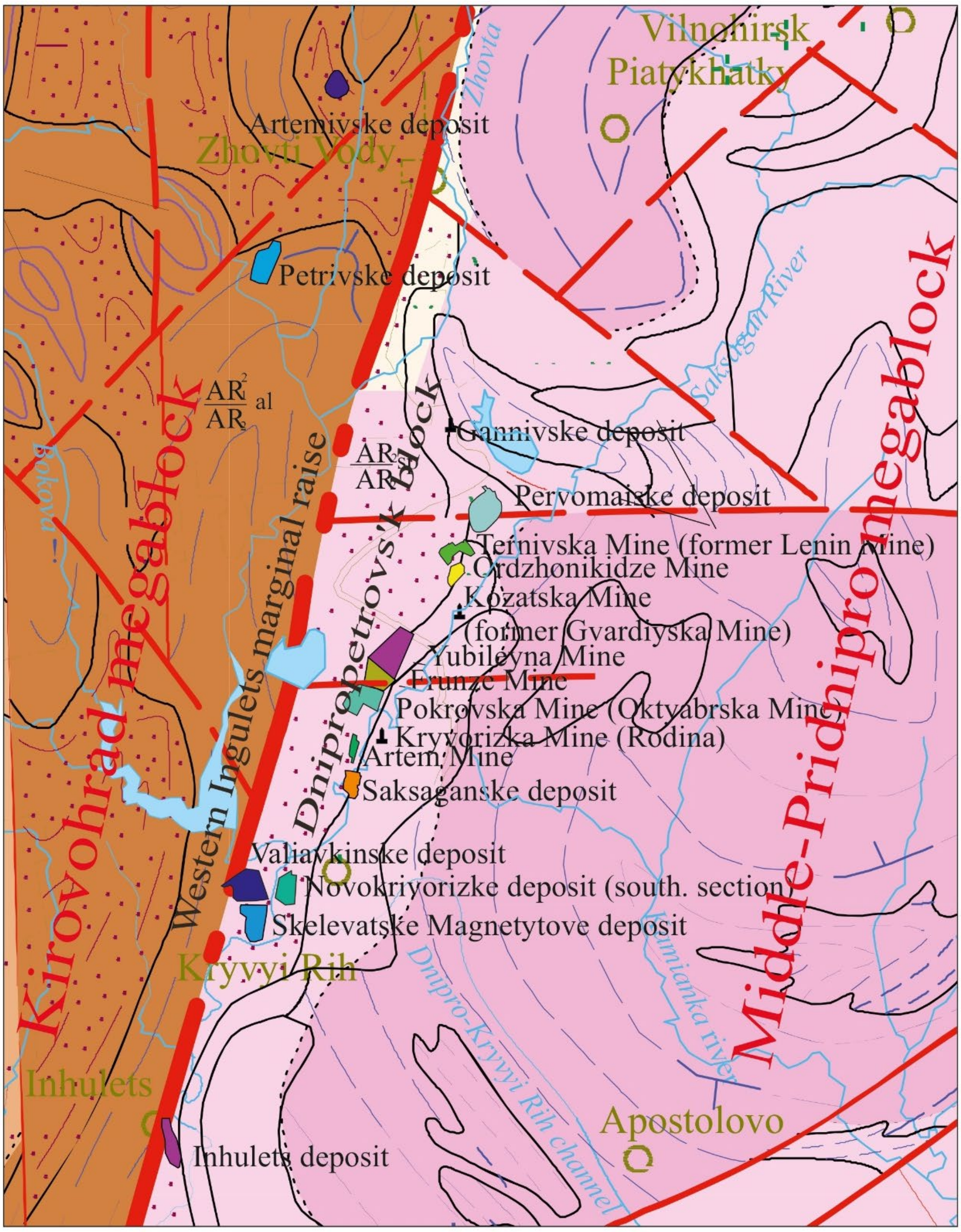


Figure 3 – Location of iron ore mines and quarries on the tectonic map of Kryvorizhzhia

Water inflows of varying intensity are observed in the mines and quarries (Table 1).

