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Conditions for biological reclamation of a mine dump in the area of the Ternivka city, Ukraine

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Abstract. The article contains the results of the observation of the waste dump of the "Zakhidno-Donbaska" mine of DTEK PAVLOGRADVUGOL private joint-stock company, located near the city of Ternivka, Pavlohrad district, Dnipropetrovsk region, Ukraine (48°32'13.9"N 36°05'58.4"E) in order to determine the conditions for biological reclamation of disturbed lands. The work used landscape, soil science, cartographic, and botanical research methods. Research indicators were determined according to the Rules for Biological Reclamation of Mine Dumps in Coal Mines of Ukraine. According to the results of the analyses, the granulometric composition of the dump rock corresponded to sandy loam. The pH of the salt extract of the soil ranged from very strongly acidic to strongly acidic. The structural and aggregate composition of the surface layer of the rock was heterogeneous, variegated, the soil structural coefficients were from 3.41 to 5.23. Strong and very strong sulfate-type salinization was observed. The lowest dry sediment values were recorded on the plateau – 0.30 %, on the slopes and at the foot of the dump – 0.39 and 1.73 %, respectively. The rock has been found to contain high concentrations of chlorides and sulfates of sodium and magnesium, and sometimes sodium carbonate, which are toxic to plants. In areas with active technological process (freshly deposited rock or early stages of external exposure), the mobile aluminum concentration was 46 mg/100 g, that makes the rock unsuitable for plant growth and development Thus, the dump requires full or partial melioration to carry out the biological stage of reclamation and reduce the negative impact on the environment. It is recommended to conduct environmental monitoring based on indicators of control and assessment of physical, physicochemical and chemical properties of mine rocks (especially the mining area), use of GIS technologies to determine the design vegetation coverage of waste dumps for the optimal choice of the method and technology of reclamation, the detection of toxic sites on waste dumps and their localization.

1. Introduction

Modern methods and technologies of coal mining and enrichment cause serious environmental disasters. They lead to depletion and pollution of water resources, pollute the atmosphere with toxic emissions, destroy soils through mining operations, and occupy large areas for rock dumps. All these processes are radically changing the natural environment, threatening its sustainability and viability [1–4].

As of 2020, there were 148 mines in Ukraine, but actual coal production was only taking place in 47. Other mines are located in occupied territories or have already ceased operations, effectively losing their functionality [5–7].

On average, the extraction of 1 million tons of coal is accompanied by the discharge into open water bodies with 150 tons of wastewater or suspended solids and 5.3 thousand tons of mineral salts, the disturbance of 9 hectares of land, and 20 hectares or more under open-pit mining, the storage of 1.8 million m^3 of solid waste on the surface of the earth, and the emission of 2 thousand tons of harmful substances into the atmosphere [8–10].

In the Western Donbas, coal mining is carried out underground way from a depth of 200–700 meters. Total coal reserves here are estimated at more than 25 billion tons, a fifth of which is located under the floodplain of the Samara River.

The negative consequences of the underground coal mining processes do not require long-term prediction; they are already widely known and manifest themselves in wilting of trees and shrubs, replacement of meadow vegetation with marsh and wetland vegetation, salinization, and the formation of a specific disastrous dump type of terrain (Fig.1).

Figure 1. The disastrous dump type of terrain in the Western Donbas area, Ukraine

In the area of the mine dump in the Ternivka city, hydrogeological changes in the landscape and their impact on the state of the ecosystems of the surrounding areas were studied [6, 7]. Two types of ecological changes had been recorded in the studied area. The first of them was associated with lowering of the surface, formation of cracks, suffusion and subsidence of the soil. The second type of changes was associated with a change in the hydrological regime of the territory such asf long-term flooding and submergence, which led to the death and loss of significant forest areas, undergrowth and grass cover, and the transformation of aquatic, coastal, forest and meadow ecosystems.

In addition, mine waste dumps are often located near populated areas – cities and towns, which are usually mono-cities whose population depends on the coal mining and coal processing industry. They can have a significant impact on the health and psychological state of the population due to various factors [11, 12]. For example, dust generation and emissions of harmful substances (heavy metals) can lead to environmental pollution and deterioration of air quality, which can affect human health, causing respiratory diseases and other problems [13]. In

addition, mining can to decrease water and soil quality, to change radically the landscape of nearby areas [14]. Stress associated with health and environmental hazards causes a significant impact of mining on the psychological state of the population. Therefore, it is important to take these aspects into account when planning and developing mining operations, as well as to take measures to reduce the negative impact on the environment by restoring transformed territories through their biological reclamation [15].

