World Journal of Environmental Biosciences
Available Online at: **www.environmentaljournals.org**

Volume 15, Issue 1: 145-154

https://doi.org/10.51847/MyG1twStKK

ISSN 2277- 8047

Assessment of Heavy Metal Contamination of the Soil Cover in the Area of a Solid Household Waste Landfill

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ABSTRACT

Soil contamination associated with solid household waste landfills represents a significant environmental concern because heavy metals can accumulate in surface horizons and migrate into adjacent ecosystems. This study aimed to assess the level and spatial distribution of heavy metal contamination in soils surrounding the solid household waste landfill adjacent to the Shchuchinsk-Borovskaya resort area, Kazakhstan. In August 2024, 12 composite soil samples were collected from the 0–20 cm layer in four directions (north, south, east, and west) at distances of 10, 50, and 100 m from the landfill. Concentrations of Pb, Cd, Zn, Cu, As, Co, Hg, Ni, Cr, and Mn were determined by atomic absorption spectroscopy and compared with maximum permissible concentrations (MPCs). At 10 m from the landfill, exceedances were recorded for seven metals, with the highest values observed for Cu (3.4 MPC), Mn (2.25 MPC), Cr (1.38 MPC), Zn (1.35 MPC), Ni (1.27 MPC), Pb (1.18 MPC), and As (1.10 MPC). At 50 m, five metals exceeded the MPC, whereas at 100 m only Cu, Mn, and Cr remained above permissible levels. Contamination generally decreased with increasing distance, although directional differences were observed. Overall, the environmental condition of the studied soils was classified as satisfactory to relatively satisfactory, while continued monitoring and remediation measures remain necessary.

Keywords: *Ecology, Heavy metal, Soil, Waste management*

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Received: 21 December 2025
Accepted: 27 March 2026

INTRODUCTION

Under conditions of intense anthropogenic influence, the influx of heavy metals into the ecosystem makes it dangerous for humans and animals. Once in the soil, heavy metals constantly migrate, passing into one form of chemical compound or another. Some of them undergo hydrolysis, while others can form insoluble compounds and become fixed in the soil environment. Heavy metals can exist in the soil in three states: non-exchangeable, exchangeable, and water-soluble (Hoornweg & Bhada-Tata, 2012; Guerrero *et al*., 2013; Faurat *et al*., 2024; Gautam *et al*., 2024; Svensson & Lindberg, 2026). All types of soil absorbency are involved in the processes of accumulation and transformation of metals.

Heavy metal contamination of agricultural lands is especially noticeable, leading to a decreased yield, increased content of solid metals in agricultural products (Pramana *et al*., 2023; Younas *et al*., 2023; Hao *et al*., 2025), reduced fertility, and deteriorated soil properties (Fadili *et al*., 2024; Jabbarov *et al*., 2024). An increase in heavy metals in meadows occurs mainly in the surface (up to 5 cm) soil layers. Animals directly consume them during grazing. Heavy metals are toxic and interfere with the activity of the soil microflora (Kurmanbayeva *et al*., 2022; Mukhambetov *et al*., 2023). Their concentration in the soil can persist for decades or even centuries. As a result, heavy metals are among the priority global pollutants of the environment, participating in biological processes and becoming part of the tissues and many enzymes of living organisms while activating or inhibiting the action of enzymes (Jaffar *et al*., 2009; Kooch *et al*., 2023; Gaur *et al*., 2024; Huang *et al*., 2024; Podlasek *et al*., 2024; Morgan *et al*., 2025).

Like all living organisms, plants can only counteract an increase in the concentration of heavy metals up to a specific limit. A further increase in their concentration leads to the suppression and death of living organisms and the need for preparations (Kassenova *et al*., 2024; Mishra *et al*., 2025). The consequence of the accumulation of heavy metals in the upper layers of the soil is the depletion of the species composition of plants and microorganisms and the deterioration of the conditions of growth and development of cultivated plants (Saha *et al*., 2023; Di Fiore *et al*., 2024). When exposed to solid household waste (SHW) landfills, environmental components are polluted, particularly the atmosphere, hydrosphere, and soil. SHW landfills are a direct source of accumulation of heavy metals in soils over significant areas, leading to irreversible processes (Zhyrgalova *et al*., 2024; Nagesh *et al*., 2025).

