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The impact of depositing waste from coal mining and power engineering on soils on the example of a central mining waste dump

Introduction

Coal mining waste dumps are the subject of numerous scientific research projects. The studies most often deal with the issues of the mineral and petrographic composition of the deposited waste, their impact on the water environment, fire hazards, reclamation and recovery of coal from waste material (Ostręga and Uberman 2005; Probierz et al. 2017; Probierz et al. 2018; Stefaniak et al. 2013).

Relatively few studies consider the impact of post-mining dumps on the pedosphere, which was the main reason for taking up the subject of the impact of disposed wastes on soil cover.

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Over 220 waste dumps covering both above-level and sub-level landforms – state: 2014 were located in the area of the Upper Silesian Coal Basin (Gawor et al. 2014; Gawor 2014; Marcisz et al. 2020). Coal mining waste dumps vary with surface, type of deposited material, period of disposing of the material, state, direction of reclamation or possibilities of recovery of coal (Gawor and Kwaśny 2015; Gawor and Marcisz 2015). Some of them may constitute anthropogenic deposits (Nieć 1999).

The authors' interest in the subject of research was aroused only by the largest dumps because it was found that they (mainly the material deposited and the period of its storage) have the largest impact on the surrounding soil cover. This was also the criterion for selecting the research facility – large-area waste dumps (so called central dumps), where the material was deposited for the longest possible period of time.

1. Localization and characteristic of the study area

The object of the study is central coal mining waste dump situated in the direct neighborhood of Gliwice, representing an above-level and sub-level landform, located in the former open pit after sand exploitation.

The dump consists of coal mining wastes and fly ash from electric power plants, constituting more or less regular overlays of various thicknesses and positions. The dump originated in the open pit of former sand mine, which has been a source of filling sands till 1955. The rock material was delivered from the mines Bobrek, Makoszowy, Pstrowski, Krupiński, Zabrze and Gliwice; Fly ash and slags from the power plant Rybnik has been stored for 17 years (1973–1990) (Regulation… 2016; Różański 2019a, 2019b).

The main chemical components in mining wastes sampled from the dumping ground in examined area, according to literature study are (average): SiO_2 – 45.22%, Al_2O_3 – 18.48%. The average contents of other significant components amount to TiO_2 count 0.99%; Fe_2O_3 – 4.06%; CaO – 1.40%; MgO – 1.41%; $K_2O + Na_2O$ – 1.21%; St – 0.442%; C – 11.69% (Różański 2019a). The composition of the waste does not differ from the composition of typical Polish carboniferous waste (Różański 2019a). The average content of elements like Zn, Co, Cu, and Ni are contained respectively in the ranges of 167, 49, 130 and 85 expressed in mg per kg of dried waste for waste deposited on the dumping ground in study area (Różański 2019a).

The dumping ground is situated in the neighborhood of the railway, so its accessibility is good. In the vicinity of the dump there is a small estate, but it is possible to exploit the dump and transport material in the safe distance from the buildings. The facility belongs to the few dumps in the USCB, which belong to the commune (Szczepańska and Twardowska 1999).

The soils around the dump belong to podzolic and pseudopodzolic soils. Brown soils occur on the slopes. Initial soils with a non-developed profile, originating from waste Carboniferous rocks (mainly sandstones, mudstones and siltstones) of anthropogenic origin are observed at the dump (Mocek 2020; Nawrocki and Becker 2017; Resolution… 2017).

A part of the dump has been reclaimed in a way of shaping the relief, improving of physical properties of the soil, regulation of water relations, strengthening of slopes and development in the direction of the forest. The plateau of the dump and northern and eastern slopes are covered with trees such as: birch, black locust and larch. The eastern part of plateau as well as western and southern slopes are covered by grass and bush, which is a result of natural succession (Figure 1). The trees are rare in that part (Patrzałek 2006; Patrzałek and Gawor 2008; Różański 2019a).

Fig. 1. The dump's plateau (photo by Ł. Gawor)

Rys. 1. Wierzchowina zwałowiska (fot. Ł. Gawor)

2. Sampling and methodology

During research field work there were collected 9 soil samples around the dump using Egner's cane (Myślińska 2016) from the depth of 30 cm (Figure 2).

Fig. 2. An exemplary sample, taken with an Egner's cane (photo by Ł. Gawor)

Rys. 2. Przykładowa próba, pobrana za pomocą laski glebowej Egnera (fot. Ł. Gawor)

The samples were collected every 1000 m around the dump. The ashes were taken 100 m from the border of the dump.

