Assessment of Landfills and their Impact on the Soil: a Local Study in Ukraine

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Abstract: Landfills are widely utilised for waste disposal due to their economic advantages and ease of implementation compared to alternative methods. However, landfills exert significant environmental and health impacts on adjacent agricultural land. Accumulation of heavy metals in soil is a risk to ecological and food safety. Methodological approaches to assess and mitigate the impact of landfills on agricultural land are essential for ensuring sustainable land use practices and safeguarding human health. In this study, landfills were assessed at the local level, and the hazard level was classified according to it. A set of priority measures for restoring technogenic disturbed areas and minimising their impact on agricultural land was determined. The need to select a set of innovative, ecologically oriented methods for remediation of landfills, depending on the type and degree of soil contamination, was identified in context of ensuring environmental and food security.

Keywords: landfill, technogenic disturbed areas, soil contamination, agricultural land, waste management

1. Introduction

The problem of solid waste is very real today. This problem is directly related to the increase in the number of people on the planet and the production rate. The amount of solid waste in the world is greatly increasing yearly; by 2025, it is predicted to be around 2.2 million tonnes yearly (Chan et al. 2016). Landfills and dumps are large and common practices of solid waste management worldwide.

Landfill is a widely accepted approach to solid waste management due to its economic benefits (Laner et al. 2012, Sofoo et al. 2022). A landfill is characterised by the placement, compaction and construction of waste embankments at designed sites. Today, landfilling still has advantages in ease of implementation, adaptability and lower costs compared to alternative disposal methods. It is the only comprehensive means of disposing of all types of waste. Although the exploitation of landfills for solid waste disposal has decreased, they are a necessary element of integrated solid waste management systems globally. Comparative analyses of different waste management strategies (including landfilling, incineration, composting, etc.) indicate that

within the realm of technological choices for managing and disposing of solid waste, landfilling or open dumping stands as the prevailing methods across many regions, owing to its comparatively lower economic overheads and less technical requirements.

The establishment of landfill sites notably influences biodiversity (Wydro et al. 2022). For instance, the establishment of landfills leads to the depletion of approximately 30-300 animal species per hectare. Concurrently, shifts in indigenous species are evident, with certain avian and mammalian populations being supplanted by species that subsist on waste, such as corvids and rodents. Approximately 78% of individuals residing close to landfills experience adverse effects from air pollution. Moreover, inhabitants residing near landfill sites exhibit elevated rates of health issues, including ocular irritation and symptoms akin to influenza (Njoku et al. 2019).

The leachate emanating from landfills contains elevated concentrations of heavy metals, presenting a significant hazard for the contamination of soil, groundwater, and vegetation (Gworek et al. 2016, Vaverková 2019, Wijekoon et al. 2022). A global apprehension revolves around the contamination of soil environments (Feng et al. 2018). Soil functions as a reservoir for heavy metals and assorted pollutants, often reaching distressingly high levels of concentration. Heavy metals pose risks to human health, with their accumulation in the environment posing potential hazards (Siddiqua et al. 2022). Consequently, restoring contaminated soils with heavy metals becomes imperative (Vaverková et al. 2018). Researchers such as Rivera et al. (2016), Shakoor et al. (2017), among others, have underscored that anthropogenic activities contribute to introducing heavy metals into soils.

The UN General Assembly Resolution No. 70/1 of 25 June 2015 states that degradation of soil quality is one of the main issues of sustainable development. Considering this, European Union policies aim to minimise the quantity of solid waste produced and increase the requirements for landfill and waste disposal sites (Brennan et al. 2016).

The consequence of anthropogenic soil pollution is the deterioration of the quality of agricultural products. The impact of anthropogenic factors on soil resources disrupts the sustainable functioning of agroecosystem mechanisms to restore soil quality characteristics and creates ecological and food risks for certain areas. Considering that technogenic disturbed areas occupy significant territories in Ukraine and pollute adjacent agricultural lands, it is necessary to study them concerning the ecological safety of those areas at the local level and to develop methods of minimising the impact of pollution sources on adjacent agricultural lands.

Therefore, the issue of the landfill impact on adjacent agricultural land and their safe functioning in the conditions of Ukraine is of great importance. The problems of reducing the area of landfills and restoring contaminated land to agricultural use remain open for scientific research.

Currently, there are no uniform methodological approaches for evaluating the environmental impact of landfills encompassing the surrounding areas. Our previous research (Pysarenko et al. 2022a, Pysarenko et al. 2022b, Pysarenko et al. 2023) has addressed the study of landfill impact on the environment and the methods of remediation of contaminated lands. Still, today, there is a lack of a comprehensive assessment approach that would allow for combining the current state of the environmental condition in the zone of impact of solid waste sites, the causes of this state, and the consequences for society.