Organic and inorganic waste in SHW landfills releases toxic substances into the soil and groundwater during decomposition, forming a so-called filtrate, which includes heavy metals (Bayazitova *et al*., 2023a, 2023b; Zhaparova *et al*., 2023; Kowalski *et al*., 2024). All this affects the health of the population (Themelis *et al*., 2002; Ziadat & Mott, 2005; Zia & Devadas, 2008; Ashikhmina *et al*., 2009; Ahmed, 2014; Joseph *et al*., 2020; Baikenova *et al*., 2021; Ofomola *et al*., 2021; Bayazitova *et al*., 2022; Caminati *et al*., 2022; Nasir *et al*., 2022; Popova, 2023; Abisheva *et al*., 2024; Bukharybaeva *et al*., 2024; Di Fiore *et al*., 2024; Kucherova *et al*., 2024; Naimanova *et al*., 2024; Ogungbemi *et al*., 2024; Olanipekun *et al*., 2024; Podlasek *et al*., 2024; Samir & Kosaj, 2024; Ahmed *et al*., 2025; Hao *et al*., 2025; Mishra *et al*., 2025; Morgan *et al*., 2025; Nagesh *et al*., 2025; Sayuti *et al*., 2025; Svensson & Lindberg, 2026).

Due to the effect of filtrate in the soil, the content of copper (Cu), manganese (Mn), chromium (Cr), zinc (Zn), nickel (Ni), lead (Pb), and arsenic (As) increases many times. Metals can enter the soil as part of SHW, such as batteries, accumulators, electronic devices, plastics, etc. Household waste emissions may contain multiple chemicals, fertilizers, and pesticides, which can also increase the content of heavy metals in the soil (Ahmed *et al*., 2025; Novak & Dvorak, 2025). The distribution of heavy metals in the soil may be caused by emissions of harmful substances resulting from the incineration and ignition of SHW and its accumulation in an open environment (Themelis *et al*., 2002; Joseph *et al*., 2020; Samir & Kosaj, 2024; Huber *et al*., 2025).

The accumulation of heavy metals and their transfer to the human body through the food chain negatively affects human health (Baikenova *et al*., 2021; Salem *et al*., 2025). When exposed to heavy metals, neurological disorders, developmental delay in children, kidney damage, respiratory problems, cardiovascular diseases, infectious hepatitis, dysentery, and some cancers can manifest themselves (Ofomola *et al*., 2021; Ogungbemi *et al*., 2024). The degree of influence depends on the concentration and type of heavy metal, time, and individual susceptibility. For example, even in small amounts, Cd and Pb can lead to cancer, high blood pressure, mental deficiency, and cardiovascular diseases (Zia & Devadas, 2008; Ashikhmina *et al*., 2009; Kajanova & Badrov, 2024).

In the current conditions of progressive urbanization, a significant amount of household waste has accumulated, which leads to problems with its disposal. Household waste is a leading cause of environmental crises and pollution (Caminati *et al*., 2022; Kurmanbayeva *et al*., 2022; Novak & Jelic, 2025).

According to statistics, about 4.5 million tons of SHW are generated annually in Kazakhstan and stored in SHW landfills. Monitoring SHW landfill sites using geographical information system (GIS) technologies revealed that only 21% of the sites complied with environmental and sanitary standards. Most were unauthorized sites, and their number increased annually by an average of 2-3% (Ahmed, 2014; Bayazitova *et al*., 2022; Nasir *et al*., 2022; Kwatra *et al*., 2024).

