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Anna Chrzan

Institute of Biology and Earth Sciences, University of the National Education Commission in Krakow, Podchorążych 2 St., 30–084 Kraków, anna.chrzan@up.krakow.pl

Biodiversity on one of the post-mining heaps in the Silesian province (Poland)

Introduction

Hazard to the environment is an inherent side effect of conducting the mining operations (Sonter et al., 2018). Hard coal mining and processing industries generate large quantities of mineral waste. Despite substantial decline in hard coal production, the mining industry still remains one of the largest producers of industrial waste in Poland (Galos, Szlugaj, 2014). In 2022, 115 million tons of industrial waste were generated (*GUS*, 2022). The main sources of waste were, as in previous years, mining and quarrying (61.3 million tons), industrial processing (21.3 million tons) and generation and supply of electricity, gas, steam, hot water –13.3 million tons (*GUS*, 2022). According to the Central Statistical Office, the largest share in the generated waste resulted from exploration, mining, physical and chemical processing of ores and other minerals (55%) and waste from thermal processess – 19% (*GUS*, 2022). The largest quantities of waste, i.e. a total of 58% of all generated waste, were generated in Lower Silesia and Upper Silesia provinces, which have significant concentrations of the mining industry (*GUS*, 2022). The dominant methods of handling waste generated in 2022 were recovery – 48.4% and landfilling 41.7% (*GUS*, 2022). The amount of waste disposed in the plants' own facilities at the end of 2022 was 1,829 million tons. The uncultivated area of landfills (excluding municipal waste) was 8,000 hectares, of which landfills, mining waste facilities, including heaps accounted for 54.6%, and tailings ponds accounted for 45.4%. During the year, 57.2 hectares of waste disposal areas were reclaimed (*GUS*, 2022).

Mining waste poses several environmental hazards, including contamination of soil, underground water, aquifers as well as secondary air pollution (Carlson, Adriano, 1993; Szczepańska, Twardowska, 1999; Tiwary, 2001; Sułkowski et al., 2008; Suponik, Blanco, 2014; Różański, 2019). Emissions of aerosol contaminations to atmosphere as well as materials deposited in the waste heaps have all contributed to degradation of the natural environment and creation of new anthropogenic habitats (Zając, Zarzycki, 2013; Sonter et al., 2018). Soil organisms are an important factor in soil formation. They determine its functioning, productivity, its detoxification and the rate of remediation (Richards, 1974; Frouz et al., 2001, 2005, 2007, 2008, 2013; Madej, 2002; Siwek, 2008; Manu et al., 2017; Radosz et al., 2019; Józefowska et al., 2020). The analyses conducted in post-mining areas included monitoring of contaminations, analyses of changes and degradation of soils, observations of changes to plant compositions in the regions around the emissions sources as well as spontaneous natural succession on heaps and landfills (Frouz et al., 2001, 2008; Zając, Zarzycki, 2013; Pietrzykowski et al., 2014, 2015; Józefowska et al., 2017; Likus- Cieślik et al., 2023).

Among pollutants, heavy metals are particularly dangerous due to their toxicity, persistence in the environment and ability to bioaccumulate (Kabata-Pendias, Pendias, 1999; Krzaklewski et al., 2002; Pietrzykowski et al., 2014). Being persistent pollutants, heavy metals accumulate in the environment and consequently contaminate the food chains. Accumulation of potentially toxic heavy metals in biota causes a potential health threat to their consumers including humans (Kabata-Pendias, Pendias, 1999; Ali et al, 2019). For the above reason, it is important to control metal concentrations in the environment, also in post-mining heaps.

The aim of the studies was to determine the content of heavy metals, such as Pb, Cd, Ni, Zn and Cu in the material collected at various distances from the peak of the mining waste heap in Czerwionka-Leszczyny and estimate their impact on quantities and diversity of soil organisms in those sites.

