

INVESTIGATION OF THE HYDRODYNAMICS OF MAN-MADE WATER BY REMOTE METHODS (ON THE EXAMPLE OF SOUTHERN KRYVBAS)

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Abstract. The purpose of this study was to identify the degree and nature of man-made changes in the condition of the hydrogeological structure of the upper part of the earth's crust in the south of the Kryvyi Rih iron ore basin (Kryvbas). Another goal was the search and localization of sources of highly mineralized waters of the studied territory.

To understand the nature of the watering (dewatering) of the section, the results of mapping the deformation of the terrain on the Sentinel-1 IW SLC space radar images were used. The resulting changes in the relief of the area were compared with the results of repeated geoelectrical observations, which showed zones of the day surface to the south of the "Livoberezhny" dumps, which are subject to subsidence and have areas of local flooding and waterlogging. They are mainly associated to the complex structure of zones of tectonic disturbances, zones of intersection of Precambrian faults of sub-meridional extension and west-northwest, which affect the distribution and localization of mineralized waters.

Analysis of the data of hydrogeological, hydrological, engineering-geological and geophysical studies of the territory at the end of the 20th and beginning of the 21st centuries showed the degree of change in the hydrogeological environment over several decades. A comprehensive interpretation of space radar and geophysical survey data made it possible to assess the physical processes that take place from the surface to depths of tens of meters below it. The carried out geoelectrical research made it possible to establish the width of the rock water table in the upper part of the section, which ranges from 50 to 150 m, and the presence of a local depression on the roof of the foundation, under pond "Lebiazhyi". The latter is due to the specificity of the connection (knot) of differently oriented faults, where highly mineralized waters preserved in the Kryvyi Rih fault system are still stored and accumulated in the form of lenses.

The conclusion is the integration of remote methods that study various properties of the geological environment increase the possibility of operational and scientifically based identification of problems of flooding of the territory and allow to control safe activities in the zone of influence of man-made objects.

Keywords: hydrogeological structure, technogenic flooding, mineralized waters, remote methods, satellite images, geoelectrical research.

1. Introduction

The territory of southern Kryvbas is characterized by the distribution of highly mineralized waters in the Quaternary and Neogene deposits, as well as in the zones of large faults of the Precambrian basement. At the same time, waters mineralization can vary both in depth and laterally. One of such objects is the Lebiazhyi pond (Fig.1), which is located between the left bank dumps and the bend of the Ingulets River (northwest of Novoselivka village). The waters of the pond have an increased mineralization, the value of which varies over time, which makes it impossible to use the waters in agriculture. Depending on the occupancy of the pond, the ways of migration of highly mineralized waters change, which affect the degree of manifestation of landslide processes along the left bank of the Ingulets River.

In order to search for and localize sources of highly mineralized waters in this area, complex studies were carried out, which included satellite data and field geophysical work with their subsequent joint processing and interpretation.

2. Methods

To determine the degree and nature of man-made changes in the state of the hydrogeological structure of the upper part of the earth's crust in the south of the Kryvyi Rih iron ore basin (Kryvbas), a method of comparative statistical analysis of previous

work and modern observations was applied. As initial data, the results of geological exploration, geological, hydrogeological, geophysical surveys and environmental and geological studies were used, which were carried out before the commissioning of the current large man-made objects of the mining and metallurgical complex. The position of the field research profiles was determined by the vertical electrical sounding (VES) method, taking into account spectral satellite images.



VES (vertical electrical sounding) observation profiles and their numbers – chains of dots; monitoring wells and their numbers - white dots

Figure 1 – Satellite images of the study area of the Lebiashyi Pond:

Theoretical and experimental part. Earth remote sensing. Field geophysical works were designed taking into account the available spectral image of the Pleiades satellites as of May 2018.

To identify hydrogeological changes in the studied massif, data from geophysical observations and remote sensing conducted in the summer of 2012 were used.

Joint interpretation of the results of ground-based observations and satellite data was carried out directly in the process of field works to determine the details of measurements in order to clarify individual elements of the study area.

At the same time, the integration of digital maps of multispectral images, interpretation and construction of lineament maps of tectonic structures and geodynamic zones were carried out in order to predict tectonophysical changes.