In this regard, the purpose of our work was to examine the waste heap of the "Zakhidno-Donbaska" mine of private joint-stock company DTEK PAVLOGRADVUGOL near the city of Ternivka, to compile the characteristics of the dump and determine the granulometric composition of the surface layer of the rock, the current acidity of the rock, the content of salts in the water extract, the amount of coverage of spontaneously sown plants, the need and possibility of carrying out its biological reclamation.

2. Research Methodology

When the "Zakhidno-Donbaska" mine dump had been examined, a complex of field and laboratory research methods was used, including landscape, soil science, cartographic and botanical methods [16]. Research indicators were determined according to the Rules for Biological Reclamation of Mine Dumps in Coal Mines of Ukraine (SOU-N 10.1-05420037-001:2007) [17]. The materials were collected using standard modern research methods. GIS technologies, remote sensing methods, and plant species inventory were used to determine the natural overgrowth of the dump [18, 19]. Remote monitoring of the research object was carried out using the QGIS platform. This open-access tool for satellite observations allows you to search, process, and extract information from satellite data to solve various geological questions. Image data was processed using Quantum GIS software. The Semi-Automatic Classification Plugin was used for atmospheric and radiometric correction of images [20]. The results were processed and interpreted using the normalized vegetation index (NDVI). During the study of vegetation, generally accepted methods were used to identify and describe the species and coenotic composition of plants. [21, 22].

Soil samples from the waste dump were taken from the top 20 cm layer in accordance with generally accepted soil science methods [23]. In total, twenty-eight rock samples were collected from different locations: from the upper plateau – 4 samples, from the slopes – 16, from the foot of the dump – 8 (Fig. 2).

They were stored in special sample bags. The samples were labeled before being delivered to the laboratory. After grinding the samples of mine rocks with a milling cutter, they were sieved through a mesh with a hole size of 2 mm for further chemical analysis. The selection and storage of samples for laboratory analysis was carried out in accordance with DSTU 4287:2004, DSTU ISO 10381-1:2004 (ISO 10381-1:2002, IDT), DSTU ISO 10381-2:2004 (ISO 10381-2:2002, IDT), DSTU ISO 10381-3:2004 (ISO 10381-3:2001, IDT), DSTU ISO 10381-4:2005 (ISO 10381-4:2003, IDT) [24–28].

Physico-chemical analysis of samples was carried out in an accredited laboratory of the limited liability company "Farmer.ua" (Ukraine). The determination of the active reaction (pH) of water and salt extraction of soil was carried out according to DSTU ISO10390:2007/ DSTU ISO10390:2022 [29]. To determine the granulometric and structural-aggregate composition of the waste dump soil, the sieve method was used in the modification of N. I. Savinov with DSTU 4744:2007 [30]. To assess the structural condition of the mine rock dump, the following indicators were used: the content of aggregates smaller than 0.25 mm and larger than 10 mm

(% of the mass of air-dry soil), the content of agronomically valuable aggregates 0.25–10 mm (% of the mass of air-dry soil), the structural coefficient – the ratio of the content of agronomically valuable aggregates 0.25–10 mm to the total content of aggregates larger than 10 mm and smaller than 0.25 mm (%).