Material and methods

The mining waste heap is located in the Silesian province, on the territory of urban township of Czerwionka-Leszczyny (50°08′56′N, 18°40′38′E) – Fig. 1. The waste heap with a total area of 140 ha was used from the beginning of the mining operations of hard coal mine KWK "Dębieńsko" in 1898 until its closure in 2000. During that period, approximately 37 million tons of mining waste were deposited in that area (Konior, 2006; Stefaniak, Twardowska, 2006). Since 2003, mineral recovery works have been carried out on the two peaks of the heap. The aim of these works is to recover minerals in an economically feasible way, which includes mostly hard coal and materials for road construction. A characteristic feature of waste minerals produced by the hard coal mining industry is that they are highly diverse from the mineral and petrographic standpoint. Individual rocks have various physical and mechanical properties, which mostly determine how they could be utilised (Góralczyk, Baic, 2009). The remaining waste is once again stored on a flat waste heap. A biological phase of reclamation, which

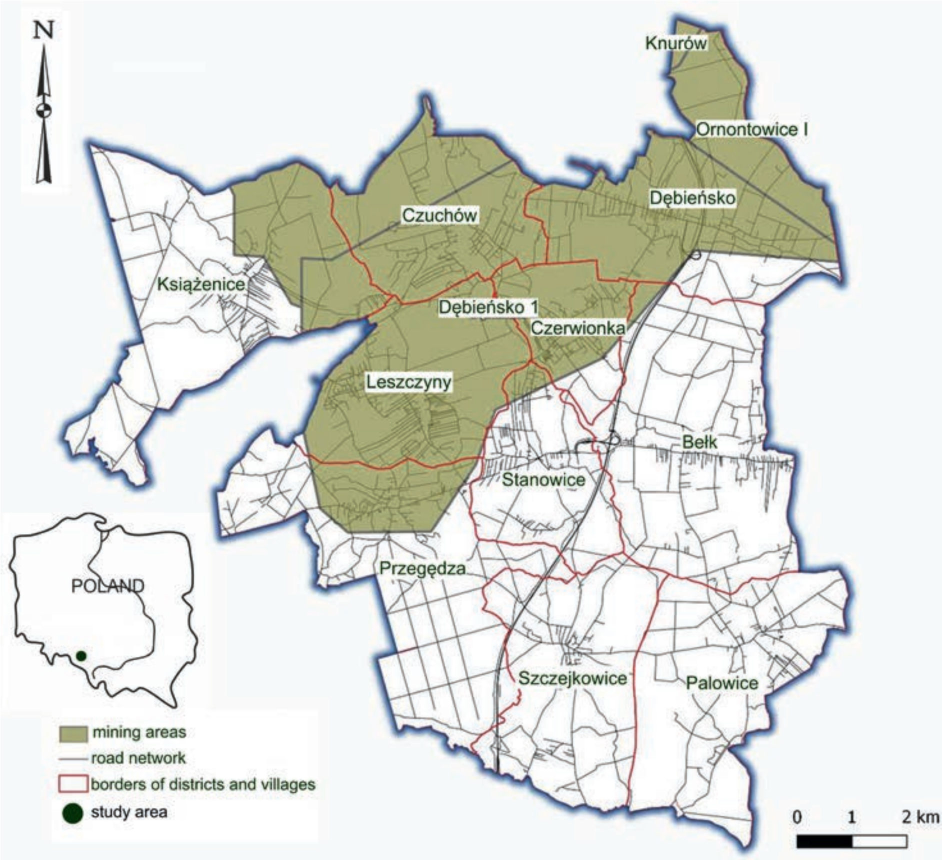

Fig. 1. Study area (Source: https://docplayer.pl/109399706; changed)

was used to initiate soil-forming processes, has been carried out on all the conical forms that make up the heap (Krzaklewski, 2001; Kasprzyk, 2009).

The reclamation works, which are currently underway, aim at planting vegetation on the mining waste heap and preparing it for future development. In addition, the plants were observed to spontaneously grow on the heap. The mining waste heap is planned to serve as sports and recreation area, with construction of bicycle trails, cross country running trails as well as an observation deck (Gawor et al., 2014).

The forms created during the operation of the "Dębieńsko" mine have the shape of cones with steep slopes (Fig. 2). Due to specific shape of the slopes, the mining waste heap experiences significant erosion and denudation processes. The deposited mining waste mostly includes clayey shales, mainly comprised of kaolinite and illite, as well as carboniferous sandstone, claystones and hard coal.

