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Web-Based Information and Analytical Monitoring System Tools – Online Visualization and Analysis of Surface Water Quality of Mining and Chemical Enterprises

Natalia Bernatska[1], Elvira Dzhumelia[2*], Vasyl Dyakiv[3], Olena Mitryasova[4], Ivan Salamon[5]

[1] Department of Physical, Analytical and General Chemistry, Lviv Polytechnic National University, Lviv, 12, St. Bandera St., 79013 Ukraine

[2] Department of Software, Lviv Polytechnic National University, Lviv, 12, St. Bandera St., 79013 Ukraine

[3] Department of Ecological and Engineering Geology and Hydrogeology, Ivan Franko National University of Lviv, Lviv, 1, Universytetska St., 79000 Ukraine

[4] Department of Ecology and Environmental Management, Petro Mohyla Black Sea National University, Mykolayiv, 68 Desantnykiv Street, 10, 54003 Ukraine

[5] Department of Ecology, Faculty of Humanities and Natural Sciences, University of Presov, Presov, 080 01 Slovakia

* Corresponding author's e-mail: elvira.a.dzhumelia@lpnu.ua

ABSTRACT

An analysis of the quality of surface water of State Enterprise Rozdil Mining and Chemical Enterprise 'Sirka' was carried out. It was established that in order to ensure ecological balance in the zone of influence of this enterprise, it is necessary to conduct regular monitoring observations, maintenance, supervision and control over the condition of hydraulic structures, elimination of sources of pollution. The obtained research results indicate that there is a need to create an information and analytical monitoring system in order to effectively store, process, and analyze the data based on the principles of comprehensive environmental monitoring for the collection, storage, and processing of data on pollution of various elements of the environment, which will provide forecasting of environmental changes in the territory of the mining and chemical enterprise. On the basis of the obtained research results, a web application was created based on an interactive map of water sampling points, visualization of the obtained results of hydrochemical monitoring of Rozdil Lakes, and a forecast of the state of the water environment.

Keywords: environmental monitoring, information and analytical system, online visualization, interactive map, mining and chemical enterprises.

INTRODUCTION

The mining and chemical industry occupies one of the leading places in the infrastructure of the country's economy (Pohrebennyk et al., 2018). However, at the same time, the activity of mining and chemical enterprises is a determining factor of technogenesis, which significantly complicates the ecological situation in local territories with a change in the forms of the relief, hydrological and biogeochemical regimes of the territories, which is caused by the accumulation of a significant amount of production waste on the earth's surface (Pohrebennyk et al., 2017). Thus, various environmental problems arise, which are connected, first of all, with the pollution of various natural components of the environment – soils, waters, vegetation, and therefore the deterioration of the health indicators of the local population (Pohrebennyk et al., 2017; Sohor et al., 2020).

One of the intensively exploited industrial basins is the Pre-Carpathian sulfur-bearing basin

(Pohrebennyk et al., 2018). At the moment, the environmental situation within the boundaries of State Enterprise (SE) Rozdil Mining and Chemical Enterprise (MCE) 'Sirka' is one of the most tense in Ukraine (Pohrebennyk et al., 2017, 2018). The half-century history of sulfur deposit development, sulfur ore enrichment, mineral fertilizer production, as well as the complex financial and economic condition of the enterprise in the last 20 years, was accompanied by a variety of negative environmental consequences: creation of deep quarries, accumulation of overburden dumps, beneficiation waste, import of dangerous industrial of waste, arrangement of returnable water sedimentation tanks and landfills on the shore of the reservoir, contamination of soils, underground and surface waters with acidic effluents, atmospheric air with hydrogen sulfide (Pohrebennyk et al., 2020). The vast majority of all solid industrial waste of the Lviv region is accumulated here – more than 100 million tons of: sulfur ore enrichment tailings, phosphogypsum, Hungarian tars, and lump sulfur (Pohrebennyk et al., 2019).