The number of samples was limited by the accessibility of the facility (partially exploited for the recovery purposes) and the close proximity of military areas.

In order to prepare soil samples for the tests they were taken up in a mixture of HCl and HNO_3 acids in a UniClever microwave mineralizer.

The content of elements in soil samples was measured by the emission spectrometry method using the ICP-AES JY 2000 spectrometer with inductively aroused plasma.

A roentgen diffractometer AERIS 1 of PANalytical with a lamp $Cu_{K\alpha}$ was used for the phase identification. Measurements were made in following conditions voltage 40 kV, current 8 mA, step 0,02° of the angle, range of the angle 2theta 4–74°, time 4,84 s. The HigScore Plus v. 4.8 program was used with database PDF-2 in the interpretation of XRD spectrum.

Samples where mullite was identified were classified as samples of class C (samples with natural grainsize) and a granulometry analysis was conducted according to the PN-ISO 3310 and PN ISO 565 standards.

3. Results

According to the legal regulations (Regulation… 2016), the study area represents the III group of grounds – wastelands.

In terms of the types of activities that constitute selected types of projects that may have a significant impact on the environment, the research object includes the extraction of minerals from the deposit using a different opencast method, for which the metals and metalloids presented in Table 1 are determined.

Regarding the observed occurrence of Fe and Sb in soil samples, the concentrations of these two metals were also additionally determined (Table 1).

In the tested samples the highest average iron content was found, amounting to 0.6%, the concentration of which in individual samples varied within a wide range from 0.1% (samples 10, 50, 57) to 1.2% (sample 70).

The average zinc content in the analyzed soil samples is 89 ppm and it varies from 12 ppm (sample 50) to 150 ppm (sample 40), then Cr (average content 21.6 ppm), where the lowest content is 0.8 ppm (sample 10), and the highest 45 ppm (sample 1) and Ni (average content 19.9 ppm), where the minimum concentration is 9.5 ppm (sample 57), and the maximum 45 ppm (sample 70) (Table 1).

Concentrations of cuprum and lead vary in a similar range, suitably Cu from 0.5 ppm (sample 57) to 24.0 ppm (sample 1); Pb from 5.5 ppm (sample 50) to 25.0 ppm (sample 40). The average concentrations of Cu and Pb in the tested samples were respectively: 9.9 ppm and 11.3 ppm (Table 1).

The average contents of other analyzed elements in soil samples do not exceed 3.5 ppm, and their concentrations vary in the range: Cd from 0.1 ppm (samples 1, 30 and 40) to

Table 1. Heavy metal content in tested samples

Tabela 1. Zawartości metali ciężkich w badanych próbkach

Symbol of the sample	Zn	Pb	Fe	Cu	Cr	As	Cd	Sb	Ni	Co
	ppm	ppm	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	120	11.0	0.5	24.0	45.0	2.5	0.1	2.5	35.0	2.5
10	65	7.5	0.1	10.0	0.8	not marked	not marked	0.3	15.0	0.5
20	112	10.0	1.1	5.6	34.0	0.6	0.2	0.2	12.0	1.1
30	50	8.5	0.5	1.2	1.2	0.4	0.1	0.5	11.0	0.6
40	150	25.0	0.7	12.0	38.0	0.1	0.1	3.5	25.0	1.8
50	12	5.5	0.1	2.5	9.4	not marked	not marked	not marked	17.0	not marked
57	89	7.5	0.1	0.5	11.0	0.1	0.1	0.4	9.5	0.7
70	125	15.0	1.2	21.0	33.0	0.3	0.3	1.8	45.0	2.1
80	75	12.0	0.8	12.0	22.0	not marked	not marked	not marked	10.0	0.6
Min.	12	5.5	0.1	0.5	0.8	0.1	0.1	0.2	9.5	0.5
Max.	150	25.0	1.2	24.0	45.0	2.5	0.3	3.5	45.0	2.5
Average	89	11.3	0.6	9.9	21.6	0.7	0.2	1.3	19.9	1.2
Standard dev.	43	5.9	0.4	8.4	16.6	0.9	0.1	1.3	12.6	0.8
Acceptable content of metals and metalloids for the III group of soils – wastelands after [16]	1 000	500	–	300	500	50	10	–	300	100

0.3 ppm (sample 70); As from 0.1 ppm (sample 40.57) to 2.5 ppm (sample 1); Co from 0.5 ppm (sample 10) to 2.5 ppm (sample 1) and Sb from 0.2 ppm (sample 20) to 3.5 ppm (sample 40) (Table 1).

