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Earth and
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To cite this article: A I Voloshchyshyn *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1415** 012130

Natural phytomelioration of coal mine waste heaps in the context of increased radiation background (on the case of Nadiya mine, Lviv-Volyn coal basin, Ukraine)

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Abstract. At the United Nations Climate Change Conference (COP26) in Glasgow in autumn 2021, world leaders and participants decided to phase out coal power. Ukraine is committed to shutting down its state-owned coal-fired power plants by 2035. Natural and technical geosystems in coal mining areas have a significant impact on environmental and anthropogenic environmental safety and require comprehensive researchThis scientific article delves into the thorough examination of the impact of augmented radiation levels in the waste piles of the Nadiya mine in the Lviv-Volyn coal basin. The exploitation of the Lviv-Volyn coal basin has led to many negative changes in the flora and fauna, atmosphere, hydrosphere and biosphere, and has significantly affected the life and health of the Ukrainian population. The Nadiya mine waste heaps are located on the outskirts of the town of Sosnivka, Chervonohrad district, Lviv region (Ukraine) on fluvioglacial sands, partially on alluvial sediments of the Western Bug River. The height of the waste heaps is over 42 m and the area is 12 hectares. The spoil heap is bounded by woody vegetation on both sides and agricultural land on the other. The spoil heap is composed of burnt and unburnt rocks with sulfuric acid zones on the burnt pieces. Spontaneous combustion is observed on the spoil heap, in particular at the top, where the radiation background was investigated. The radiation power at the top of the spoil heap was found to be significantly higher than in other areas. The investigations of the radiation background of the Nadiia mine spoil heap showed the equivalent dose rate at the top of the heap, which is 0.42 μSv/h, exceeding the permissible standards of 0.3 μSv/h. It should be noted that the excess radiation background is due to the combustion of rock.

1. Introduction

The coal industryis the basis for sustainable development of the national economy and energy security. Coal mining areas are often plagued with an array of environmental and socio-economic issues, such as land deformations, flooding, salinization, underground and surface water pollution, and depressed zones, all of which pose significant challenges. Coal mines in Ukraine are developed with old and dilapidated coal equipment in challenging mining and geological environments. Chronic underfunding of coal mine environmentalization projects has led to serious changes in the environmental state of the affected areas [1, 2]. The depletion of balance sheet reserves, unprofitability of most mines, difficult geological conditions of mining, and unstable economic situation have led to large-scaleliquidation of mining enterprises. The heightened danger of surface subsidence, flooding of lands, drastic alterations in ground and surface water quality, and impairment of structures and facilities is a direct consequence [3]. Coal mining destroys the landscape and also causes large amounts of wastewater entering mine workings. The treatment of mine water in closed mine reservoirs remains unresolved, and standards governing its discharge into the hydrological network remain to be defined. Mine water contaminated with mineral salts, suspended solids, sulfates and other pollutants causes contamination of aquifers and disruption of their hydrology [4].

The geographical location of the Lviv-Volyn coal basin corresponds to the Lesser Polissya area, whose climate is influenced by Atlantic air masses. Since the Chervonohrad mining district of the Lviv-Volyn coal basin was the first to be developed, its waste heaps contain the largest amount of rock. One of the largest mines in the district is the Nadiya mine, with a waste heap volume of over 2869.4 thousand m^3. The ash content in the rock is over 83.1% and sulfur is 2.4%The density of the rock is over 2.25 kg/m^3. The base area of the waste heap is 120 thousand m^2, the height is 53 m, the angle of rock dumping along the contour is 36°, and the annual rock supply to the heap is more than 9.8 thousand m^3 (according to the Passport of the waste heap No. 1 of the Nadiya mine, as adjusted in September 2021). In general, rock dumping began in August 1962, and rock combustion began in September 1963 and continues in several locations to this day. Intensive rock combustion took place from 1975 to 1979 [5]. Currently, the surface of the waste heap is inhabited by pioneer species, including the moss *Campylopus introflexus*. Within a relatively short period of time, *Campylopus introflexus* has significantly increased the projective cover on the waste heap, additionally, the species contributes to the accumulation of organic carbon and the formation of a humus layer of the substrate. It was noted that a decrease in the chlorophyll *a/b* ratio, and an increase in the content of chlorophylls versus carotenoids under conditions of inhibition of chlorophyll photochemical activity play an important role in protecting the photosynthetic system of C. *introflexus* [6, 7].

