JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(12), 407–418
https://doi.org/10.12911/22998993/174291
ISSN 2299–8993, License CC-BY 4.0

Received: 2023.10.07
Accepted: 2023.10.28
Published: 2023.11.11

Assessment of the Impact of a Recultivated Landfill on the Soil Environment

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ABSTRACT

Recultivated landfills, despite remedial actions, may pose a threat to human health and the environment, and therefore require long-term monitoring. The aim of the work was to investigate the impact of recultivation treatments on changes in the physical and chemical properties of soils in the vicinity of a landfill for waste other than hazardous and neutral. In order to carry out the work, drillings were made around the tested landfill, from which samples were taken and selected physical and chemical properties were determined, including substances causing risks that are particularly important for the protection of the earth's surface. The tested soils were characterized by a neutral and alkaline reaction and a high degree of saturation of the sorption complex with exchangeable basic cations after the use of dust and ash as a recultivation material. Leaks and leachate accumulation were found in the northern part of the facility. The permissible metal contents for industrial areas (group IV) and forest areas (group III) were not exceeded. In the northern part of the landfill area, the permissible content of cadmium was exceeded, while in the southern part, the permissible content of zinc, lead and cadmium was exceeded for agricultural areas (group II). The use of dust and ashes for the recultivation of the landfill in its southern part limited the migration of pollutants deeper into the profile and resulted in an improvement in the physical and chemical properties of the tested soils. The conclusion stated that there is a need to undertake further remediation activities and monitoring studies in order to minimize potential migration of pollutants into the soil and water environment, posing a threat to human health and the environment.

Keywords: landfill, substances causing risk, metals, recultivation, impact, migration of pollutants, degradation

INTRODUCTION

Municipal waste and waste from the economic sector deposited in landfills are a potential source of environmental pollution (NIK, 2020). If the landfill is not properly sealed (natural or artificial), leached pollutants may be introduced into the soil environment (Tereshchenko and Tingaev, 2021). The most common reason for the migration of contaminants deep into the soil profile and their movement into groundwater is the lack of a barrier that prevents their movement (You et al., 2020). The extent of the spread of pollutants in groundwater is influenced by, among others: the permeability of the landfill substrate and the filtration coefficient, which is used to assess the possibility of water circulation in the soil (Balegh and Sellaf, 2022). When it reaches high values, faster flows occur and the possibility of retaining pollutants is limited. One of the sources causing the spread of substances polluting the soil and water environment is leachate. They are created due to the biochemical decomposition of organic compounds and through washing out of soluble mineral and organic fractions by rainwater and surface runoff (Abdul et al., 2023).

In 2021, of the municipal waste collected and received in Poland, 8.2 million tons were intended for recovery, including 60% of municipal waste generated. 3.7 million tons (27%) were allocated for recycling, 2.7 million tons (20%) for thermal transformation with energy recovery, and 1.8 million tons (13%) for biological processing (composting or fermentation). The amount of waste intended for disposal in a landfill in 2021 was 5.5 million tons, of which 5.3 million tons (39% of municipal waste generated) was intended for landfilling and the remaining 0.2 million tons (1%) for disposal through thermal transformation without energy recovery.

The amount of waste intended for disposal in the landfills in 2022 decreased compared to 2021 from 5,296 thousand tons in 2021 (GUS, 2022) to 5,108 thousand tons in 2022 (GUS, 2023). Approx. 43% of municipal waste generated in 2019 was intended for landfilling (GUS, 2020). This method is still one of the main methods of municipal waste management in Poland (Figure 1).

The increase in public awareness of environmental protection means that the number of operating waste landfills in Poland has been decreasing in recent years (Figure 2). In 2022, municipal waste was deposited in 259 landfills with a total area of 1,624.2 ha, and by the end of the year, 11 facilities with a total area of 45.3 ha were closed (GUS, 2023).

Closing waste landfills that do not meet technical requirements means that these facilities may pose a threat to human health or the environment. Therefore, various recultivation procedures are undertaken to limit their impact, including primarily the impact on the soil and water environment (Hutniczak et al., 2019).

The operation of a waste landfill includes preparatory work for its implementation, construction and the stage of its operation. These stages are divided into three phases:

- pre-operational – the period before obtaining the first final decision approving the instructions for its operation,
- operational – the period from the date of obtaining the first final decision approving the instructions for its operation to the date of completion of the recultivation of the waste landfill,
- post-operational – a period of 30 years counted from the date of completion of its recultivation, which is also considered the date of closure of the landfill (Waste Act, 2012; Sauve and Van Acker, 2020).

The last two phases are included in the instructions for operating a waste landfill. This manual includes, among others: information on the types and quantities of waste accepted, the technical devices necessary for the proper operation of the landfill and the control and measurement equipment together with a diagram of the location of measurement points are specified, and the method of technical closure of the landfill along with an indication of the direction of its recultivation (Waste Act, 2012). A landfill affects many components of the environment in all phases of its operation. It is a source of both noise due to the use of machines and vehicle traffic, as well as odors and dust generated mainly when waste is collected on the premises. Improper storage of