As a result of the powerful man-made impact of SE Rozdil MCE 'Sirka' on the adjacent land areas, natural watercourses and artificial reservoirs, the hydro-ecological conditions of the territory have fundamentally changed. When the entire industrial complex was in operation, the reverse water supply system functioned with a negative balance, because the predominance of water consumption over inflow was due to the use of water for technological needs, as well as the burial of water during the filling of industrial waste accumulation sites (Malec & Borowski, 2017; Bakharev et al., 2017). After the cessation of sulfur production and the production of mineral fertilizers, the water balance became positive, whereas hydrotechnical structures began to overflow with water due to the excess of precipitation over evaporation. On the territory of the plant of complex mineral fertilizers, the level of groundwater rose, they flooded basements, lakes and swamps appeared around them, water began to interact with industrial waste in places of their storage (Fig. 1, 2) (Pohrebennyk et al., 2018).

SE Rozdil MCE 'Sirka' is at the stage of liquidation, but still poses a threat to the environment. Therefore, there is a need to create an information and analytical monitoring system (IASM) (Pohrebennyk et al., 2019). IASM is a computer system, with the help of which it is possible to obtain and create information as well as carry out its processing and analysis. Processing and analysis are not the only advantages of the information and analytical system. It can also provide forecasting, determining the consequences of the situation (Bakharev et al., 2017; Karpinski et al., 2018). The forecasting function predicts possible changes in the environment based on data on the current environmental state of the enterprise's territory. The purpose of such a system is efficient storage, processing and analysis of data (Bondarenko et al., 2021; Jiao et al., 2022). The organization of the monitoring system at mining facilities, depending on the types of impact, must be considered according to the sources of environmental impact, since each source can have several types of impact on the elements of the biosphere (Bondarenko et al., 2021; L. Chen & Zhang, 2022; Fang et al., 2023; Malec & Borowski, 2017). The creation of such a system is an important step towards improving the environmental safety of the territory, because timely information on the environmental condition ensures timely elimination of the problem with minimal risks and consequences (Bondarenko et al., 2021; L. Chen & Zhang, 2022; Christian et al., 2005; Havrys et al., 2023; Szatyłowicz et al., 2017). Important in the information and analytical subsystem of industrial waste is the creation of an information base – information on the formation, presence, removal and use of industrial waste, placement of man-made objects such as mining, industrial waste accumulation zones and changes in their quantity and size over time (Bakharev et al., 2017; Dzhumelia & Pohrebennyk, 2021). The information about the composition and danger of waste for environmental elements is also important (L. Chen & Zhang, 2022; Jaguś, 2020; Ligocka, 2018; Malec & Borowski, 2017; Mokryi et al., 2023; Shevchenko et al., 2017; Szatyłowicz et al., 2017). Environmental monitoring of water bodies on the territory of the enterprise should be based on the following data: sampling, data collection, analysis of the existing set of environmental measures to reduce the level of pollution of water bodies, identification of sources of water body pollution, assessment of the ecological state of water bodies, forecasting process of pollution of water bodies and disturbance of ecological balance, creation of an information-analytical or geoinformational observation and monitoring system, development of measures to improve the ecological state and restore ecological balance (Bakharev

Fig. 1. Spills of acidic water at the lump sulfur warehouse

et al., 2017; Dzhumelia & Pohrebennyk, 2021; Karpinski et al., 2018; Pysarenko et al., 2022).

The general scheme of IASM of a mining and chemical enterprise (Pohrebennyk et al., 2017):

1) collection of experimental data,
2) laboratory studies of selected samples,
3) computer processing of data,
4) comparison of the obtained results with normative indicators,
5) database of the results of sample analyzes and territory research,
6) overlaying element-by-element digital research results on the map,
7) a map of the total indicators of the result of the study of the elements of the environment,
8) ecological map of the studied territory,
9) forecasting changes in chemical, biological, physical pollution of environmental elements of the studied territory,
10) measures to improve the ecological safety of the studied territory.

The state of environmental monitoring in the region can be significantly improved by speeding up and improving the work of employees of scientific research ecological stations, as well as

Fig. 2. Leaks of hydrogen sulfide waters from the drainages of the eastern part of tailings storage facility No. 1

visualization of the ecological state of the area in the form of interactive pollution maps (P. Chen, 2019; Lu et al., 2017). Visual information is better perceived as well as enables to quickly and effectively convey thoughts and ideas to the viewer (Novak et al., 2021). Physiologically, perception of visual information is basic for a person. In addition to the beautiful processing of our brain, data visualization has several advantages (Novak et al., 2021):

- focusing on different aspects of the data,
- analysis of a large data set with a complex structure,
- reducing the information overload of a person and keeping their attention,
- unambiguity and clarity of derived data,
- highlighting relationships contained in information.