Table 1 – Water inflows to the mines of Kryvorizhzhia

Name of mines	Water inflows by year, thousand m^3					Average water inflows
	2012	2013	2014	2015	2016	
Ternivska Mine (former Lenin Mine)	1463.8	1584.4	1439.2	1368.4	1199.5	1411.06
Kozatska Mine (former Gvardiyska Mine)	1110.5	1232.2	1310.4	1136.6	929.3	1143.8
Yuvileyna Mine	746.2	1002.4	1006.1	843	796.4	878.82
Kolachevskyi Mine (former Ordzhonikidze Mine)	161.2	159.3	146.1	126	136	145.72
Pershotravneva-Drenazhna Mine	585.4	628	569.9	563.4	587.1	586.76
Pokrovska Mine (former Oktyabrska Mine)	1500.3	1482.6	1466.5	1273.9	1287.8	1402.22
Kryvorizka Mine (former Batkivshchyna Mine)	3281.1	3709.8	4416.6	4619.1	4784.3	4162.18
Frunze Mine	665.4	782.2	661.5	805.7	986.1	780.18
Mine Administration ArcelorMittal Kryvyi Rih (former Artem 1 Mine)	3673.1	3454.8	3229	3066.4	2791.1	3242.88
Gigant-Drenazhna Mine	3143.6	3326.5	3291.9	3121.8	2704.8	3117.72

About 17–20 million m^3 of highly mineralized mine water (mineralization from 5 g/l to 96 g/l [24]) is pumped out to the surface annually.

Part of the mine water is used by the enterprises as return water supply for the technological cycle, and the excess water is discharged into storage ponds and further into the Saksagan River and the Ingulets River. After discharge of excess return and mine waters, the channels of the mentioned rivers are washed with water from the Dnipro River, in accordance with the Orders of the Cabinet of Ministers of Ukraine.

However, in the conditions of insufficient water resources in this region (see Fig. 1), such solutions are not rational.

Therefore, in the conditions of insufficient local water resources in Ukraine in the mining regions, it is worth reviewing the directions of mine water management.

However, to ensure the population's water supply, it is necessary to forecast possible resources.

For this, a correlation-regression analysis was performed based on the available data in order to establish the dependence of water inflow volumes on various factors: the depth of the deposit development, the area of the licensed area, the volume of ore extraction, the age of the mine, geological characteristics of the ore deposits. However, a stable dependence of water inflows on the specified factors was not found, except for the depth of the deposit development and volumes of ore extraction, which is demonstrated below in the graphs (Figs. 4–5).

At the same time, characteristic is the upward pattern of changes in water inflows due to the depth of the deposit development and the downward pattern of changes due to the volume of ore extraction. For the dependence of the change in water inflows with depth, it was established that the mines were located in two rows of points (see Fig. 4). The analysis of the location of the mine fields (Fig. 3) showed that three mines in the south are located behind a discontinuity, which formed a dike filled with water-bearing rocks. It is the presence of the dike in the direction of the incoming flow which causes increased water inflows into the group of mines behind the dyke. Therefore, for the further analysis, it was decided to divide the mines into two groups - northern and southern.

