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Long-term changes in the chemical composition of the water of the Inhulets and Saksahan rivers within the Kryvorizkyi Iron Ore Basin (1980–2020)

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Abstract. The article presents the generalized results of chemical composition research of waters from Inhulets and Saksahan rivers on the territory adjacent to the Northern and Inhulets mining and processing plants in the period of 1980–2020. Mining in Kryvyi Rih is connected with pumping of underground waters (mine and quarry), which have an abnormal chemical

composition, high mineralization and contain high concentrations of microcomponents. The following scheme of mine water utilization is used in the Kryvyi Rih iron ore basin: the mines of the northern part of Kryvbas discharge water into the tailings dam of Northern Iron Ore Dressing works (Northern GZK); mines of the southern part discharge mine waters into the storage pond of the Svistunov creek during the year, and in the winter its waters are discharged into the Inhulets River with subsequent washing of the river in the spring-summer period. Such treatment of mine and quarry waters has led to the formation of a hydrochemical anomaly on the territory of Northern GZK with the center in the tailings. The mineralization of water in the pond reaches 23 g / l (2020). There is a high content of microcomponents: lead, cadmium, vanadium, manganese, boron, bromine, nickel, mercury, thiocyanates. As a result, the mineralization of the Saksahan River water increases over time (up to 5.4 g / l), the content of microcomponents also increases and becomes quite high. Prolonged use of the Inhulets River for utilization of mine water from the Svistunov creek storage pond has led to a change in the type of water: instead of type II (river water), Inhulets water belongs to the type III (metamorphosed waters). There are no regularities in the change of chemical composition of water (hydrochemical regime) in Inhulets, which is a consequence of the introduction of the scheme "discharge – flushing" for the disposal of mine water. Among the microcomponents in the water of Inhulets there is an increased content of vanadium, boron and bromine (7–8 times), single excess of lead content. The analysis of equilibria in the carbonate-calcium system of the Inhulets and Saksahan rivers confirmed that the existing hydrochemical regime for the studied rivers is stationary, thus, the environmental measures implemented will not have rapid consequences.

Keywords: Kryvorizkyi Iron Ore Basin, rivers, Inhulets, Saksahan, mine waters, chemical composition of water, monitoring

Багаторічні зміни хімічного складу води річок Інгулець та Саксагань у межах Криворізького залізрудного басейну (1980–2020 рр.)

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Анотація. У статті наведено узагальнені результати досліджень хімічного складу води річок Інгулець та Саксагань на території, прилеглої до Північного та Інгулецького гірничо-збагачувальних комбінатів у період 1980–2020 рр. Видобуток корисних копалин у Криворіжжі пов'язаний зі відкачуванням підземних вод (шахтних та кар'єрних), які мають аномальний хімічний склад, високу мінералізацію та містять високі концентрації мікрокомпонентів. У Кривбасі застосована наступна схема утилізації шахтних вод: шахти північної частини Кривбасу скидають води у хвостосховище Північного гірничо-збагачувального комбінату (ПівніГЗКу); шахти південної частини скидають шахтні води у ставок-накопичувач балки Свистунова впродовж року, а в зимовий період води з нього скидаються в р. Інгулець з подальшою промивкою річки у весняно-літній період. Таке поводження з шахтними та кар'єрними водами призвело до формування гідрохімічної аномалії на території ПівніГЗКу з центром у хвостосховищі. Мінералізація води у ставку досягає 23 г/дм³ (2020 р.), відзначається високий вміст мікрокомпонентів: свинцю, кадмію, ванадію, марганцю, бору, бром, нікелю, ртуті, тіоціанатів. Внаслідок цього у воді р. Саксагань з часом підвищується мінералізація води (до 5,4 г/дм³), вміст мікрокомпонентів також зростає і стає досить високим. Тривале використання р. Інгулець для утилізації шахтних вод зі ставка-накопичувача балки Свистунова призвело до зміни типу води: замість II типу (річкові води) інгулецька вода має III тип (води метаморфізовані). Не прослідковуються закономірності у зміні хімічного складу води (гідрохімічний режим) у р. Інгулець, що є наслідком впровадження схеми "скид – промивка" для утилізації шахтних вод. Серед мікрокомпонентів у воді Інгульця відзначається підвищений вміст ванадію, бору і бром (у 7–8 разів), поодинокі перевищення вмісту свинцю. Аналіз рівноваг у карбонатно-кальцієвій системі річок Інгулець та Саксагань підтвердив, що для досліджуваних річок існуючий гідрохімічний режим є стаціонарним, тому природоохоронні заходи, що впроваджуються, не матимуть швидких наслідків.

Ключові слова: Криворізький залізрудний басейн, річки, Інгулець, Саксагань, шахтні води, хімічний склад води, моніторинг.

Introduction

Iron ore mining in the Kryvorizkyi Iron Ore Basin has been going on for over 130 years. Currently, the procedure is performed by mining and quarrying with mandatory drainage. The long-term problem of Kryvyi Rih is that groundwater pumped from mines and quarries has a high mineralization – up to 160 g / l (Batkivshchyna mine) (Haletskyy, 2014).