Considering the numerous scientific studies of [8–10] related to the assessment of the environmental hazard of coal mine waste heaps, it should be noted that the problem is extremely relevant today. Technogenic and environmental safety of coal mines directly depends on the state of financing and timeliness of environmental protection measures. Identifying and eliminating the root causes of an environmental issue is usually a more cost-effective strategy than the present expenses incurred in battling the aftermath of the same issue. Mining activities lead to a number of phenomena and processes that have a negative environmental and technological impact. These phenomena and their consequences are currently poorly understood, unpredictable and mostly uncontrollable. The potential danger posed by a waste dump to the environment is influenced by various factors, including the chemical and mineral makeup of the rocks, physical and chemical properties of internal and external transformation along with climatic and hydrogeological conditions, sensitivity of degradation processes, and heightened radiation levels [11]. Each waste heap has certain characteristics and a specific negative impact on the environment, flora and fauna, and human health, depending on its location [12]. The degree and scope of the impact caused by a human-made hazard is determined by its geographical placement and the individual who is affected by its adverse effects [13, 14].

Thus, factors such as the age of the dumping and the processes of combustion of waste rock prompted us to investigate the technogenic hazard of the Nadiya mine dump in the Lviv-Volyn coal basin [15].

2. Material and methods

2.1. Edaphic and climatic conditions of the research

Chervonohrad is situated in the northern region of Lviv oblast, at a distance of 80 km from the oblast's center and 70 km from the border with the Republic of Poland. The area of the region is 21 km^2 (Chervonohrad – 17.8 km^2; Sosnivka – 2 km^2; Hirnyk – 1.2 km^2). The study area is characterized by the dominant processing and mining industry. The city of Chervonohrad is located in the Western Ukrainian forest-steppe zone and Lesser 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, characterized by mildness and high humidity. Main natural resources: Zabuzhske and Mezhyrychanske coal deposits. The region has over 2097 hectares in use, including 1779 hectares in Chervonohrad, 198 hectares in Sosnivka, and 120 hectares in Hirnyk. The Nadiya mine is located on the outskirts of Sosnivka on fluvio-glacial sands, partly on alluvial deposits of the Western Bug River, and has been in operation since 1962. The height is over 42 m, the base area is over 12 hectares. The spoil heap is bounded by woody vegetation on both sides and agricultural land on the other [16]. The elevated section comprises embankments, depressions, and overgrown regions. The spoil heap is formed by burnt and unburnt rocks with sulfuric acid zones on the burnt pieces. Linear erosion is present on the side surfaces [17]. In some places, the slopes of the waste heap are quite steep and abrupt and form vertical walls. The southeastern side of the spoil heap and the western part of the spoil heap are covered with mine rock, making the topography of the spoil heap even more complicated [18–20].

2.2. Edaphic and climatic conditions of the research

We chose 7 different sites near the Nadiya mine to analyze the environmental situation and take substrate samples for radiation background analysis. The samples were taken from depths of 0-15 cm and 0-20 cm, as well as from an anthropogenic reservoir which accumulated the waste formed from anthropogenic activities (figure 1).

Seven study areas of the Nadiya mine were selected to study the radiation background of the waste heap, since the combustion process was observed there: 1 – at the foot of the spoil heap in relatively favorable growth conditions; 2 – on the slope, where intensive water-erosion outcrops 1-2 m wide and 0.5-1 m deep are present; 3 – on the terraced slope, with numerous places of water-erosion outcrops (1-1.5 m wide, 0.5-1 m in width, 0.5-1 m in depth), deflation (wind erosion), places of fire, discharge of fuels and lubricants, household waste, as well as increased soil cover density, and as a result, almost complete absence of above-ground grass cover; 4 – at the foot of the spoil heap of the forest area, in some places there are traces of soil washout and exposure of tree root systems (danger of tree fall); 5 – on the top of the waste heap, mostly flat with small hilly areas and minor relief depressions; 6 – control, at a distance of 3 km from the waste heap in the forest area with practically no anthropogenic impact (there are natural forest roads); 7 – from an anthropogenic reservoir, at a distance of 2 km from the western side of the waste heap.

