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Ecological Safety of Soils from Abandoned Mines of the Lviv-Volyn Coal Basin (on the Example of Chervonohrad Mining and Industrial District)

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ABSTRACT

This paper assesses the mass concentration of heavy metals in the soils of abandoned mines in the Chervonohrad mining district. The main negative factors of coal mining dumps include high acidity, exceeding the maximum permissible concentration of heavy metals, low organic matter content, low humidity, high temperature of substrates, wind and water erosion, steepness and large area of slopes. Heavy metals not only accumulate in the soils of the industrial zone, but also leak into the underground water. Soils in this area are heavily polluted, with the highest levels of contamination occurring at the foot of the dumps. The highest mass concentrations of aluminum and iron were found to exceed 1 mg/kg, indicating oversaturation with these metals. High concentrations of heavy metals can lead to changes in soil biological communities, impacting soil fertility. An analysis of cadmium levels near the coal mine dump showed a higher content of 0.62 mg/kg compared to the background area but did not exceed the maximum permissible concentration (MPC) of 0.7 mg/kg. The average metal content did not exceed 0.35 mg/kg. Cobalt levels in the study area ranged from 0.2 to 2.2 mg/kg, below the background level of 3.0 mg/kg and the MPC of 5 mg/kg. The waste from the coal industry exhibited a low content of mobile zinc, with a maximum concentration of 5.84 mg/kg, which is 0.15 MPC but exceeds the background concentration by more than 30%.

Keywords: coal mine spoil heaps, soil contamination, heavy metals, safety, environment.

INTRODUCTION

The development of human society and its needs is accompanied by the constant extraction and use of natural resources, leading to the formation and accumulation of industrial waste. Waste management is a pressing issue and a priority in all developed countries. In Ukraine, the problem is particularly acute due to the large volume of waste generated. Industrial production results in the emergence of industrial deserts with little or no vegetation in areas where various enterprises and mineral extraction sites are located, often near settlements. Soils are contaminated with industrial emissions, building debris, ash from thermal power plants, rocks extracted from mines and quarries, and petroleum products, leading to significant environmental pressure (Akanchise et al., 2020; Bosak et al., 2020b; Hook et al., 2023).

In such areas, soils become so degraded that they lose their fertility. In 2023, the weight of industrial waste worldwide exceeded 100 billion tons, with up to 30% being solid industrial waste from municipal and agricultural sectors. The bulk of waste is generated by ferrous and non-ferrous metallurgy enterprises, mining, chemical, forestry, and woodworking industries. The development of the mining industry leads to environmental quality deterioration (Brodny et al., 2022; Watson et al., 2023).

The environmental situation at liquidated mining enterprises is one of the most challenging in Ukraine. The problem of closing mining enterprises and restoring technogenic landscapes to their natural state is a priority environmental issue for Ukraine at its current stage of development (Ulytskiy et al., 2019).

The mines of the Lviv-Volyn coal basin are ecologically and technologically dangerous, with unresolved environmental and technological threats. These threats include flooding during mining operations, spoil heap collapses and landslides, surface subsidence, increased radiation background in spoil heaps and adjacent areas, and the release of toxic elements, compounds, and combustion products from spoil heaps into water bodies, soil, and air (Petlovanyi et al., 2019; Popovych et al., 2022).

Today, one of the Lviv region's most important priorities is solving environmental issues caused by mining enterprises' production activities. Industrial enterprises in Ukraine pollute the biosphere with numerous harmful substances, with heavy metals being significant negative factors. According to the National Scientific Centre of the Institute for Soil Science and Agrochemistry, more than 20% of Ukraine's territory is contaminated with heavy metals, negatively affecting the ecological state of the environment (Pohrebennyk et al., 2019; Singh et al., 2023).

Excessive heavy metals in soils pose a dangerous environmental threat, exacerbated by their penetration into groundwater, accumulation in plants, harmful effects on soil organisms, and the appearance of dangerous products. Unreclaimed mine sites, unliquidated quarry products, and mine voids remain due to unresolved reclamation issues from the activities of the SE Rozdil State Mining and Chemical Enterprise "Sirka", Yavoriv State Mining and Chemical Combine (SE "Sirka", SE "Podorozhnensky Mine" and Stebnytsia SE "Polymineral"), and coal mines of the Chervonohrad Mining and Industrial District. Underfunding from the state budget has hindered the completion of complex projects on restructuring and liquidating mining and chemical enterprises and implementing urgent environmental protection measures in their areas of activity (Pohrebennyk et al., 2020; Chilikwazi et al., 2023; Zhang et al., 2023).

The analysis of recent studies is considered in the works of many scholars and scientists. The problem of topsoil contamination is typical in areas near mining enterprises, where industrial waste accumulates on the soil surface. In western Ukraine, the Sokal district of the Lviv region, where the coal industry is concentrated, is a hotspot for such environmental pollution. Landscape devastation is one of Ukraine's most severe environmental problems, particularly in industrial provinces like the Lviv-Volyn coal basin, especially its central part – the Chervonohrad mining district within the Small Polissia region (Abramowicz et al., 2024; An et al., 2024).