The mine water is pumped by pumping stations from the southern mines' group to the south (12–13 million m³ / year) and pumped entirely to the storage pond of mine water in the Svistunov creek for their temporary accumulation and subsequent discharge in the intervegetation period into the river Inhulets. After the mine water is discharged, the bed of the Inhulets River is washed with water from the Karachunivsky Reservoir, where the water is supplied by the Dnipro-Inhulets Canal (Sherstiuk, 2016).

Mine waters are pumped north (3.0–4.0 million m³ / year) from the northern group of mines into the tailings of the Northern Mining and Processing Plant (MPP), where it is used in the plant's circulating water supply cycles.

According to any scheme, as a result of pumping mine water, hydrochemical anomalies are formed on the earth's surface. In the Svistunov creek, the accumulated mineralization of water reaches 38 g / l. Waters of the northern group of mines with mineralization up to 45 g / l are discharged into the tailings pond of the Northern MPP, as a result of which the mineralization of water in the circulating water supply pond reaches 20 g / l. The Inhulets and Saksahan rivers are in close proximity to the territory of iron ore mining, beneficiation and processing.

The aim of the study

The aim of the study is to analyze changes in the chemical composition of the Inhulets and Saksahan rivers, located in the region of mining industry, for the period of 1980–2020. During this time, many environmental measures have been implemented in Kryvyi Rih region, that must have brought positive changes to the chemical compound of rivers water.

Materials and methods of research

The initial data for the study are the results of chemical analyzes of water samples taken by the state enterprise "Ukrchormetgeologiya". To process the results of chemical analyzes of water samples, researchers used traditional methods for determining the type of water by Kurlov and Alekin. Equilibria in the carbonate-calcium system of river waters are estimated according to the known thermodynamic schemes (Khilchevskiy, Osadchyi, Kurylo, 2012). Graphic constructions are

made both in the forms of traditional for hydrochemical researches and in the forms proposed by the authors.

The theoretical basis of the research is a systematic approach to the study of landscapes and its components, which are natural waters. An important feature of the landscape – coherence follows from the system approach, that is the correspondence of its various components to each other (Perelman, 1999).

The coherence (system unity) of the landscape determines the presence of feedback on the migration of atoms, which determines the integrity and qualitative originality of the landscape, and the existence of self-regulation in it. The components of the landscape interact each other and strive for a state in which the consumption of matter, energy and information would be equal to their receipt. As a result, the landscape is a self-regulating system, which in conditions of constant supply of matter and energy seeks to achieve a stable state. This possibility is provided by the fact that the landscape consists of subsystems that have feedback. Subsystems, in turn, function as systems with autoregulation, and this quality gives the macrosystem -landscape – a significant susceptibility to internal and external impulses.

In the landscape, the processes of self-organization determine the durability, stability of the structure and functions, their preservation when changing external conditions. If a certain natural or natural-technogenic system has reached a steady state, then according to the principle of Le Chatelier, it seeks to change in such a way as to minimize the effect of external influences. It is necessary to take into account such stationary states both for the analysis of the existing hydrochemical situation and for the design of environmental measures. A non-stationary system in which equilibria have not yet been established is easier to manage than a system with stationary hydrochemical processes.

Systematic approach in the study of natural systems known as "centralized", which have a characteristic "structural center", is extremely important. In natural and natural-technogenic landscapes, the structural center determines the geochemical features of landscapes of lower hypsometric levels. In Kryvyi Rih region, the highest hypsometric marks are most often found in tailings, which are a geochemical anomaly and cause the formation of geochemical halos in landscapes.

Results and analysis

Currently, about 300 deposits of rich ores are known in Kryvorizkyi Iron Ore Basin, which are united in 25 deposits within the basin. Some of them have already been worked out. In total, 5.5 billion tons of iron ore have been extracted since the beginning of industrial development of the Kryvorizkyi Iron Ore Basin sub-soil, and another 231.6 million tons have been explored

in the depth range from 1500 to 2000 m. The average iron content in them is 53.83 %. Currently, in mines with underground extraction of raw materials, work is carried out in the depths of 800–1350 m, and preparatory work – in the limit depths for the current technology. At the beginning of the XXI century the basin contained 9 mines, 5 mining and processing plants that conduct ore mining in 9 quarries.

To increase the iron content in the final product (iron ore concentrate and pellets) to 60–66 %, the technological scheme of magnetite quartzite enrichment is used. Enrichment waste or tailings (pulp) are stored in tailings hydraulically.

Tailings are usually arranged in depressions – gorges, ravines, depressions at a distance of several kilometers from the concentrator. The tailings pond is fenced off by a dam, which is washed away from the tails and additionally strengthened. It gradually settles the solid phase of the "tails", sometimes with the help of reagents that are added specifically – coagulants and flocculants. Settled waters are accumulated in circulating water ponds, is treated and discharged into local water bodies or returned to the concentrator for reuse in technological processes (Sherstyuk, 2011).

The natural-technogenic complex of the Northern MPP includes a tailings pond and a section of the Saksahan River (Fig. 1).