2.3. Research devices

The radiation levels of the waste heaps were measured with the SOEKS environmental tester (shown in figure 2) in compliance with the guidelines of Ukraine's Radiation Safety Standards (NRBU-93) [21]. Modeling of radiation background is carried out using computer program Surfer. The intensity of illumination was determined using a digital luxmeter with a remote sensor (model LX1010BS, measuring range 1-100000 Lx), measurement accuracy ± 4% operating temperature of the environment -10°C...+50°C. Humidity and air temperature were determined using a UNI-T UT333 digital thermo-hygrometer (humidity 0-100% temperature: -10°C...+60°C), error ±1°C/±5%. The wind speed was measured using a mini-anemometer HT-383, measurement accuracy ±1.5 m/s, measurement range 0...30 m/s. The substrate temperature was measured using an AMT-300 analyzer, temperature error ±1°C, measuring range from +9°C to +50°C.

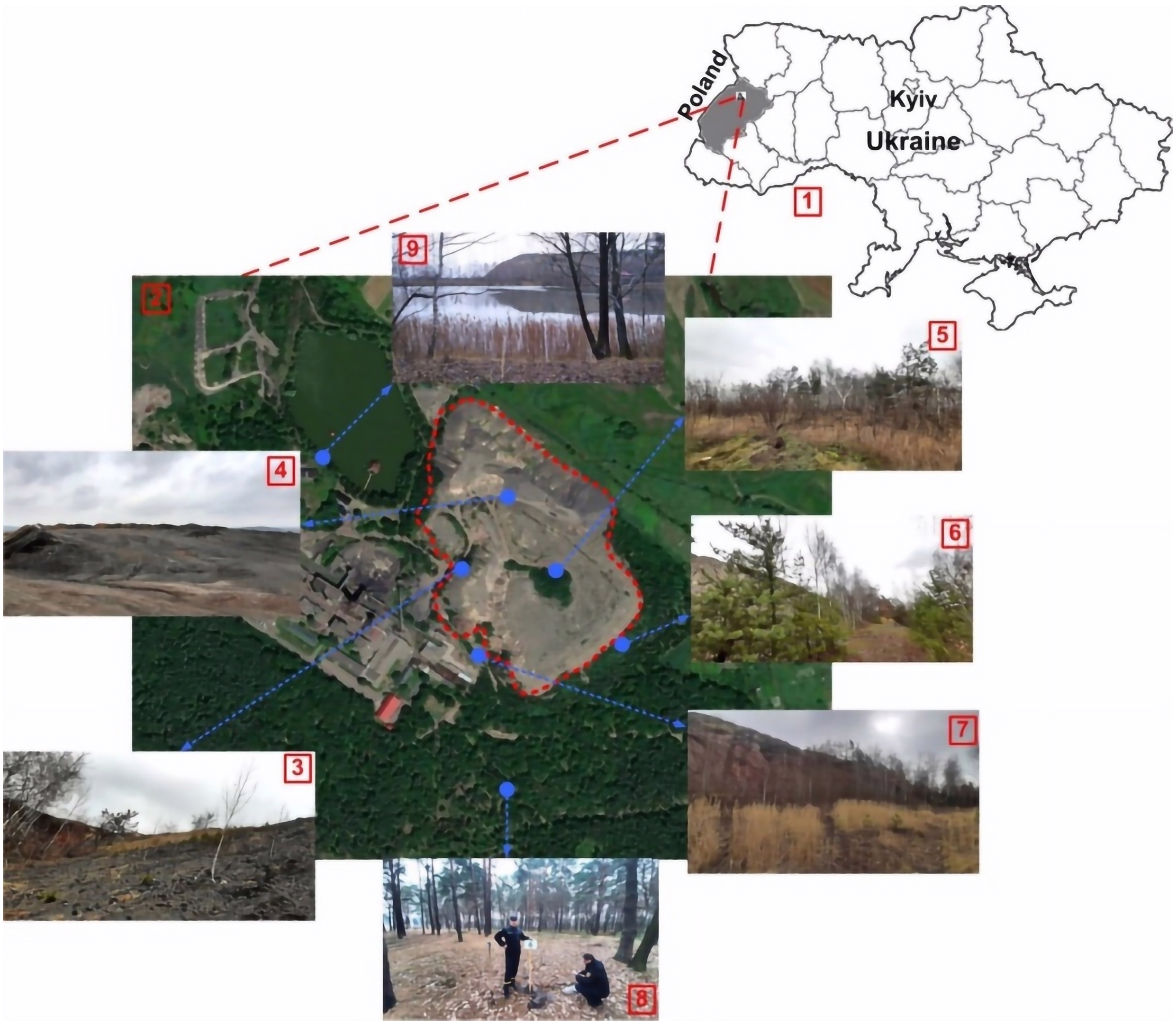

Figure 1. Location of the study site: 1 – map of Ukraine with the designation of the Nadiya mine; 2 – image of the waste heap of the Nadiya mine using GoogleMaps; 3-9 – sampling points.

3. Results and discussion

3.1. Radiation background research

The radiation background with distance from the waste heap was measured to study the impact of waste heaps on natural phytomelioration. The general characteristics of the studied areas are shown in table 1.