Negative consequences of land devastation include loss of biological and landscape diversity and even desertification. Part of the solid waste is dispersed by wind and precipitation along with toxic elements, including heavy metals and other components. Thus, coal mine waste heaps pollute soil, water bodies and the air. They also damage the aesthetic value of small town landscapes. Coal mining waste, which forms spoil heaps and waste heaps, needs to undergo a number of physical and chemical transformations to become suitable for living organisms again.

In most cases, coal industry waste is a large-scale anthropogenic source that causes a permanent negative impact on the environment. The analysis of recent studies suggests that at all stages of rock dumps, progressive internal heating of the rock mass, oxidation of unstable compounds, leaching of reactive elements, acidic runoff of newly formed solutions, air and water, and erosion of dump slopes occur.

Rocks that form heaps on the Earth's surface are subject to different thermodynamic conditions than those in deeper layers, making them very unstable in atmospheric conditions and susceptible to dangerous physical and chemical transformations. Under the influence of moisture and air, they rapidly oxidize due to the property of the waste layer to absorb oxygen, which reacts chemically with coal. This process generates heat, increasing temperature and further intensifying the oxidation reaction. The release of harmful compounds and dust into the atmosphere can cause negative changes in the chemical composition of the air, adversely affecting plant communities and increasing public morbidity (Popovych et al., 2019b; Królak, 2021; Segui et al., 2021).

Environmental pollution enclaves are formed in mining areas, and their volumes affect overall health and atmospheric flow distribution in the area. The Donetsk and Lviv-Volyn coal basins, with developed mining company infrastructures, pose a threat and are becoming environmental disaster areas. Regarding the substantiation of soil properties near waste heaps, it is worth noting the results (Chelovechkova et al., 2023) of modeling the physical properties of groundwater for reclamation of coal mine dumps, as well as the established physical parameters of the formed layers in the forest-steppe zone. In addition to waste heaps, oil contamination from emergencies also causes significant environmental damage.

The environmental hazard of landfills depends on many factors: chemical and mineralogical composition of rocks, physical and chemical characteristics of internal and external transformation in combination with climatic and hydrogeological conditions, susceptibility to degradation processes, etc. Each landfill has certain characteristics and its specific negative impact on the environment and human health, depending on its location. The nature and intensity of the consequences of such man-made hazards depend directly on the conditions of their location and the person affected. Additionally, the chemical composition of overburden and waste rock has undergone serious changes during accumulation, not corresponding to the initial composition and not meeting the pre-established hazard level (Oziegbe et al., 2021; Silva et al., 2021; Khalil et al., 2023; Yang et al., 2023).

In the international context, many scientific studies are devoted to the environmental hazards of waste rock disposal. Among these studies (Nadudvari et al., 2021) recognize changes in organic and mineral substances in coal waste affected by temperature changes. Uneven cracks are present in the middle and parts near the oxidized organic matter and at the edge of the plasticized and evaporated material. The distribution of vegetation area due to heat changes over three periods within the selected transect was studied, and three types of surfaces with external heat and spontaneous combustion directions were identified. The temperature range at a depth of 20 cm is from +9.9 °C to +139 °C, while the surface temperature is from +3.1 °C to +69.0 °C. The concentration of total nitrogen ranged from 0.023% to 0.29%, and the soil reaction (pH) ranged from 5.8 to 8.0.

This study (Wu et al., 2019) investigated the waste heaps of the Chengzhuang mine (China). The results of the programmed heating tests helped to apply that CO and C_2H_4 can be used as indicator gases to predict the degree of self-heating of coal rocks. The results show that the method of insulation by stacking wood can effectively inhibit the self-heating process. In addition, the CO release and O_2 consumption of the rock are also reduced. The studies also show that in the case of forest layering, the inhibitory effect on spontaneous combustion of coal and rocks increases with the increase of the forest layer thickness.

The research work (Woch et al., 2018) investigated the assessment of the relationships between vegetation, physicochemical and microbial properties of the ash and sludge dumps substrate. The properties of ash and sludge had a negative impact on microbial biomass and enzyme activity, while alkaline earth metals, heavy metals and macroelements showed a significant negative correlation with enzyme activity or microbial biomass, and a positive correlation of these parameters with metabolic rate. Domestic scientists (Popovych et al., 2019a; Bosak et al., 2020a) believe that the Lviv-Volyn coal basin has a special character as the centre of industrial development in Western Ukraine. The basin slag has a high acidity and a high content of various salts and sulphate ions. The high salinity of the wastewater is caused by the water entering the collection site and the interaction of this water with the rock.

At work (Welch et al., 2021) suggest five important factors to consider in research: climatic conditions, physical characteristics of the dump, geochemical processes, water conditions, and environmental load over time due to the dumped masses. Key measurements for each element are identified to guide best practices. The paper (Terekhov et al., 2021) analyze the impact of reclamation mechanization technology on the quality of reclaimed land in the context of open-pit mining. A systematic approach to the selection of reclamation mechanization options based on the qualitative indicators of artificial agricultural land formation as a factor of their monetary value, as well as the level of costs for their reproduction, is proposed.