Today, an important scientific task is not only the creation of systems for managing the state of environmental components, but also the provision of intellectualization of management decision-making support functions for more accurate, fast and reliable implementation (Pohrebennyk et al., 2019, 2020; Pysarenko et al., 2022).

Information and analytical support for regional environmental monitoring is necessary for the implementation of such opportunities as receiving primary data from monitoring subjects, saving, processing, transmitting and analyzing information about the state of the natural environment. The latter is necessary, in particular, for modeling and forecasting the development of the ecological situation in the region and making scientifically based management decisions in the field of environmental protection and environmental safety (McDonald et al., 2019; Shpynkovska & Bakunova, 2015).

The purpose of this work was to analyze the dynamics of hydrochemical parameters of surface waters of the territory of SE Rozdil MCE 'Sirka' and to develop an interactive map and visualization web application based on the obtained results.

MATERIALS AND METHODS

The object of conducted study was the surface water in influence zone of State Enterprise Rozdil Mining and Chemical Enterprise 'Sirka'. The northern quarry of enterprise is divided into three parts. To the west is Lake Chyste, which was formed in a separate part of the quarry. The absolute level of water in the lake is 270 m, the depth of the lake is 17 m (Pohrebennyk et al., 2019). It is fed by atmospheric precipitation and springs that flow on the high west bank. During the rainy season, water from the lake flows into the Kolodnytsia River. Lake Serednie occupies the largest area. It contains 10.6 million m^3 of fine fractions of sulfur ore beneficiation waste. The thickness of the waste layer is 33 m (Pohrebennyk et al., 2019). Then, the recess was filled with circulating water and atmospheric precipitation, a lake with a depth of up to 16 m was formed. The volume of water is 9.9 million m^3, the absolute mark of the water level is about 270.5 m, the area is 93.5 hectares. To improve the situation on the lake, it is necessary to lower the water level to 265 m to reduce the depth of the lake to 7–10 m. The eastern part of the quarry was flooded to a mark of 253 m, the Deep Lake was formed here. The area of the lake is 280 hectares, the area is 82 hectares, the depth reaches 40 m (Pohrebennyk et al., 2019). There is a 3 km long canal to drain water from the lakes into the Dniester River. Atmospheric precipitation from the catchment area of the tailings reservoir accumulates in the relief depressions in the western and eastern parts, and from there it infiltrates through the dam of the tailings reservoir and flows into the sump and the Dniester River (Pohrebennyk et al., 2019). Tailings storage facility No. 2 was created in the residual recess of the North Quarry. Gypsoanhydrites lie at the bottom, as if they were covered by the fallout and compaction of a layer of clay. Higher up in the sides, native outcrops of clays and marls or internal dumps are exposed (Pohrebennyk et al., 2019).

RESULTS AND DISCUSSION

The results of the hydrochemical monitoring of Rozdil lakes show that in the surface layer of water of all Rozdil lakes and at the outlet from Hlyboke Lake, an excess of normative indicators was recorded for mineralization and sulfates, and for phosphates in Serednie Lake. According to the results of the chemical analysis of the waters flowing through the canal from Hlyboke Lake to the Dniester, it was established that the level of water mineralization exceeded the MPC by 2.4 times, sulfates by 3 times. This year, no measures were

taken to prevent pollution of Dniester River. At the same time, the monitoring of Strontium and Fluorine content, which was foreseen by the monitoring program in previous years, has ceased to be carried out. Groundwater condition was not monitored in observation wells and piezometers on tailing dams. The network of observation wells has been almost completely destroyed, there are no piezometers. An urgent task for the enterprise today is to solve the problems of the use of lakes and spillways, sources of financing for their maintenance, supervision and control. The assessment of water quality indicators makes it possible to establish the conformity or nonconformity of the water of a certain water object with the requirements put forward by certain water users (Pohrebennyk et al., 2020). According to the obtained data, in the surface layer of waters of all Rozdil lakes, an excess of normative indicators for mineralization (MPC – 1000 mg/dm^3) and sulfates (MPC – 100 mg/dm^3) is recorded, and in Kysle Lake and Serednie Lake – and for phosphates (MPC – 0 mg/dm^3), in Kysle Lake pH is 5.25, while the norm is from 6.5 to 8.5. In the channel of Lake Hlyboke-Dniester River, the maximum limit was exceeded according to the following indicators: pH is 6.05 (norm – from 6.5 to 8.5), sulfates – 1665.3 mg/dm^3 (maximum limit – 100 mg/dm^3), ammonium nitrogen – 4.6 mg/dm 3 (MPC – 0.5 mg/dm^3), mineralization – 2498.6 mg/dm^3 (MPC – 1000 mg/dm^3).