According to the radiation background studies of the Nadiya mine waste heap, it was found that at the level of 10 m from the foot of the heap and on the terraced slope (where there are numerous places of water erosion outlets, places of waste heap fire, fuel and lubricants drainage, household waste), the radiation power is significantly higher than in other areas, except for the top of the heap. Studies of the radiation background of the Nadiya mine spoil heap showed that the equivalent dose rate of photon ionizing radiation on the surface of the decaying heap is 0.42 μSv/h, which exceeds the permissible radiation background values established by the radiation safety standards of Ukraine (0.3 μSv/h). In addition to exceeding the permissible standards, the radiation background at the top of the waste heap at Nadiya mine also exceeds the background values for Sosnivka (0.12 μSv/h). It should be noted that the highest values of the equivalent

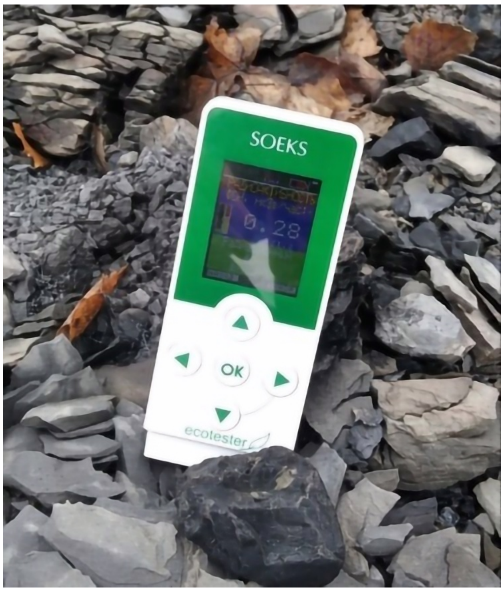

Figure 2. SOEKS environmental tester operation.

Table 1. Characteristics of the studied areas of the Nadiya mine waste heap.

Location	Radiation background, μSv/h	Lighting intensity, lux	Air humidity, %	Wind rate, m/s	Substrate temperature, °C
The foot of the heap	0.25	28350	82	3.6	5
Slope	0.18	30170	80	3.9	6
Terraced slope	0.29	32100	79	4.1	6
The foot of a terraced forest plot	0.21	25390	84	2.5	4
Top of the heap	0.42	34630	72	4.5	6
Control point 3 km from the waste heap	0.12	22480	83	1.6	5
Reservoir	0.17	–	–	–	–

dose rate were observed near the burning areas of certain parts of the waste heap and amounted to 0.21, 0.25, 0.29 and 0.42 μSv/h (figure 3). The lowest values were recorded in the forest area 3 km from the waste heap and near the man-made reservoir 2 km from the waste heap, which amounted to 0.12 and 0.17 μSv/h.