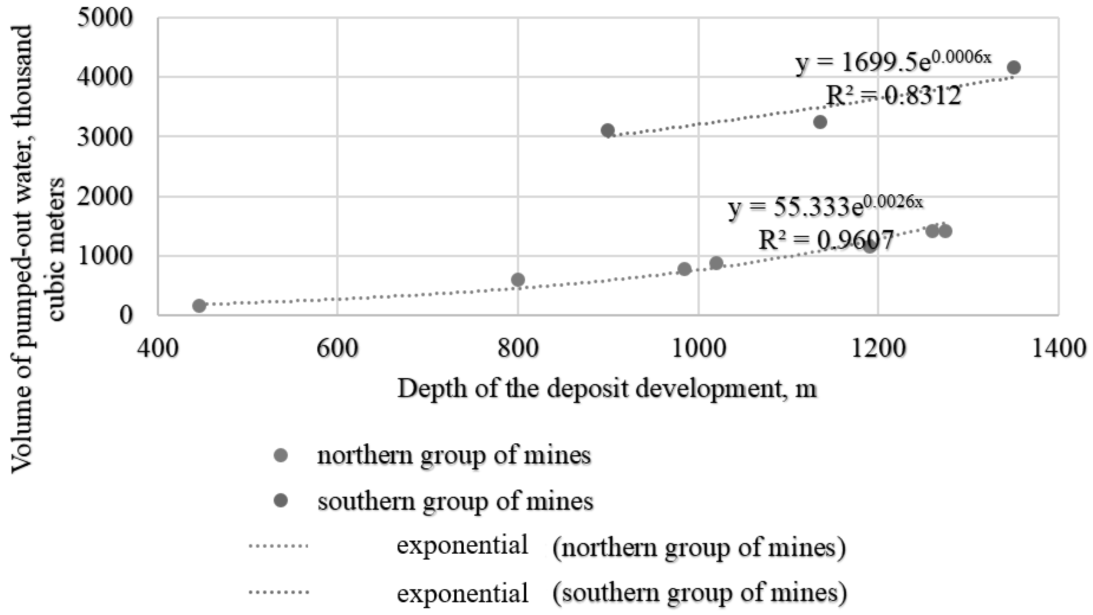


Figure 4 – Dependence of water inflows on the depth of the deposit development

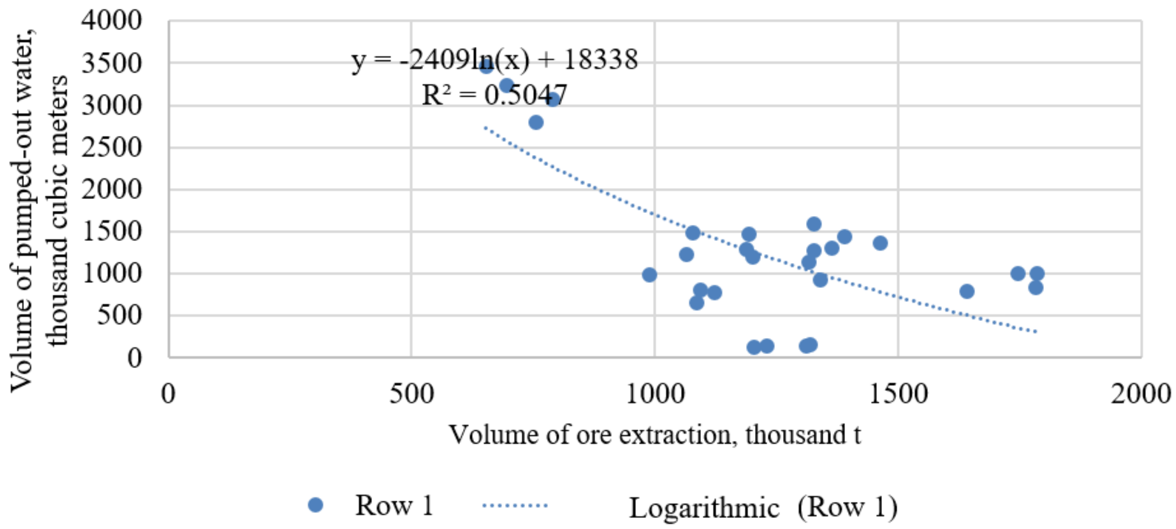


Figure 5 – Dependence of water inflows on extraction volumes

The nature of the regularity of changes in water inflows with depth is the same for both groups, the correlation coefficients of the obtained dependencies are high (R^2=0.97 for the northern group and R^2=0.85 for the southern group).

The dependence between the water inflows and the volumes of ore extraction is noticeable, the correlation coefficient is R^2=0.5.

Several attempts were made in order to establish a functional multifactorial dependence: linear dependence (expression (1)) and various forms of non-linear dependence (expressions 2–5), which would take into account the change in water inflows with changes in the depth of the deposit development and volumes of mined ore.

According to the results of the correlation-regression analysis, the following equations were obtained

$$Q = -175.908 + 2.87 \cdot A - 1.037 \cdot H, \quad (1)$$

$$Q = 5669.934 - 5.60 \cdot A - 2.318 \cdot H + 0.004 \cdot A \cdot H, \quad (2)$$

$$Q = -2962.82 + 1807644 \cdot \frac{1}{A} + 2.824 \cdot H, \quad (3)$$

$$Q = 21276.84 - 2675.73 \cdot ln\, A - 0.51 \cdot H, \quad (4)$$

$$Q = 11976.3 - 1725.2 \cdot ln\, A + 94.596 \cdot e^{0.0026H}, \quad (5)$$

where Q is water inflows, thousand m^3/year; A is volume of ore extraction, thousand tons/year; H is depth of the deposit development.

The results of regression statistics according to equations (6) – (10) are shown in Table 2.