The main objectives of our study were to assess soil contamination near the Shchuchinsk-Borovskaya resort area (SBRA) (Kazakhstan) SHW landfill site and to study the level and distribution of heavy metals in soils in the SHW landfill site. Assessment and control of the soil quality is essential, as it ensures effective monitoring of changes occurring in the soil and timely development of recommendations for its remediation.

MATERIALS AND METHODS

Study design

The study, conducted in August 2024, focused on a comprehensive evaluation of the concentration of heavy metals in the soil cover of the SBRA SHW landfill, using field and laboratory analysis methods to assess the degree of contamination.

Study location

The SBRA SHW landfill is located in the Akmola region at a distance of 17 km from Shchuchinsk, near Lake Kumdykol. The nearest settlements are the villages of Savinka, located west of the site, and Sotnikovo, situated to the south of it. The land area is 54.8778 ha. The population of Shchuchinsk is 6,000 people. SHW from the SBRA and Shchuchinsk is accepted at the landfill. The geographical coordinates of the SBRA SHW landfill are the following: 1. N 52°54'29" E 70°05'30"; 2. N 52°54'32" E 70°05'52"; 3. N 52°54'25"E 70°06'48"; 4. N 52°54'11" E 70°06'47"; 5. N 52°54'08" E 70°06'05";6 N 52°54'19" E 70°05'38".

The SBRA is characterized by a continental climate with pronounced seasonality. The average temperature in July, the warmest month, varies from +18.5 to +21.5°C, while in January, the coldest month, it drops to -13...-18°C. The absolute maximum temperature reaches +39...+42°C, and the minimum in severe winters can drop to -49...-52°C (Kazhydromet, n.d.).

Precipitation and moisture from the SHW landfill and hot summers contribute to the intensive dissolution of the contents of the SHW landfill and the transfer of pollutants into the soil.

Study course

To assess the level of soil pollution in the SBRA SHW landfill in the summer (August), samples were taken from the SHW landfill site in four directions (north, south, east, and west) **(Figure 1)**. Soil sampling was conducted according to the Interstate standard GOST 17.4.4.02-2017 (Interstate Council for Standardization, Metrology and Certification, 2017; Abdoul-Latif *et al*., 2025).

In total, 12 combined soil samples (mixtures of at least five point samples) were taken using the envelope method from 0-20 cm depth at the following distances: 10, 50, and 100 m from the SHW landfill in four directions. These distances are due to the study of the impact of the SHW landfill on the environment, depending on the distance from it.

Figure 1. Soil sampling scheme of the SBRA SHW landfill

To determine the level of soil pollution made by the SBRA SHW landfill, the presence of the following 10 heavy metals was established: barium (Ba), cadmium (Cd), Mn, Cu, As, Ni, mercury (Hg), Pb, strontium (Sr), and Cr. These toxic substances belong to the first and second hazard classes. Therefore, it is necessary to monitor their content.

Methods

The content of Pb, Cd, Zn, Cu, As, cobalt (Co), Hg, Ni, Cr, and Mn in the soil was determined by atomic-absorption spectroscopy according to the Standard of the Republic of Kazakhstan (ST RK) 2.377-2015 (State System for Ensuring the Uniformity of Measurements of the Republic of Kazakhstan, 2015; Zairkhanova *et al*., 2024). Atomic absorption analysis is a method of analytical chemistry based on the selective absorption of electromagnetic radiation of a specific wavelength by neutral atoms of a particular element free from all molecular bonds (State System for Ensuring the Uniformity of Measurements of the Republic of Kazakhstan, 2015).

The assessment of chemical contamination of soils was carried out according to the criteria for assessing the environmental situation of territories (State System for Ensuring the Uniformity of Measurements of the Republic of Kazakhstan, 2015). To assess pollutants of non-natural origin, the concentration coefficient was determined as a quotient of the mass fraction of the pollutant and its maximum permissible concentration (MPC).