Therefore, methodological approaches to the diagnosis of the state of the environmental condition within the influence zone of technically disturbed areas on agricultural land should be based on laboratory studies of the ecotoxicological state of soils at different distances from the source of influence, landfill leachate, and the state of atmospheric condition.

The methodology for the assessment of technogenic disturbed sites should consist of the following stages:
- the preparatory stage (collection of technical documentation, identification of the peculiarities of this landfill/refuse dump, errors in its design, etc.),
- laboratory and field research,
- analysis and processing of information (assessment of the ecological state of the technogenic disturbed areas, impact of the landfill on the adjacent areas (especially agricultural areas),
- development of a set of environmental protection measures for cleaning and restoring the technogenic disturbed areas under the landfill and ensuring the safe ecological state of the environmental components in the area affected by the landfill.

According to the analysis of the literary sources (Vasudevan et al. 2003, Kim et al. 2010, Ren et al. 2021, Travar et al. 2020, Marsum et al. 2022, Mendoza-Burguete et al. 2023), the methods of remediation of technogenic disturbed areas can be divided into three groups: technical or radical (complete extraction of polluted soil layer and its replacement with "clean" one that has undergone special treatment); biological (use of plant properties to neutralise pollutants); microbiological; physical and chemical (washing contaminated soil, changing soil acidity, etc.).

2. Materials and Methods

Considering that most municipal landfills in Ukraine are unauthorised, it is proposed to classify the technogenic disturbed areas according to the author's generalised expert methodology, as shown in Table 1.

The object of the study is the territory of the Senchan Rural Territorial Community (RTC) of the Myrhorod district of the Poltava region, Ukraine, which was chosen as an example to test the methodology.

Soil samples were selected according to DSTU 4287:2004, sample preparation according to DSTU ISO 11464-2007. Samples were collected in triplicate on the landfill sites and on the border with agricultural land closest to the landfill. The lead content was determined using the atomic absorption method using the C-115 U atomic absorption spectrophotometer (methodology of DSTU 4770.9:2007); petroleum products – according to GOST 23740-79. Laboratory analysis of soil samples was carried out using the Poltava State Agrarian University laboratory. Data processing was carried out using Microsoft Office Excel.

Table 1. Expert methodology for the assessment of the landfill impact on agricultural land, considering local characteristics

Hazard category**	$T1^*$	$T2^*$	Hazard subcategory**	$T3^*$	Hazard level**	Exceeding of the MPC	Type of pollution***
I	*<10 m³*	*<15 m²*	*a*	*< 200 m*	**H₀**	*missing*	
					H₁	*Available on the territory of landfill (E1)*	*HM*
							PP
							HM+PP
					H₂	*Available at the boundary between the landfill site and the agricultural land (E2)*	*HM*
							PP
							HM+PP
			b	*>200 m*	**H₁**	*Available on the territory of landfill*	*HM*
							PP
							HM+PP
II	*10-1000 m³*	*15- 1000 m²*	*a*	*<200 m*	**H₀**		
					H₁	*Available on the territory of landfill*	*HM*
							PP
							HM+PP
					H₂	*Available at the boundary between the landfill site and the agricultural land*	*HM*
							PPP
							HM+PP
			b	*>200 m*	**H₁**	*Available on the territory of landfill*	*HM*
							PP
							HM+PP
III	*>1000 m³*	*>1000 m²*	*a*	*<200 m*	**H₀**		
					H₁	*Available on the territory of landfill*	*HM*
							PP
							HM+PP
					H₂	*Available at the boundary between the landfill site and the agricultural land*	*HM*
							PP
							HM+PP
			b	*>200 m*	**H₁**	*Available on the territory of landfill*	*HM*
							PP
							HM+PP

*Technical indicators: T1 – volume of removed waste, m³; T2 contaminated area, m²; T3 – the distance to agricultural land; m; Environmental indicators: E1 – the level of pollutants on the territory of solid waste landfills, C_i/MPC (maximum permissible concentration). E2 – the level of pollutants ay the boundary between the landfill and agricultural land, C_i/MPC (maximum permissible concentration) HM – heavy metals; PP – petroleum products; HM+PP – heavy metals and petroleum products.