It was determined that permissible contents of metals and metalloids for the III group of grounds – wastelands (Regulation... 2016) have not been exceeded.

The identification of phases by the X-ray diffraction method (examples in Figure 3) revealed a significant variation in both the quality of the phases present in the tested samples and their amounts (Table 2).

The presence of quartz and feldspars, which shares vary accordingly in ranges 36.3––85.5% and 2.0–27.4% was determined in all the samples.

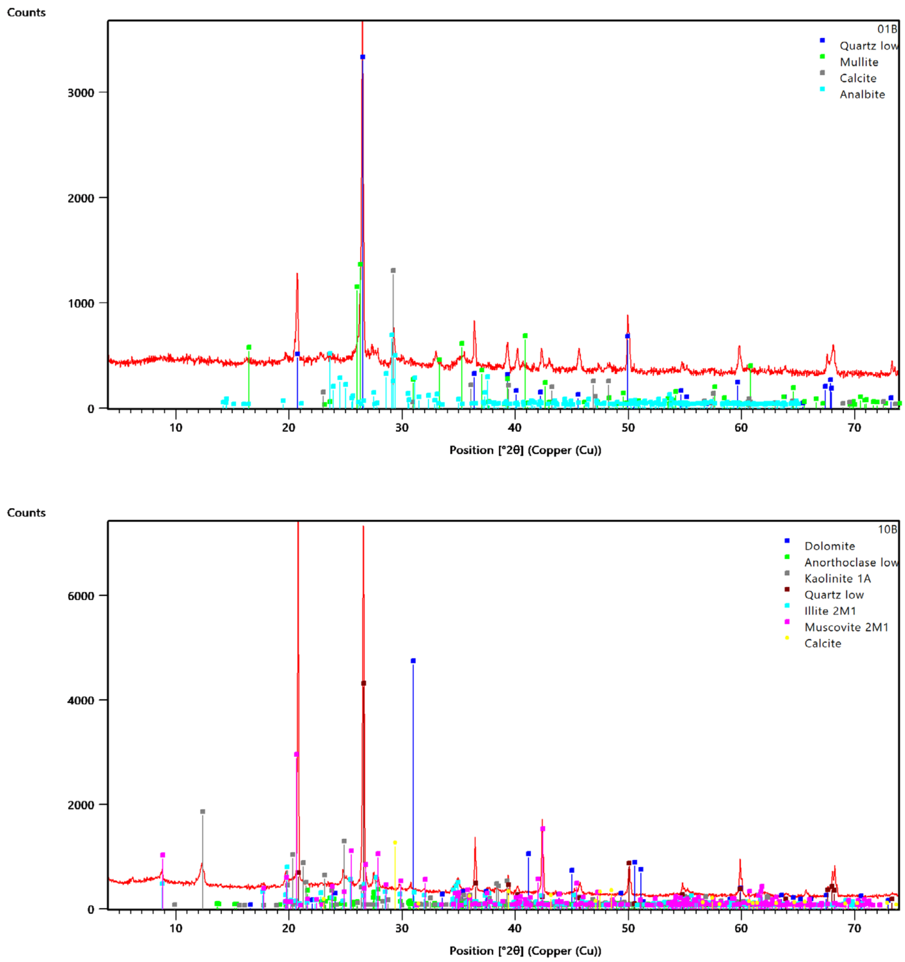


Fig. 3. X-ray diffraction pattern of soil samples 1 (top) and 10 (bottom)

Rys. 3. Dyfraktogram rentgenowski próbki gleby 1 (u góry) i 10 (na dole)