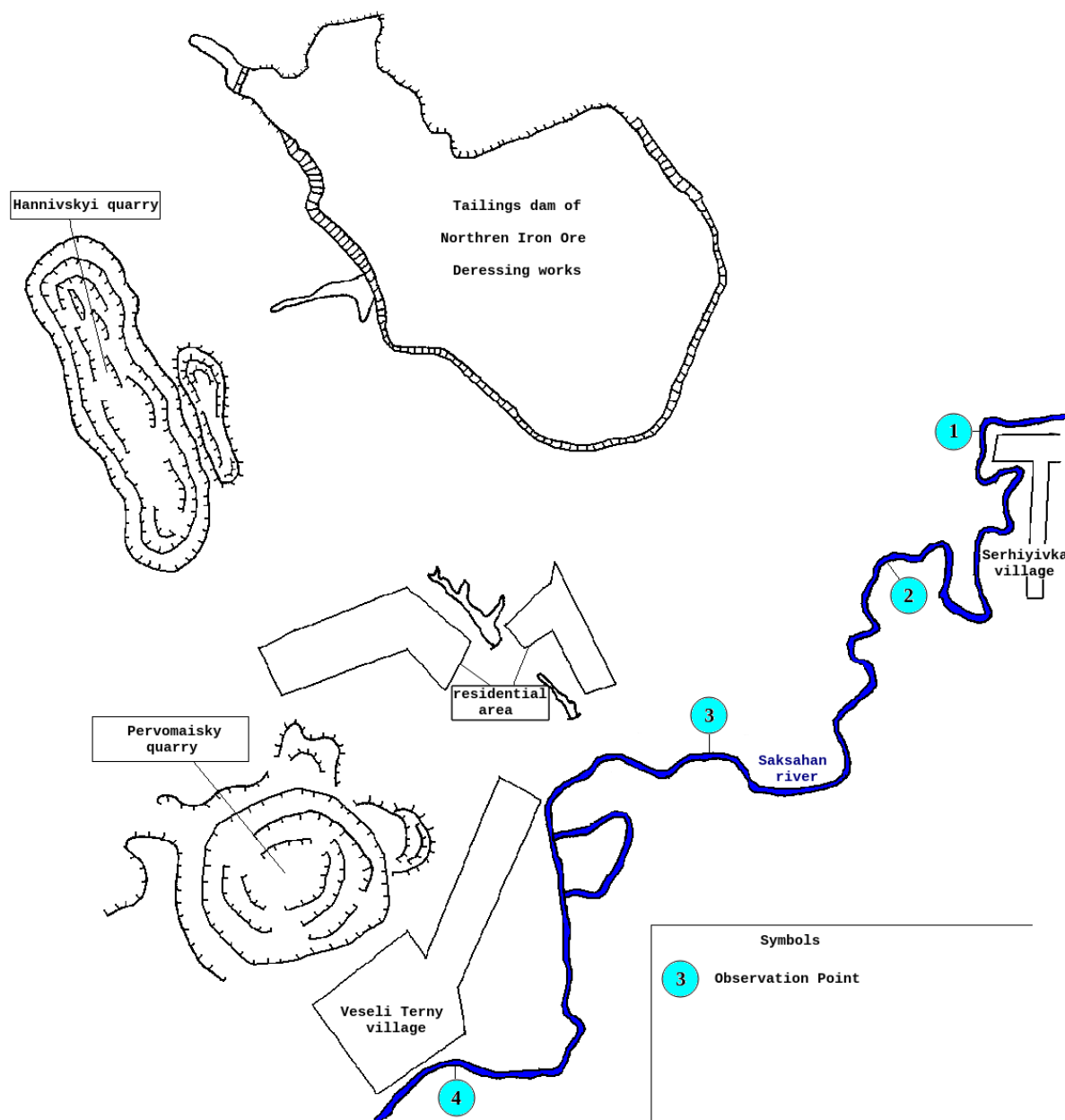


Fig.1. Map of Saksahan river in the district of Northern Iron Ore Processing Plant in Kryvbas with observation points for chemical composition of river water (downstream) No. 1 – Motyna creek; No. 2 – the first water meter post; No. 3 – the second water meter post; No. 4 – Veseli Terny village

The Northern MPP tailings pond has been operated since 1963. The main dam of the Northern MPP tailings pond is located at a distance of 2.5 km from the mouth of the Petrykov creek, which flows into the Saksahan River. Also, in Petrykov creek along the outer contour of the right-bank enclosing dam, tailings, two emergency tanks were created: the first one is in the western part and the second one is in the northern part of the tailings. The area of the tailings pond is 1295 ha (of which the tailings pond itself is 980.0 ha, the circulating water pond is 315.0 ha). The length of the tailings pond is 17.3 km (tailings pond – 11.0 km, circulating water pond – 6.3 km). The contour of the tailings pond is closed by a 1.2 km long dividing dam, which separates the circulating water supply pond from the tailings pond itself. In addition to sludge pulp, quarry water (2.5 million m³ / year), mineralization mine water (5.5 million m³ / year), wastewater from treatment plants (36.15 thousand m³ / year), and precipitation are discharged into the tailings pond, and surface filtration waters that were made from drainage systems built around the storage. (Sherstyuk & Khilchevskiy, 2012).