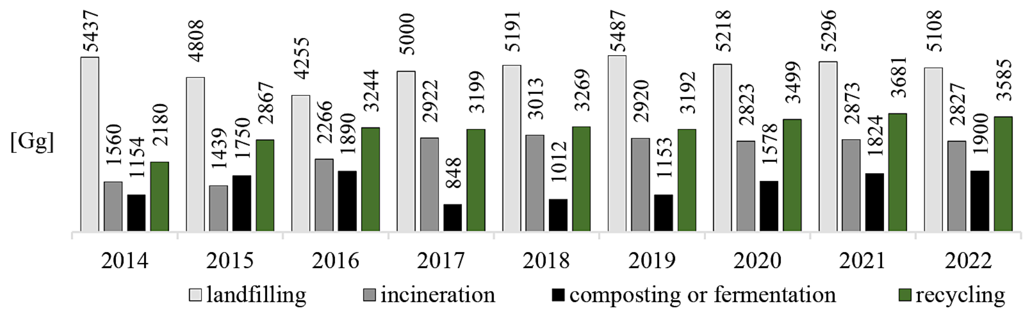


Figure 1. Municipal waste management in Poland in 2014–2022, in thousands of tons (GUS, 2015–2023)

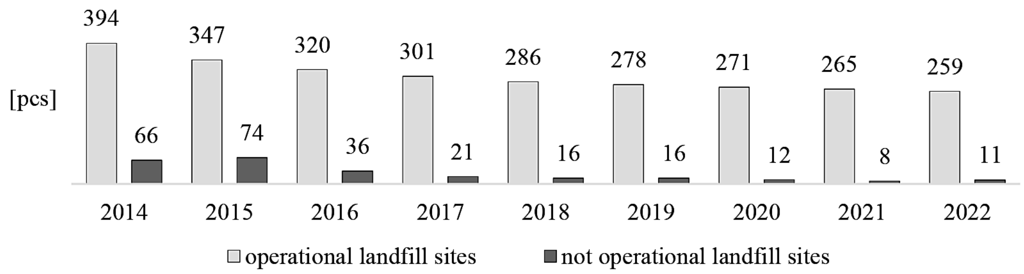


Figure 2. Operational and closed landfill sites in Poland in 2014–2022 (GUS, 2015–2023)

waste, leakage of the protection of the landfill site and leachate tanks, their surface runoff or infiltration deep into the profile may cause soil and ground contamination as well as contamination of surface waters or underground waters.

Due to the nature of the facility, the operator of a landfill has many obligations, including: the need to conduct monitoring. The first monitoring of individual environmental components is carried out at the pre-operational stage and is aimed at identifying the initial state, i.e. determining the background. During the operation phase, the following activities are carried out, among others: monitoring the level of groundwater, the volume of surface water flow, as well as controlling the subsidence of landfill surfaces (Regulation on landfills, 2022). Reclamation of the waste landfill is carried out in accordance with the work schedule, which includes, among others: protection of surface and groundwater against the negative impact of the facility, which are specified in decisions granting consent to the closure of the facility or the closure of a waste landfill. Due to the specificity of the facility, including the possibility of leakage or damage to technical protection, monitoring of individual environmental components is carried out also after the completion of landfill recultivation (Regulation on landfills, 2022). The legislator provides for the possibility for the competent authority to reduce the frequency of tests of individual indicator parameters, including, among others: metals such as copper, zinc, lead, cadmium, chromium, and mercury, if monitoring carried out within 5 years from the date of closure of the landfill shows that the facility does not impact the environment (Regulation on landfills, 2022). This rule does not apply to hazardous waste landfills.

The aim of the work was to investigate the impact of recultivation treatments on changes in the physical and chemical properties of soils in the vicinity of a landfill for waste other than hazardous and neutral. Drillings were made around the tested landfill, samples were taken from various levels, and then selected physical and chemical properties were determined, including the content of zinc, copper, lead, chromium, and cadmium. The research paid particular attention to the soil on the northern side of the facility, where there was a problem of local variations contributing to the stagnation of rainwater and meltwater, as well as leaks from under the foot of the landfill.

MATERIAL AND METHOD

The landfill covers an area of approximately 5.5 ha, has a trapezoid shape, is subject to constant monitoring (Regulation on the video control system, 2019) and has the required operating documents and an integrated permit.

The landfill location area is within the protected landscape area, and within a radius of 5 km there are two protected natural sites and a special area of habitat protection. In the research the influence of the landfill on local flora and fauna was not examined. Based on the local spatial development plan and its own observation, it was found that the landfill may be a potential unorganized source of odor emission, which depends on meteorological conditions, waste composition and occurs during delivery, unloading and their development. The odors nuisance worsens during the summer and in the first phase of anaerobic decomposition of the organic components. The emission is minimized by insulation (0.2 m of material for every 2 m of waste) and compaction. Microbiological pollution appears most often during unloading. It was assumed that at the distance of over 50 m the number of microorganisms equals to the level for the background. The noise and vibration are worse during the day during the operation of the landfill.

During recultivation, many works were carried out to seal and drain the landfill. This was to remove leachates. Sewage pumping stations were built, the new site has been equipped with an insulation and drainage system that meet the applicable regulations. The leachates were discharged into the leachate's reservoir.

Six drillings were made in the area of the recultivated landfill. The location points of the collected samples were marked with symbols P-1 to P-6. Additionally, three drilling were made in the areas adjacent to the landfill (K-1 from the north-west, K-2 from the north-east and K-3 from the south-west), from which samples were taken for testing. The collected samples were designated as control soils. The locations of the drillings are shown in Figure 3. In each of the drillings, two samples were taken from two different depths of 0-0.25 m and 0.8-1.0 m below ground level in accordance with the regulation (Regulation on the method of assessing surface contamination land from, 2016).