Electrical prospecting research. Geophysical work of the *Dnipropetrovsk Geophysical Enterprise «Dniprogeofizyka» (DGE «Dniprogeofizyka»)* between the left bank dumps, the bend of the Ingulets River and the Novoselivka village by profiles 7, 9, 11, 3.1 (Fig. 1). In the study of the geoelectric section to increase the detail and high quality of work in the presence of intense industrial electromagnetic interference, the technique of successive spacing of the supply line was applied. The number of measurements exceeded the standard one by 1.7 times. In this case, such half-spaces of the supply line were used as $AB/2 = 1.5; 2; 3; 5; 6; 8; 11; 15; 20; 25; 30; 40; 50; 60; 80; 110; 150$ m (AB - the distance between the supply electrodes).

The maximum spacing of the line $AB/2 = 150$ m made it possible to study the geoelectric section with a depth of more than 70 m.

The actual average relative error of the survey in the area of work was 1.87%. It was calculated as the average of the measurement errors at individual points.

During the work, the dependences of the electrical resistivity of individual rocks, as well as the granulometric composition, clay content and porosity on the mineralization of the waters present in them were analyzed. The dependence of the parameter ρ on the moisture content of sandy-argillaceous rocks and the concentration of dissolved salts was given in the same way as in the work [5]. The dependence shows that the dependence of resistivity on a single indicator of rock properties has a correlation character with the degree of closeness of the relationship.

Also, to characterize the geoelectric section (geological layer parameters) of the study area, the results of the interpretation of parametric VES performed in the vicinity of existing wells were used.

Visualization of the results of field measurements by the VES method were presented in the form of qualitative sections of apparent resistivity, average value ρ_k , field asymmetry ρ_k and axial lines of anomalies of these fields along complex geophysical profiles or their individual intervals using the COSCAD software package.

3. Results and discussion

Two types of fracturing of crystalline rocks are distinguished in the study area: exogenous - developed in areas of their shallow occurrence and is associated with their stratification as a result of weathering; endogenous - due to tectonic processes in the upper part of the earth's crust. It should be noted that the water abundance of fractured zones depends on many factors: the thickness of the overlying sedimentary deposits; the petrographic composition of rocks; the degree of tectonic disturbance; the nature and age of tectonic faults (healed or living); etc. Neotectonic faults are more watery, ancient faults are characterized by a lack of water, which is due to secondary processes leading to crack healing.

The thickness of sedimentary deposits of the Quaternary and Cenozoic ages lying on the uneven surface of the basement, depending on their thickness, composition, water saturation and mineralization of the waters of individual horizons, is characterized by a wide range of types of VES curves: H, HA, HAA, HAK, HKH, QH, QHA, KHA, AKH, QHKH, etc.

Results of complex researches. Conducted electrical exploration work in the modification of the VES (Fig. 1, profiles 7, 9, 11, 3.1) between the left bank dumps, radiated by the Ingulets River and Novoselivka village no areas of continuous flooding were identified (Fig. 2).

Along the profiles in the upper part of the geological section from 2-5 to 10 m, in most cases, increased resistivity values are noted, which indicate the absence of watering within the study area (Fig. 2).

When analyzing water samples from the left bank dumps, it was found that they were formed by atmospheric precipitation, their geochemical load is only due to the

presence of calcium, magnesium, chlorine, sulfate ion and other chemical components in them, mainly from loams containing nests of carbonates and gypsum, partly from hematite quartzite and shale rock dumps. The content of chemical components in the water composition of the studied samples is significantly lower than similar indicators of water from observation hydrological wells No. 1736 and 1743 (Fig. 1, 2, 3) and the Lebiazhyi pond. This is explained by the fact that the borehole samples contain water not only from atmospheric precipitation and perched water, but also from the Cenozoic aquifer, characterized by increased mineralization..