RESULTS AND DISCUSSION

Table 1 shows the heavy metal content in the upper soil horizons at a distance of 10 m from the SBRA SHW landfill.

Table 1. Heavy metal content in soil samples at a distance of 10 m from the SBRA SHW landfill

No.	Name of the indicator being determined	MPC	Sample No. 1 (south)	Sample No. 2 (east)	Sample No. 3 (north)	Sample No. 4 (west)	Background
1	Pb	32.0	**35.4**	**36.5**	**32.9**	**37.8**	21.5
2	Cd	0.5	0.4	0.3	0.02	0.35	0.09
3	Zn	23.0	**31.2**	**28.9**	**23.9**	**25.1**	10.3
4	Cu	3.0	**10.2**	**9.3**	**5.8**	**8.4**	2.1
5	As	2.0	**2.2**	1.9	1.4	1.2	0.4
6	Co	5.0	4.8	3.08	3.05	4.06	1.7
7	Hg	2.1	1.9	1.5	1.6	1.02	0.59
8	Ni	4.0	3.8	**5.1**	3.55	2.98	2.09
9	Cr	6.0	**8.3**	**7.9**	**6.3**	**7.1**	1.67
10	Mn	400	**900**	**644**	356	**415**	115.5
	pH (water)		7.3	6.4	5.8	5.1	5.4

According to **Table 1**, the analyzed soil samples taken 10 m from the SBRA SHW landfill showed the presence of all the heavy metals in question. Seven of these heavy metals exceeded the MPC. The most pronounced excess of MPC was observed for Cu. The indicators for the Cu samples were distributed as follows: in sample No. 1 in the southern direction, Cu exceeded the permissible concentration by 3.4 times; in sample No. 2 in the eastern direction, by 3.1; in sample No. 3 in the northern direction, by 1.9, and in sample No. 4 in the western direction, by 2.8; the average excess was 2.8 times.

The excess of the permissible Mn concentration in the soil was observed in three sampling samples: in sample No. 1 in the southern direction, by 2.25 times, in sample No. 2 in the eastern direction, by 1.61 times, and in sample No. 4 in the western direction, by 1.03 times.

A slight excess of the MPC was observed in the Cr content in all four directions. The maximum excess of Cr in sample No. 1 in the south direction was 1.38 times. In sample No. 2 in the eastern direction, it was 1.3 times; in sample No. 4 in the western direction, it was 1.18 times. The lowest Cr value was detected in sample No. 3 in the northern direction, which was 1.05 times.

The Zn content was also excessive in four directions: in sample No. 1 in the southern direction, by 1.35 times, in sample No. 2 in the eastern direction, by 1.25 times, and in sample No. 4 in the western direction, by 1.09 times. The smallest excess of Zn was noted in sample No. 3 in the northern direction.

The Pb exceeded the MPC in four directions. The highest Pb excess was observed in sample No. 1 in the southern direction and was 1.1 times; the second highest value was recorded in sample No. 4 in the western direction (1.18 times), the third value in sample No. 2 in the eastern direction (1.14 times), and the fourth value in sample No. 3 in the northern direction (1.05 times).

Point exceedances of the MPC were detected for the As content in sample No. 1 in the east direction, exceeding the MPC by 1.1 times, and for Ni in sample No. 2 in the east direction, exceeding the MPC by 1.27 times. Thus, the obtained data indicate soil contamination 10 m from the landfill with Cu, Mn, Cr, Zn, Pb, As, and Ni. The most significant contamination was detected in sample No. 1 (six metals), located south of the landfill. The lowest contamination rates were observed in sample No. 3 (four metals), located in the northern direction **(Figure 2)**.