In order to obtain a high degree of homogeneity of the test material, the soil samples were dried and ground through a sieve with a mesh diameter of 2 mm. The following physical and chemical properties were determined in the soils: smell of soil, color according to the Munsell color scale, granulometric composition with sieve method / the Casagrande method using Prószyński's modification according to the Polish Society of Soil Science, permeability, pH in w H_2O and 1 M KCl, electrolytic conductivity (EC), chloride and sulphate content, total organic carbon content (TOC), hydrolytic acidity (H), content of exchangeable basic cations (CEC) by the Kappen method. The total metal content of the soil was established after the mineralization of the samples in a 3:1 mixture of concentrated perchloric acid ($HClO_4$) and nitric acid (HNO_3). The metal contents in the studied sample soils were determined using atomic spectrometry, with the technique of inductively coupled plasma optical – mass spectrometry (ICP-MS), using Agilent 7900 ICP-MS (PN-EN ISO 17294-2:2016-11). For each series of measurements, blank samples were prepared in parallel, and their values were included when calculating the results for the samples. The dry mass was also included in the calculations.

The geoaccumulation index (I_{geo}) represents the level of enrichment of an exogenous metal in an assessed area. Initially, I_{geo} was used by Muller (1969) in order to define metal contamination in sediments by comparing actual concentrations with preindustrial levels. Currently, it is being used for evaluating soil contamination (Adimalla, 2018; Khademi et al., 2019). This method uses the geochemical background value in the soil as the standard. The I_{geo} is calculated as follows (She et al., 2022) (Equation 1):

$$I_{geo} = log_2\left(\frac{C_i}{kB_i}\right) \tag{1}$$

where: C_i – concentration of the metal in soil sample (mg/kg);
k – coefficient representing fluctuations in the background level (k = 1.5), the constant 1.5 being introduced to minimize the lithospheric effects in the background matrix (Muller, 1969; Adimalla, Wang, 2018);
B_i – "background" concentration of the metal in soil (mg/kg).

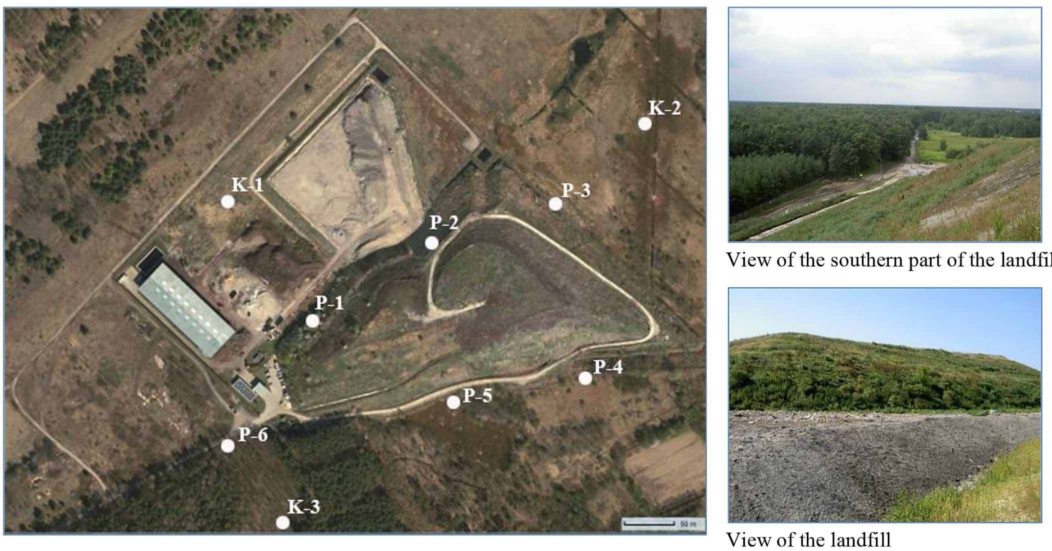
To give an assessment of the overall pollution status for a sample, the integrated pollution load index (PLI) can be employed (Chen et al., 2015). The PLI can be calculated using (Equation 2):

$$PLI = \sqrt[n]{(PI_1 \times PI_2 \times PI_3 \times \ldots \times PI_n)} \tag{2}$$

where: n – number of heavy metals (Chen et al., 2015).

Based on the literature (Li et al., 2014; Chen et al., 2015; Chen et al., 2022), were used values of the used parameters required for evaluation of the exposure risks to metals in soil. Toxic effects are likely to ensue when the exposure dose of the target contaminant exceeds the reference dose, which is generally articulated as noncarcinogenic risk index (HQ). The HQ can be calculated with Equation 3:

$$HQ = \frac{ADI}{RfD} \tag{3}$$



View of the southern part of the landfill

View of the landfill

Figure 3. Location of drillings in the area of the recultivated landfill

where: *RfD* – the toxicity threshold value of a specific metal (mg/kg·day).

When the HQ value is greater than 1, it indicates that the contamination can pose a noncarcinogenic risk; for the HQ value less than 1, the noncarcinogenic risk is defined as small (Chen et al., 2022). The carcinogenic risk of a single pollutant index (ILCR) is calculated as follows Equation 4:

$$ILCR_{ij} = ADI \times SF_{ij} \quad (4)$$

where: SF_{ij} – the carcinogenic slope factor of metal *i* under exposure pathway *j* (kg·day/mg).

