

Research Article

<https://doi.org/10.31489/2026FEB3/43-55>

UDC 504.054

Received: 16.02.2026 | Accepted: 8.06.2026 | Published online: 30.09.2026

Z.E. Bayazitova*, A.S. Kurmanbayeva, N.M. Safronova, S.B. Zhaparova

Kokshetau University named after Sh. Ualikhanov, Kokshetau, Kazakhstan

*Corresponding author: z_bayazitova@mail.ru

Ecological and biological assessment of the state of soils and vegetation cover of the closed municipal solid waste landfill in Kokshetau

The ecological state of a closed municipal solid waste (MSW) landfill in Kokshetau, operated from 1960 to 2017 and lacking engineered protective systems, was assessed with a focus on heavy metal contamination and its effects on vegetation. Soil analysis revealed substantial exceedances of maximum permissible concentrations (MPCs) and background concentrations. Maximum concentrations reached 4230 mg/kg for Zn, 870 mg/kg for Cu, 299 mg/kg for Pb, 58 mg/kg for As, and 145 mg/kg for Ni, exceeding MPCs by 42.3, 15.8, 9.3, 29.0, and 3.6 times, respectively. Compared with background concentrations, these values were 48.1, 8.5, 19.9, 4.1, and 3.2 times higher, respectively. A pronounced radial contamination gradient was identified, with maximum concentrations in the central zone and a gradual decrease toward the periphery. However, even peripheral areas showed elevated concentrations relative to background levels, indicating persistent anthropogenic impact despite landfill closure. The geo-accumulation index (Igeo) classified the central soils as strongly to extremely contaminated, particularly with respect to Zn and Pb, while the phytotoxicity index (FTI) indicated a high level of phytotoxicity. Geobotanical analysis revealed substantial transformation of the vegetation, which was dominated by herbaceous and short-lived species, with annual species accounting for 49% of the recorded flora. The prevalence of *Asteraceae*, *Poaceae*, *Brassicaceae*, and *Chenopodiaceae* is consistent with adaptation to chemically stressed environments. The dominance of *Bassia scoparia* suggests its potential as a bioindicator of technogenically disturbed soils. Overall, the landfill represents a long-term anthropogenically transformed ecosystem requiring integrated environmental monitoring and reclamation measures.

Keywords: landfill of solid household waste, soil contamination, phytotoxicity, anthropogenic impact, heavy metals, ecosystem disturbance.

Introduction

Landfills of solid household waste (MSW), including closed and recultivated ones, remain long-term sources of soil pollution with heavy metals due to the accumulated “technogenic legacy”, lack/insufficiency of engineering protection (screens, filtrate collection) and the continued secondary intake of pollutants from surface runoff and dust transport [1]. International studies emphasize that soil pollution around landfills often persists for years and is accompanied by environmental risks to the soil and plant system, including the potential entry of metals into the biota [2].

For Kazakhstan, the problem is particularly significant against the background of an increase in the volume of accumulated waste and the need for environmentally sound management of landfill stock. Modern reviews and applied works on solid waste management in the Republic of Kazakhstan indicate the scale of waste accumulation and the importance of assessing the environmental effects of existing and closed facilities [3-4].

Kazakhstani studies demonstrate that landfills are capable of forming local anomalies in the content of Zn, Cu, Pb, As, Ni and other elements in soils, as well as influencing adjacent environmental components (including soils and groundwater) [5]. Thus, for the Karasai landfill (Almaty), soil pollution with heavy metals and its anthropogenic causes are shown. Similarly, earlier works on landfill sites emphasized the migration of heavy metals in the soil–water system, which makes an integrated approach to assessing the state of anthropogenic territories relevant [6]. In recent years, studies have been published on landfills in Kazakhstan (including in the Astana area), where excess of permissible levels of heavy metals and the need for environmental hazard assessment are noted, which confirms the current practical relevance of such work [7].

The study of closed landfills is of particular relevance, since the cessation of operation does not mean the cessation of exposure: pollutants can persist in soils and maintain a phytotoxic background, affecting the

restoration of vegetation and the structure of phytocenoses [8]. In this regard, it is important not only to record the concentrations of elements, but also to use integral indices (for example, Igeo) for a comparable assessment of the degree of anthropogenic accumulation and the allocation of functionally the most dangerous zones.