Table 2 – Results of regression statistics

Parameter	According to the equation (1)	According to the equation (2)	According to the equation (3)	According to the equation (4)	According to the equation (5)
Multiple R	0.63811166	0.647729	0.677341	0.590252	0.729247
R-square	0.40718649	0.419553	0.458791	0.348397	0.5318
Normalized R-square	0.3663028	0.357362	0.421466	0.28634	0.499511
Standard error	1065.36793	1072.857	1017.942	683.684	946.7952
Number of observations	32	32	32	24	32

According to the results of regression statistics, equation (5) has the highest correlation coefficient. However, according to the Chaddock scale, R^2=0.53 shows only a moderate relationship. In order to find a more accurate dependence, it was decided to take into account the peculiarities of the geological structure of the territory and to perform further processing by groups of mines (see Fig. 3).

For the northern group of mines, equation (5) takes the form

$$Q = 136.74 \cdot \ln A + 44.803 \cdot e^{0.0026H} - 847.607\,, \qquad (6)$$

For the southern group of mines, equation (5) takes the form

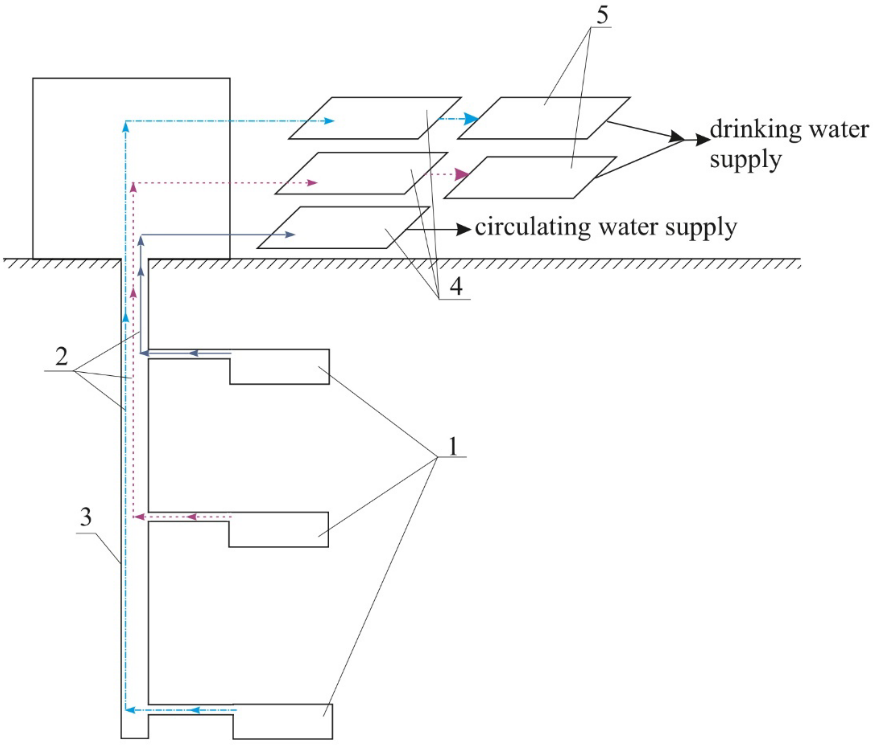
$$Q = -5604.07 - 388.318 \cdot \ln A + 5700.129 \cdot e^{0.0006H}\,. \qquad (7)$$

The correlation coefficients are equal to R^2=0.86 for expression (6) and R^2=0.83 for expression (7), which indicates a high correlation.

3. The results and their discussion

According to the results of the correlation-regression analysis, the regularities of changes in water inflows in the Kryvorizhzhia mines were established, according to which it is possible to establish forecasting indicators with changes in the depth and volumes of ore extraction, which will make it possible to determine project values for water supply to the population.

It is known that mine waters feature high mineralization. Earlier studies [23, 25, 29–31] established that waters in different horizons of mines and quarries differ significantly in terms of mineralization. In addition, in mines, underground water is usually collected at different horizons in the equipped reservoirs. Therefore, in order to ensure the use of such waters for the water supply, it is suggested not only to collect them, but also to pump them out and treat them separately (Fig. 6).



1 – reservoirs on different horizons of the mine; 2 – water pipes; 3 – mine shaft; 4 – sedimentation tanks on the earth's surface; 5 – water treatment plants

Figure 6 – Scheme of separate collection and treatment of mine waters

The following technological scheme is proposed (see Fig. 6). Mine water is collected into reservoirs 1 on different horizons and then is pumped out to the surface into separate sedimentation tanks 4 through the separate pipelines 2 located in the workings of the shaft yards and the shaft 3. After sedimentation, the most mineralized water (usually a Quaternary aquifer) is fed to the circulating water supply system for technical needs of the enterprise itself. Other part of water is supplied to separate treatment plants, where it is further purified to the quality of drinking water. Methods of water treatment depend on the quality of the water and the content of mineral components in it (it is not subject of this article). After treatment, water from various treatment plants is fed into the common water main for supplying to consumers.