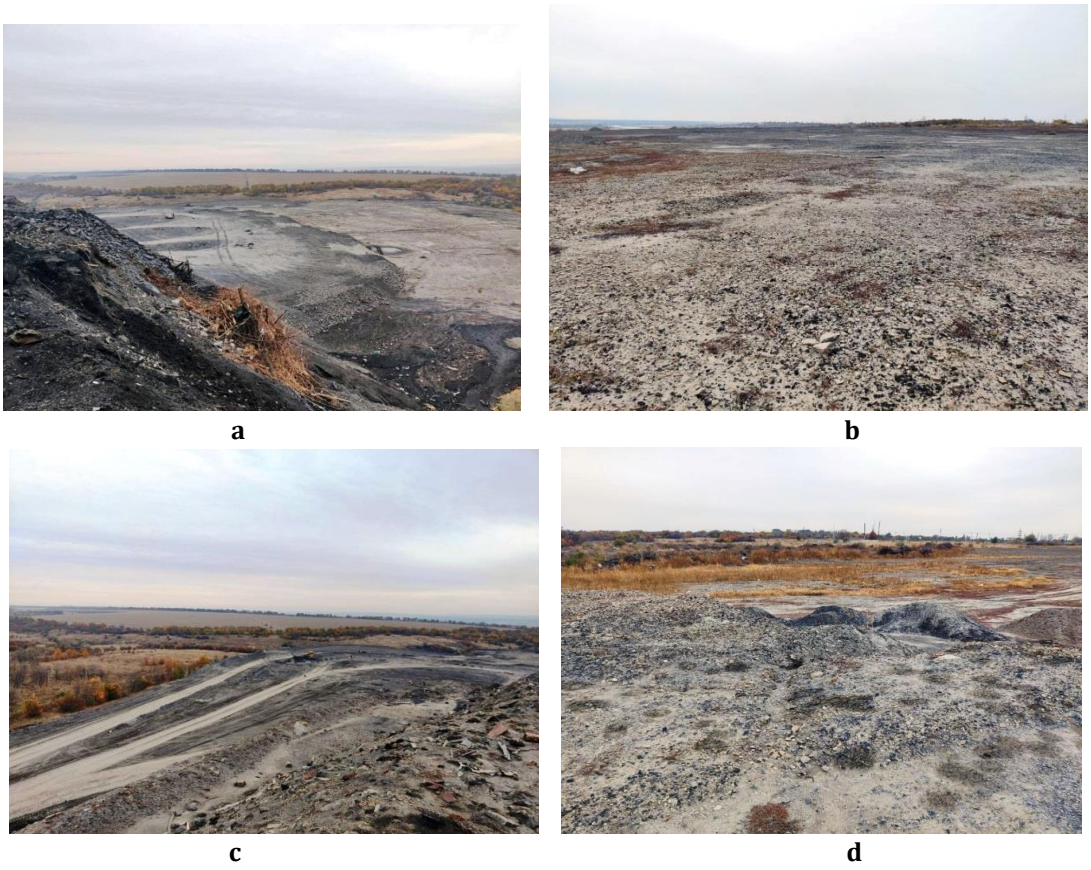

Figure 2. View of the waste dump of the "Zakhidno-Donbaska" mine in the suburbs of the Ternivka city, Ukraine: a – landscape panorama, b – upper plateau, c – slope of the dump, d – foothills.

To process and analyze the results, standard statistical methods and application packages Microsoft Excel for Windows and STATISTICA 6.0 were used.

3. Results and Discussion

The "Zakhidno-Donbaska" mine is located in the territory of Western Donbass in the Pavlohrad district, Dnipropetrovsk region (Ukraine).

The climate of the study area is temperate continental with hot summers and winters with unstable snow cover and frequent thaws, with an average annual air temperature of plus 8.5°C.

The geomorphologically described area is located on the watershed plateau of the right-bank part of the Samara River and the left-bank part of the Mala Ternivka River. All surface flows are characterized by variability in flow and water quality, depending on the amount of precipitation and the season.

The "Zakhidno-Donbaska" mine has a flat waste dump (Fig. 3), which was put into operation in 1979 and expanded in 2000. As of 2021, the area occupied by the waste dump was 25.8 hectares with a volume of stored rock of 7.33 million m^3.

Figure 3. Location of the waste dump of the "Zakhidno-Donbaska" mine, the Ternivka city, Ukraine

The waste dump of the "Zakhidno-Donbaska" mine is located 600 m north of the residential areas of the Ternivka city (48°32'13.9"N 36°05'58.4"E). According to the Sanitary Classification of Enterprises, Production Facilities and Structures, the mine's industrial site has a sanitary protection zone of 500 m. All mine rock is removed to the surface. According to previously developed projects, part of the mine rock is used for the technical stage of land reclamation near the mine industrial site, part of the rock is stored in a waste dump.

As a result of the inspection of the waste dump of the "Zakhidno-Donbaska" mine, as of December 31, 2022, it was established that the area of the base of the waste dump is 25.8 hectares, the shape of the waste dump is flat, the maximum height is 60 m, the volume of the stacked rock is 7383 thousand m^3 of rock, the slope angle in the dumping zone along the contour of the dump is 37–39°, the ash content is 86.3 %, the sulfur content is 0.41 %, the bulk density is 2400 kg/m^3 (Table 1). Thermal state is non-combustible. Operating state is operational.

Table 1. Characteristics of the waste dump of the "Zakhidno-Donbaska" mine, the Ternivka city, Ukraine

Volume weight		Height, m	Area, hectares
Thousand tons	Thousand m^3		
The project data			
24000	10000	60	29.9
Actual data			
15800	6667	60	25.8

The results of our previous studies showed a sharp differentiation of the mine dump into two zones was revealed: 1) with vegetation cover and 2) with phytotoxic substrate. For area 1, the average NDVI value was 0.23 (range of 0.01–0.55). A wide range of NDVI values indicated

uneven vegetation cover. The average NDVI value for area 2 was 0.07 (range of 0.03–0.10), which confirmed the absence of vegetation. Thus, it was established that the natural overgrowth of the dump is uneven, occupying 10.3 hectares, which is 33 % of the total area [18, 19].