Figure 3. Results of burning certain areas of the waste heap at Nadiya mine (photo by A. Voloshchyshyn and P. Bosak)

IOP Conf. Series: Earth and Environmental Science **1415** (2024) 012130 doi:10.1088/1755-1315/1415/1/012130

3.2. Modeling the spread of radiation background

Researchers say that burning waste rock can lead to an increase in the radiation background [22]. According to the studies, it was confirmed that the radiation power on the top and slopes of the Nadiya mine spoil heap, where the heap is burned, is much higher than in other areas [23]. The study of the radiation background of the investigated waste heap showed an average equivalent dose rate on the surface of the decaying waste heap of 0.27 μSv/h, which does not exceed the radiation safety standards but exceeds the background values for the region [24, 25]. The modeling of radiation background propagation in the edaphic horizons of the Nadiya mine waste heap is shown in (figure 4).

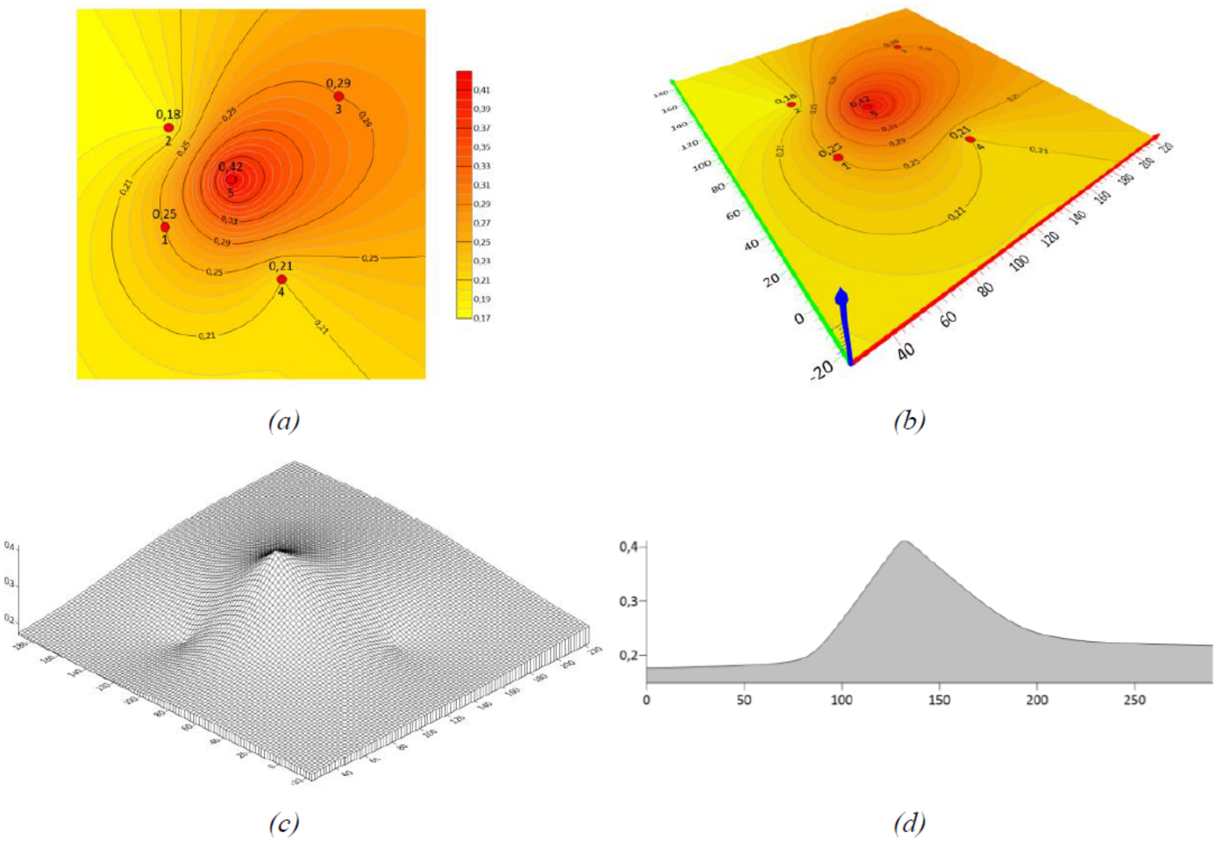

Figure 4. Radiation background propagation in the edaphic horizons of the Nadiya mine waste heap, μSv/h ((a), (b) – spread of the highest equivalent dose rate of photon ionizing radiation; (c), (d) – mine waste heap horizon 0-0.5 m).