With a general norm of 4.11 m^3/month per person and with population of 603.904 people, the annual level of water consumption in the city of Kryvyi Rih is 29,784.545 thousand m^3. Almost half of the required amount of water can be provided by mining enterprises after water treatment.

In addition, the man-made load on the hydrographic network, which is the receiver of settled highly mineralized mine waters, will decrease.

5. Conclusions

In some regions of Ukraine, there is a great insufficiency of local water resources. Most of these regions also have high levels of water consumption due to the large number of mining and industrial enterprises and high population density. However, in areas with highly-intensive mineral extraction, a great volume of mine/quarry water is pumped out, which is mostly unused and discharged into the hydrographic network after clarification. Such water use is unacceptable due to pollution of surface fresh water and irrational use of underground water. In order to determine possible resources of mine water which can be used for supplying water to the population, a correlation-regression analysis of statistical data on Kryvorizhzhia mines was performed, which showed the existence of a logarithmic-exponential relationship between the volumes of water inflows and the depth and volumes of ore extraction.

However, the disturbance of the massif also causes a significant impact on the water inflows. Thus, the presence of a powerful dyke between the mines led to a different level of their water level, therefore, two dependencies were proposed for the calculation of forecasting water inflows, respectively, for the northern and southern groups of mines. It should be noted that the given dependences is applicable only for the mines of Kryvorizhzhia for forecasting calculation of mine water resources.

In the conditions of the mines, it is proposed to arrange separate collection, pumping out and treatment of underground water on different horizons, since they feature different mineralization and composition, which requires different methods for their purification and lead to different possibilities of water use.

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ОБҐРУНТУВАННЯ РІШЕНЬ ЩОДО ВОДОЗАБЕЗПЕЧЕННЯ НАСЕЛЕННЯ В ГІРНИЧОДОБУВНИХ РЕГІОНАХ В УМОВАХ НЕДОСТАТНОСТІ МІСЦЕВИХ РЕСУРСІВ

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Анотація. Розглянуто питання можливості водозабезпечення населення за рахунок наявних ресурсів шахтних / кар'єрних вод, що утворюються при видобутку корисних копалин. В статті показано, що в Україні недостатній рівень забезпеченості місцевими водними ресурсами. Особливо негативна ситуація в промислово розвинених регіонах, де високе водоспоживання. Проте в цих ще регіонах розвинена гірничодобувна промисловість, діяльність якої супроводжується різним рівнем обводнення гірничих виробок. Наразі шахтні / кар'єрні води відкачуються та після відстоювання скидаються в гідрографічну мережу, забруднюючи її. Показано, що найраціональніше шахтні води збирати, очищувати та використовувати.

В роботі використані методи математичної статистики: кореляційно-регресійний та дисперсний аналізи, за допомогою яких проаналізовано дані з 10 шахт м. Кривого Рогу за п'ятирічний період. Аналізувався річний рівень водоприпливів, глибина ведення робіт, об'єми видобутку руди, площі ліцензійних ділянок, геологічні характеристики рудних покладів тощо. Помітна кореляція встановлена тільки між рівнями водоприпливів та глибиною розробки і об'ємами видобутку руди. Тому в подальшому виконано багатофакторний аналіз саме цих чинників. При попередньому аналізі встановлено, що між шахтами ім. Фрунзе та «Покровська» знаходиться потужна дайка, та шахти що розташовані по різні сторони цієї дайки в рази відрізняються за водоприпливами. Через це виділено північну та південну групи шахт, дані по яких оброблено окремо. Проаналізовано зв'язок між водоприпливами, глибиною ведення робіт та об'ємами видобутку за лінійною та різними нелінійними залежностями. Найбільший коефіцієнт кореляції (0,83–0,86) показує експоненціальна залежність водоприпливів від глибини робіт та логарифмічна – від об'ємів видобутку. За наведеними в статті залежностями рекомендується встановлювати прогнозні водоприпливи для проєктування систем очищення шахтних вод для питного водопостачання.

В статті запропонованого загальну технологічну схему окремого збирання, відстоювання та очищення шахтних вод. Для умов Криворіжжя це дозволить покрити майже половину водоспоживання населення.

Ключові слова: водні ресурси, шахтні води, скидання, закономірності, водозабезпечення, очищення.