At the same time, an urgent task is not only to fix the level of pollution, but also to develop approaches to restoring disturbed ecosystems. It is necessary to study the prospects of biorecultivation of landfills using plant species resistant to stressful conditions, capable of functioning in conditions of increased heavy metal content and transformed water-salt regime [9]. This highlights the need for a comprehensive analysis combining chemical pollution indicators and a geobotanical assessment of the vegetation cover.

Geobotanical characteristics (the taxonomic structure of the flora, the proportion of short-lived life forms, and the dominance of ruderal/stress-tolerant species) can act as bioindicative signs of ecosystem transformation under the influence of metals, complementing the calculations of phytotoxicity (FTI) and making it possible to substantiate the ecological consequences for vegetation cover [10].

Thus, the relevance of this study is determined by: (1) the ecological significance of closed landfills as long-term sources of soil pollution with heavy metals [11]; (2) the lack of data on spatial heterogeneity of pollution within the body of the landfill; (3) the need to integrate chemical indicators (exceeding standards, Igeo, FTI) with the geobotanical assessment of vegetation cover transformation for scientifically based monitoring and selection of reclamation priorities in the conditions of Northern Kazakhstan.

Experimental

The study was performed at a closed solid waste landfill located in the eastern part of the city of Kokshetau (Akmola region, Northern Kazakhstan), on the border of the southwestern edge of the West Siberian Plain and the northern slopes of the Kokshetau upland (53.320833°N, 69.478333° E). The territory belongs to a moderately arid forest-steppe zone characterized by a sharply continental climate, a large annual temperature range, and insufficient precipitation.

The 36.5-hectare landfill was operated from 1960 to 2017. It is a multilayered waste body covered with soil, without waterproofing liners or leachate collection systems. The height of the garbage dumps reaches 5–7 m. Despite the official closure, unauthorized waste storage remains in some areas, which increases the anthropogenic burden on the ecosystem.

Soil sampling on the territory of a closed MSW landfill was carried out according to a radial gradient scheme in order to assess the spatial distribution of heavy metals depending on the distance from the center of the landfill. The zone of maximum capacity of a man-made body and the greatest accumulation of waste was considered as a conditional center. Figure 1 shows the sampling points from the closed MSW landfill in Kokshetau.

Ten sampling points were established within the landfill body and grouped into functional zones: the core (points 1–3, up to 50 m from the center), the middle zone (points 4–6, 50–150 m), and the marginal zone (points 7–10, 150–300 m). One control soil sample was collected outside the landfill's impact zone (5–10 km away) under comparable natural conditions and used as a background reference for pollution assessment (Tab. 1).

At each sampling point, one composite sample representing the site was collected. In total, 11 samples were analyzed (10 from the landfill and 1 background sample). The sampling design was aimed at assessing spatial variability; therefore, no replicates were taken, and each point was treated as an independent observation unit.