Man-made changes in hydrogeological conditions, together with the presence at the enterprise of a large number of hydraulic structures and specific chemical production (production of sulfuric, phosphoric and nitric acids), have led to the formation of hydrogeochemical pollution anomalies. When the entire industrial complex was in operation, a return water supply system with a negative balance was in operation (Karpinski et al., 2018). The advantage of water consumption over supply was due to the use of water for the preparation of steam during autoclave smelting of sulfur, as well as the disposal of water when filling tailings. After the cessation of sulfur production, the water balance became positive, hydrotechnical structures began to overflow with water due to the excess of precipitation over evaporation (Karpinski et al., 2018). On the territory of the fertilizer plant, the level of groundwater rose, it flooded basements, and lakes and swamps appeared around them. There was a threat of a breakthrough of polluted man-made waters in the Dniester River (Karpinski et al., 2018). The ecological situation in Dniester river basin over the last 15–20 years under the influence of anthropogenic factors has become a crisis. In this regard, the research in the zone of influence of SE Rozdil MCE 'Sirka' of water pollution is particularly relevant. Testing was carried out of the largest water bodies in the area of influence of SE Rozdil MCE 'Sirka'– Lakes Serednie, Hlyboke, and Kysle, located near industrial waste storage areas (sulfur and ultra-acidic waters on sulfur storage, sulfur flotation tailings, phosphogypsum, tar residues, solid household waste) and the water from which flows into the transboundary Dniester River through the Mining channel (Hlyboke – Dniester reset channel).

The authors have conducted the research aimed at improving the methodology for evaluating indicators that determine the level of environmental danger after the closure of a mining and chemical enterprise based on the analysis of the processes of impact on the environment of the main sources of danger.

The conducted studies established that the main sources of hydrosphere pollution in the zone of influence of SE Rozdil MCE 'Sirka' are:

1. Tailings No. 1 and No. 2, where sulfur ore enrichment tailings of various fractions are stored, from sandy size in the sides to siltstone size in the beach part of the tailings and clay fraction in the core. The waste is a source of hydrogen sulfide water with a mineralization of about 3 g/l and an unpleasant smell.
2. A dump of phosphogypsum with a total volume of 3 million m^3 and a sedimentation tank for acidic waters around it. Leaching of acids from the phosphogypsum dump leads to the formation of acidic waters enriched with heavy metals. This is the largest source of pollution of the hydrosphere.
3. An open composition of lump sulfur, which is the source of highly acidic waters entering the hydrosphere.
4. Three acid tar dumps, one of which is on the shore of Lake Hlyboke, which are the source of oil products and acid waters entering the hydrosphere.
5. The landfill of Novyi Rozdil City on the shore of Lake Serednie, which is the source of leachate and microplastics entering the hydrosphere.

In order to ensure ecological balance in the zone of influence of SE Rozdil MCE 'Sirka', it is necessary:

- conducting regular monitoring observations,

- determination of stable sources of funding for maintenance, supervision, and control over the state of hydrotechnical structures,
- elimination of existing sources of pollution – tar warehouse, landfill site of the city, lump sulfur warehouse, phosphogypsum dump,
- reclamation of disturbed lands on the territory of the dry mineral fertilizer plant.

According to the obtained results of the studies of the polluted area, the principles of environmental safety of the mining and chemical enterprise at the stage of liquidation were developed, which are based on the principle of comprehensive environmental monitoring based on the collection, storage and processing of data on the pollution of various elements of the environment (soil, surface and underground water, atmospheric air), which will provide forecasting of environmental changes in the territory of the mining and chemical enterprise. To reduce the threat to the environment from mining and chemical enterprises at the stage of liquidation, it is necessary to create an information and analytical system for storage, processing and analysis of monitoring data.