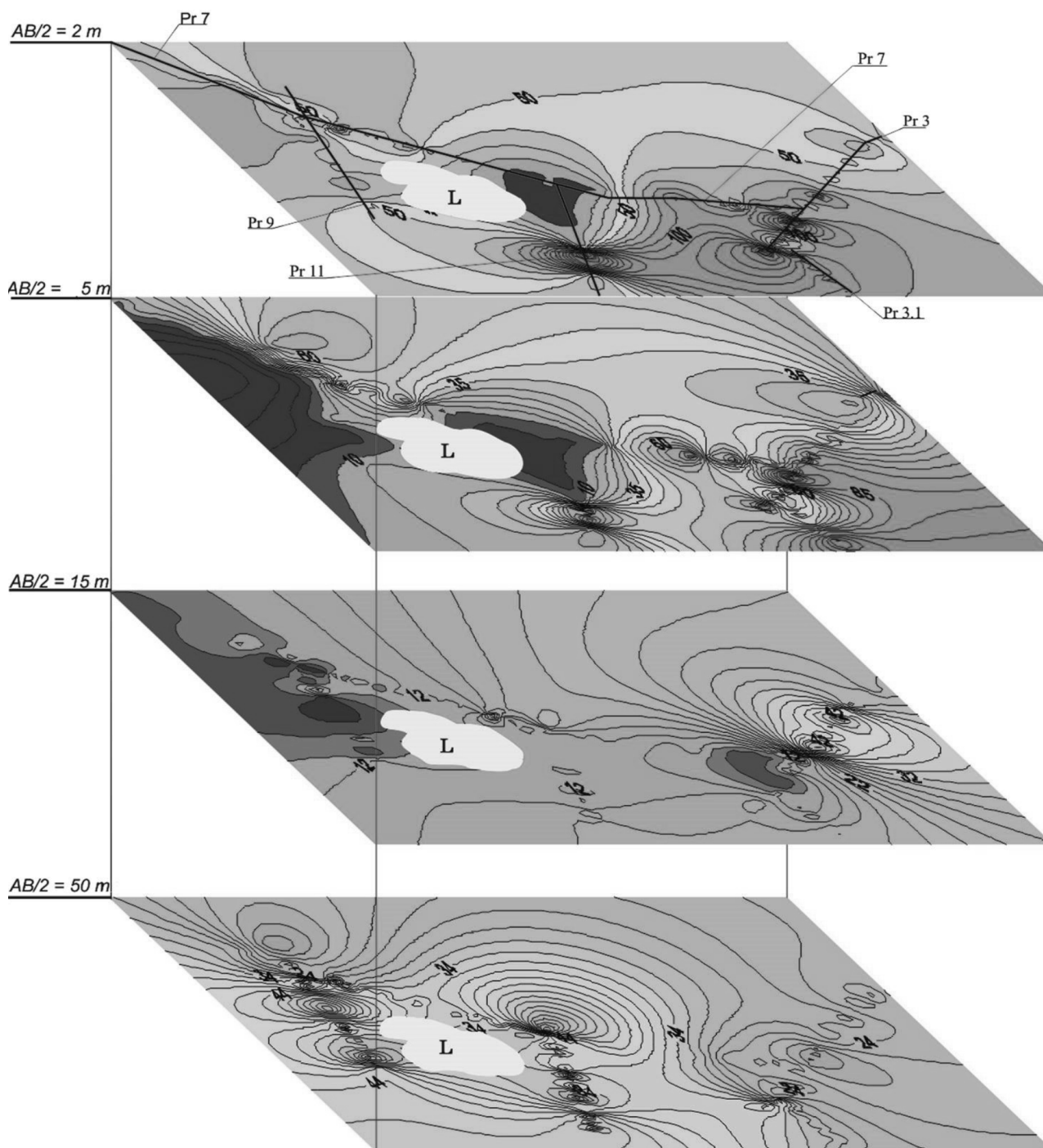
To the south of the left bank dumps, separate areas (lenses) of local flooding and swamping were identified. The processing of interferometric images (2015-2018) made it possible to identify zones on the day surface of the territory that are experiencing modern subsidence. They are quite well manifested in the spectral satellite image (Fig. 1) by the change in the tint of the spectrum, which is due to vegetation associated with shallow groundwater. These lenses of flooding can be associated with the complex structure of zones of tectonic faults, zones of intersection of Precambrian faults of submeridional and west-northwest strike (Fig. 2, 3), which affect the distribution and localization of mineralized waters.