To assess the total risk for the tested metals for the noncarcinogenic and carcinogenic effects, the following formulas are used Equations 5 and 6 (Chen et al., 2022):

$$HQ_T = \sum_{i=1}^{m} \sum_{j=1}^{n} HQ_{ij} \quad (5)$$

$$ILCR_T = \sum_{i=1}^{m} \sum_{j=1}^{n} ILCR_{ij} \quad (6)$$

For value of the ILCR index less than 1.00×10^{-4}, the metal does not pose a carcinogenic risk to human health. Otherwise, the metal has a carcinogenic risk (Li et al., 2014; Chen et al., 2015).

All analyses, calculations, and graphical representations of the results were carried out in Microsoft® Excel® for Microsoft 365 (version 2104) using the Analysis ToolPak.

RESULTS AND DISCUSSION

Table 1 shows the results of control samples of soil taken from the areas in vicinity around the landfill. According to the PTG (2008) guidelines, control soils marked with the symbol K-1–K-3 were classified as very light soils with a granulometric composition of loose sands and sands. In the vicinity of the waste landfill, meadows and mainly coniferous forests were identified. The control soils were characterized by an earthy smell, acidic (K-1) and strongly acidic (K-3) reactions and very low sorption capacity. Only in the K-2 drilling, neutral soil was found in the sample taken from the layer (0–0.25 m below ground level), while alkaline soil was found in the layer (0.8–1.0 m below ground level). Samples taken from this drilling were characterized by high sorption capacity. The pH values in all control soils measured in H_2O and 1 M KCl increased with depth (Table 1). Electrolytic conductivity values in control soils were low, with the highest values observed for the topsoil K-2. The literature distinguishes 4 classes of organic carbon content in soils: low (<1.0%), medium (1.0–2.0%), high (2.0–3.5%) and very high (>3.5%) (Ostrowska et al., 1991). The control soils were characterized by a low class of organic carbon content in the layer (0.8–1.0 m below ground level), and a medium class of content in the surface layer. The exception was a sample taken from the surface layer of the P-1, which had a low organic carbon content class.

The resistance of land to pollution depends on many factors, both natural and anthropogenic. Their identification allows for an appropriate assessment of the resistance of a specific type of soil and allows for the identification of zones more and less susceptible to anthropopressure. The skeletal parts improve soil aeration and influence the regulation of water content, while the clay parts are rich in nutrients (Gorlach and Mazur, 2001). In research Uziak et al. (2005) observed that as the particle diameter decreases, the content of carbon, organic compounds and nitrogen in soil fractions increases. During the migration of pollutants in the ground environment, some of

Table 1. Physical and chemical properties of control soils K-1–K-3

No. sample	Sampling depth [m BGL]	pH		H cmol(+)/ kg d.m. of soil	EC [µS/cm]	CEC cmol(+)/ kg d.m. of soil	SC cmol(+)/ kg d.m. of soil	BCSR [%]	TOC [%]
		H_2O	1M KCl						
K-1	0.0–0.25	4.80	4.70	3.50	47.2	0.5	4.0	12.5	0.21
	0.8–1.0	5.90	5.50	1.50	66.1	0.8	2.3	34.8	0.24
K-2	0.0–0.25	7.48	6.62	2.85	310.7	38.2	41.1	92.9	1.01
	0.8–1.0	8.72	8.20	0.68	129.9	41.8	42.5	98.4	0.14
K-3	0.0–0.25	3.85	3.70	4.95	25.0	1.7	6.7	25.4	1.27
	0.8–1.0	4.10	3.90	3.08	40.1	0.4	3.5	11.4	0.67

the substances are retained due to precipitation and sorption. The amount of retained pollutants increases as the thickness and uniformity of soil grain size decrease (Tabor, 2008). In order to reduce the permeability of the subsoil at the landfill, recultivation works were carried out, consisting of mixing sandy formations with more compact formations. The presence of dust and ashes was found in drillings P-1, P-2, P-3 and P-4 (Table 2). These materials were used during the recultivation of the landfill to reduce the permeability of the subsoil and stabilize the reaction of the tested soil. The dust and ash were to be used to absorb possible leachates released from the landfill area, preventing contamination of groundwater. The presence of recultivation materials was confirmed by the dark gray or gray color appearing in the soil profiles located especially on the northern side of the landfill.

The smell of soil is not a clear parameter characterizing the degradation processes taking place in the soil, but together with other physical features it allows to confirm changes taking place in the soil environment. The earthy smell indicates conditions typical of properly developed soils with a dominant role of humus. A specific odor may have various origins, e.g. related to the presence of various forms of pollution. Only in the P-6, in the vicinity of the waste landfill, an earthy odor was found in the sampled soils in both layers. In the remaining drillings, a weakly or strongly specific odor was identified both in the surface layer 0–0.25 m below ground level and 0.8–1.0 m below ground level, which indicates changes taking place in the soil environment in the area of the recultivated landfill.

Various substances are used in the literature to improve the physical and chemical properties of soils, including stabilizing their reaction. This effect can be achieved, among others: by liming, introducing organic and mineral-organic materials, clay minerals (Kabata-Pendias, 1979; Pusz, 2007; Karczewska et al., 2008; Karczewska and Kabała, 2010; Pusz and Wiśniewska, 2017; Pusz et al., 2021), organic fertilizers (e.g., manure or sewage sludge) (Karczewska et al., 2008). The introduced substances can additionally provide nutrients necessary for plant growth and stimulate the biological activity of soils (Galende et al., 2014). Neutral and alkaline soils were found in the drillings around the landfill; only the soil taken from the P-6 was highly acidic. In P-6 drilling, hydrolytic acidity values ranged from 4.65 to 5.18 cmol/kg of soil, reaching values similar to those in control soils (Table 3).