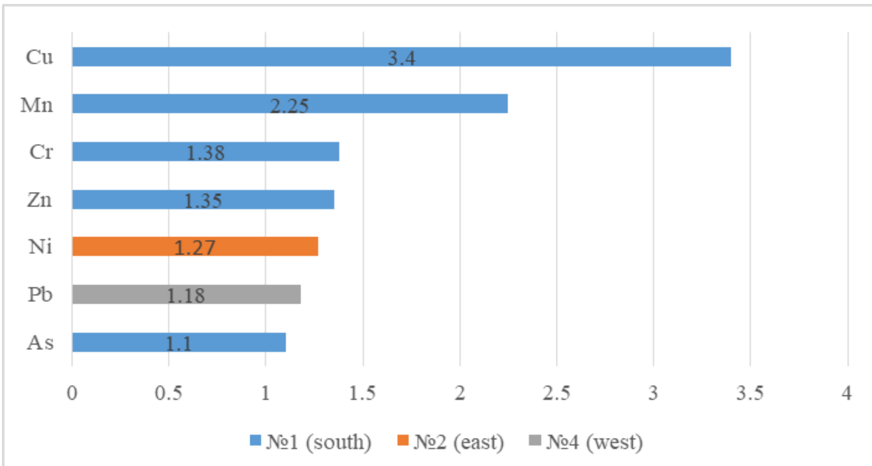

Figure 2. Concentrations of heavy metals exceeding the MPC in soils at a distance of 10 m from the SBRA SHW landfill

The data obtained on the studied sites (No.1-4) at a distance of 10 m from the SHW landfill allow us to construct an elemental series of accumulation of heavy metals in descending order of their concentrations in soils: Cu (3.4 MPC) → Mg (2.25 MPC) → Cr (1.38 MPC) → Zn (1.35 MPC) → Ni(1.27 MPC) → Pb (1.18 MPC) → As (1.1 MPC) **(Figure 3)**.

Table 2 shows the results of the chemical analysis of soils at a distance of 50 m from the SBRA SHW landfill.

Table 2. Results of soil sample analyses at a distance of 50 m from the SBRA SHW landfill

No.	Name of identifiable indicator or indicators	MPC	Sample No. 5 (south)	Sample No. 6 (east)	Sample No. 7 (north)	Sample No. 8 (west)	Background
1	Pb	32.0	**33.8**	**34.0**	31.3	**34.7**	21.5
2	Cd	0.5	0.3	0.02	0.02	0.02	0.09
3	Zn	23.0	**25.6**	**23.5**	21.0	15	10.3
4	Cu	3.0	**8.2**	**7.5**	**4.2**	**3.6**	2.1
5	As	2.0	1.53	1.55	1.67	1.1	0.4
6	Co	5.0	3.9	1.5	2.2	1.3	1.7
7	Hg	2.1	1.1	0.2	0.9	0.7	0.59
8	Ni	4.0	1.67	3.5	2.8	1.78	2.09
9	Cr	6.0	**6.8**	**6.1**	5.8	**7.2**	1.67
10	Mn	400	**730**	**650**	**590**	**710**	115.5
	pH (water)		6.5	5.8	5.3	5.7	5.4

According to **Table 2**, at a distance of 50 m from the SBRA SHW landfill, the analyses showed an excess of the MPC for five heavy metals. The observed Cu excess was the highest. The Cu content exceeded the MPC in four directions: in sample No. 5 (south), an excess of 2.7 times was noted; in sample No. 6 (east), 2.5 times; in sample No. 7 (north), 1.4 times; and in sample No. 8 (west), 1.2 times.

The second-highest value was observed for Mn in all four directions. In sample No. 5 (south), it exceeded the MPC by 1.8 times; in sample No. 6 (north), by 1.6 times; in sample No. 8 (west), by 1.7 times; and in sample No. 7 (north), the lowest excess of Mn content was noted.

The Cr content exceeded the MPC in three samples. The largest excess was noted in sample No. 8 (west) and amounted to 1.2

times. In sample No. 5 (south), the excess was 1.13 times. The lowest Cr content was found in sample No. 6 (east).

Zn demonstrated the second-largest excess of the MPC. Zn exceeded the MPC in two directions: in sample No. 5 in the southern direction by 1.11 times and in sample No. 6 in the eastern direction by 1.02 times **(Figure 3)**.