This is not the case when coal mines place waste dumps on agricultural land. In addition to direct land alienation and withdrawal from agricultural use, the impact of waste dumps on the ecological state of soil systems is associated with a complex set of anthropogenic processes, including acid runoff from the surface and soil leaching minerals. Removal of components from the surface of the rock dump contributes to the transformation of salts of alkaline and alkaline earth elements, sulphides, heavy metals, etc. into solutions. One of the main ways to get toxic substances into the human body is through food, which means that when eating food grown in contaminated areas, the damage to human health increases (Tymchuk et al., 2021; Kumari et al., 2023; Petlovanyi et al., 2023). Researching the content of heavy metals in rocks and soils at coal mine dumps is a pressing issue today, and the results of such studies are an integral part of monitoring environmental safety in mining areas.

The aim of the study is to determine the level of geochemical contamination of soils of abandoned mines in the Lviv-Volyn coal basin (using the Chervonohrad mining and industrial district as an example) and to select the most appropriate approach to cleaning the soils of abandoned mines from heavy metals content in them.

MATERIALS AND METHODS

To achieve this goal, it is necessary to implement a number of research objectives:to assess the level of mass concentration of heavy metals in the soils of the abandoned mines of the Chervonohrad mining district and to assess the prospects for solving the identified environmental problems (Figure 1). The object of the study was the dump of the Nadiya coal mine in the Chervonohrad mining district (Chervonohrad, Lviv Oblast, Ukraine), which occupies the central part of the Lviv-Volyn coal basin and borders the Novovolynsk Mining District in the northeast. The eastern and southern borders run along a strip of Lower Visean limestone, and the southwestern border along the Velykomostivske thrust, which in the northeast passes into the Kamianko-Buzka tectonic zone. This area is considered the main one in the basin. Mine operations began in 1957. It contains more than 70% of the balance sheet coal reserves and more than half of the operating mines. The highest coal content is in the southern part of the district (the area of the Velykomostivsky mines). Further to the east, the coal content decreases due to a decrease in the number of working coal seams and their thickness.

The climate of the area is temperate continental with early warm spring and rainy autumn. The number of days with precipitation varies greatly by month. Most of it falls in the warm season in the form of heavy and prolonged rains. The snow cover is unstable, forming in December and melting in February and March. Climatic conditions affect the hydrological regime of the rivers in the district, which is important when calculating the volume of mine water discharged into rivers,

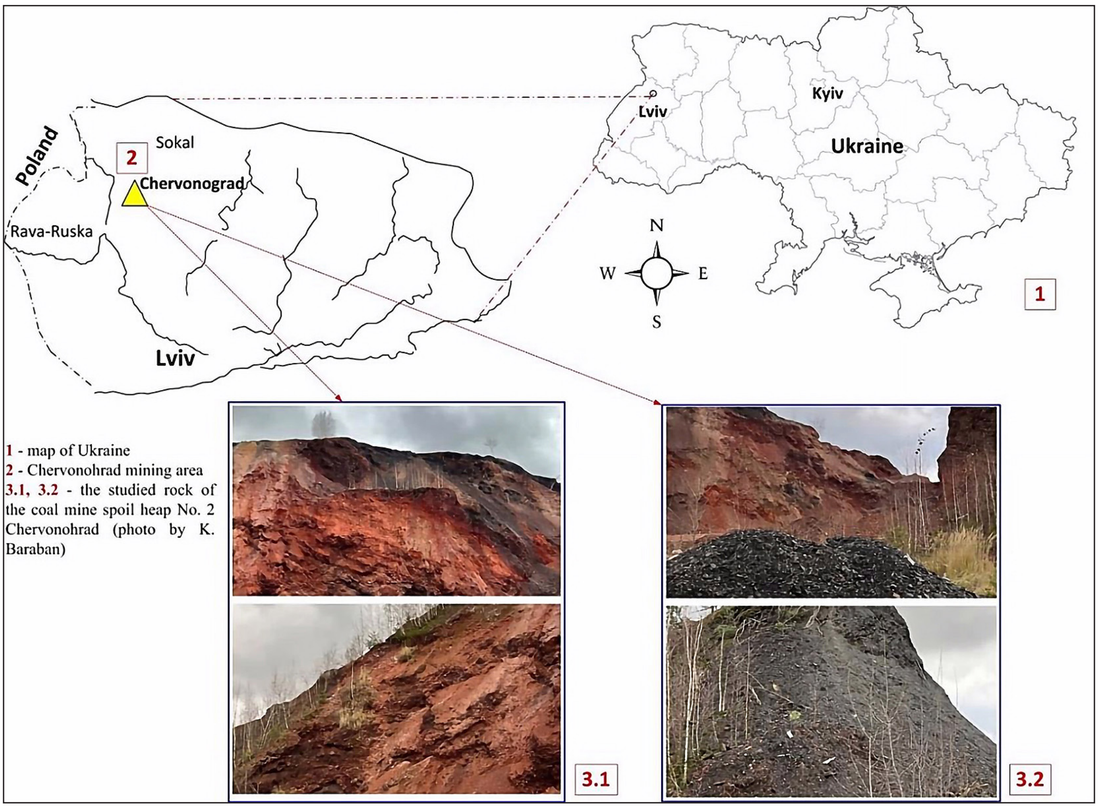

Figure 1. Location of the investigated coal mine spoil heap in the mining area

especially the Western Bug River. The Chervonohrad Mining District is located in the northwestern part of the Volyn-Podilska Upland. In general, the surface is undulating and flat, sloping northwards towards Polissya. The area is also characterised by significant swampiness and numerous saucer-shaped depressions filled with water. The district is located in the Western Ukrainian forest-steppe physiographic province, within the Small Polissya.