The results of modeling the spread of radiation background are consistent with the data of phytocoenological studies. The slopes exhibit a multitude of instances of erosion caused by wind and water, fire-prone areas, release of household waste, fuel and lubricants, and high-intensity water erosion.

3.3. Influence of radiation background on the development of vegetation species composition in a coal mine

During the study of the spread of radiation background in the edaphic horizons of the Nadiia mine waste heap, a variety of species composition of the grass cover was observed, which was greater. Only single groups of Canada bluegrass (*Poa compressa* L.) are found in the grass cover. The smallest distance from the control site with virtually no anthropogenic impact (natural forest plantation with significant forest litter and Scots pine *Pinus sylvestris* L.) is characterized by the foot of the waste heap of the forest site. There are quite favorable growing conditions here. The projected cover of the grass cover is more than 65% and of the tree species more than 60%İn addition to the Canada bluegrass (*Poa compressa* L.), there are such plants as dandelion (*Taraxacum officinale* Webb. ex Wigg.), narrowleaf plantain (*Plantago lanceolata* L.) and other species. Narrow-leaved lupine (*Lupinus angustifolius* L.) and common broom (*Cytisus scoparius* (L.) Link.) also occur on the top and slopes of the waste heap. As for the tree species, silver birch (*Betula pendula* Roth.) 7-9 m high, Scots pine (*Pinus sylvestris* L.) 1-2 m high (up the slope and at the foot (forest zone) of the waste heap can reach 6-7 m high), and *Robinia pseudoacacia* L. – 3-6 m high. The following species grow sporadically: common hawthorn (*Crataegus monogyna* Jacq.), common dog rose (*Rosa canina* L.), goat willow (*Salix caprea* L.) – over 2-5 m high and pedunculate oak (*Quercus robur* L.) – 2-4 m high.

Thus, the models of dynamic or spatial distribution of vegetation, the relationship between vegetation and tree species and the impact of the radiation background, and the assessment of the human impact of the waste heaps at the Nadiia mine can be explained in terms of categories of directions and distances in the multidimensional feature space. However, to reduce the radiation background on waste heaps (especially where it reaches 0.27 μSv/h and above), we recommend planting vegetation and tree species (protective afforestation that reduces the spread of radionuclides) in the ecological and technogenic areas of the waste heap, because radiation has no borders.

4. Conclusions

Thus, the coal industry contributes pollutants to the soil, underground and surface water bodies, air and biota, creating a huge anthropogenic load on subsystems of natural objects. Coal mining and processing waste contains a large number of useful components. In accordance with the requirements of environmental safety and rational nature management, the most efficient way to deal with waste heaps is their complete elimination, but in modern society this way has almost no prospects of realisation, which is due to many economic reasons. That is why the development of new technologies related to environmentally safe and cost-effective disposal of waste heaps is of great importance today.

As mentioned earlier, the coal sector is a major problem for the coal industry and, consequently, for environmental protection. Taking into account the large number and high heterogeneity of waste heaps, as well as excessive radiation background values inherent in areas where rock combustion processes occur (0.21-0.42 μSv/h), any rational decision-making process, despite numerous studies of waste heaps, would not require more information about their composition, structure and location, but much more about appropriate solutions, namely closure of state-owned coal-fired power plants in Ukraine by 2035 (in accordance with the decision at the UN Climate Change Conference to phase out coal-fired power and gradually subsidize fossil fuels, reduce methane emissions by 30% by 2030, and stop deforestation), succession of the vegetation cover of waste heaps, and gradual introduction of natural phytomelioration on coal mine spoil heaps. Environmental safety studies of the natural and technological system of a mining district should be systematic and use a large number of methods and equipment, as their significant impact on the environmental safety of the region is obvious. The prospects for using the research results open up practical bases for the application of methods of the biological stage of reclamation (the so-called natural and artificial phytomelioration), which can reduce radiation and man-made pollution. Thus, continued research in mining areas will expand the range of methods needed to clean the atmosphere, soil, and water bodies from coal mine spoil heaps, while improving the environmental condition of the region. Studying and researching the process of restoring the natural vegetation cover of disturbed lands in the vicinity of coal mines and developing methods for restoring devastated landscapes is extremely important for all coal regions of Ukraine.