[**]Hazard category and subcategory of technogenic contaminated sites are distinguished using technical and environmental indicators. Hazard category I – relatively polluted areas with a small surface area (volume of MSW disposal up to 10 m^3, surface area up to 15 m^2); Hazard category II – contaminated areas, (volume of MSW disposal up to 1000 m^3, surface area up to 100 m^2); Hazard category III– highly polluted areas outside the settlement, (volume of MSW disposal up to 1000 m^3, surface area up to 1000 m^2); Hazard subcategory a – the distance to agricultural land < 200 m; Hazard subcategory b – the distance to agricultural land > 200 m. Hazard level H_0 – no exceedance of MPC (maximum permissible concentration); Hazard level H_1 – exceedance of MPC on landfill territory; Hazard level H_2 – exceedance of MPC at the boundary between the landfill site and the agricultural land.

[***]Type of pollution. The type of pollution should be specified: heavy metals, petroleum products or heavy metals and petroleum products to select measures to restore technogenic disturbed territories and reduce their negative impact on agricultural land.

Technogenic disturbed areas on the territory of settlements, depending on their volume, are divided into:
1) relatively polluted areas of a small area (with a small volume of removed MSW – up to 10 m^3),
2) polluted areas within the settlement, where 100-150 m^3 of MSW have accumulated,
3) heavily polluted areas outside the settlements, where the volume of waste collected exceeds 1000 m^3, and the area exceeds 1 ha.

3. Results and Discussion

Based on the study of the local conditions of the territory of the selected object (Senchanskaya RTC) it was established that 17 landfills have *hazard category I* (they have an area of up to 15 m^2 and the volume of solid waste removed is less than 10 m^3); 12 landfills belong to the *subcategory a* and have a distance to agricultural land of more than 200 m (by 11 times); 5 landfills belong to the *subcategory b* and have a distance to agricultural land of less than 200 m (by 6 times). Three MSW landfills have *hazard category II* (have a landfill area up to 1000 m^2, the volume of removed waste is less than 1000 m^3). Of these, one landfill belongs to *subcategory a* and has a distance to agricultural land of more than 200 m, and two landfills belong to *subcategory b* and have a distance to agricultural land of less than 200 m. One solid waste landfill has *hazard category III and subcategory b*: accumulation volume is more than 1000 m^3 (9140 m^3) and an area of landfill more than 1000 m^2 (2.1 ha). This landfill is located on agricultural land (distance to the nearest agricultural land from 0 to 15 m).

The content of heavy metal (Pb) and petroleum products was determined directly on the territory of technogenic disturbed lands and the border with agricultural lands. The results of an expert assessment of technogenic disturbed areas concerning their impact on agricultural land, such as the Senchana Rural Territorial Community (RTC), are shown in Table 2.

According to the analysis results, exceedances of the MPC for petroleum products were observed in 1 landfill site on the border with agricultural land. For the other landfills, there were no exceedances of the MPC on the border with agricultural land. On the territory of technogenic disturbed land, there are MPC exceedances of Pb (by 1.1-1.3 times) in 2 landfills Ib hazard category, 1 landfill IIb hazard category and 1 landfill for IIIb hazard category. The MPC exceedance of petroleum products (by 1.1-1.2 times) on the territory of technogenic disturbed areas is defined for 3 landfills of Ib hazard category, 1 landfill of IIb hazard category IIb, 1 landfill of IIIb hazard category.

Based on the expert assessment of technogenic disturbed areas and their impact on agricultural land (using the example of the Senchan Rural Territorial Community (RTC), Myrhorod district, Poltava region, Ukraine), an algorithm was developed for selecting the first priority measures for returning contaminated agricultural land from landfills to economic circulation (Table 3).

Table 2. Results of an expert assessment of technogenic disturbed areas concerning its impact on agricultural land