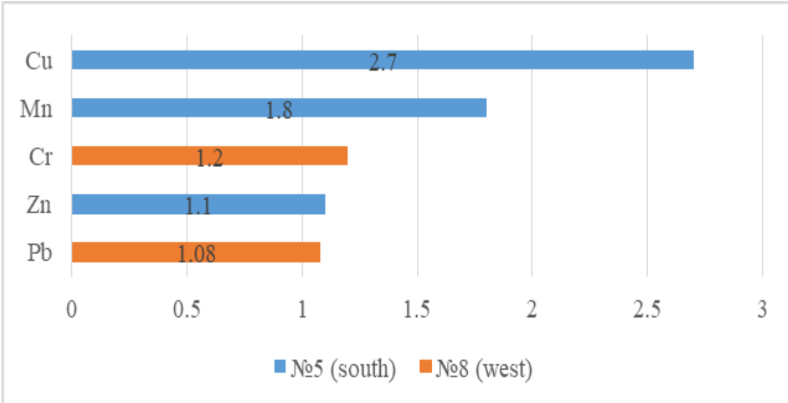

Figure 3. Heavy metal content in soils at a distance of 50 m from the SBRA SHW landfill, exceeding the MPC, times

Table 3 shows the results of the chemical analysis of soils at a distance of 100 m from the SBRA SHW landfill.

Table 3. Results of soil sample analyses at a distance of 100 meters from the SBRA SHW landfill

No.	Name of identifiable indicator or indicators	MPC	Sample No. 9 (south)	Sample No. 10 (east)	Sample No. 11 (north)	Sample No. 12 (west)	Background
1	Pb	32.0	26.5	25.6	23.0	26.7	21.5
2	Cd	0.5	0.2	0.01	0.1	0.05	0.09
3	Zn	23.0	15	13	12.6	11	10.3
4	Cu	3.0	**4.2**	**3.3**	**4.5**	2.7	2.1
5	As	2.0	1.5	0.7	0.05	1.45	0.4
6	Co	5.0	1.8	2.5	1.03	1.78	1.7
7	Hg	2.1	0.5	0.87	0.45	0.56	0.59
8	Ni	4.0	2.5	1.78	2.25	1.85	2.09
9	Cr	6.0	**6.3**	5.05	4.08	5.08	1.67
10	Mn	400	**615**	**415**	278	354	115.5
	pH (water)		6.0	5.5	5.3	5.1	5.4

According to **Table 3**, an excess of Cu, Cr, and Mn was detected at a distance of 100 m from the landfill.

In comparison with other metals, the greatest excess was recorded for Mn. Mn exceeded the MPC in two directions: in sample No. 9 in the southern direction by 1.5 times and in sample No. 10 in the eastern direction by 1.03 times.

The Cu content exceeded the norm in three directions: the most significant excess was noted in sample No. 11 in the northern direction and amounted to 1.5 times. In sample No. 9 in the south direction, it exceeded the MPC by 1.4 times. The lowest excess of the MPC was noted in sample No. 10 in the eastern direction **(Table 3)**.

The lowest excess rate was observed in Cr in sample No. 9 in the south direction and amounted to 1.1 times.

Based on the obtained data for the studied sites (No. 9 – 12) at a distance of 100 m from the SHW landfill, the following descending sequence of heavy metal contamination was established: Cu (1.5 MPC) → Mn (1.5 MPC) → Cr (1.1 MPC).