The research was conducted using complex theoretical and field methods. Theoretical research used methods such as monitoring, analysis, and logical construction. The novelty of the study is to determine experimentally which heavy metals are characterized by the highest level of mass concentration in the soils of the liquidated mines of the Chervonohrad mining district, which will allow us to choose the most appropriate method of soil clean-up from the identified heavy metals.

The study area, namely the city of Chervonohrad, Ukraine, is located in the northern part of the Lviv Oblast, 80 kilometres from the regional centre and 70 kilometres from the border with the Republic of Poland. The city is located in the Western Ukrainian forest-steppe zone and Small Polissia, at the confluence of the Solokia and Rata tributaries into the Western Bug River. Chervonohrad is located in a humid, moderately warm agroclimatic zone with sufficient soil moisture. The climate is temperate continental, characterised by mildness and high humidity. The territory covers 21 km^2. The administrative-territorial division of the population is over 65 thousand people. The region is characterised by industrial, processing and mining industries (Skrobala et al., 2022).

The sampling methodology was determined by the results of spectrointrusive tests in accordance with DSTU 4362:2004 Soil Quality (Ukraine). Soil sampling was carried out both near the studied waste heap and at a distance of 10–100 metres from the heap. The actual material used in the study includes more than 15 chemical analyses. To determine the temporal changes in the chemical composition of soils, graphical analysis methods were used, such as diagrams, histograms, graphs and maps. To determine the content of heavy metals, the substrate samples were burned in porcelain crucibles in a muffle furnace at a temperature of 400–500 °C for 4–6 hours until a homogeneous ash colour was obtained. After that, the samples were treated with a mixture of HCl and HNO_3 in a ratio of 3:1.

To investigate the site, we chose more dangerous heavy metals that have a negative impact on the environment and the area. Other heavy metals showed results that do not exceed the MPC or are absent and do not pose a threat to the environment. As for the MPC for heavy metals in soils, the Ukrainian legislation does not set MPC for aluminium and ferrous metals, but rather their average background concentration is set by Clarke.

The topography of the coal mine spoil heaps is also unusual for the surrounding area, with heights of over 80 m and slopes with steepness that can exceed 45°, which increases the contrasting incoming solar radiation and winds. Climatic changes, i.e. the creation of special microclimates that differ from the territory with general climatic conditions, some of the following topographic elements: foothills, terraces, shelters, peaks, which are characterised by specific microclimatic conditions.

According to the results of studies of waste heaps of coal mines in the Chervonohrad mining district, it was found that the chemical composition is dominated by such substances as Pb, Co, Cd, Co and others (but does not exceed the MPC). The geochemical background in the waste rock exceeded the concentrations of Pb and Zn, which cause a negative impact on the environment. The real hazard of heavy metals is reflected in the content of their mobile compounds, and the total content of these metals should be used to provide a general characterisation of the subgrade conditions and its apparent hazard.

RESULTS AND DISCUSSION

The liquidation of mines leads to the deterioration of the ecological condition of soils in the Lviv region. For this reason, it is necessary to regularly monitor the level of geochemical contamination of the abandoned mines of the Chervonohrad mining and industrial district. The purpose of monitoring is to determine the mass concentration levels of heavy metals in the considered soil samples.

Study of soil samples from the spoil heap

In the soil samples examined that silver, boron, bismuth, indium, sodium, and titanium were not detected in the soil samples under consideration. Cadmium was detected only in sample No. 1, and lithium, mercury – in samples No. 1 and

No. 2. The mass concentration of heavy metals in the soil samples did not exceed the value of 0.050 mg/kg for such metals as calcium, cobalt, chromium, copper, magnesium, nickel, lead, strontium, and zinc. This means that the level of heavy metals in the soil samples can be defined as insignificant.

The mass concentration of heavy metals in the soil samples did not exceed the value of 0.100 mg/kg for such metals as barium, gallium, potassium, which allows to determine the level of heavy metals in the soil samples as average. The mass concentration of heavy metals in soil samples did not exceed the value of 0.400 mg/kg for such metals as arsenic and manganese (exceptions are the results of samples No. 1 and No. 4, where the values did not exceed the value of 0.050 mg/kg). The highest level of mass concentration of aluminium and iron was found, with values exceeding 1 mg/kg, except for sample No. 1. The highest levels of aluminium and iron were found in samples No. 2, No. 3 and No. 5. This means that the content of aluminium and iron in the soil samples was several times higher than the content of other metals, indicating that the soil is oversaturated with aluminium and iron. High concentration level of heavy metals in the soil lead to changes in the soil biocenosis, the functioning of which maintains the level of soil fertility (Figure 2).

To study the impact of mine waste on the environment, the quantitative characteristics of the accumulation of mobile forms of heavy metals at a distance from the surface were analyzed.

Study of heavy metal accumulation

The mine spoil heap of mine No. 2 in Chervonograd is characterized by an increased content of mobile lead with an average value of 7.22 mg/kg. The lowest concentration in the rock was 5.6 mg/kg at a distance of 10 m from the dump site, and the highest concentration was 8.26 mg/kg at a distance of 50 m. The maximum permissible concentration (MPC) indicates that the accumulation of this element may have a negative impact on the environment. The study area is located at the dump site and consists of agricultural land with grass-podzolic soil and deep soddy soil.