The width of the band of water cut in the rocks of the upper part of the section along the lateral ranges from 50 to 150 m, taking into account the mineralized water from the Lebiazhyi pond.

The pond was formed in the 90s of the last century on the northwestern outskirts of the Novoselivka village due to the accumulation of atmospheric precipitation, seepage waters mainly from the Voikove tailing dump and due to the water that is squeezed out by the left bank dumps. The area of the pond is 1.5 - 2.5 ha (Fig. 1), but its dimensions are not constant; in summer, in dry weather, they decrease due to intensive water evaporation (Fig. 1). Its technogenic origin is evidenced by the data of the analysis of the surface waters of the pond in 2017. The mineralization was: 10.1 mg/dm³, total hardness 79.0 mg-eq/dm³, content of chlorides – 6279.0 mg/dm³, sulfates – 7.0 mg /dm³ [5].

Zones of modern subsidence of the daytime relief, taking into account the fault-block structure of the rock massif along the left bank of the river. Ingulets leave to the southwest, capturing the territories of the villages of Novoselivka and Novolatovka. This band also includes the well No. 1743, revealing a highly mineralized aquifer of Quaternary alluvial deposits located in the thalweg of the Mikushyn beam. A tectonic fault passes along the thalweg of the beam, crossing the thrust zone of the Tarapakovskyi fault. Drilling data from wells No.1735 and No.1743 show a shallow occurrence of crystalline rocks and their weathering crusts (Fig. 3).

As shown in fig. 4, the minimum amount of dry residue in wells No.1735 and No.1743 was recorded in 2004, the maximum amount was recorded in 2008. An increase in the amount of dry residue was observed in the period from 2004 to 2008 (at that time, its amount was maximum), with a sharp jump in the direction of increase in 2007. The following three years after 2008, a smooth decline of this parameter is observed. In the period from 2011 to 2016, the amount of dry residue in the samples from the well changed little, and then declined again.



Intensity of the apparent resistance, $\text{Om}\cdot\text{m}$



Figure 2 – Maps of horizontal sections (in axonometry) of resistance p_k at spacings $AB/2$ from 1.5 to 50 m