The water in the tailings is going through the closed cycle: the pulp (tails and water) comes from concentrators; the pulp is distributed on alluvial maps; after settling the tailings, the water enters the compartment where the pond of the circulating water supply is located, where it is fully lit and pumped to the concentrator for reuse.

To replenish the volume of the plant's circulating water supply system, quarry water from the Pervomaisky and Hannivsky quarries of the Northern MPP, as well as the water from the northern group of Kryvbas mines is constantly supplied to the tailings pond.

In low water years, the volume of the circulating water supply system can be replenished by attracting domestic wastewater from the northern aeration station of the Kryvyi Rih and water supply from the Saksahan River from the shore pumping station of the plant. (Optimizatsiia ..., 2017)

With a closed water supply scheme of the plant in the tailings pond, an excess of return water is periodically formed. In order to avoid emergencies, the company periodically discharges excess return water into the Saksahan River.

The excess of return water from the tailings into the Saksahan river is discharged by two water outlets, which are located on the right bank of the river, 48 and 50 km from its mouth, respectively, downstream from the Serhiyivka village. (Optimizatsiia ..., 2017).

In 2010, the water-salt balance of the tailings was calculated (Sherstyuk & Khilchevskiy, 2012) and it was concluded that under the current regime of discharges into the tailings, the mineralization of water in the pond of circulating water supply will increase. The data availability after 2010 allowed to assess the trend of changes in mineralization and chemical composition of water. As of 2020, the salinity of water in this pond reached 23.4 g / l, water type Cl^{Na}_{III}. Since the most important hydrochemical process in the tailings is mixing, it is advisable to assess the tendency of water mineralization to change the rate of circulating water supply over time. The regression equation has the form of:

$$M = 0.93X + 4975 \quad (R^2 = 0.81), \quad (1)$$

where X is the day from the beginning of discharges into the mine water reservoir – 1978 (Fig. 2).

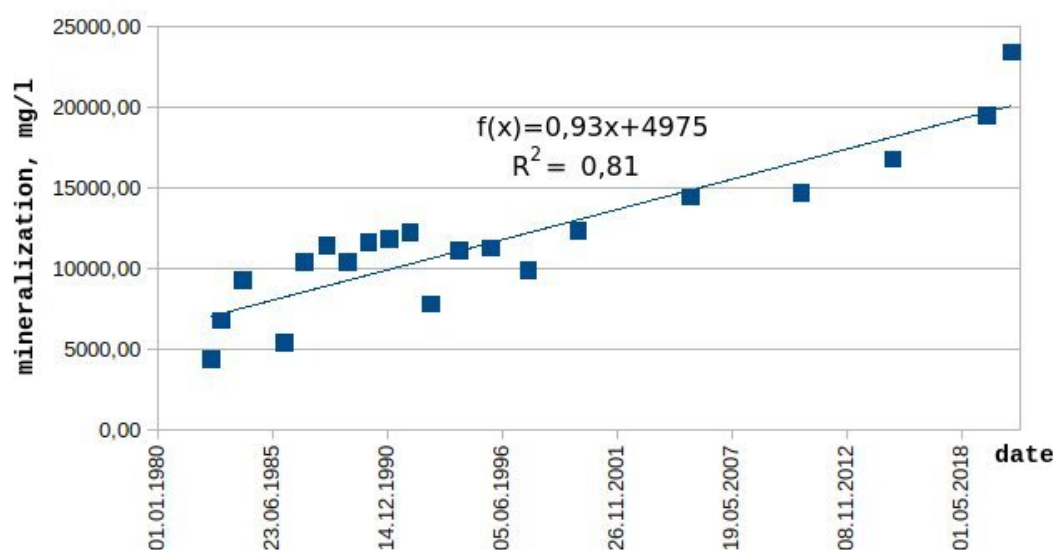


Fig. 2. Change of water mineralization in the pond of circulating water supply in the tailings of the Northern Iron Ore Processing Plant during 1980–2020 and the corresponding trend, Kryvbas

The equation allows to identify the main trend of change in water mineralization in the circulating water supply rate and to estimate its intensity. Continuation of this mode of the tailing use with the discharge of mine water with a salinity of 40–44 g / l will further lead to an increase in water salinity by 340 mg / l per a year. It should be noted that the regression equation is not predictive, but only allows to estimate the direction of the process. A more accurate forecast of changes in the chemical composition of water in the rate of circulating water supply of the tailings can be made on the basis of the calculation of water-salt balance.

It should be noted that the water rate of the reversible water supply of the tailings also has an increased content of microcomponents: lead, cadmium, vanadium, manganese, boron, bromine, nickel, mercury, thiocyanates.

The microelement composition of the current enrichment waste of the Northern MPP in the non-magnetic fraction is more than 0.03 mm (g / t): manganese – 700; lead – 4; vanadium – 6 (Gubina & Zaborovskiy, 2015).

According to research (Savosko, 2016), the aerial emission of heavy metals of the Northern GZK from the activities of quarries, concentrators, tailings is: manganese 26.9 t / year, nickel – 537.1 kg / year, lead – 574 kg / year, cadmium – 5.1 kg / year.