According to the results of the analyses, on the plateau the granulometric composition corresponded to the value of sandy loam, in which the particle size distribution was as follows: clay – 8.75 %, silt – 16.25 %, sand – 75.00 %. On the slopes of the dump the granulometric composition corresponds to the same class as on the plateau – sandy loam with a distribution of clay – 6.25 %, silt – 21.25 %, sand – 72.50 %. The foot of the waste dump is also represented by sandy loam, in which clay was 10.00 %, silt – 20.00 %, sand – 70.00 % (Table 2).

Table 2. Physico-chemical parameters of the dump rock composition of the "Zakhidno-Donbaska" mine, the Ternivka city, Ukraine

Indicators	Upper plateau	Slope of the dump	Foothills
pH (saline), pH units	4.25	4.28	2,71
Granulometric composition:	Sandy loam	Sandy loam	Sandy loam
Clay, %	8.75	6.25	10.00
Sludge, %	16.25	21.25	20.00
Sand, %	75.00	72.50	70.00
Structural and aggregate composition:			
Sum of particles less than 0.25 mm, %	12.56	16.40	1.57
Sum of particles larger than 10 mm, %	10.11	5.30	14.47
Sum of particles less than 0.25 mm and more than 10 mm, %	77.33	21.70	16.04
Sum of particles from 0.25 to 10 mm, %	22.67	78.30	83.96
Soil structural coefficient	3.41	3.61	5.23
Dry residue, %	0.30	0.39	1.73

The actual acidity of the rock depends on its chemical and mineralogical composition of the mineral part of the rock, the presence of free salts, the content and quality of organic matter, the composition of soil air, humidity, and the vital activity of microorganisms. The most important regulator of the soil reaction is the salts contained in it. Thus, the pH of the water extract ranged from 3.5 to 7.8, from strongly acidic, neutral to alkaline reaction.

The pH values of the salt extract ranged were from 2.71 to 4.25 units, from very strongly acidic to strongly acidic. Such a wide and contrasting range of indicators is associated with different stages of the mine rock behavior on the surface. In the initial stages, there is weathering of rock fragments and active oxidation of sulfur compounds, an increase in the acidity of substrates under the influence of atmospheric agents, thion and sulfur bacteria. This stage can last 10–15 years. Over time, there is a decrease in hydrolytic and exchangeable acidity, as well as a decrease in the content of mobile aluminum to 10.5–14.8 mg/100 g of rock; partial or complete leaching of fine soil from easily soluble salts, including toxic ones; increase in the absorption capacity of "young soils" and their saturation with calcium while reducing the content of exchangeable Na^+. "Young soil", due to its edaphic properties, becomes suitable for the growth of herbaceous and woody-shrubby plants.

The generalized salt content in the aqueous extract was 0.557 %. The lowest dry matter values were recorded on the plateau – 0.30 %, on the slopes and at the foot of the dump – 0.39 and 1.73 %, respectively. Thus, it should be noted that according to the results of water extraction analyses conducted by the testing laboratory of the limited liability company "Farmer.ua", in the upper part of the dump, where the process of self-growth was actively taking place, the rocks were not salty or slightly salty because the salt content was within the range of 0.3–0.39 %. On other relief elements that are under the influence of the technological process, namely, the removal of mine rock and its storage in the dump, strong and very strong sulfate-type salinization was observed, which depends on the active oxidation of sulfur compounds and the increase in the acidity of the substrates.

When considering the general requirements for the physicochemical parameters of the composition of dump rocks, which determine the conditions for plant growth and development and their possible use for biological reclamation, attention should be paid to their unfavorable physical properties. The dump soils are composed of rocky and semi-rocky rocks, they can be cemented and uncemented, and crust formation is characteristic. According to the structural and aggregate composition, skeletal fractions are represented mainly by rock fragments, coal shales, and to a lesser extent by sandstones. Their content can reach 75 %, which is due not so much to the different resistance of shales to weathering, but to the deflation and washing away of fine-grained particles on the surface of the rock, which is periodically exposed on the sides of the dump. The rockiness degree of the rocks can range from slightly tj moderately rocky wity stone content up to 5 % and up to 10 %, respectively in cases of long-term exposure to the open surface. Freshly poured rock was very rocky with stone content exceeding 10 %.