Table 4. Assessment of environmental pollution by heavy metals

Elements	Hazard class	MPC, mg/kg	Maximum actual concentration, mg/kg	Plot number	Exceeding the MPC, times	Type of environmental situation
Pb	1	32.0	37.8	4	1.18	Relatively satisfactory
Cd	1	0.5	0.4	1	-	Satisfactory
Zn	3	23.0	31.2	1	1.35	Satisfactory
Cu	2	3.0	10.2	1	3.4	Relatively satisfactory
As	1	2.0	2.2	1	1.1	Satisfactory

Co	2	5.0	4.8	1	-	Satisfactory
Hg	1	2.1	1.9	1	-	Satisfactory
Ni	1	4.0	5.1	2	1.27	Relatively satisfactory
Cr	1	6.0	8.3	1	1.38	Relatively satisfactory
Mn	3	400	900	1	2.25	Satisfactory

According to the total indicator of soil contamination of the SBRA SHW landfill with heavy metals, the environmental situation near the studied sites can be classified as satisfactory and relatively satisfactory **(Table 4)**.

The study showed that the functioning SHW landfill of the SBRA did not meet the sanitary and epidemiological requirements No. KR DSM-331/2020 for the collection, use, application, neutralization, transportation, storage, and disposal of industrial and consumer waste. There is no protective barrier and trench on the landfill territory, mesh fences in storage areas, or a drainage ditch. These violations increase environmental pollution with harmful substances and create a fire hazard; the lack of a safety shield made of mechanically durable insulating material contributes to groundwater contamination.

The excess content of heavy metals reached its maximum level near the SHW landfill. The analysis showed that the concentrations of heavy metals in the studied soil samples significantly exceeded the MPCs. The greatest attention should be paid to the high levels of Cu, Mn, Cr, Zn, Ni, Pb, and As. The concentrations of these metals exceeded the MPC 3.5 to 1.1 times in samples 1-4, located 10 m from the landfill **(Figure 3)**. There is a decrease in the contents of all the studied heavy metals with increased distance from the SHW landfill. For example, the Cu content decreased at a distance of 50 m from the landfill from 3.5 times to 2.7; Mn from 2.25 to 1.8; Cr from 1.38 to 1.2; Zn from 1.35 to 1.1; and Pb from 1.18 to 1.08 times; the content of other metals was within the normal range. At a distance of 100 m from the SHW landfill, an excess of the MPC was detected only in three studied soil samples, No. 9-11. The concentrations of Mn, Cu, and Cr were found to be higher than the MPC in these samples.

The Cu, Mn, Cr, Zn, Ni, Pb, and as found in the soils of the SHW landfill in concentrations exceeding the MPC are explained by the discrepancy between the technical and technological arrangement of the SHW landfill and the climatic and geological conditions of the region. The hot summer days enhance the biological decomposition of household waste, thereby contributing to an increase in the content of toxic substances, which may contain heavy metals. The resulting toxic substances can enter the filtration waters of the landfill and then into surface and underground sources. As a result of soil and filtration water pollution, heavy metals enter grasses and shrubby plants growing on the territory of the SHW landfill and further along the food chain (plant-animal-human) enter the human body, which causes concern.

Similar studies of the territories adjacent to the household waste landfills are conducted in other places, which allows us to compare the situation with the one at our research facility.

In Nigeria, particularly in Akura, the impact of the solid waste processing site on the pollution of the surrounding soil with certain toxic elements was studied. The content of potentially toxic elements (PTEs) such as Zn, Cu, Pb, Ni, Cd, and Cr, their potential biological availability, and degree of contamination were studied, as well as the potential risk associated with landfill and surrounding soil samples. The study concluded that the dumping of waste into landfills contributes to soil contamination with PTEs (Ziadat & Mott, 2005; Olanipekun *et al*., 2024; Nguyen *et al*., 2025) with the same substances obtained in our study.

Comprehensive studies of unauthorized SHW landfills were also conducted in the Tobolsk district of the Tyumen region, Russia. As a result, 15 unauthorized SHW landfills were identified (six SHW landfills within the city and nine SHW landfills in the area). Heavy metals were found in the soils of unauthorized landfills: Zn (11.2-54.3 mg/kg), Cd (0.1-3.1 mg/kg), and Pb (5.0-18.1 mg/kg). In terms of toxicity, these metals belong to hazard class I (Popova, 2023; Aksoy & Akaydin, 2024; Elango & Govindaraju, 2025).