Table 2. Minerals content in tested samples

Tabela 2. Zawartości minerałów w badanych próbkach

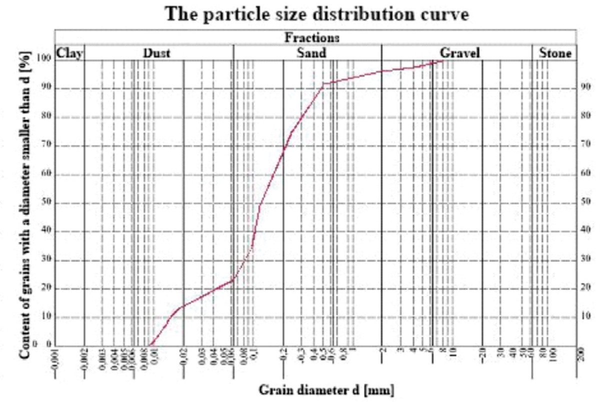
Symbol of the sample	Quartz	Feldspars	Muscovite	Kaolinite	Illite	Chlorite	Calcite	Dolomite	Mullite
	%	%	%	%	%	%	%	%	%
1	78.8	11.7					3.5	traces	6.0
10	39.6	5.7	3.0	23.1	27.3	traces	1.0	0.3	
20	36.3	6.6	4.8	15.8	36.5	traces		traces	
30	62.5	2.0						traces	35.5
40	73.2	9.0	4.4		12.7	traces	0.7		
50	71.9	27.4		0.7					
57	79.7	11.0	4.2	2.0	3.1	traces			
70	85.5	10.1		0.3	4.1	traces		traces	
80	85.2	8.3		0.1	6.4	traces			
Min.	36.3	2.0	3.0	0.1	3.1		0.7	0.3	6.0
Max.	85.5	27.4	4.8	23.1	36.5		3.5	0.3	35.5
Average	68.1	10.2	4.1	7.0	15.0		1.7	0.3	20.8
Standard dev.	18.5	7.1	0.8	9.9	13.8		1.5		20.9

The presence of clay minerals, represented by kaolinite and illite was found in six of the nine tested samples. Their amounts range from 0.1 to 23.1% for kaolinite and 3.1–36.5% for illite. In four samples tested (10, 20, 40 and 57) the presence of muscovite was demonstrated, the share of which does not exceed 5%.

In some samples minerals from the carbonates group were found. They are represented by calcite (samples 1, 10 and 40) and dolomite (sample 10), although their amounts are small (0.7–3.5% of calcite and 0.3% of dolomite).

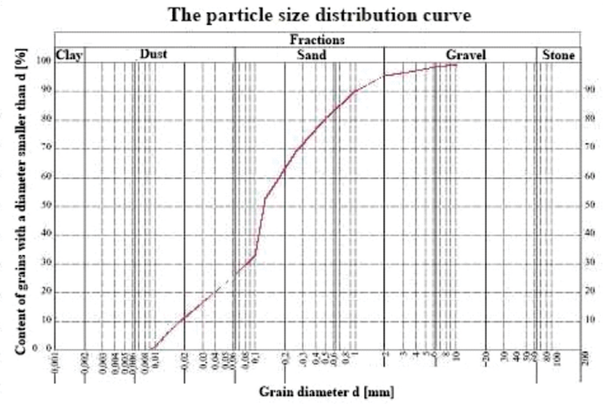
An important phase in the tested samples is mullite, shown in two of them, i.e. samples 1 and 30, the share of which amounts to 6.0 and 35.5%, respectively. This compound does not occur in the wastes form hard coal mining in the USCB. In such wastes mullite is known only in the case of thermal activity of the dump. No such activity was recorded on the examined object, so the source of mullite is a different material from coal mining waste. Mullite is a common phase in energy waste. A particularly high proportion of mullite is observed in fly ash. Therefore, the fly ash was deposited in the tested landfill in its eastern part (soil sampling area 1) and in the north-western part (soil sampling area 30). That prompted the authors to take samples of fine waste material in the neighborhood of the mentioned soil samples (A, B, C, D).

Equivalent diameter of grains [mm]	Content of grains [%]	Percent content [Σ%]
25.00	0	100.00
16.00	0	100.00
10.00	0.92	100.00
8.00	0.36	99.08
6.30	1.22	98.72
4.00	0.55	97.50
2.00	1.61	96.95
1.00	2.80	95.34
0.50	18.48	92.54
0.25	25.37	74.06
0.125	12.12	48.69
0.100	13.16	36.57
0.063	9.13	23.41
0.02	11.94	14.28
0.01	2.34	2.34
0.005	0.00	0.00
0.002	0.00	0.00



Content of stone fraction 0 %; gravel 2,50 %; sand 74,09 %; dust 23,41 %; clay: 0,0 %
Name of the ground after PN-86/B-02480: -; after. ISO: siSa