A component of IASM is a web application created on the basis of an interactive map of water sampling points and visualization of the obtained results of hydrochemical monitoring of Rozdil Lakes. This web application is available on the Internet via the link http://ecotest.infostore.in.ua/. The display of the interactive monitoring map is configured using Leaflet interactive maps, an open-source JavaScript library for displaying maps on html pages (Fig. 3, 4). The library implements the support of map layers, which are built according to the technology: WMS, GeoJSON, or vector surface mapping. Web-based map applications can be effective tools for making a variety of geologic data sets accessible and visual, due to their convenient web browser access, interactive visualization, and ease of use.

Chart.js – is a popular tool designed for creating graphs and charts Chart.js was used to build the display of graphical information (Fig. 5–7). This library allows creating graphs and charts of

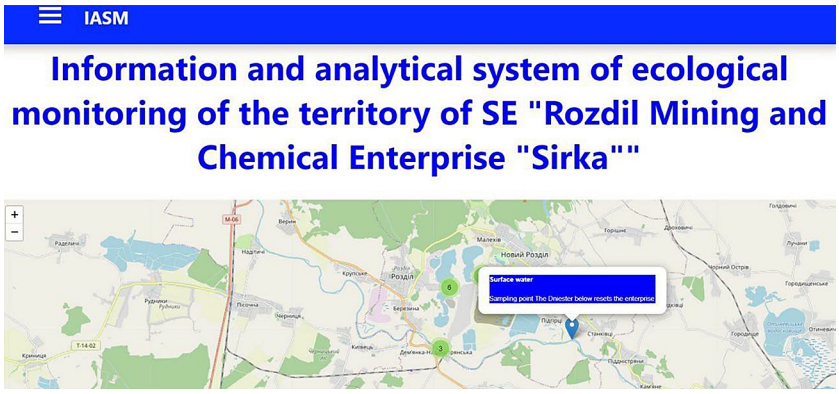

Fig. 3. Screenshots of the web application of the interactive map of water sampling in the area of SE Rozdil MCE 'Sirka'

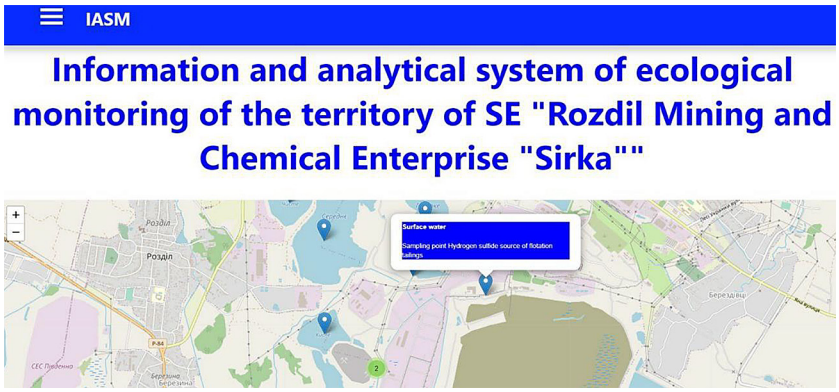

Fig. 4. Screenshots of the web application of the interactive map of water sampling in the area of SE Rozdil MCE 'Sirka'