Researchers from Poland and the Czech Republic analyzed soil pollution with an emphasis on environmental risk assessment for the following heavy metals: Ni, Zn, Cd, Cu, and Pb in SHW landfills. This approach aims to assess how different waste disposal methods and environmental conditions affect soil contamination with PTEs and the associated environmental risks (Jannath *et al*., 2024; Podlasek *et al*., 2024).

At the Azov SHW landfill in the Rostov region, Russia, researchers identified increased levels of Cr, Sr, Zn, vanadium (V), Cu, Ni, Co, Pb, and As in the soil. Furthermore, soil contamination with As exceeded the MPC/approximate permissible concentration (APC) by 7 times, and Cr exceeded it by 1.4 times. The highest concentration of heavy metals prevailed in the body of the landfill. Depending on the distance from the landfill, the concentration of heavy metals in the soil decreases. The negative influence of the Azov landfill on the microbiological, biochemical, and phytotoxic parameters of the soil was established (Kucherova *et al*., 2024; Chandrasekhar *et al*., 2025).

Due to the data obtained by other researchers and us, solving this problem requires special discussion. Unlike the atmosphere and hydrosphere, where self-purification processes from heavy metals occur, the soil practically does not have this ability. Metals accumulating in soils are removed slowly, mainly as a result of leaching, accumulation by plants, and during erosion and deflation. Therefore, to reclaim soils contaminated with heavy metals, it is essential to develop agrotechnical measures to reduce pollutants in soils, thereby contributing to the biological remediation of the SHW landfill (Abisheva *et al*., 2024; Benhmida & Trabelsi, 2024). The use of phytoremedial plants for the restoration of polluted lands is becoming critical for the sustainable development of land use and is a more environmentally compatible and cheaper method compared with physicochemical and technical methods (Naimanova *et al*., 2024; Liedekerke *et al*., 2025). According to researchers, the dominant wild plant species with high accumulating abilities are the most promising for reclamation work (Nasir *et al*., 2022; Bukharybaeva *et al*., 2024; Dobrzynski *et al*., 2024; Sayuti *et al*., 2025).

CONCLUSION

As a result of the conducted studies based on assessing soil contamination with heavy metals near the SBRA SHW landfill, we concluded that the SHW landfill is a source of soil contamination with heavy metals. However, the soil cover of the territories adjacent to the SHW landfill is less polluted with heavy metals as the distance increases. The maximum excess of the MPC was established for the following heavy metals: Cu (3.4 MPC) → Mg (2.25 MPC) → Cr (1.38 MPC) → Zn (1.35 MPC) → Ni (1.27 MPC) → Pb (1.18 MPC) → As (1.1 MPC), in the south direction at a distance of 10 m from the landfill.

Based on the total indicator of heavy metal contamination of the soils of the SHW landfill, the environmental situation is not critical and can be assessed as satisfactory and relatively satisfactory. Failure to comply with measures for the maintenance and operation of an SHW landfill can lead to more serious contamination of soils with toxic substances. Based on previous research results from other SHW landfills, efforts should be made to prevent environmental degradation to the point of crisis. To do this, it is necessary to develop and implement several measures using phytoremedial plants that will help improve the soil condition. It is also essential to strengthen state monitoring of the environment at the SBRA by creating environmental maps and using GIS to model and predict the future state of the SHW landfill.

ACKNOWLEDGMENTS: None

CONFLICT OF INTEREST: None

FINANCIAL SUPPORT: The research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan. Grant financing of scientific and/or) scientific and technical projects for 2024-2026 with an implementation period of 36 months. Project topic: Development of a technology for the reclamation of a closed solid municipal waste landfill in the Akmola region by creating a model of artificial phytocenoses. IRN project: AP23487981.

ETHICS STATEMENT: None

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