Equivalent diameter of grains [mm]	Content of grains [%]	Percent content [Σ%]
25.00	0	100.00
16.00	0	100.00
10.00	1.84	100.00
8.00	0.6	98.16
6.30	1.19	97.56
4.00	0.55	96.37
2.00	5.54	95.82
1.00	8.63	90.28
0.50	12.28	81.65
0.25	15.11	69.37
0.125	22.08	54.26
0.100	5.75	32.18
0.063	15.15	26.43
0.02	10.32	11.28
0.01	0.96	0.96
0.005	0.00	0.00
0.002	0.00	0.00



Content of stone fraction 0 %; gravel 3,63 %; sand 69,94 %; dust 26,43 %; clay 0,00 %
Name of the ground after PN-86/B-02480: -; after ISO: grsiSa

Fig. 4. The results of the granulometric analysis of samples A (top) and C (bottom)

Rys. 4. Wyniki analizy granulometrycznej próbki A (u góry) C (na dole)

Detailed tests started with the granulometric analysis of samples A and C (Figure 4).

The results of the granulometric analysis proved that fine waste material represents fly ash.

There were also measured selected heavy metals in the ashes (Table 3) and oxides content (Table 4).

Table 3. Selected heavy metal content in tested samples (ppm)

Tabela 3. Zawartości wybranych metali ciężkich w badanych próbkach [ppm]

Symbol of the sample	Zn	Pb	Cd
	ppm	ppm	ppm
A	750	250	10.1
B	620	450	9.9
C	770	210	7.8
D	690	199	8.1
Min.	620	199	7.8
Max.	770	450	10.1
Average	708	277	9.0
Standard dev.	68	117	1.2

Table 4. Oxides content in tested samples (% mass.)

Tabela 4. Zawartości tlenków w badanych próbkach [% wag.]

Symbol of the sample	SiO_2	Fe_2O_3	MgO	CaO	K_2O	Na_2O	Al_2O_3
	% mass.	% mass.	% mass.	% mass.	% mass.	% mass.	% mass.
A	49.5	5.2	2.9	12.3	3.1	0.99	17.6
B	51.2	6.1	3.1	15.5	3.3	1.21	19.1
C	52.3	6.4	3.7	12.3	3.5	0.97	18.1
D	55.1	6.5	4.1	16.7	3.9	1.11	17.9
Min.	49.5	5.2	2.9	12.3	3.1	0.97	17.6
Max.	55.1	6.5	4.1	16.7	3.9	1.21	19.1
Average	52.0	6.1	3.5	14.2	3.5	1.07	18.2
Standard dev.	2.4	0.6	0.6	2.2	0.3	0.11	0.7

The wastes disposed on the dumping ground represent a mixture of Carboniferous mining waste and fly ash. The selected heavy metals mentioned above, which have been measured in the ashes may affect the content of these elements in the soils.

The composition of oxides also prove origin of fine particles of wastes as fly ash.

The chemical composition of the wastes, both mining and originating from the power industry shows a potential relationship between the chemical compounds e.g. concentrations of Fe or the presence of a high value of Cu in the waste material and in the soils.

Conclusions

The study area represents the III group of grounds – wastelands (Regulation… 2016). The obtained results showed that heavy metal contents in the neighborhood of the dump vary in a broad range.

In the analyzed samples iron reaches the highest concentrations (average content 0.6%). Concentrations of other elements in the soils of examined area do not exceed 0.02%, average zinc content amounts 89.0 ppm, chrome and nickel 45.0 ppm.

Lower concentrations of lead and copper counting respectively 11.3 ppm and 9.9 ppm and trace amounts of cadmium, arsenic, cobalt and antimony, the amounts of which did not exceed 3.5 ppm in the soils were observed.

The contents of Pb and Zn in the examined soils were comparable to the values given in (Resolution… 2017), contrary to Cu, Cr and Ni, which exceeded these values in the majority of measurement points. These elements, particularly Cu (average content in the wastes exceed 130 mg/kg dry weight) may be linked with stored mining wastes.

It has been stated that admissible contents of metals and metalloids for the III group of grounds had not been exceeded.

In the mineralogical composition of soil samples compounds typical for the soils of coal mining waste dumps e.g. quartz, feldspars and clay minerals represented by kaolinite and illit predominate.

In four soil samples the presence of muscovite with a share < 5%, was also observed. The carbonate minerals calcite and dolomite are much less frequent, and their share in the mineral composition did not exceed 3.5% and 0.3%, respectively.