Thus, heavy metals enter the tailings water from the tailings. Microcomponents such as boron and bromine enter the tailings pond with mine waters.

Saksahan river. Saksahan flows in the southeastern part of the Dnipro Upland. The left tributary of the Inhulets belongs to the category of small rivers. Its source is located near the Malooleksandrivka village of the Upper Dnipro district of the Dnipropetrovsk region at an altitude of 153 m above sea level. In the middle of the twentieth century the length of the Saksahan River was 144 km, the area of the basin was 2025 km. The river has an unbranched channel, its predominant width is 20–40 m (except for the Kresivske and Makortivske

reservoirs). The flow velocity is negligible. The river has undergone significant changes as a result of the development of the mining industry. Since 1953, the mining industry began to develop intensively, new quarries were laid, namely the quarry of the Central Mining Company MPP. To organize its operation, the downstream of the Saksahan river was directed into an underground tunnel with a diameter of 3.5 m and a length of 5.32 km. As a result, Saksahan flows into the Inhulets 1.43 km below its natural mouth (Sherstiuk & Khilchevskiy, 2012). Currently, the length of the river is 140 km, the area of the basin is 1970 km².

At the research site on the Saksahan River, which is 25 km long, there are 4 observation points (OP) for the chemical composition of river water (from top to bottom): OP No. 1 – Motyna creek; OP No 2 – the first water meter post; OP No 3 – the second water meter post; OP No 4 – Veseli Terny village (see Fig. 1).

It should be noted that the right bank of the Saksahan river is located at a distance of 2.5 km from the tailings of the Northern MPP, which has a high (135 m) absolute mark and is the geochemical center. In addition, the Saksahan runoff is artificially blocked in accordance with the Ihulets river washing regulations (during the irrigation season) (Indyvidualnyi rehlyament ..., 2018). Significant changes in the hydrological regime of the river (construction of reservoirs, discharges of excess water from the tailings, runoff) have a decisive influence on the formation of the water chemical composition.

In the river Saksahan – OP No 1 (Motyna creek) there is a constant increase in water mineralization from 1.1 g / l in 1980 to 4.2 g / l in 2020 (Table 1). The linear approximation of this process is well described by the linear equation:

$$M = 0.19X + 1389.1 \quad (R^2 = 0.84), \quad (2)$$

X – day, since 1987.

Table 1. Change in mineralization and hydrochemical type of water in the river Saksahan during 1980–2020.

Observation point On Saksahan river	Mineralization of water, g/l		Hydrochemical type of water	
	1980 p.	2020 p.	1980 p.	2020 p.
OP No 1 – Motyna creek	1.1	4.2	S ^{Ca} _{III}	S ^{Na} _{II}
OP No 2 – the first water meter post	1.7	5.4	S ^{Na} _{II}	S ^{Na} _{II}
OP No 3 – the second water meter post	1.8	4.0	S ^{Na} _{II}	S ^{Na} _{II}
OP No 4 – Veseli Terny village	1.7	3.6	S ^{Na} _{II}	S ^{Mg} _{III} , Cl ^{Na} _{III}

The type of water gradually changes from S^{Ca}_{III} to S^{Na}_{II}, with a tendency to precipitate CaCO₃ and the carbonate system reaches equilibrium. Such changes in the chemical composition of water and in the carbonate-calcium system indicate that the hydrochemical processes have acquired the features of stationarity since 2010.

In the river Saksahan – OP No 2 (the first water meter post) from 1980 to 2020 water salinity increased

from 1.7 g / l to 5.4 g / l, the type of water in most samples remains unchanged – S^{Na}_{II}, carbonate-calcium system is prone to precipitation. This may indirectly indicate a greater anthropogenic impact in this section of the river than upstream (in OP No 1 – Motyna creek). The tendency of water mineralization change in time is approximated by the linear regression equation: $M = 0.26X + 1085.2$ ($R^2 = 0.77$) – Fig. 3 (X - days, since 1988).

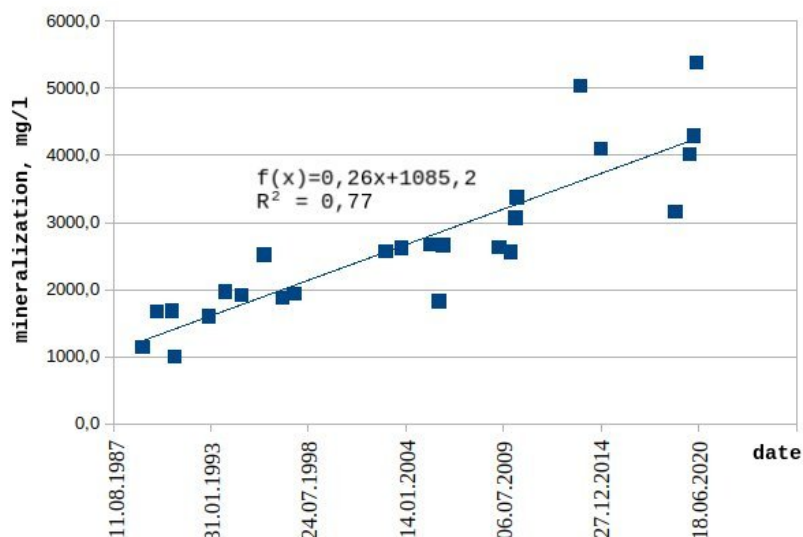


Fig. 3. Change of mineralization of water in the Saksahan river – OP No 2 (the first water meter post) in the area of Northern Iron Ore Processing Plant, Kryvbas

In Saksahan – OP No 3 (second water meter post) water mineralization varies from 1.8 g / l in 1980 to 4.0 g / l in 2020, water type for the whole time of S_{II}^{Na} observations, carbonate-calcium the system is equilibrium. The regression equation describing the change in mineralization over time has the form:

$$M = 0.16 X + 1710.4 \quad (R^2 = 0.65), \quad (3)$$

X – day, since 1988.