Hazard category	Hazard subcategory	Hazard level	Location coordinates	Volume of removed waste, m^3	Landfill area, m^2	Distance to agricultural land, m	Pb content in the soil on the landfill, Ci/ MPC	Pb content in the soil at the border with agricultural lands, Ci/ MPC	Petroleum product content in the soil on the landfill site, Ci/ MPC	Petroleum product content in the soil outside the landfill site at the border with agricultural lands, Ci/ MPC
I	a	H_0	$50^014′57.24′′$ N; $33^019′37.74′′$ E	10	15	≥200	0.2	<0.1	<0.1	<0.1
			$50^014′53.17′′$ N; $33^019′38.25′′$ E	10	15	≥200	<0.1	<0.1	<0.1	<0.1
			$50^014′48.57′′$ N; $33^020′13.10′′$ E	8	10	≥200	0.3	<0.1	<0.1	<0.1
			$50^014′17.36′′$ N; $33^020′10.63′′$ E	5	7	≥200	0.2	<0.1	<0.1	<0.1
			$50^015′02.03′′$ N; $33^020′54.54′′$ E	7	8	≥200	0.3	<0.1	<0.1	<0.1
			$50^015′12.86′′$ N; $33^020′20.69′′$ E	10	15	≥200	<0.1	<0.1	<0.1	<0.1
			$50^015′28.00′′$ N; $33^020′36.59′′$ E	10	14	≥200	<0.1	<0.1	<0.1	<0.1
			$50^015′20.90′′$ N; $33^020′57.78′′$ E	8	10	≥200	<0.1	<0.1	<0.1	<0.1
			$50^015′55.83′′$ N; $33^020′46.80′′$ E	10	14	≥200	0.2	<0.1	<0.1	<0.1
			$50^016′05.68′′$ N; $33^021′36.09′′$ E	10	13	≥200	0.1	<0.1	<0.1	<0.1
			$50^015′49.82′′$ N; $33^021′39.84′′$ E	8	10	≥200	<0.1	<0.1	0.5	0.1
	b	$H_1\ PP$	$50^016′29.03′′$ N; $33^022′11.36′′$ E	10	11	30	0.5	0.1	0.2	0.1
			$50^016′15.62′′$ N; $33^022′06.41′′$ E	10	13	25	0.7	0.2	**1.1**	0.6
			$50^014′50.56′′$ N; $33^021′57.00′′$ E	10	14	150	0.5	0.2	**1.2**	0.1
			$50^014′35.51′′$ N; $33^021′34.45′′$ E	10	15	120	0.9	0.3	**1.1**	0.3
		$H_1\ HM$	$50^014′11.59′′$ N; $33^022′16.44′′$ E	10	11	30	**1.1**	0.5	0.7	0.2
			$50^013′52.13′′$ N; $33^022′19.58′′$ E	10	13	25	**1.2**	0.7	0.1	0.1
II	a	H_0	$50^014′57.24′′$ N; $33^019′37.74′′$ E	100	75	≥200	<0.1	<0.1	<0.1	<0.1
	b	$H_1\ PP$	$50^015′57.66′′$ N; $33^021′47.69′′$ E	90	100	120	0.1	<0.1	**1.2**	0.3
		$H_1\ HM$	$50^014′56.88′′$ N; $33^021′50.78′′$ E	120	87	100	**1.1**	0.22	0.2	0.1
III[*]	b	$H_1\ PP$ $H_2\ PP$	$50^013′47.88′′$ N; $33^022′24.88′′$ E[**]	9140	21000	0-15	0.58	0.39	**1.5**	**1.2**

[*]It is located on the agricultural land

[**]It is located outside the settlement (west of Sencha village, 1.4 km away)

Table 3. An algorithm for selecting measures to return contaminated agricultural land to economic circulation, considering the hazard category of the landfill*

Hazard category	Hazard subcategory	Hazard level	Priority measures
I	a	H_0	1. Technical recovery: cleaning of illegally removed municipal waste. 2. Biological reclamation using perennial greening.
	b	H_1 PP	1. Technical recovery: cleaning of illegally removed municipal waste. 2. Soil remediation (remediation of heavy metals or petroleum products). 3. Biological reclamation using perennial greening.
		H_1 HM	
II	a	H_0	1. Technical recovery: cleaning of illegally removed municipal waste. 2. Use for infrastructure purposes (within residential buildings) or for biological reclamation.
	b	H_1 PP	1. Technical recovery: cleaning of illegally removed municipal waste. 2. Soil remediation (remediation of heavy metals or petroleum products). 3. Biological reclamation using perennial greening.
		H_1 HM	
III	b	H_1 PP+HM H_2 PP	1. Technical recovery: cleaning of illegally removed municipal waste. 2. Soil remediation (remediation of heavy metals or petroleum products). 3. Phytoremediation. 4. Soil cleaning of adjacent agricultural land. 5. Returning technogenic contaminated land to economic use for growing agricultural products.

* Algorithm designed by the author.

Therefore, in the system of restoration of technogenic disturbed areas, the following measures can be created:
1) Technical stage of recovery. Cleaning municipal waste; sorting valuable fractions and sending them for processing; selecting organic waste and composting it.
2) Soil remediation on the territory of technogenic disturbed areas and selection of measures according to the existing contamination. Soil cleaning on the territory of adjacent agricultural areas (if necessary).
3) Biological remediation. Phytoremediation of contaminated soil with heavy metals and petroleum products (if necessary). If the area of the technogenic disturbed land is located in a residential area, green areas or infrastructural use should be created. If the area of technogenic disturbed land is located on agricultural land – the return of disturbed land to the economic cycle for the cultivation of agricultural products.