Fig. 2. Orthophotomap of a dump in Czerwionka-Leszczyny (Source: portal.gison.pl/czerwionka-leszczyny)

Because the material has been laying on the heap for a long time, it is significantly eroded. Its specific density is 2.24 g/cm3, and bulk density is 1.60–1.76 g/cm3. Given the foregoing figures, the ground is highly water-permeable and susceptible to infiltration. Moreover, the deposited mining waste is very susceptible to frost-induced erosion, which causes the material to split into fractions, i.e. sand and even dust, which is further susceptible to wind erosion.

Soil samples were collected in the township of Czerwionka-Leszczyny at five sites located at various distances from the peak of the highest mining waste heap:

1) approx. 11 meters from the peak, i.e. at the site where the grass was observed nearest the peak;
2) approx. 80 meters from the peak, at the site where the initial soil with loose structure begins to form;
3) at the bottom of the heap, approx. 230 meters from the peak, at the site where the mining waste material, which is deposited on the heap, is the oldest;
4) 300 meters from the peak, at the site located at short distance from the mining waste heap;
5) one kilometre from the peak, at the site where the waste heap's impact of the waste heap. At that site, grass was also collected for the analysis of heavy metal content.

The field research, encompassing soil temperature and pH measurements and collection of soil material, was conducted twice in 2015 (in the spring and in the autumn).

Soil samples were collected from the examined sites using soil frames with dimensions of 25×25 cm and an area of 1 m2 (Górny, Grum, 1981). The frame was thrust into the soil to a depth of 10 cm. Four soil samples were taken from each site on the same side of the heap. Temperature and pH measurements of the soil were conducted with 330 WTW 330/SET-1 pH-meter (Wissenschaftlich – Technische Werkstätten 82362 Weilheim) pocket pH-meter equipped with an electrode for temperature measurements. In the laboratory, Tullgren funnel (dynamic method) was used to extract living organisms from the soil samples (Murphy, 1962; Górny, Grum, 1981). The preserved soil organisms were identified through keys (Brauns, 1954, 1975; Pławilszczikow, 1972) with use of binocular magnifiers. The identified organisms were classified to the level of orders or families. Grass was also collected from a site located about 1km from the post-mining heap, in which the concentration of heavy metals was also determined. The aboveground part of the plants was cut out from the plots from which soil was taken for testing. The grass cover of the meadow consisted mainly of meadow timothy *Phleum pratense* L. with the addition of perennial ryegrass *Lolium perenne* L. and smooth meadow-grass *Poa pratensis* L.

The analyses also involved measurements of heavy metal content in the soil and grass. Heavy metal content in soil and grass was determined by FAAS after previous soil mineralisation. For this purpose, soil samples were initially dried at 105°C, then the 2 g of dried soil from each location was weighed. Mineralisation of the soil was carried out using the Velp Scientifica DK-20 mineraliser, in concentrated nitric acid at 120°C. The resulting solutions were poured into measuring flasks and filled with distilled water to 10 cm3. In the samples thus prepared, concentration of heavy metals (cadmium, lead, nickel, copper and zinc) was determined by Buck Scientific 200A Flame Atomic Absorption Spectrophotometer FAAS.

The AAS limits of detection (LoD) and quantification (LoQ) for Pb were set at 0.027 ppm and 0.083 ppm (mg/cm3), respectively, for Cd 0.011 ppm (LoD) and 0.033 ppm (LoQ), for Ni 0.017 ppm (LoD) and 0.05 ppm (LoQ), for Cu 0.012 (LoD) and LoQ = 0.035 ppm and for Zn: LoD = 0.023ppm and LoQ = 0.069 ppm.

Statistica 13.3 software was used for statistical calculations. To determine the differences between the obtained experimental values, the standard deviation (±SD) was calculated for each parameter and Duncan's test was used ($n = 5$, at $p \leq 0.05$). Pearson's correlation coefficient was used to calculate the relationship between the variables.

Results and discussion

Results of soil temperature and pH measurements are presented in Tab. 1. At the top of the heap, only soil temperature and pH were measured. The obtained results show that the temperature on the peak of the heap exceeded 50°C, which makes it difficult for the plants to grow there (Tab. 1). Other authors have also observed an increase in surface temperature of mining heaps with increasing height (Zając, Zarzycki, 2013; Surovka et al., 2017; Radosz et al., 2019). Due to high temperatures, no material was collected for testing.