Lower hydrolytic acidity values in the remaining drillings were related to the migration of leachates observed during the on-site inspection, as well as the use of dust and ash for landfill recultivation. The use of recultivation materials also improved the sorption properties of soils. The tested samples were characterized by a high degree of saturation of the sorption complex with exchangeable basic cations, the exception being the P-6 drilling, for which the low values of the tested feature were the same as for the control soils. The electrolytic conductivity was characterized by an increased value in soils at individual soil horizons, which may indicate an increased

Table 2. Type of soil, color and smell of samples collected around the recultivated landfill

No. sample	Sampling depth [m BGL]	Permeability [m/s]	Soil type	Munsell soil color	Scent*
P-1	0.0–0.25	$1x10^{-3}$	sand	dark brown 10YR 3/3	earthy (3)
	0.8–1.0	$1x10^{-4}$	sand + ash	brown 10YR 4/3	specific (3)
P-2	0.0–0.25	$1x10^{-3}$	sand	brown 10YR 4/3	specific (1)
	0.8–1.0	$1x10^{-4}$	sand + ash	very dark grey 10YR 3/1	specific (3)
P-3	0.0–0.25	$1x10^{-3}$	sand	brown 10YR 4/3	earthy (3)
	0.8–1.0	$1x10^{-4}$	sand + ash	very dark grey 10YR 3/1	specific (2)
P-4	0.0–0.25	$1x10^{-3}$	sand	very dark grey 10YR 3/1	specific (1)
	0.8–1.0	$1x10^{-6}$	loamy sand+ ash	yellow 10YR 7/6	specific (2)
P-5	0.0–0.25	$1x10^{-5}$	loamy sand	dark brown 10YR 3/3	earthy (3)
	0.8–1.0	$1x10^{-2}$	sand	yellow 10YR 7/6	specific (2)
P-6	0.0–0.25	$1x10^{-3}$	sand	black 10YR 2/1	earthy (1)
	0.8–1.0	$1x10^{-2}$	sand	yellow 10YR 7/6	earthy (1)

* Scent intensity: (1) weak, (2) medium, (3) strong.

Table 3. Physical and chemical properties of soil around the recultivated landfill

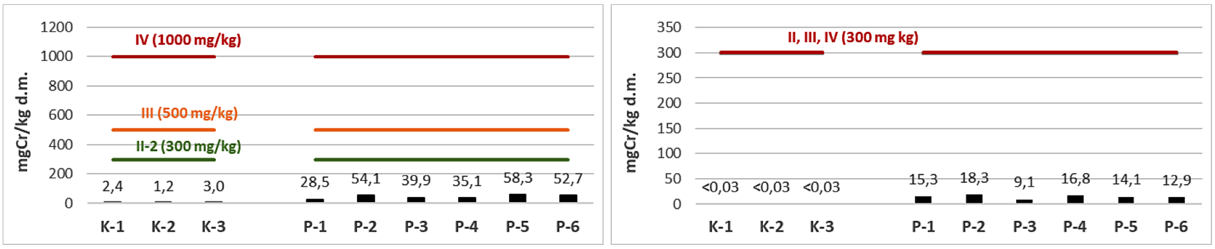
No. sample	pH		H cmol(+)/kg d.m. of soil	EC [µS/cm]	CEC cmol(+)/kg d.m. of soil	SC cmol(+)/kg d.m. of soil	BCSR [%]	TOC [%]
	H_2O	1M KCl						
P-1	7.43	6.64	1.16	890.3	8.2	9.4	87.2	2.22
	8.40	8.06	0.38	1019.3	4.4	4.8	91.7	1.04
P-2	8.45	7.87	0.53	1877.7	42.4	42.9	98.8	1.83
	8.97	8.56	0.30	1611.3	8.0	8.3	96.4	0.78
P-3	7.96	7.45	0.53	262.9	11.4	11.9	95.8	3.09
	7.85	7.27	0.86	439.2	17.7	18.6	95.2	2.24
P-4	7.51	7.25	0.53	950.1	38.5	39.0	98.7	2.94
	7.88	7.66	0.45	694.7	4.9	5.4	90.7	1.48
P-5	8.07	7.59	0.49	717.4	33.5	34.0	98.5	3.60
	8.64	8.36	0.30	812.2	5.8	6.1	95.1	1.35
P-6	5.00	3.89	5.18	115.4	2.0	7.2	27.8	2.52
	5.21	4.46	4.65	39.4	2.6	7.3	35.6	0.47

content of other substances, e.g., chlorides, sulfates. The highest value of electrolytic conductivity was characteristic of soils taken from the P-1 and P-2 drillings, which was related to the accumulation of leachates in the northern part of the facility. The content of organic carbon directly and indirectly affects its properties, including buffering capacity, sorption capacity, structure, and nutrient content, and indicates soil fertility and increased content of various organic compounds (Ostrowska et al., 1991). Tests of the organic carbon content indicate the presence of recultivation materials. Soils collected from the surface layer were characterized by medium (P-2), high (P-1, P-3, P-4, P-6) and very high (P-5) organic carbon content classes. However, the soils collected in the layer (0.8–1.0 m below ground level) were characterized by low (P-2, P-6), medium (P-1, P-4, P-5) and high (P-3) organic carbon content class (Table 3).