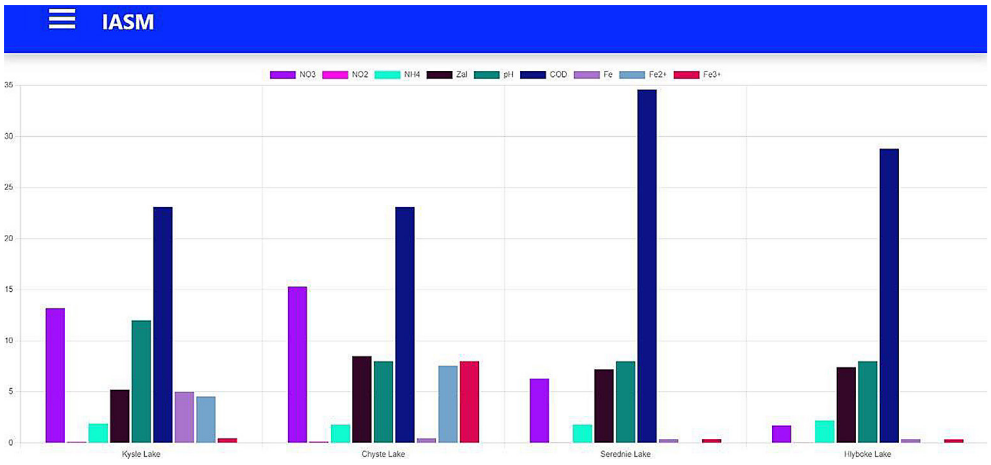

Fig. 5. NO_3, NO_2, NH_4, Dry residue (Zal), pH, Chemical oxygen demand, Fe, Fe^{2+}, Fe^{3+} content visualizations in IASM

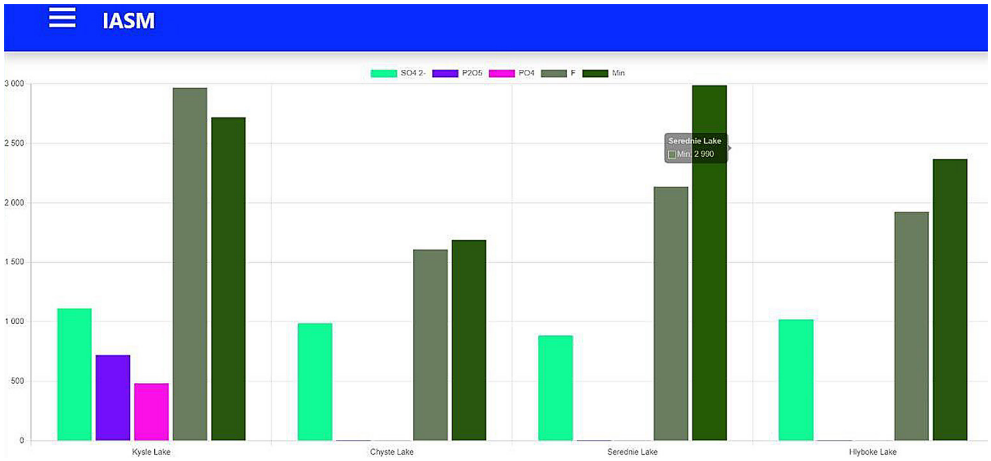

Fig. 6. SO_4^{2-}, P_2O_5, PO_4, F, Mineralization (Min) content visualizations in IASM

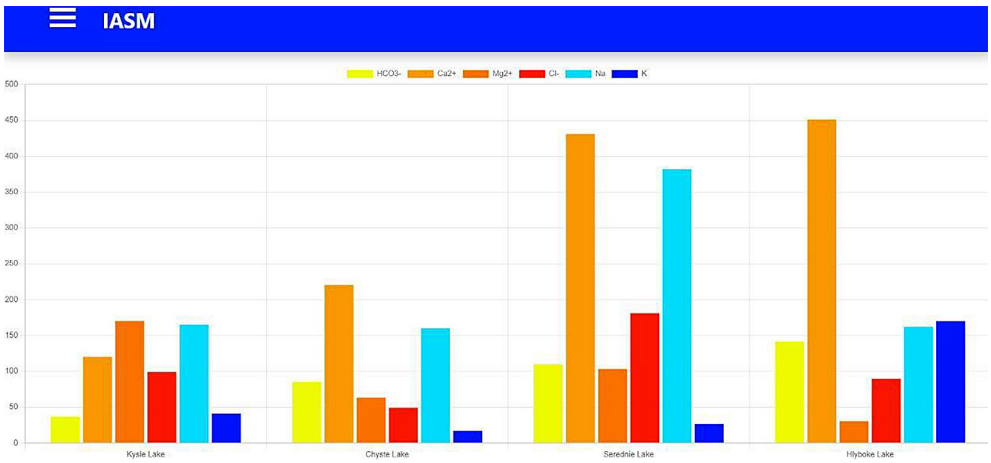

Fig. 7. HCO^{3-}, Ca^{2+}, Mg^{2+}, Cl^-, Na, K content visualizations in IASM

any type, as well as plot data on a time range and a logarithmic scale. It also has built-in tools for working with animation, which will enable to effectively modify graphics depending on new data, as well as experiment with colour.