We believe that today (in difficult times for Ukraine), it is necessary to carry out reclamation and greening of waste heaps (spoil heaps) and reduce its anthropogenic impact on the urban environment in order to improve the environmental and technological safety of the area. By carrying out these projects, we can not only make rational use of the land damaged by mining, but also dramatically diminish the environmental harm caused by human activity in the state.

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References

[1] Gorobei M, Yermakov V and Lunova O 2020 Man-made pollution of the environment with coal dust as a result of operation and closure of coal mines *Journal of Geology, Geography and Geoecology* **29**(4) 693–700 DOI https://doi.org/https://doi.org/10.15421/112062

[2] Muzychenko O, Lishchuk S and Karaim O 2021 Ecological structure of the flora of waste heaps of Novovolynsk mining district *Notes in Current Biology* (2(390)) 38–44 DOI https://doi.org/10.29038/2617-4723-2020-390-2-38-44

[3] Popovych V, Voloshchyshyn A, Bosak P and Popovych N 2021 Waste heaps in the urban environment as negative factors of urbanization *IOP Conference Series: Earth and Environmental Science* vol 915 (IOP Publishing) p 012001 DOI https://doi.org/10.1088/1755-1315/915/1/012001

[4] Neiva A M R, Antunes I M H R, Carvalho P C S and Santos A C T 2016 Uranium and arsenic contamination in the former Mondego Sul uranium mine area, Central Portugal *Journal of Geochemical Exploration* **162** 1–15 DOI https://doi.org/10.1016/j.gexplo.2015.12.004

[5] Mokryi V, Petrushka I, Dyakiv V, Dzhumelia E and Salamon I 2023 Information Supply of Hydrotechnical Reconstruction Concept of Stebnyk Tailings Storage (Ukraine) *Ecological Engineering & Environmental Technology* **24**(2) 120–130 DOI https://doi.org/10.12912/27197050/156977

[6] Kochmar I M and Karabyn V V 2022 Some heavy metals distribution in rock of waste dumps of the central enrichment factory "Chervonohradska" of Lviv-Volyn coal basin *Bulletin of Lviv State University of Life Safety* **25** 5–12 DOI https://doi.org/10.32447/20784643.25.2022.01

[7] Sokhanchak R, Lobachevska O and Beshlei S 2013 Sezonni zminy u pihmentnomu kompleksi mokhu campylopus introflexus (hedw.) brid. na vershyni vidvalu shakhty "nadiia" *Visnyk Lvivskoho universytetu. Ser. : Biolohichna* **62** 180–187 URL http://nbuv.gov.ua/UJRN/VLNU_biol_2013_62_25

[8] Haidin A and Sobko B 2018 *Hydroecology in mining operations* (Dnipro: Litograph)

[9] Henyk Y V 2012 Lisovidnovlennia skladnykh tekhnohennykh ekosystem Lvivshchyny *Visnyk Dnipropetrovskoho derzhavnoho ahrarnoho universytetu* (1) 117–120 URL http://nbuv.gov.ua/UJRN/vddau_2012_1_29

[10] Kochmar I M and Karabyn V V 2022 Ekolohichna nebezpeka horinnia vuhilnykh terykoniv ta perspektyvni metody vykorystannia vidkhodiv vuhlevydobutku *Ekolohistyka. Teoriia i praktyka upravlinnia smittiezvalyshchamy* (Holovna shkola Pozhezhnoi sluzhby) pp 183–197 URL https://sci.ldubgd.edu.ua/jspui/handle/123456789/11280

[11] Welch C, Barbour S L and Hendry M J 2021 The geochemistry and hydrology of coal waste rock dumps: A systematic global review *Science of The Total Environment* **795** 148798 DOI https://doi.org/10.1016/j.scitotenv.2021.148798