The content of metals Cr, Zn, Cd, Cu and Pb in control soils K-1–K-3 and in soils taken from P-1–P-6 drillings are shown in Figures 4–8. The red horizontal line indicates the permissible metal content for industrial areas (group IV), the orange line - for forests (group III), and the green line - for arable land, permanent meadows, and pastures (group II). The state of contamination of the ground environment with metals was determined on the basis of metals total content. The metal contents were related to the permissible values of substances causing risk that are particularly important for the protection of the earth's surface, constituting Annex No. 1 to the regulation (Regulation on the method of assessing land surface pollution from, 2016), divided into groups of land separated based on their use.

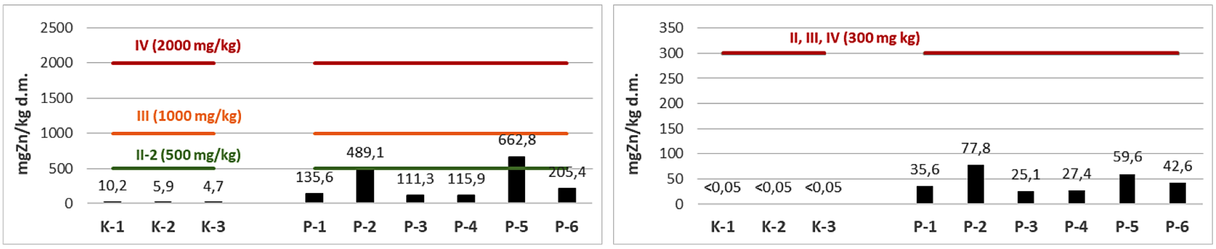
In the vicinity of the analyzed waste landfill there are areas belonging to land group II, i.e., arable land, permanent meadows and permanent pastures, as well as land group III, i.e., forests. The obtained results were also related to the permissible metal contents for the areas adjacent to the recultivated landfill.

The control soils were characterized by a very low content of the tested metals (Cr, Zn, Cd, Cu, Pb) in both layers, and the permissible metal contents for industrial areas, as well as for arable land, meadows, permanent pastures and forests were not exceeded. The contents of tested metals in soils taken from drillings around the landfill were not exceeded in the surface layer in relation to the permissible values for forest lands (group III) and industrial areas (group IV). However, in the surface layer, the contents of Cd in soils taken from the P-2 and Cd, Zn and Pb in the soils taken from the P-5 were exceeded, in relation to the permissible values for arable land, meadows and permanent pastures (group II). Zinc is an element that is more mobile in the environment than other metals (Wang et al., 2015). It can be bound by calcium and magnesium carbonates, in an exchangeable form with clay minerals and organic matter, or it can be adsorbed on their surface (Gorlach, Mazur, 2001). As the pH value decreases, this metal may be released through filtration and washing deep into the soil profile. The low pH value, related to the grain size of the tested formations, indicates the potential migration of pollutants. Metals release can also occur in alkaline environments. Brümmer (1986) emphasized that this is related, for example, to the formation of complex combinations of metals with ammonium ions and



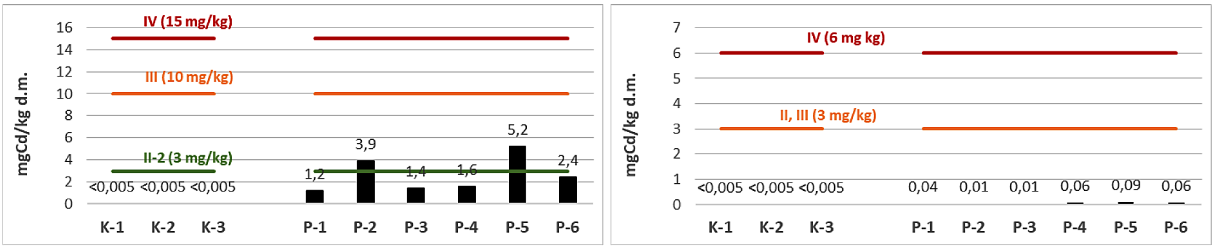
(a) (b)

Figure 4. Chromium content in soils taken from drillings K-1 – K-3 and P-1 – P-6 from a depth of (a) 0.0–0.25 m BGL; (b) 0.8–1.0 m BGL



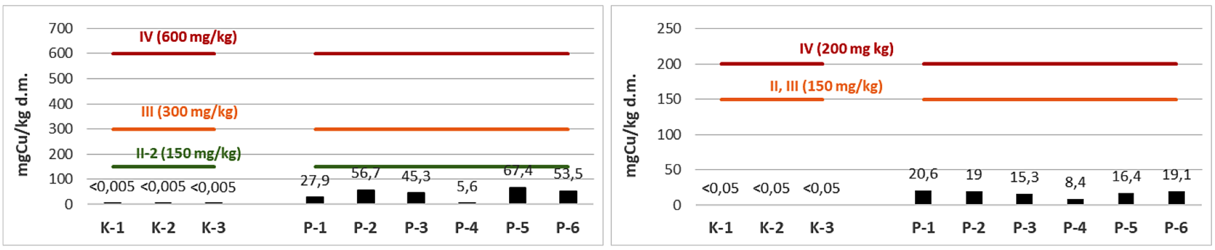
(a) (b)