To assess and forecast the state of the water ecosystem, four hydrochemical indicators were analyzed, as well as the indicator of water temperature over time (Fig. 8). Integral indicators of a sanitary nature were chosen, namely:

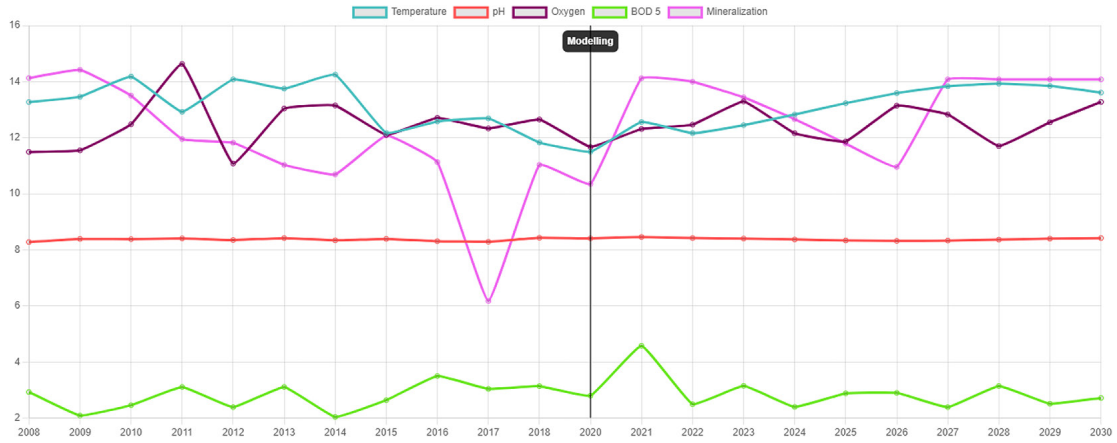

Fig. 8. Screenshot of the web application displaying the results of forecasting the state of the water environment for 2021–2030

- pH,
- dissolved oxygen,
- BOD_5,
- suspended substances.

It was decided that for the completeness of the results, it is necessary to cover both general dynamics of averages for years, their maximums and minimums, as well as quarterly maximum, average and minimum values. In the course of the study, a regression analysis of the dynamics of average annual and their seasonal quarterly dynamics was performed during 2002–2020. On the basis of the obtained functions, forecasts for 2021–2030 were developed based on average annual indicators. The main anomalous values of the measurements in 2008−2020, as deviations from the given function, were determined, and the causes of such anomalies, which are of anthropogenic origin as a result of the activities of the communal and agrarian sectors of the economy, were determined as well.

CONCLUSIONS

The investigation of the quality of surface and underground waters of the mining and chemical enterprise at the stage of liquidation was carried out. According to the obtained data, in the surface layer of waters of all Rozdil lakes, an excess of normative indicators is recorded. According to the hydrochemical index, the water bodies of SE Rozdil MCE 'Sirka' belong to waters with satisfactory, poor and very poor ecological status.

It was established that in order to ensure ecological balance in the zone of influence of SE Rozdil MCE 'Sirka', the following are necessary:

- conducting regular monitoring observations,
- maintenance, supervision and control over the state of hydrotechnical structures,
- elimination of pollution sources,
- reclamation of disturbed lands on the territory of the mineral fertilizer plant.

According to the obtained results of the studies of the polluted area, the principles of environmental safety of the mining and chemical enterprise at the stage of liquidation were developed, which are based on the principle of comprehensive environmental monitoring based on the collection, storage and processing of data on the pollution of various elements of the environment, which will ensure the forecasting of ecological changes in the territory of the mining and chemical enterprise.

The dynamics of hydrochemical indicators of surface and underground waters in the territory of the SE Rozdil MCE 'Sirka' were analyzed. On the basis of the analysis of extensive time monitoring data, a forecast of integral hydrochemical parameters was made: pH, suspended solids, dissolved oxygen, BOD_5.

On the basis of the obtained research results, a web application was created based on an interactive map of water sampling points and visualization of the obtained results of hydrochemical monitoring of Rozdil Lakes.

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