At the distance of approx. 11 meters from the peak, the soil temperature dropped to 30°C (Tab. 1).

Tab. 1. Characteristics of the studied sites (temperature of soil, soil pH, density, diversity of pedofauna, percentage)

Parameters	Distance from the top of post-mining dumps						Pearson's correlation coefficient
	The top of post-mining dumps	11 m	80 m	200 m	300 m	1 km	
Temperature of soil [°C]	>55	27.7–29.0	12.0–15.0	13–17.7	13.5–19.7	14–19	
Soil pH	5.38	6.51	6.69	6.55	6.79	7.06	0.619
Diversity (number of soil fauna orders)	no	8	9	9	11	12	0.883*
Density of pedofauna [N/m^2]	no	7032	2056	3480	7152	17754	0.905*
Order of soil fauna [%]:							
Enchytraeidae Vejdo.		0	9.73	3.91	0.89	0.13	-0.412
Collembola Lubb.		53.01	13.23	25.29	7.16	15.73	-0.412
Coleoptera L.		1.02	1.56	0.92	2.24	0.41	-0.367
Formicidae Latre.		0.91	9.73	0.69	60.18	2.21	-0.066
Homoptera		0.11	6.23	0.23	2.12	0.58	-0.304
Acari (Acarina)		43.46	49.80	63.45	24.38	76.92	0.623

*correlation is significant at the 0.05 level

The thermophysical properties of the soil depend on several factors (Pikoń, Bugla, 2007; Zając, Zarzycki, 2013). The most important one of them is the solar radiation energy. The rate of heating up of the soil depends on the colour of the soil, its humidity and structure, as well as its granulometric composition, landscape, exposure of the area to elements and the plants that grow on it. In case of mining waste heaps, a significant role is also played by exothermic reactions which continuously occur in the deposited material (Pikoń, Bugla, 2007). The heating of coal and pyrite occurring in the waste material causes self-ignition and endogenous fires of the mining waste heaps. This process increases the temperature of the mining waste heap even further and generates smoke (Zając, Zarzycki, 2013; Różański, 2019; Sułkowski et al., 2008; Łączny et al., 2012; Surovka et al., 2017; Fabiańska et al., 2018). Therefore, to prevent fires, waste material from the mining waste heaps should be directly utilised through reclamation or other engineering projects (levelling the area, building embankments, etc.) (Gawor et al., 2014). To avoid fire hazard and to improve the properties of the waste material as well as the options for its utilisation, it would be helpful to separate coal from the mining waste (Różański, 2019).

The pH of the analysed material ranged from slightly acidic to neutral (5.4–7.06) (Tab. 1). The lowest average pH value was recorded at the top of the heap and the highest 1km from the top of the heap. Development of soil on mining waste heaps is a long-term process with significant contribution of biotic elements such as plants, microorganisms as well as soil fauna (Madej, 2002; Manu et al., 2017; Radosz et al., 2019). However, analyzes of the processes taking place on mining heaps mainly concern plant formations, while few studies are conducted on soil organisms inhabiting even the most degraded biotopes. Radosz et al. 2019 points out that the participation of soil organisms in the soil-creation processes is just as important in the post-industrial areas as it is in natural and semi-natural ecosystems. By providing access and ensuring circulation of elements, soil mesofauna and soil plants have a significant share in plant succession.

Research of quantitative and qualitative aspects of pedofauna occurring in areas affected by a significant human footprint largely focuses on the groups of organisms most abundant in these areas, namely mites and ticks, and springtails. The sites with the initial plant cover are characterised by low density and diversity of the species of mites of the Oribatida order, however, after a few years, their numbers increase to several thousand per 1 square meter (Madej, 2002). This is also confirmed by the analyses of the soil fauna in Czerwionka-Leszczyny (Tab. 1). However, the correlation of the percentage of selected systematic groups with the distance from the heap is not statistically significant.