Thus, the author's proposed expert method of assessing the impact of technogenic disturbed lands on agricultural lands, considering the local characteristics, allows the classification of solid waste landfills according to the level of hazard and to formulate priority directions for restoration of territories according to the degree and type of soil contamination. Therefore, it is necessary to select a complex of innovative ecologically oriented methods of restoration of technogenic disturbed lands according to the type and degree of soil pollution to bring agricultural lands into economic flow associated with ensuring environmental and food security in the region and establishing sustainable agro-ecosystems.

Abdolkhaninezhad et al. (2022) confirm in their research that evaluating environmental indicators during landfill risk assessment is essential to identify efficient criteria and provide beneficial solutions for effective waste management and control. After all, landfills contribute to environmental risks for human habitation. Employing the bowtie model can manage and mitigate environmental and safety risks arising from municipal waste disposal while adopting an integrated approach, which offers a versatile tool for assessing and enhancing municipal landfill systems. Abdolkhaninezhad et al. (2022) conducted a risk assessment study, identifying environmental and health safety as the primary concerns within the landfill.

A study by Albizzati et al. (2024) confirms the importance of including environmental indicators in the circular economy's monitoring and impact assessment, as described in the EU-27 New Circular Economy Action Plan. So far, the monitoring framework is limited to two mass indicators: the overall level of recycling and the level of recycling for specific types of waste. A closer look at the environmental impact of waste management paves the way for more detailed impact analysis, which is needed to develop policies to track waste streams generated, collected and recycled.

Researchers Cecere et al. (2024) emphasise the need to consolidate methodological practices to improve the application of LCA. Ensuring broader implementation of the methodologies will only be achievable by adopting standardised, established, and widely accepted practices. This facilitates the evaluation of potential disparities, the recognition of diverse national protocols, and the formulation of cohesive recommendations to enhance the proposed framework. Integrating standardised guidelines is essential for advancing the creation of dependable protocols that facilitate LCA application. As highlighted by researchers Cecere et al. (2024), employing a comprehensive methodological approach enables the assessment of LCT implementation status for WMP development.

Scientists Rybalova et al. (2024) also studied the issue of contaminated soil by heavy metals. They developed a methodology for comprehensively assessing soil contamination with heavy metals at regional and local levels. According to the proposed method, the soil was classified according to contamination with trace elements of metals. The study results indicate that, according to the proposed methodology, landfills are the most dangerous objects. Rybalova et al. (2024) confirm that assessing the level of danger of contaminated soil with heavy metals will enable scientifically grounded decisions regarding the prioritisation of environmental protection measures.

Zhang et al. (2014) developed an integrated health risk assessment (HRA) methodology for solid waste. HRA methodologies were developed for three types of landfills: with a defined operation period, with post-closure maintenance and management, and without any restrictions. The main investigated environmental pollutants were gases and dust during landfill operation. The HRA endpoints for MSW are the individual lifetime carcinogenic risk and the hazard index (HI) for all non-carcinogenic chemical pollutants for landfill workers (during operation only) and for the population living near landfills (all three phases).

El Fadili et al. (2022) explored the risks of soil contamination by heavy metals near landfills. Our study confirms their findings, indicating that landfills serve as focal points for hazardous elements, exerting detrimental effects on soil quality and adjacent regions, thereby endangering human health and the ecosystem. Their investigation revealed that the mean concentrations of heavy metals (Zn, Cd, Fe, Cu, Ni, Pb, Cr) surpassed their respective geochemical backgrounds. Pollution index values indicated moderate to severe soil contamination (PLI = 1.84), particularly by Cd and Pb. El Fadili et al. (2022) also calculated the hazard index (HI) for heavy metals in the soil. Research results show that hazard assessment methodology is useful for formulating recommendations for technical remediation of open landfills.

4. Conclusions

The author's expert method of assessing the impact of technogenic disturbed areas on agricultural land, considering local characteristics, is highlighted. The methodology provides an algorithm for classifying solid waste landfills according to the hazard level. It allows waste management specialists to formulate priority directions for restoring technogenic disturbed territories, considering the degree and type of soil contamination.

An assessment of technogenic disturbed areas was carried out at the local level (using the example of the Senchan RTC, Myrhorod district, Poltava region, Ukraine), a classification of solid waste landfills according to the hazard level was made, and a set of priority measures for the restoration of technogenic disturbed areas and minimisation of their impact on agricultural land was determined. The need to select a set of innovative, ecologically oriented methods for the remediation of technogenic contaminated sites, depending on the type and degree of soil contamination, to rehabilitate these sites and return them to economic circulation in the context of ensuring the ecological and food security of the region and creating sustainable agro-ecosystems was identified.

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