The results of the cadmium analysis in the soil near the coal mine dump show that, compared to the background area, the cadmium content is higher (0.62 mg/kg), but does not meet the MPC (0.7 mg/kg). The average value for metals does not exceed 0.35 mg/kg. The amount of cobalt in the study area did not exceed either the background concentration of 3.0 mg/kg or the MPC of 5 mg/kg, ranging from 0.2 to 2.2 mg/kg. Waste from the coal industry is characterized by a low content of mobile zinc, with a maximum concentration of 5.84 mg/kg, which is 0.15 MPC but is more than 30% higher than the background concentration in the soil.

According to the results of studies carried out on the territory of mine No. 2, the content of mobile cadmium in the soil ranges from 0.1 to 0.6 mg/kg, with the maximum value occurring 10 m from the foot of the dump at 0.62 mg/kg.

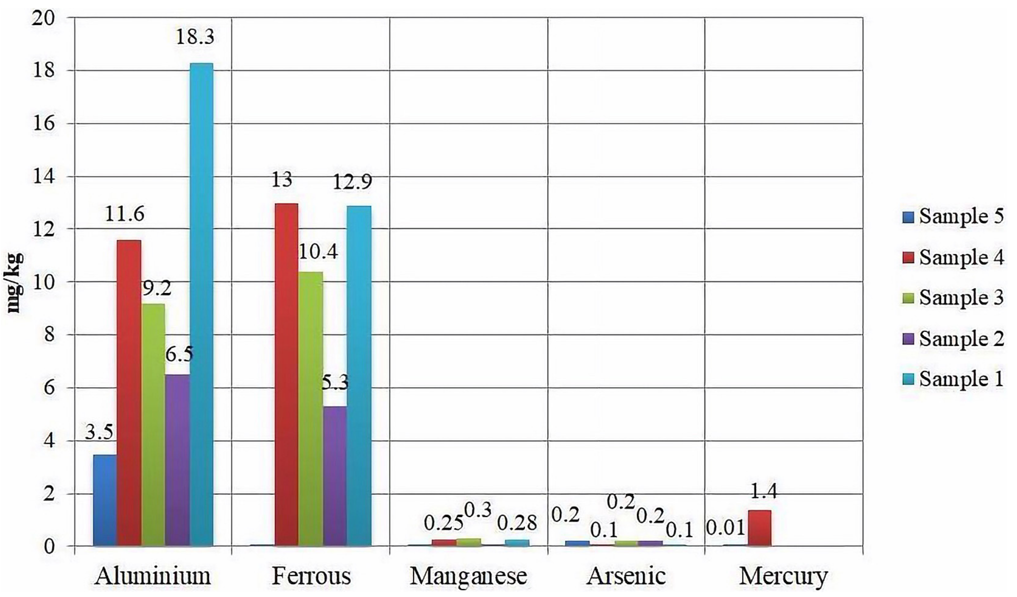

Figure 2. High concentration of heavy metals in the soil

Its content decreases with an increase in distance from the spoil heap to 100 m at 0.11 mg/kg. The contamination of the soil cover with mobile forms of lead exceeded the maximum permissible levels by 2–3 times at all sampling distances. However, at different distances, it varies greatly from 5.8 mg/kg to 8.26 mg/kg. The maximum cobalt content is observed in soil samples taken at a distance of 10 m from the foot of the mine spoil heap. Its content gradually decreases with a distance of 100 m to 0.2 mg/kg. As for mobile zinc, its maximum values from 4.63 to 5.84 mg/kg were recorded at a distance of 10–50 m from the foot of the waste heap. A slight exceedance of the MPC for zinc was detected in the vicinity of the waste heap, but its content gradually decreases with a distance of 100 m to 2.5 mg/kg. Therefore, some of the studied heavy metals (lead and zinc) are characterized by mobile forms that exceed the maximum permissible concentrations, despite the distance from the waste heap, especially at sampling points at a distance of 50 meters (Figure 3).

The results of the study show that the content of heavy metals in mobile forms does not always decrease with increasing distance from the coal mine spoil heap. The analysis shows that in some cases their content increases. We believe that the main reason for this fluctuation is the alternating morphology of the depression and upland and the corresponding different types of soil cover.

According to the calculations, the soil near the spoil heap of coal mine No. 2 in Chervonohrad, Lviv region is classified as permissible in terms of contamination. This means that although the content of chemicals in the soil exceeds the background level, it does not exceed the maximum permissible concentrations. Since all types of crops can be grown on such soils, the impact of pollution can be reduced through reclamation and phytomelioration of coal mine spoil heaps.

Increased concentrations of heavy metals in the environment affect animal productivity and the quality of agricultural products. They also have a toxic effect on the digestive, cardiovascular, endocrine, nervous, and reproductive systems in humans. Thus, there is a need to clean up the soils of abandoned mines from heavy metals to reduce their harmful effects on the environment.

Limiting the concentration of heavy metals in soils can be achieved through two approaches to soil washing. The first approach involves excavating the soil to the surface and washing it with an aqueous solution of an appropriate extractant on the ground surface in special basins or on inclined platforms. The advantage of this approach is the subsequent use of metals extracted from the soil as raw materials. The second approach involves the extraction of contaminants from the soil with water or special aqueous solutions without removing it to the surface. Such washing is carried out by passing the extraction liquid through the soil at the site of contamination through a well or by using the process of natural infiltration. The advantage of this approach is the removal of heavy metals from the soil.