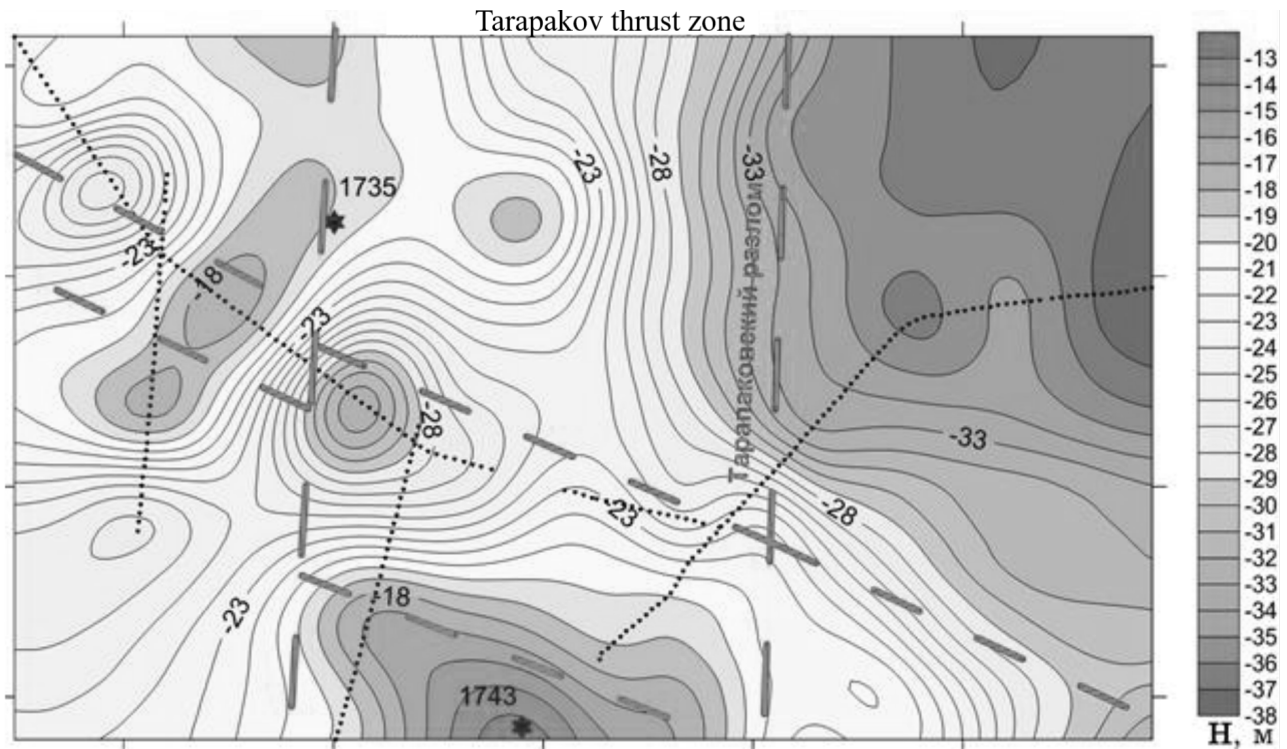


Figure 3 – Map of the calculated depths of the Precambrian basement according to the data of works using the VES method with a scheme of faults

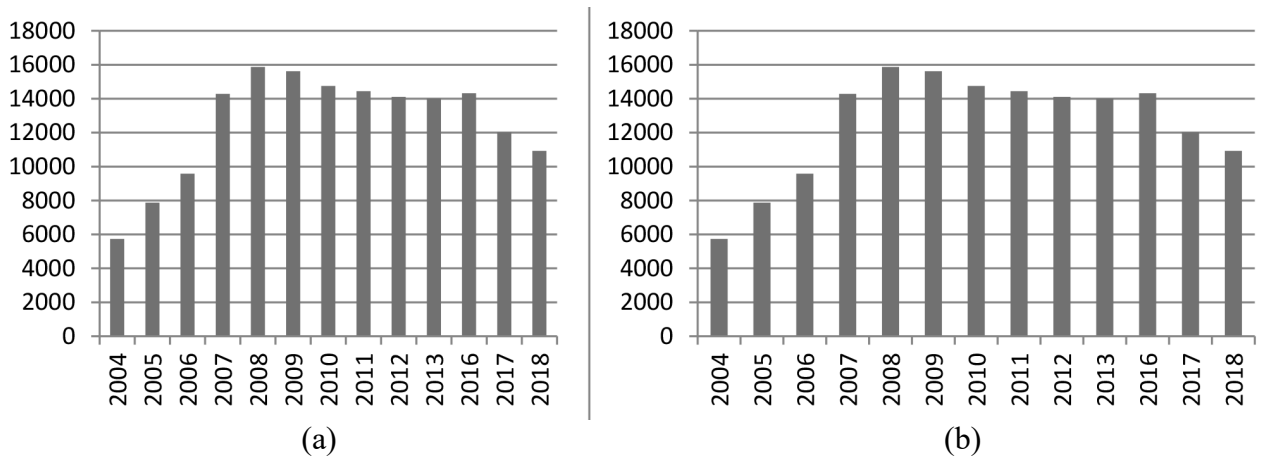


Figure 4 – Histograms of the amount of dry residue in wells No.1735 (a) and No.1743 (b)

It should be noted the similarity of the behavior of the histograms for wells No. 1735 and No.1743 in the period from 2008 to 2018. The synchronous change of the dry residue in these wells may indicate their location in the same tectonic fault zone.

The geoelectrical studies performed by us made it possible to build a predictive map of the depths of the Precambrian rocks, with the presence of a local depression along the roof of the basement, at the base of the Lebiazhyi pond. The described zone is due to the specificity of the junction (knot) of differently oriented discontinuities, where highly mineralized waters preserved (accumulated) in the form of lenses are

still preserved in the Kryvyi Rih system of faults and waters that migrated in 1978 along the diagonal faults of the northwestern strike from the pond - storage of mine waters in dell Svistunov. These lenses of highly mineralized waters can be diluted by minor, less mineralized springs from the fault zones at the base of the Voikoho tailings bed. Horizontal sections of the VES (Fig. 2) show the migration of mineralized waters (dark blue) at different stratigraphic levels.