Water sampling in the Saksahan river – OP No 4 (Veseli Terny village) was performed until 2015. From 1980 to 2015, the mineralization of river water increased from 1.7 g / l to 3.6 g / l, water type varied from S_{II}^{Na} to S_{III}^{Mg} and Cl_{III}^{Na} , which reflects the combined effect of the Northern MPP and Veseli Terny village. The carbonate-calcium system is prone to precipitation during the predominant period of time. A number of hydrochemical observations are described by the regression equation:

$$M = 0.16 X + 1479.0 \quad (R^2 = 0.79), \quad (4)$$

X – day, since 1987.

Regarding microelements in the water of the Saksahan River, the content of which exceeds the maximal permissible concentrations (MPC) for water bodies for drinking and cultural use, the same set is observed as in the tailings, namely: lead, cadmium, manganese, boron, bromine, nickel, mercury, thiocyanates.

As a result, it can be noted that a stable hydrochemical anomaly has formed on the territory of the Northern Iron Ore Processing Plant. Its center is a tailings pond, when remote from it, the intensity of increasing water mineralization in Sakasahan decreases, and hydrochemical processes in the river water become equilibrium. Environmental protection measures in this area

should be aimed primarily at stopping the discharge of mine water into the tailings, their demineralization.

Inhulets river. The hydrological and hydrochemical regime of the Inhulets river within Kryvbas has been completely transformed. Intensive mining of iron ore inevitably raises the question of pumping mine and quarry water. Until 1993, highly mineralized mine waters were discharged directly into the Inhulets river in volumes of 40 to 60 million m³ annually (Khilchevskiy, Kravchynskiy, Chunarov, 2012).

From 2011 to the present time, a scheme of year-round accumulation of mine waters of the southern group of mines in the storage pond of the Svistunov creek with their subsequent discharge into the Inhulets river in the intervegetation period has been introduced. The discharge of annual surpluses of return waters of the mining enterprises of Kryvbas in Inhulets river is regulated by the orders of the Cabinet of Ministers of Ukraine. (Optimizatsiia ..., 2017).

Currently, the following scheme of using Inhulets for utilization of mine waters has been introduced: in winter, excess Kryvbas mine water is discharged from the Svistunov creek reservoir, which accumulates in it during the year. In the process of discharging mine water into the bed of the river Inhulets, through the Dnipro-Inhulets channel, Dnipro water is supplied. After the mine water is discharged (in the end of February), the process of washing the Inhulets riverbed with water from the Dnipro-Inhulets canal begins (in early April). Flushing lasts until mid-August.

This measure makes it possible to use Inhulets water during the growing season for irrigation of agricultural lands in Snihurivsky and Vitovsky districts of Mykolaiv region through the channels of Inhulets irrigation system, which is located in the lower reach-

es of Inhulets in Mykolaiv region. At the same time, the Ministry of Environmental Protection and Natural Resources of Ukraine warns: "... since August the water of the Inhulets River has a tendency of a sharp increase in chloride content to 1000–2000 mg / l ..." (Ministry of Environmental Protection ..., 2020). That is, this scheme of water use does not fully meet the requirements for water quality in Inhulets during the year.

In our study, we used the results of hydrochemical observations in the section of the Inhulets river near the

Inhulets MPP, downstream from the discharge of mine water from the Svistunov creek (Fig. 4). Hydrochemical observations were carried out at different times in different observation points, so the following observation points were selected for analysis, which have the longest and most complete series: OP No 1 – bridge; OP No 2 – well 1726; OP No 3 – riffle; OP No 4 – Andriyivka village.