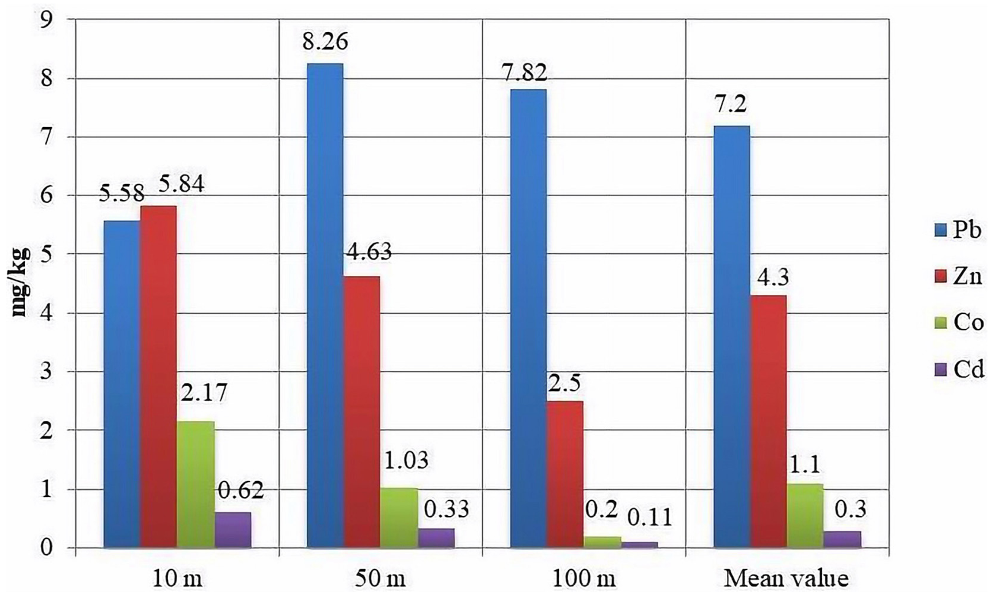

Figure 3. Heavy metal content with distance from the coal mine waste heap

For decades, the disposal of coal mine waste on the Earth's surface has hindered the natural recycling of the land. The soil of coal mine tailings has high acidity, heavy metal content and high temperature, which is not conducive to plant growth. The natural mechanisms that regulate the development of vegetation do not work here, and ecosystems recover at a slow rate, with cycles lasting for decades or even centuries. Restoration is hampered by the huge spatial size of the disturbed areas and the radical transformation of biogeocenoses.

The degree of environmental risks of man-made waste heaps

The dumping of industrial waste (coal mine spoil heaps) leads to the deterioration of the ecological state of biota and the emergence of environmental risks. This situation is exacerbated by the lack of clear and reasonable criteria for assessing the degree of environmental risks of anthropogenic waste heaps.

In our opinion, the following measures should be taken to address the problems of improving environmental safety in mining areas: develop a methodological approach to prioritising the implementation of environmental protection measures in the territories of coal mines; develop a system of criteria for assessing environmental and anthropogenic processes in the technosystems formed during the storage and disposal of coal industry waste that will not lead to heavy metal contamination of soil, groundwater, etc; to determine the regularities of the processes of transformation of heavy metal forms in eco-technogenic objects, which will allow to improve and develop the provisions of the concept of environmental safety of coal mining regions; to study the main characteristics of the absorption properties of natural materials – sedimentary rocks in relation to heavy metals; improve the technologies for reclamation of coal mining dumps to maintain a state of defined environmental safety at the waste storage areas.

Business activities in any industry involve the use of existing natural resources, resulting in the limited availability of natural resources and the emergence of waste from business activities. The activities of mining and chemical enterprises are associated with the extraction of minerals. The active operation of mining and chemical enterprises and the liquidation of their activities have a negative impact on soil condition due to heavy metals. In connection with the need to solve environmental problems in the Lviv region, the state of soils of liquidated mines in the Chervonograd mining district was chosen as the object of research.

In our view, new methods of active step-by-step multi-stage regulation of the succession process in the disturbed areas will not only reduce the harmful impact, but also ensure the restoration of disturbed ecosystems. Thus, reclamation should now become a continuous process of restoring anthropogenic damage to the biosphere, carried out in stages in accordance with the existing patterns of natural succession.

CONCLUSIONS

In the course of the study, the levels of mass concentration of heavy metals in soil samples from the liquidated mines of the Chervonohrad mining district were determined. Based on the results of the analysis, it was determined that the highest levels of aluminum, iron, arsenic, and mercury were found in the soil samples under consideration.

The maximum permissible concentrations of cadmium were found to be 0.7 mg/kg and not to exceed 0.35 mg/kg. The cobalt content does not exceed the background level (3.0 mg/kg), ranging from 0.2 to 2.2 mg/kg. Waste from the coal industry is characterized by a low content of mobile zinc, with a maximum concentration of 5.84 mg/kg, which is 0.15 MPC but exceeds the background concentration in soil by 30%. Mine rocks contain elevated concentrations of heavy metals that are dangerous for biota. The content of cadmium and cobalt above the background value indicates the accumulation of these elements, which can negatively affect the environment.