Figure 5. Zinc content in soils taken from drillings K-1 – K-3 and P-1 – P-6 from a depth of (a) 0.0–0.25 m BGL; (b) 0.8–1.0 m BGL



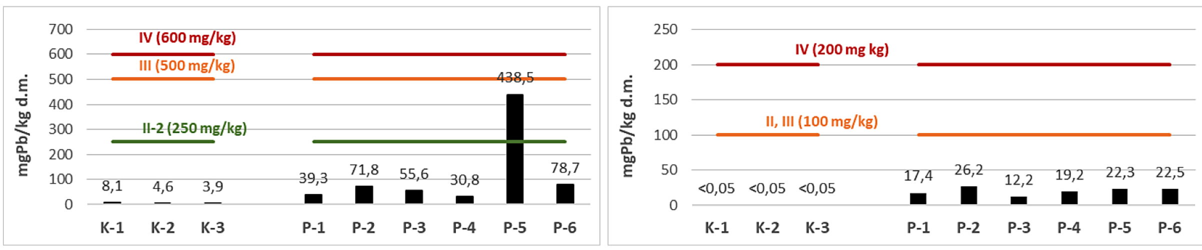
(a) (b)

Figure 6. Cadmium content in soils taken from drillings K-1 – K-3 and P-1 – P-6 from a depth of (a) 0.0–0.25 m BGL; (b) 0.8–1.0 m BGL



(a) (b)

Figure 7. Copper content in soils taken from drillings K-1 – K-3 and P-1 – P-6 from a depth of (a) 0.0–0.25 m BGL; (b) 0.8–1.0 m BGL



(a) (b)

Figure 8. Lead content in soils taken from drillings K-1 – K-3 and P-1 – P-6 from a depth of (a) 0.0–0.25 m BGL; (b) 0.8–1.0 m BGL

low-molecular-weight organic compounds. The high pH value in the P-5 meant that the tested metals were not released and migrated, which is confirmed by the results of the analysis of metal content in the layer 0.8–1.0 m below ground level. Permissible contents of individual metals for soils taken from the layer 0.8–1.0 m below ground level, both for industrial areas (group IV), as well as for arable land, meadows and permanent pastures (group II) and forests (group III), do not have been exceeded.

Table 4 presents the I_{geo} and PLI results for the metals tested, calculated on the basis of formulas 1 and 2. For the surface layer (0.0–0.25 m below ground level), the I_{geo} values for Cr and Cu in the P-2, P-5 and P-6 and for Cu in the P-3 drillings were qualified as mild to moderate pollution. For the remaining drillings, no pollution was found for both elements and for Cr in the P-3. For Zn, mild to moderate pollution was found in drillings P-1, P-3, P-4 and P-6, moderate to heavy pollution was found for P-2 and P-3, and for the remaining drillings K-1, K-2 and K-3 no pollution was found. In the case of Cd, heavy pollution was found in P-1, P-3 and P4, heavy to extreme pollution was found in P-2 and P-6, and extreme pollution was found in P-5. In the remaining drillings K-1, K-2 and K-3 was no contamination. For Pb, mild to moderate pollution was found in P-1, P-3 and P-4, in P-2 and P-6 was moderate pollution, and only in the case of P-5 was heavy pollution. No pollution was found in drillings K-1, K-2 and K-3. For all tested metals, no pollution was found in drillings taken from the layer (0.8–1.0 m below ground level).

Based on the calculated PLI values for the surface layer (0.0–0.25 m below ground level), unpolluted soil was found in the P-4. In drillings taken from P-1 and P-3, unpolluted to moderately polluted soil was found, while in the P-6, moderately to highly polluted soil was found. Very highly polluted soil was found in drillings taken from P-2 and P-5. In the case of soils K-1, K-2 and K-3 collected from the surface layer (0.0–0.25 m below ground level) and from the layer (0.8–1.0 m below ground level), background concentration was found. For all soil samples taken from the layer (0.8–1.0 m

Table 4. Values of I_{geo} and PLI for metals (Cr, Zn, Cd, Cu, Pb)

Sampling depth	Sample site	Igeo					PLI
		Chromuim	Zinc	Cadmium	Copper	Lead	
0-0.25 m BGL	K-1	-4.45	-3.38	0.00	-2.97	-1.89	0.00
	K-2	-5.45	-4.17	0.00	-3.85	-2.71	0.00
	K-3	-4.13	-4.50	0.00	-4.46	-2.94	0.00
	P-1	-0.88	0.35	3.03	-0.43	0.39	2.11
	P-2	0.04	2.20	4.73	0.60	1.26	5.10
	P-3	-0.40	0.06	3.25	0.27	0.89	2.64
	P-4	-0.58	0.12	3.44	-2.74	0.04	1.56
	P-5	0.15	2.64	5.14	0.85	3.87	8.66
	P-6	0.01	0.95	4.03	0.51	1.39	3.90
< 0.25 m BGL	K-1	0.00	0.00	0.00	0.00	0.00	0.00
	K-2	0.00	0.00	0.00	0.00	0.00	0.00
	K-3	0.00	0.00	0.00	0.00	0.00	0.00
	P-1	-1.78	-1.58	-1.88	-0.86	-0.79	0.58
	P-2	-1.52	-0.45	-3.88	-0.98	-0.20	0.57
	P-3	-2.53	-2.09	-3.88	-1.29	-1.30	0.32
	P-4	-1.64	-1.96	-1.29	-2.16	-0.64	0.52
	P-5	-1.90	-0.84	-0.71	-1.19	-0.43	0.74
	P-6	-2.02	-1.32	-1.29	-0.97	-0.42	0.65