The number of organisms could be observed to steadily grow with the increase in the distance from the peak of the heap. The only exception was the site located 11 m from the peak, which may be attributable to a well-developed plant community in the higher part of the highest mining waste peak. A very high degree of correlation exists between the distance from the heap and pedofauna density, while a high degree of correlation was noted between the distance from the heap and pedofauna diversity (Tab. 1). The highest abundance and diversity of soil invertebrates was observed at site 5 (1 km from the post-mining heap). In addition to Enchytraeidae, Colembolla, Coleoptera, Formicidae, Homoptera and Acarina, Nematoda, Gastropoda, Isopoda, Myriapoda, Diptera and Aranea also occurred here. Radosz et al. (2019) pointed out a positive impact of the plant cover on the number of nematodes and Enchytraeidae worms in the soils in post-industrial areas. Density and species richness in most of investigated groups of soil biota gradually increased with increasing succession age (Frouz et al., 2001). Also, Frouz et al. (2008) emphasised that the greatest density of soil macrosaprophages, which are the most important organisms for decomposition of mulch and mixing of soil, was observed in the oldest mining waste heaps in and around the town of Sokolov, Czech Republic

(Frouz et al., 2008). Frouz et al. (2014) showed that the influence of tree species on soil development is substantially mediated by soil fauna activity.

Monitoring and analysis of heavy metal concentrations in the environment are necessary for pollution assessment and control (Ali, Khan, 2019). The analyses also involved measurements of heavy metal content in the soil. Concentrations of heavy metals varied.

The heavy metal contents ranged for Cd from 1.18 to 1.54 mg/kg of dry mass (DM), for Cu from 20.82 to 66.20 mg/kg DM, for Zn from 97.79 to 222 mg/kg DM, for Pb from 27.20 to 50.18 mg/kg DM and for Ni from 5.55 to 56.23 mg/kg DM (Tab. 2). According to the Regulation (2016), the soils of the investigated dump are classified in group IV, which includes industrial areas, areas of active mining activities, communication areas, including roads, railroads, other communication areas, as well as areas intended for the construction of public roads or railroads. They were not found to be excessively contaminated with metals (Regulation, 2016). Pietrzykowski et al. (2014) also found that in forested areas affected by coal, sand, lignite and sulphur mining, there was no risk of trace element concentrations in mine soils.

Copper content ranged from 20 to 37 mg/kg DM, averaging at 28.32 (Tab. 2). The content of copper in the soil was statistically insignificant.

Tab. 2. Content of heavy metals in soil at various distances from the peak of the post; SD – standard deviation, BCF – bioconcentration factor; mean values marked with different letters differ significantly according to Duncan test $p \leq 0.05$

Distance from the top of post-mining dumps	Statistical parameters	Metal [mg kg-1]				
		Cu	Cd	Pb	Zn	Ni
11 m	Average	20.82 b	1.18 b	50.18 a	97.79 b	40.28 b
	Mediana	19.96	1.19	50.24	95.47	41.55
	SD	±2.16	±0.20	±4.85	±19.02	±5.82
80 m	Average	34.29 ab	1.54 a	48.04 a	174.66 a	49.20 b
	Mediana	35.39	1.26	45.75	174.89	45.64
	SD	±0.15	±0.02	±0.09	±2.30	±1.18
200 m	Average	37.72 ab	1.54 a	38.01 b	177.05 a	56.23 b
	Mediana	37.60	1.52	35.86	173.90	54.57
	SD	±2.11	±0.10	±5.37	±5.75	±9.42
300 m	Average	25.11 b	1.43 ab	27.20 c	183.53 a	41.77 b
	Mediana	25.52	1.39	27.08	184.00	41.09
	SD	±2.41	±0.11	±2.39	±18.98	±5.11
1 km (soil)	Average	23.64 b	1.51 a	30.08 c	222.19 a	5.55 c
	Mediana	21.64	1.44	31.06	224.93	5.41
	SD	±1.88	±0.23	±3.26	±16.52	±1.13
1 km (grass)	Average	66.20 a	1.31 ab	27.49 c	203.89 a	150.06 a
	Mediana	57.61	1.37	28.81	185.80	146.83
	SD	±13.48	±0.49	±5.73	±27.27	±18.46
	BCF	2.80	0.87	0.91	0.92	27.04

Elevated levels of copper were reported by Bzowski (2013) in the mining waste heaps of the Lubelskie Coal Basin as well as Różański (2019) in the Upper Silesia Coal Basin (Tab. 3).