The structural and aggregate composition of the surface layer of the rock is heterogeneous, variegated, and depends on many factors. Thus, the generalized data of the analysis results diagnose it as a heavy silty-dusty loam with a range of fluctuations in the size of elementary soil particles: 1–0.25 mm – 18.57 % (3.11–32.68 %), 0.25–0.05 mm – 16.97 % (4.90–34.15 %), 0.05–0.01 mm – 17.76 % (11.04–24.82 %), 0.01–0.005 mm – 10.01 % (5.86–15.75 %), 0.005–0.001 mm – 14.23 % (5.62–21.86 %), parts size less than 0.001 mm – 22.47 % (17.47–27.79 %). Thus, physical sand was 53.29 %, varying from 34.60 to 66.99 %, physical clay was 46.71 % (33.01–65.40 %), respectively. According to the results of the analyses, the granulometric composition corresponded to the value of sandy loam, in which the particle size distribution was as follows: clay – 8.33 %, silt – 19.17 %, sand – 72.50 %, which were respectively in the following ranges 6.25–10 %, 16.25–21.25 %, and 70–75 %. The values of the soil structural coefficient varied from 3.41 to 5.23.

In addition to negative physical properties, sulfur-containing mine waste dumps also had a number of unfavorable chemical and physicochemical properties.

By chemical properties, mine rocks are sulfide. The most important regulator of soil reaction is the salts contained in it. Thus, the pH of the water extract ranged from 3.5 to 7.8, from strongly acidic, neutral to alkaline. The pH of the salt extract ranged from 2.71 to 4.25 units, from very strongly acidic to strongly acidic. Analysis of the water extract showed that the sulfide rock of the dump, based on the amount of easily soluble salts, can be unsalted (0.3 %) or slightly salted (0.39 %) in areas with intensive water and wind weathering. On other relief elements that are under the influence of the technological process, namely, the removal of mine rock and its storage in the dump, strong and very strong sulfate-type salinization was observed, which depends on the active oxidation of sulfur compounds and the increase in the acidity of the substrates. The rock has been found to contain high concentrations of chlorides and sulfates of sodium and magnesium, and sometimes sodium carbonate, which are toxic to plants.

In the studied rock, mobile aluminum was within 10.5–14.8 mg per 100 grams in areas with the greatest degree of weathering, which cannot be detrimental to plants. In areas that are in the technological process (freshly deposited rock or early stages of external influence), mobile aluminum was 46 mg/100 g, i.e. more than 18.0 mg per 100 g of rock mixture, which makes it an unsuitable rock for plant growth and development.

4. Conclusion

The results of the soil examination of the waste dump of the "Zakhidno-Donbaska" mine of DTEK PAVLOGRADVUGILLYA private joint-stock company, located near the Ternivka city in the Pavlohrad district, Dnipropetrovsk region (Ukraine), showed that the composition and properties of the mine rock negatively affect the environment of the adjacent territory, which affects people health, landscape, vegetation, and wildlife. Thus, rocks are phytotoxic due to their physical, water, physicochemical, and chemical properties. In this regard, they should be considered unsuitable rocks, as evidenced by the very slow course of the natural overgrowth process (less than 20% of the dump area has been developed during its existence), taking into consideration the general requirements for the physicochemical parameters of the dump rock composition, which determine the conditions for plant growth and development, as indicators of the weathering degree and the stage of impact on the above-mentioned objects. In such cases, the dumps require full or partial significant melioration to carry out the biological stage of reclamation in order to radically reduce the negative impact on the environment.

The mine dump can have a serious impact on the surrounding areas due to a number of risks: dust generation, contamination of soil, groundwater and surface water, landslides. The mine dump can be a significant source of dust generation due to fine particles (sand, clay, silt) on its surface. Dust generated by wind deflation can contain harmful substances (heavy metals) that pollute the air and soils of agricultural lands and gardens located in the surrounding area. Harmful substances from the dump can seep into the soil and water bodies, which leads to pollution and a threat to human and animal health. The accumulation of a large amount of waste in the dump can lead to landslides, damage to buildings and infrastructure in the surrounding areas.

To prevent and minimize potential risks, it is important to use special technologies and measures, such as green plantings, the introduction of soil restoration systems. In the future, environmental monitoring is needed according to the following indicators: control and assessment of the physical, physicochemical and chemical properties of mine rocks (especially

the tailings, which are directly located in the area of residence and functioning of people, plants, and animals), the use of GIS technologies to determine the design vegetation coverage of dumps, which will contribute to the optimal choice of the method and technology of reclamation; identification of toxic sites in dumps and their localization.

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