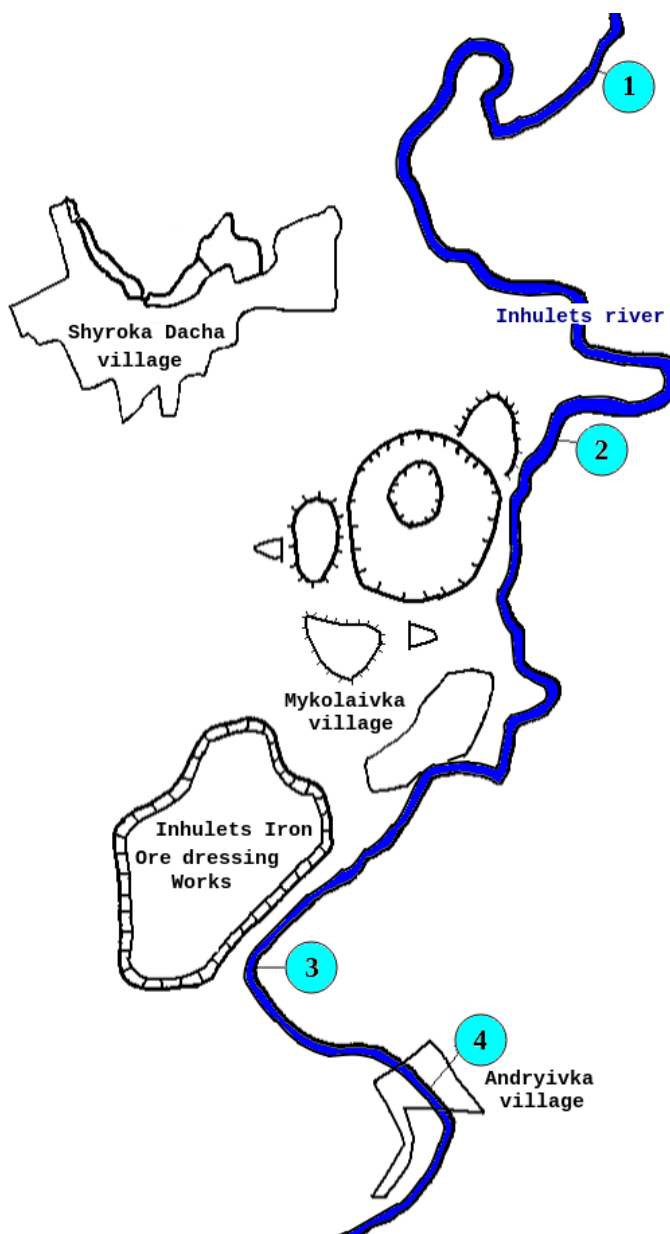


Fig. 4. Map of the Inhulets River in the area of the Inhulets Iron Ore Processing Plant in Kryvbas with observation points for the chemical composition of river water (downstream): No 1 – bridge; No 2 – well 1726; No 3 – riffle; No 4 – Andriyivka village

The Inhulets Mining and Processing Plant was built on the basis of the Inhulets Magnetite Quartzite Deposit and put into operation in 1961–1966 with an annual productivity of 18.0 million tons of raw ore. In 1967–1970, 1975, 1986, 1997, 2004–2006, projects were

developed and implemented aimed at increasing and maintaining the production capacity of Inhulets MPP with an annual program of raw ore production of up to 34.5 million tons and the production of concentrate up to 14.1 million tons.

Iron ore is mined from a quarry. Quarry water is pumped into the tailings pond with subsequent use in the cycle of circulating water supply of concentrators of Inhulets MPP.

The results of chemical analysis of water samples were calculated by known methods (Khilchevskiy, Osadchyi, Kurylo, 2012; 2019) to obtain the Kurlov's formula and Alekin index, equilibria in the carbonate-calcium system were determined. It draws attention to the fact that the vast majority of water samples from the Inhulets river during observations (since 1990) belong to the chloride class, sodium group, type III, i. e.

are metamorphosed. Thus, the chemical composition of water was formed as a result of mixing.

It should also be noted that at any of the observation points in the fluctuations of water mineralization is not determined by a significant linear trend (by the coefficient of determination). The calcium-carbonate system is mainly in a state of equilibrium and precipitation, with isolated states of dissolution.

In the Inhulets river – OP No 1 (bridge) water mineralization varies from 1.1 g / l (1994, April) to 4.3 g / l (April 2002) (Fig. 5), the total hardness reaches its maximal value in September 2020 (34 mmol / l).

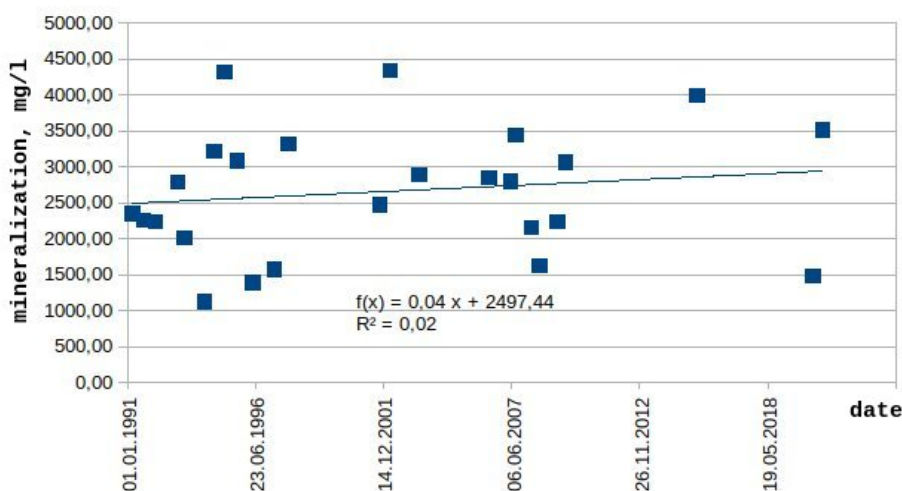


Fig. 5. Change of mineralization of water of Inhulets river – Substation No 1 (bridge) in the area of Inhulets Iron Ore Processing Plant, Kryvbas

Downstream in the Inhulets River – OP No 2 (well 1726) the mineralization of water in Inhulets varies from 1.7 g / l (2008, April) to 5.5 g / l (2019, September), the total hardness in the same time has a maximum value of 40 mmol / l. High mineralization of Inhulets water is observed after the completion of washing with Dnipro water (August 10, 2019) and low rainfall in August and September 2019.