The research results showed that with increasing distance from the waste heap, the content of mobile forms of heavy metals does not always decrease, and in some cases their content increases. Some of the studied mobile forms of heavy metals, despite the distance from the waste heap, are characterised by exceeding the MPC, especially at sampling points at a distance of 10–50 m from the foot of the heap. The accumulation of a significant level of their concentration in the soil samples of abandoned mines leads to a decrease in soil fertility, as well as has a negative impact on animal productivity and causes deterioration of the functioning of the digestive, cardiovascular, endocrine, nervous, and reproductive systems in humans.

The combination of negative effects of accumulated levels of heavy metals creates the need for soil leaching using two methods, which result in soil purification from heavy metals. The difference between the first method and the second is that it is possible to use the obtained heavy metals as raw materials in business activities. Thus, the application of the above measures helps to partially solve existing environmental problems.

REFERENCES

1. Abramowicz A.K., Rahmonov O. 2024. Element cycling at thermally active coal-waste dumps: a case study of Calamagrostis epigejos and Solidago canadensis. Resources., 13, 73. https://doi.org/10.3390/resources13060073
2. Akanchise T., Boakye S., Borquaye L.S., Dodd M., Darko G. 2020. Distribution of heavy metals in soils from abandoned dump sites in Kumasi, Ghana. Scientific African, 10, e00614. https://doi.org/10.1016/j.sciaf.2020.e00614
3. An R., Wang Y., Zhang X., Chen C., Liu X., Cai S. 2023. Quantitative characterization of drying-induced cracks and permeability of granite residual soil using micron-sized X-ray computed tomography. Sci. Total Environ., 876, 163213 https://doi.org/10.1016/j.scitotenv.2023.163213
4. Bosak P., Popovych V., Stepova K., Dudyn R. 2020a. Environmental impact and toxicological properties of mine dumps of the Lviv-Volyn Coal basin. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2(440). 48–54. https://doi.org/10.32014/2020.2518-170X.30
5. Bosak P., Popovych V., Stepova K., Marutyak S. 2020b. Environmental impact and toxicological properties of mine dumps of the Lviv-Volyn coal basin. News of National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 5(443). 39–46. https://doi.org/10.32014/2020.2518-170X.1
6. Brodny J., Tutak M. 2022. Challenges of the polish coal mining industry on its way to innovative and sustainable development. Journal of Cleaner Production, 375, 134061 https://doi.org/10.1016/j.jclepro.2022.134061
7. Chelovechkova A., Komissarova I., Eremin D. 2018. Using basic hydrophysical characteristics of soils in calculating capacity of water-retaining fertile layer in recultivation of dumps of mining and oil industry. IOP Conf. Series: Earth and Environmental Science, 194, 092004. https://doi:10.1088/1755-1315/194/9/092004
8. Chilikwazi B., Onyari J.M., Wanjohi J.M. 2023. Determination of heavy metals concentrations in coal and coal gangue obtained from a mine, in Zambia. International Journal of Environmental Science and Technology, 20, 2053–2062. https://doi.org/10.1007/s13762-022-04107-w
9. Hook K., Marcantonio R. 2023. Environmental dimensions of conflict and paralyzed responses: the ongoing case of Ukraine and future implications for urban warfare. Small Wars & Insurgencies, 34(8), 1400–1428. https://doi.org/10.1080/09592318.2022.2035098
10. Khalil A., Taha Y., Benzaazoua M., Hakkou R. 2023. Applied Methodological approach for the assessment of soil contamination by trace elements around abandoned coal mines – a case study of the Jerada coal mine, Morocco. Minerals., 13, 181 https://doi.org/10.3390/min13020181
11. Królak E. 2021. Negative and positive aspects of the presence of canadian goldenrod in the environment. Environmental Protection and Natural Resources, 32, 6–12. https://doi.org/10.2478/oszn-2021-0002
12. Kumari M., Bhattacharya T. 2023. A review on bioaccessibility and the associated health risks due to heavy metal pollution in coal mines: Content and trend analysis. Environmental Development, 46, 100859. https://doi.org/10.1016/j.envdev.2023.100859
13. Nadudvari A., Abramowicz A., Ciesielczuk J., Cabala J., Misz-Kennan M., Fabianska M. 2021. Self-heating coal waste fire monitoring and related environmental problems: case studies from Poland and Ukraine. Journal of Environmental Geography, 14(3-4), 26–38. https://doi.org/10.2478/jengeo-2021-0009
14. Oziegbe O., Oluduro A.O., Oziegbe E.J., Ahuekwe E.F., Olorunsola S.J. 2021. Assessment of heavy metal bioremediation potential of bacterial isolates from landfill soils. Saudi Journal of Biological Sciences, 28(7), 3948–3956. https://doi.org/10.1016/j.sjbs.2021.03.072
15. Petlovanyi M., Kuzmenko O., Lozynskyi V., Popovych V., Sai K., Saik P. 2019. Review of man-made mineral formations accumulation and prospects of their developing in mining industrial regions in Ukraine. Mining of Mineral Deposits, 13(1), 24–38. https://doi.org/10.33271/mining13.01.024
16. Petlovanyi M., Sai K., Malashkevych D., Popovych V., Khorolskyi A. 2023. Influence of waste rock dump placement on the geomechanical state of underground mine workings. IOP Conf. Series: Earth and Environmental Science, 1156, 012007. https://doi:10.1088/1755-1315/1156/1/012007
17. Pohrebennyk V., Dzhumelia E. 2020. Environmental assessment of the impact of tars on the territory of the Rozdil state mining and chemical enterprise «Sirka» (Ukraine). Sustainable Production:

Novel Trends in Energy, Environment and Material Systems. Studies in Systems, Decision and Control. Springer, 1(198), 201–214. https://doi.org/10.1007/978-3-030-11274-5_13

18. Pohrebennyk V., Koszelnik P., Mitryasova O., Dzhumelia E., Zdeb M. 2019. Environmental monitoring of soils of post-industrial mining areas. Journal of Ecological Engineering, 20(9), 53–61. https://doi.org/10.12911/22998993/112342 6
19. Popovych V., Stepova K., Voloshchyshyn A., Bosak P. 2019a. Physico-chemical properties of soils in Lviv Volyn coal basin area. E3S Web of Conferences, 105, 02002. https://doi.org/10.1051/e3sconf/201910502002
20. Popovych V., Voloshchyshyn A. 2019b. Features of temperature and humidity conditions of extinguishing waste heaps of coal mines in spring. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 4(436). 230–237. https://doi.org/10.32014/2019.2518-170X.118
21. Popovych V., Voloshchyshyn A., Tyndyk O., Menshykova O., Shuplat T., Bosak P. 2022. Monitoring of heavy metals migration into edaphic horizons of coal mine dumps. Ecologia Balkanica, 14(2), 63–74.
22. Segui P., Safhi A.E.M., Amrani M., Benzaazoua M. 2023. Mining wastes as road construction material: a review. Minerals., 13, 90. https://doi.org/10.3390/min13010090
23. Silva L.C.R., Lambers H. 2021. Soil-plant-atmosphere interactions: Structure, function, and predictive scaling for climate change mitigation. Plant Soil., 461, 5–27 https://doi.org/10.1007/s11104-020-04427-1
24. Singh S., Maiti S.K., Raj D. 2023. An approach to quantify heavy metals and their source apportionment in coal mine soil: a study through PMF model. Environmental Monitoring and Assessment, 195, 306. https://doi.org/10.1007/s10661-023-10924-4
25. Skrobala V., Popovych V., Pinder V. 2020. Ecological patterns for vegetation cover formation in the mining waste dumps of the Lviv-Volyn coal basin. Mining of Mineral Deposits, 14(2), 119–127. https://doi.org/10.33271/mining14.02.119
26. Skrobala V., Popovych V., Tyndyk O., Voloshchyshyn A. 2022. Chemical pollution peculiarities of the Nadiya mine rock dumps in the Chervonohrad Mining District, Ukraine. Mining of Mineral Deposits, 16, 71–79. https://doi.org/10.33271/mining16.04.071
27. Terekhov Ye., Litvinov Yu., Fenenko V., Drebenstedt C. 2021. Management of land reclamation quality for agricultural use in opencast mining. Mining of Mineral Deposits, 15(1), 112–118. https://doi.org/10.33271/mining15.01.112
28. Tymchuk I., Malovanyy M., Shkvirko O., Chornomaz N., Popovych O., Grechanik R., Symak D. 2021. Review of the global experience in reclamation of disturbed lands. Inzynieria Ekologiczna, 22(1), 24–30. https://doi.org/10.12912/27197050/132097
29. Ulytskiy O., Yermakov V., Lunova O., Miliekhin P. 2019. Development of an algorithm for classifying potentially hazardous objects by industry sectors and their impact on the environment. Environmental Sciences, 1(24), 12–19. https://doi.org/10.32846/2306-9716-2019-1-24-2-3
30. Watson B., Lange I., Linn J. 2023. Coal demand, market forces, and U.S. coal mine closures. Economic Inquiry, 61(1), 35–57. https://doi.org/10.1111/ecin.13108
31. Welch C., Barbour S.L., Hendry M.J. 2021. The geochemistry and hydrology of coal waste rock dumps: a systematic global review. Science of The Total Environment, 795, 148798. https://doi.org/10.1016/j.scitotenv.2021.148798
32. Woch M.W., Radwańska M., Stanek M., Łopata B., Stefanowicz A.M. 2018. Relationships between waste physicochemical properties, microbial activity and vegetation at coal ash and sludge disposal sites. Science of The Total Environment, 642, 264–275. https://doi.org/10.1016/j.scitotenv.2018.06.038
33. Wu Y., Yu X., Hu S., Shao H., Liao Q., Fan Y. 2019. Experimental study of the effects of stacking modes on the spontaneous combustion of coal gangue. Process Safety and Environmental Protection, 123, 39–47. https://doi.org/10.1016/j.psep.2018.12.025
34. Yang W., He S. 2023 Coal mine safety management index system and environmental risk model based on sustainable operation. Sustainable Energy Technologies and Assessments, 53, 102721 https://doi.org/10.1016/j.seta.2022.102721
35. Zhang C., Bai Q., Han, P. 2023. A review of water rock interaction in underground coal mining: problems and analysis. Bulletin of Engineering Geology and the Environment, 82, 157. https://doi.org/10.1007/s10064-023-03142-2