[12] Vo T L, Nash W, Del Galdo M, Rezania M, Crane R, Mousavi Nezhad M and Ferrara L 2022 Coal mining wastes valorization as raw geomaterials in construction: A review with new perspectives *Journal of Cleaner Production* **336** 130213 DOI https://doi.org/10.1016/j.jclepro.2021.130213

[13] Šebelíková L, Csicsek G, Kirmer A, Vítovcová K, Ortmann-Ajkai A, Prach K and Řehounková K 2019 Spontaneous revegetation versus forestry reclamation—Vegetation development in coal mining spoil heaps across Central Europe *Land Degradation & Development* **30**(3) 348–356 DOI https://doi.org/10.1002/ldr.3233

[14] Yuan Y, Zhao Z, Li X, Wang Y and Bai Z 2018 Characteristics of labile organic carbon fractions in reclaimed

mine soils: Evidence from three reclaimed forests in the Pingshuo opencast coal mine, China *Science of The Total Environment* **613-614** 1196–1206 DOI https://doi.org/10.1016/j.scitotenv.2017.09.170

[15] Abramowicz A, Rahmonov O and Chybiorz R 2021 Environmental Management and Landscape Transformation on Self-Heating Coal-Waste Dumps in the Upper Silesian Coal Basin *Land* **10** 23 DOI https://doi.org/10.3390/land10010023

[16] 2021 Environmental passport of Lviv region for 2021 URL https://drive.google.com/file/d/1f8bUHgOIX7ylfyKE5XCQoi7mHtXpJb15/view

[17] Abramowicz A, Rahmonov O, Ryszard C and Ciesielczuk J 2021 Vegetation as an indicator of underground smoldering fire on coal-waste dumps *Fire Safety Journal* **121** 103287 DOI https://doi.org/10.1016/j.firesaf.2021.103287

[18] Ishkov V V, Kozii Y S and Chernobuk O I 2023 Geochemical peculiarities of germanium, arsenic, mercury, beryllium, fluorine and total sulfur in the C8H coal seam of the Dniprovska mine field *Geo-Technical Mechanics* (164) DOI https://doi.org/10.15407/geotm2023.164.021

[19] Karabyn O, Karabyn V and Kochmar I 2022 Lead Speciation in the Technogenesis Zone of Coal Mining Sites (Case of Vizeyska Mine of Chervonohrad Mining Area, Lviv Region, Ukraine) *Petroleum and Coal* **64**(2) 445–454 URL https://sci.ldubgd.edu.ua/jspui/handle/123456789/11193

[20] Silveira F A O, Rossatto D R, Heilmeier H and Overbeck G E 2022 Fire and vegetation: Introduction to the special issue *Flora* **286** 151985 DOI https://doi.org/10.1016/j.flora.2021.151985

[21] 1997 DHN 6.6.1.-6.5.001-98 Derzhavni hihiienichni normatyvy. Normy radiatsiinoi bezpeky Ukrainy (NRBU-97) URL http://www.insc.gov.ua/docs/nrbu97.pdf

[22] Pirikov O, Lunova O and Tyutyunnyk N 2022 Determination of Environmental Risks of Agricultural Land of Urbanized Territories around Mining Enterprises *Ecological Engineering & Environmental Technology* **23**(5) 72–83 DOI https://doi.org/10.12912/27197050/151624

[23] D'yachenko N O, M H D and Ozirska S M 2023 Assessment of the impact of the coal mining industry on the environmental situation in technologically loaded regions *Mining Geology & Geoecology* (2(7)) 57–66 DOI https://doi.org/10.59911/mgg.2786-7994.2023.2(7).295200

[24] Petlovanyi M V and Medianyk V Y 2018 Assessment of coal mine waste dumps development priority *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* (4) 28–35 DOI https://doi.org/10.29202/nvngu/2018-4/3

[25] Sadovenko I, Ulytsky O, Zahrytsenko A and Boiko K 2020 Modeling of geofiltration parameters of radionuclides' Cs and Sr transport in the hydrosphere under the coal mines flooding conditions *PSTC Forum of Miners, Ukraine* (Dnipro) URL https://ir.nmu.org.ua/handle/123456789/156768