	no pollution (Igeo ≤ 0)		background concentration (PLI = 0)
	mild to moderate pollution (0 < Igeo ≤ 1)		unpolluted (0 < PLI ≤ 1)
	moderate pollution (1 < Igeo ≤ 2)		unpolluted to moderately polluted (1 < PLI ≤ 2)
	moderate to heavy pollution (2 < Igeo ≤ 3)		moderately polluted (2 < PLI ≤ 3)
	heavy pollution (3 < Igeo ≤ 4)		moderately to highly polluted (3 < PLI ≤ 4)
	heavy to extreme pollution (4 < Igeo ≤ 5)		highly polluted (4 < PLI ≤ 5)
	pollution extreme (5 < Igeo)		very highly polluted (PLI > 5)

below ground level), it was found that the soil was unpolluted.

In this study, the risk factors for non-carcinogenic HI and carcinogenic ILCR were calculated using formulas 3–6 (Fakhri et al., 2018). Based on the calculated non-carcinogenic risk (HI) and carcinogenic risk (ILCR) results for all tested metals, negative values were found (below 0 - that is why the results were not included in the paper), which means there is no risk to human health both through ingestion and dermal contact.

The use of dust and ashes for the recultivation of the landfill in its southern part limited the migration of pollutants deeper into the profile and resulted in an improvement in the physical and chemical properties of the tested soils. The research shows that further remediation activities and monitoring studies should be undertaken to minimize the potential migration of pollutants into the soil and water environment, posing a threat to human health and the environment.

Monitoring of a waste landfill is an indispensable element used to control the possible impact of the object on the natural environment, and in particular on groundwater (Wiater, 2011). Proper monitoring of the state of landfills enables early detection of potential threats and taking action to minimize their effects and prevent environmental degradation. In accordance with legal requirements, monitoring of individual elements of the environment is carried out in the pre-operational, operational and post-operational phase of the waste landfill. The assessment of soil degradation indicates that the soils around the landfill are poorly degraded, with most of the samples examined very strong degradation resistance. This is demonstrated by the low ratio of hydrolytic acidity, soil sorption capacity and the high content of the sum of exchangeable alkaline cations. This indicates the use of ash and dust in the recultivation, which improved the condition of the soil. The values of the sorption capacity of the soil tested in the upper layers are in most samples very high, which indicates strong sorption. These values decrease with depth and are correlated with the soil reaction. The average organic carbon values prevail in the tested samples, typical for soils in Poland, variable humus content in the profile and the occurrence of soils of various granulometric compositions indicates the mixing of soils as a result of recultivation process. Conducted research did not show soil degradation in terms of protection of the earth's surface (analyzed metals). In connection with increased electrolytic conductivity, monitoring of indicator parameters such as pH, electrolytic conductivity and the content of the metals especially for zinc, lead and cadmium should be monitored for surface waters and leachates.

In the case of soil samples taken from the top layer, there were no exceedances of substances (metals) causing risk in relation to the III and IV of the group, while for the II group exceedances were found for zinc, lead and cadmium. If there is no remediation process, the area cannot be developed for agricultural purposes.

Taking into account the above research, it would be necessary to check the subsidence of the landfill surface, which consists in assessing the course of subsidence of the landfill surface using geodetic methods, using established benchmarks, and assessing the stability of slopes determined by geotechnical methods. The assessment of the course of recultivation work should also be carried out by observing the health condition of the plants and their percentage. It should be emphasized that the plant cover, especially at the initial stage of recultivation, requires careful care and treatment. Non-compliance for the plant treatment is a common reason for the lack of effects, leading in extreme cases to the creation of the so-called "Secondary wasteland". The biologically active recultivation layer initiates soil-forming processes and produces habitat conditions for the further development of plants, which guarantees integration of the recultivated object in the landscape. Over time, the landfill is inhabited by the surrounding vegetation, usually with a wide ecological amplitude, which is confirmed by floristic and phytosociological studies of other landfills (Dyguś, 2013).

CONCLUSIONS

We can conclude that the investigated material can have multiple usages, such as:

1. The tested soils were characterized by a neutral and alkaline pH, and the high content of the sum of exchangeable alkaline cations. This indicates the use of ash and dust in the recultivation, which improved the condition of the soil and limited the possibility of migration of pollutants.
2. In soils taken from drillings around the landfill metal contents for industrial areas (group IV) and forest lands (group III) were not exceeded. In the surface layer, the contents of Cd in soils

taken from the drilling P-2 and zinc, lead and cadmium in the soils taken from the drilling P-5 were exceeded, in relation to the permissible values for arable land, meadows, and permanent pastures (group II).
3. The elevated values of I_{geo} for all tested metals were found in drillings P-1–P-6, the highest values were found for cadmium.
4. For non-carcinogenic risk (HI) and carcinogenic risk (ILCR) for all tested metals results were negative, which means there is no risk to human health both through ingestion and dermal contact.
5. It is necessary to check the subsidence of the landfill surface and assessing the stability of slopes determined by geotechnical methods.
6. The plant cover, especially in the initial phase of recultivation, requires careful care and treatment, so it should be monitored by observing the health condition of the plants and their percentage.

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