The presence of mullite, a component typical of waste from the power industry, was identified in the studied soil samples. In soils from the area of the post-mining waste dump, which was the object of research, the presence of this mineral was associated with the deposition of fly ash in its eastern and north-western parts, which was proven by the analysis of fine waste material, which represents fly ash.

The article is a part of the results obtained as part of scientific research work with the symbol BK218/RG6/2020 carried out at the Institute of Applied Geology of the Silesian University of Technology.

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THE IMPACT OF DEPOSITING WASTE FROM COAL MINING AND POWER ENGINEERING ON SOILS ON THE EXAMPLE OF A CENTRAL MINING WASTE DUMP

Keywords

soil, heavy metals, coal mining, waste dumps, flying ash

Abstract

The purpose of the study was determining of degree of contamination of soil cover as a result of disposing of different industrial wastes and comparison of the soil quality with quality of soils and the grounds described in standards in relation to the reclamation works carried out on the dump. Analysed waste dump belongs to the sparse objects of this type in the Upper Silesian Coal Basin, where both coal mining wastes as well as flying ashes occur.

During investigations there was done a collection of 9 soil samples around the dump using Egner`s cane from the depth of 30 cm. The content of heavy metals was determined (Cd, Co, Cr, Cu, Ni, Pb, Zn) using method of emission spectrometry (ICP-AES) and phase composition studies using the X-ray diffraction method (XRD).

Obtained results enabled determination of impact of disposed wastes on the degradation of pedosphere of studied area, which represents III group of fallow lands. The contents of heavy metals in soil samples vary in wide spectrum, but do not exceed permissible content of metals and metalloids for the aforementioned soil group. The highest concentrations reaches iron (average content 0,6%), while concentrations of other elements do not exceed 0.02%. In the mineral composition of soil samples the dominant components are typical for soils in the area of post-mining dumps, i.e. quartz, feldspars, clay minerals, represented by kaolinite and illite. The presence of muscovite with a share of < 5% was also found. Minerals from the carbonate group – calcite (< 3.5%) and dolomite (< 0.3%) occur rarely. In the investigated samples there was identified presence of mullite, component typical for wastes coming from energy sector.

WPŁYW DEPONOWANIA ODPADÓW Z GÓRNICTWA WĘGLOWEGO I ENERGETYKI NA GLEBY NA PRZYKŁADZIE CENTRALNEGO ZWAŁOWISKA ODPADÓW GÓRNICZYCH

Słowa kluczowe

metale ciężkie, gleby, górnictwo, popioły lotne, zwałowiska odpadów

Streszczenie

Celem badań było określenie stopnia zanieczyszczenia powłoki glebowej wskutek deponowania różnorodnych odpadów przemysłowych oraz porównanie jej jakości z określonymi standardami jakości gleby i ziemi, w odniesieniu do przeprowadzonych prac rekultywacyjnych na zwałowisku (należącym do nielicznych obiektów tego typu na obszarze GZW), gdzie występują zarówno węglowe odpady pogórnicze, jak i popioły elektrowniane.

W ramach badań pobrano 9 próbek glebowych wokół zwałowiska (za pomocą próbnika – laski Egnera) z głębokości do 30 cm. Wykonano oznaczenia zawartości metali ciężkich (Cd, Co, Cr, Cu, Ni, Pb, Zn) metodą spektrometrii emisyjnej (ICP-AES) oraz badania składu fazowego metodą dyfrakcji rentgenowskiej (XRD).

Uzyskane wyniki umożliwiły określenie wpływu deponowanych odpadów na degradację pedosfery badanego obszaru, reprezentującego III grupę gruntów – nieużytki. Zawartości badanych metali ciężkich w pobranych próbkach gleb zmieniają się w szerokim zakresie, lecz nie przekraczają dopuszczalnych zawartości metali i metaloidów dla wspomnianej grupy gruntów. W największych koncentracjach występuje żelazo (średnia zawartość 0,6%), natomiast koncentracje pozostałych pierwiastków nie przekraczają 0,02%. W składzie mineralnym próbek gleb dominują elementy typowe dla gleb rejonu zwałowisk pogórniczych, tj. kwarc, skalenie, minerały ilaste, reprezentowane przez kaolinit i illit. Stwierdzono również obecność muskowitu o udziale <5%. Znacznie rzadziej występują minerały z grupy węglanów: kalcyt (< 3,5%) i dolomit (<0,3%). W badanych próbkach gleb zidentyfikowano obecność mullitu, składnika typowego dla odpadów pochodzących z energetyki.