4. Conclusions

The research results indicate a significant differentiation of rocks in terms of the electrical resistivity of the geological section of the study area, which makes it possible to identify watered areas with varying degrees of mineralization.

Analysis and comparison of previously performed hydrogeological, engineering-geological and geophysical studies on the territory adjacent to the industrial area of JSC "South Mining Plant" modern observations over the past decades indicate significant changes in the hydrogeological environment. In particular, the mineralization of groundwater and the direction of distribution of highly mineralized waters lead to the active development of landslide processes along the left bank of the Ingulets river.

Our comprehensive studies made it possible to build a predictive map of the depths of the Precambrian rocks and to establish the presence of a local depression along the basement roof, at the base of the Lebiazhyi Pond. The described zone is due to the specificity of the junction of differently oriented faults, where highly mineralized waters preserved in the Kryvyi Rih fault system are preserved in the form of lenses.

The integration of remote methods studying various properties of the geological environment shows the possibility of prompt and scientifically substantiated identification of many of the listed problems of flooding in order to ensure safe operation in the zone of influence of man-made objects.

The results of complex studies allow us to conclude that, in addition to the existing methods of monitoring observations and control, a satellite-terrestrial remote sensing system is included, which makes it possible to quickly and without disturbing the continuity of the geological environment in real time to predict regional and local changes in the natural and technogenic situation near industrial facilities and structures of the mining and metallurgical complex.

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ДОСЛІДЖЕННЯ ГІДРОДИНАМІКИ ТЕХНОГЕННИХ ВОД ДИСТАНЦІЙНИМИ МЕТОДАМИ (НА ПРИКЛАДІ ПІВДЕННОГО КРИВБАСУ)

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Анотація. Метою даного дослідження було виявлення ступеня та характеру техногенно обумовлених змін у стані гідрогеологічної структури верхньої частини земної кори на півдні Криворізького залізрудного басейну (Кривбас). Ще однією метою був пошук та локалізація джерел високомінералізованих вод досліджуваної території.

Для осмислення природи обводнення (зневоднення) розрізу було залучено результати картування деформації рельєфу місцевості по космічних радіолокаційних знімках Sentinel-1 IW SLC. Отримані зміни рельєфу місцевості були зіставлені з результатами повторних геоелектричних спостережень, які показали зони денної поверхні на південь відвалів «Лівобережні», що зазнають опускання та мають ділянки локального підтоплення та заболочування. Вони переважно пов'язані зі складною будовою зон тектонічних порушень, зонами перетину докембрійських розломів субмеридіонального простягання та захід-північно-західного, які і впливають на поширення та локалізацію мінералізованих вод.

Аналіз даних гідрогеологічних, гідрологічних, інженерно – геологічних та геофізичних досліджень кінця ХХ початку ХХІ сторіччя території, показав ступінь зміни гідрогеологічного середовища за кілька десятиліть. Комплексна інтерпретація даних космічної радарної та геофізичної зйомок, дозволила оцінити фізичні процеси, що проходять від денної поверхні до глибин в десятки метрів під нею. Виконані геоелектричні дослідження дозволили встановити ширину смуги обводненості порід верхньої частини розрізу, що коливається від 50 до 150 м та наявність локальної депресії по покрівлі фундаменту, під ставком «Лебязий». Остання зумовлена специфікою з'єднання (вузлом) різноорієнтованих розривних порушень, де у вигляді лінз, досі зберігаються та накопичуються високомінералізовані води, законсервовані у Криворізькій системі розломів.

Зроблено висновок, що комплексування дистанційних методів, що вивчають різні властивості геологічного середовища, підвищують можливість оперативного та науково обґрунтованого виявлення проблем підтоплення території та дозволяють контролювати безпечну діяльність у зоні впливу техногенних об'єктів.

Ключові слова: гідрогеологічна структура, техногенне підтоплення, мінералізовані води, дистанційні методи, космічні знімки, геоелектричні дослідження.