Tab. 3. Content of selected heavy metals in waste and permissible values

Metal	Bzowski (2013) LCB Lublin Coal Basin	Różański GOW (2019) Upper Silesian Coal Basin	Czerwionka-Leszczyny (2016)	The highest permissible value in grounds acc. Ordinance ME 2016, mg kg^{-1} (DM) Group IV
Cd	<2	no	1.2–1.5	15
Cu	65	87–155	20.8–37.7	600
Ni	52	58–111	5.55–56.2	500
Pb	29	no	27.2–50.2	600
Zn	137	110–201	97.8–183.5	1000

Nickel content ranged from 5.5 mg/kg DM in the distance of 1km from the mining waste heap to 56.2 mg/kg DM in the distance of 200 m from the heap (Tab. 2). Higher contents of that metal were reported by Różański (2019) on the Przezchlebie mining waste heap in the Upper Silesia Coal Basin (Tab. 3). Bian et al. (2006) found the soil levels of cadmium, nickel, lead and zinc to be much lower at the distance of 150–180 m from the mining waste heap in the Yanzhou Coal Basin in China. The content of Ni in the soil was statistically lover at the distance of 1km from dump than at 11, 80, 200 and 300 m distances (Tab. 2).

The cadmium concentration ranged approx. from 1.2 to 1.5 mg/kg DM (Tab. 2). According to the findings, there was a significant decrease in the Cd content at a distance of 11 meters compared to the other distances that were analysed. Similar results were recorded in the Lubelskie Coal Basin (Tab. 3).

Zinc concentration was increasing as the distance from the peak of the mining waste heap was growing, but the differences were not statistically significant (Tab. 2). The highest concentration of 222 mg/kg DM was recorded at the distance of 1 km from the mining waste heap.

Lead concentration in soil was statistically lower at 200 m, 300 m and 1000 m from the landfill than at 11 m and 80 m (Tab. 2). At the distance of approx. 1 km from the mining waste heap, it ranged from 25–32 mg/kg DM. Similar lead concentrations were recorded by Bzowski (2013) in the mining waste heaps of the Lubelskie Coal Basin (Tab. 3).

The studied soils were classified as pollution degree II, i.e., moderately contaminated in respect of heavy metal content, according to IUNG guidelines (Kabata-Pendias, 1995). In addition, the heavy metal content of plants collected at a distance of 1km from the post-mining dump was determined. The results presented in table (2) indicate that the content of copper and nickel in the dried grass was significantly higher than in the soil. The content of copper in plants varies greatly depending on the part of the plant, stage of development, plant variety and species, and its density in habitat and climatic conditions. Plants growing in mining pits and mining waste heaps are exposed to excessive concentrations of that metal (Kabata-Pendias, Pendias 1999). Terelak et al. (2001) give the average Cu concentration in grass at 5.5 mg/kg DM. On the other hand, the paper shows much higher contents of copper, ranging from 36 to 128 mg/kg DM (average of 66.2 mg/kg DM) (Tab. 2).

Nickel is easily absorbed by plants. In most cases, this element is absorbed at the rate similar to its concentration in soil. In plants, nickel is very mobile and easily moves to above-ground parts of the plant, mostly to its seeds. Plants growing in contaminated areas have much higher nickel contents (Terelak et al., 2001; Jasiewicz, Antonkiewicz, 2004). According to research by Pietrzykowski et al. (2014), in Europe in afforested areas affected by hard coal, sand, lignite and sulphur mining, there is no risk of trace element concentrations in mine soils.

The degree of accumulation of heavy metals in grasses is denoted by the bioaccumulation factor (BCF), which is defined as the ratio of metal concentration in plant biomass to that in the soil. In the analysed plant material, the bioaccumulation factor (BCF) was the highest for nickel, followed by copper. Other metals had lower accumulation rates of BCF <1 (Tab. 2).

Conclusions

Industrial and post-industrial areas are characterised by significant changes to the environment and local spatial planning for the given territorial unit. The mining waste heap located in Czerwionka-Leszczyny significantly affected not only that city's landscape but it also impacted the quality of certain elements of nature. Several land reclamation projects are carried out in order to mitigate the waste heap's adverse impact on the environment. Reclamation procedures were carried out on all conical forms comprising the mining waste heap. Such procedures involved planting trees and allowing the plants to spontaneously grow on the heap.