In Inhulets river – OP No 3 (riffle) water mineralization varies from 1.6 g / l (2009, May) to 5.4 g / l (2019, September), with a total hardness of 40 mmol / l.

In the Inhulets river – OP No 4 (Andryivka village) there are no such significant fluctuations of water mineralization as in the observation points upstream. The water mineralization here varies from 1.5 g / l in April 2020 to 3.1 g / l in September 2009. The water type in about 40 % of samples varies from Cl_{III}^{Na} to S_{II}^{Na} .

Among the microcomponents there is an increased content of vanadium, boron and bromine in Inhulets water (exceeding the MPC by 7–8 times for water bodies for drinking and cultural use), there are isolated excesses of lead content.

As a result, it should be noted that the applied scheme of mine water utilization due to their discharge

into the Inhulets river and its subsequent washing changed the hydrochemical profile of the river. There is a natural decrease in water mineralization downstream: the chloride class of water changes to sulfate, which is typical of most rivers of the Middle Dnieper (Khilchevskiy, Kurylo, Sherstyuk, 2018; Khilchevskiy, Kurylo, Zabokrytska, 2020), and most importantly – the type of water from III (metamorphosed water) changes to II (river water).

However, it should be noted that according to the calculations (Indyvidualnyi rehlyament ..., 2018) obtained in the control area (village Andryivka, state control post), drinking and cultural standards of water quality must have a volume of water 1040.4 million m^3 or water flow in the river 104.7 m^3 / s . But the supply of such a volume of water from the Karachunivsky Reservoir is impossible both from a technical and economic point of view.

In 2020–2021, an alternative scheme (regime) of accumulation of the remnants of circulating mine water in the storage pond of the Svistunov creek and their discharge into the Inhulets River will be provided. It is proposed to increase the time of discharge of mine water in the Inhulets River, increase the amount of water for

dilution, exclude the period when the river had a minimal flow after the discharge period. This approach is likely to change the hydrochemical regime of Inhulets, but will not solve the problem completely.

In our opinion, the only effective way to dispose mine water is their demineralization. It is clear that this approach has been repeatedly considered and has certain disadvantages (utilization of salts formed; energy consumption, etc.).

Conclusions

1. In Kryvyi Rih there is a dangerous ecological and hydrochemical situation due to the existence on the earth's surface of water bodies with abnormally high mineralization and ion content, which are elements of intensive biological accumulation (S, Cl, Br).

2. On the territory of the Northern Mining and Processing Plant, the geochemical center is a tailings pond into which mine (40–45 g / l) and quarry waters, as well as waters from concentrators and other sources are discharged. Water salinity in the pond of the circulating water supply of the tailings as of 2020 reaches 23.4 g / l, water type Cl^{Na}_{III} .

3. When the tailings pond of the Northern MPP overflows, return waters are discharged into the Saksahan river with water discharges from the Makortovsky Reservoir, which worsens the ecological and hydrochemical situation in the river.

4. Mineralization of water of the Saksahan River (on the territory of the Northern MPP) from 1980 to 2020 increases with intensity from 0.24 to 0.16 g / l per a year, water belongs to the sulfate class, sodium group, type II.

5. The content of microelements in the water of the Saksahan river exceeds the maximal permissible concentrations for water bodies for domestic and cultural

use: lead, cadmium, manganese, boron, bromine, nickel, mercury, thiocyanates.

6. The hydrological and hydrochemical regime of the Inhulets River below the Karachunivsky Reservoir has been radically changed: there is no low winter limit with increased water mineralization; instead, there are maximum water consumption and high mineralization (due to mine water discharges); instead of high spring floods with minimal mineralization – low costs (natural) with high water salinity; summer mean water with low costs and high water salinity is replaced by high costs with minimal water salinity (due to the regime of river washing).

7. The difficulty of studying, and more predicting, the hydrochemical regime of Inhulets is the lack of a natural analogue, which would greatly facilitate the development of the optimal possible discharge of mine water.

8. The consequence of the application of the “discharge-flushing” regime for Inhulets is the absence of any regularity in the change of mineralization and chemical composition of water in the area near Inhulets Mining and Processing Plant. It is constant that in most observation points the water belongs to the chloride class, sodium group, type III, i. e. is metamorphosed.

9. The equilibrium carbonate-calcium system formed in the water of the Saksahan and Inhulets rivers indirectly confirms the equilibrium of the entire hydrochemical system. This must be taken into account when implementing environmental measures, as the system will try to return to the equilibrium it currently has.

10. It is necessary to carry out constant hydrochemical monitoring of all technogenic waters entering natural water bodies.

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