In this study, correlations were found between the distance from the heap and the density and diversity of pedofauna. A very high degree of correlation was noted between density and a high degree of correlation between distance from the heap and pedofauna diversity. The contents of the analysed metals did not exceed their permitted levels in soil and earth as defined by the Regulation of the Minister of Environment of 2016 in the matter of the procedure for conducting the assessment of soil surface contamination.

No clear regularities were observed in the content of heavy metals in the soil at various distances from the top of the heap. The obtained results indicate that the content of copper and nickel in the dried grass was significantly higher than in the soil.

Conflict of interest

The author declares no conflict of interest related to this article.

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Abstract

Waste generated by the hard coal mining and processing industries pose significant environmental hazard through, among others, impacting water and soil. The process that is particularly dangerous is trace element accumulation. Excessive quantities of heavy metals pose grave threat to plants, humans and soil organisms. The purpose of the studies was to determine the content of heavy metals, such as Pb, Cd, Ni, Zn and Cu in the material collected at various distances from the peak of the mining waste heap in Czerwionka-Leszczyny and estimate their impact on quantities and diversity of soil organisms in those sites. Studies have shown a high degree of correlation between the distance from the top of the heap and the density and diversity of pedofauna. The highest abundance and diversity of soil invertebrates was observed at site 5 (1 km from the post-mining heap). The content of heavy metals in the tested soils ranged for Cd from 1.18 to 1.54 mg/kg of dry mass (DM), for Cu from 20.82 to 66.20 mg/kg DM, for Zn from 97.79 to 222 mg/kg DM, for Pb from 27.20 to 50.18 mg/kg DM and for Ni from 5.55 to 56.23 mg/kg DM. The contents of the analysed metals did not exceed their permitted levels in soil and earth as defined by the *Regulation of the Minister of Environment of 2016 in the matter of the procedure for conducting the assessment of soil surface contamination*. The obtained results indicate that the content of copper and nickel in the dried grass was significantly higher than in the soil.

Key words: heavy metals, soil fauna, waste heaps

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Streszczenie

Odpady powstające w przemyśle wydobywczym i przetwórczym węgla kamiennego stanowią poważne zagrożenie dla środowiska, między innymi poprzez oddziaływanie na wody i gleby. Szczególnie niebezpiecznym procesem jest akumulacja pierwiastków śladowych. Nadmierne ilości metali ciężkich stanowią poważne zagrożenie dla roślin, ludzi i organizmów glebowych. Celem badań było określenie zawartości metali ciężkich, takich jak Pb, Cd, Ni, Zn i Cu, w materiale pobranym w różnych odległościach od szczytu hałdy w Czerwionce-Leszczynach oraz oszacowanie ich wpływu na liczebność i różnorodność organizmów glebowych na tych stanowiskach. Badania wykazały wysoki stopień współzależności między odległością od szczytu hałdy a zagęszczeniem i różnorodnością pedofauny. Największą liczebność i różnorodność bezkręgowców glebowych stwierdzono na stanowisku 5 (1 km od hałdy poeksploatacyjnej). Zawartości metali ciężkich na badanych stanowiskach wahały się dla Cd w przedziale od 1,18 do 1,54 mg/kg suchej masy (DM), dla Cu od 20,82 do 66,20 mg/kg DM, dla Zn od 97,79 do 222 mg/kg DM, dla Pb od 27,20 do 50,18 mg/kg DM i dla Ni od 5,55 do 56,23 mg/kg DM. Zawartości analizowanych metali nie przekroczyły dopuszczalnych poziomów w glebie i ziemi, określonych w *Rozporządzeniu Ministra Środowiska z 2016 r. w sprawie sposobu prowadzenia oceny zanieczyszczenia powierzchni ziemi*. Uzyskane wyniki wskazują, że zawartość miedzi i niklu w wysuszonej trawie była istotnie wyższa niż w glebie.

Słowa kluczowe: fauna glebowa, metale ciężkie, odpady pogórnicze

Information on the author

Anna Chrzan; https://orcid.org/ 0000-0002-2186-3126

Assistant professor at the Department of Ecology and Geoinformation of the Institute of Biology and Earth Science. She deals with environmental monitoring and soil ecology. She also conducts soil biomonitoring research in environments under various anthropopressure.