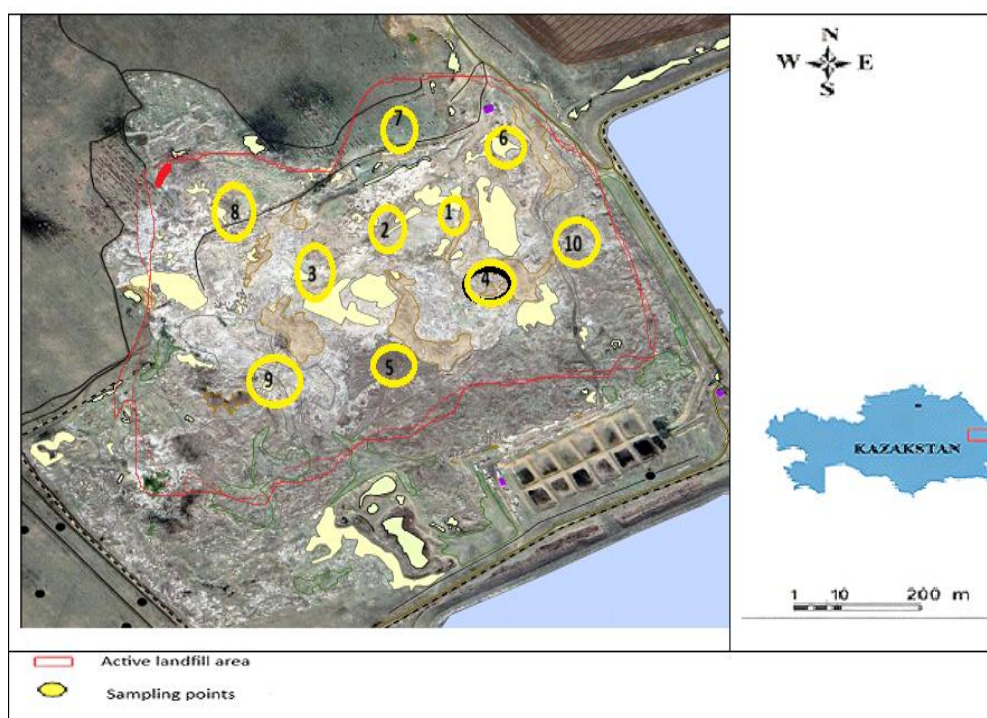


Figure 1. Map of the closed MSW landfill in Kokshetau (sampling points)

Table 1

The content of elements in soil samples of the closed MSW landfill in the city of Kokshetau

Samples	Zn	Cu	Mn	Sr	Pb	As	Ni
MPC	100	55	1500	30	32.0	2.0	40
Point 1	4230	760	1790	306	248	50	123
Point 2	2410	710	1830	389	299	45	145
Point 3	1620	870	1210	323	292	58	103
Point 4	1640	610	960	264	208	46	141
Point 5	1660	566	1140	225	151	42	124
Point 6	1100	440	1010	261	104	29	106
Point 7	249	237	930	211	128	29	76
Point 8	510	184	690	161	90	26	103
Point 9	235	144	660	126	71	24	62
Point 10	700	234	500	153	64	21	52
BACKGROUND	88	102	450	89	15	14	46

The sampling depth varied depending on the morphological position of the site. In the central part of the body of the landfill, samples were taken from a depth of 0–50 cm, which is due to the significant capacity of the anthropogenic horizon and the vertical migration of pollutants. In the middle and marginal parts of the body of the landfill, samples were taken from the upper soil layer (0–20 cm), which is most actively involved in the processes of interaction with vegetation.

This approach made it possible to identify the spatial gradient of soil pollution and assess the decrease in heavy metal concentrations as they moved away from the center of the landfill.

The total concentrations of heavy metals (Pb, Zn, Cu, Ni, As, Hg) in soil samples were determined using a portable X-ray fluorescence (XRF) analyzer, Olympus Vanta Pro series VCR, equipped with GeoChem software.

The analytical method is based on the X-ray fluorescence effect: when a sample is irradiated with primary X-rays, the atoms become excited and emit secondary (fluorescent) radiation. The energy spectrum of this radiation is characteristic of each chemical element, allowing both qualitative and quantitative determination.

The Olympus Vanta Pro analyzer is equipped with a 4 W X-ray tube with a rhodium (Rh) anode and a high-resolution large-area silicon drift detector (SDD, up to 50 mm²), ensuring high sensitivity and measurement accuracy for elements starting from magnesium (Mg) and above in the periodic table.

The instrument is also fitted with an integrated GPS module and a digital camera, enabling georeferencing of sampling locations and improving the accuracy of spatial analysis and contamination mapping.

The level of soil contamination was assessed by comparing the measured concentrations with the maximum permissible concentrations (MPCs) of heavy metals established by current sanitary and hygienic standards for soils. The background sample was used as a local geochemical reference for comparative assessment and for calculating integrated pollution indices [12].

Geobotanical studies were carried out on the territory of the closed MSW landfill in Kokshetau in August–October 2025. The vegetation survey was carried out by the route-site method with the laying of test areas (10 × 10 m) within the functional zones of the polygon body (core, middle and marginal parts) (Fig. 2), identified by the results of the analysis of the spatial distribution of heavy metals in soils.

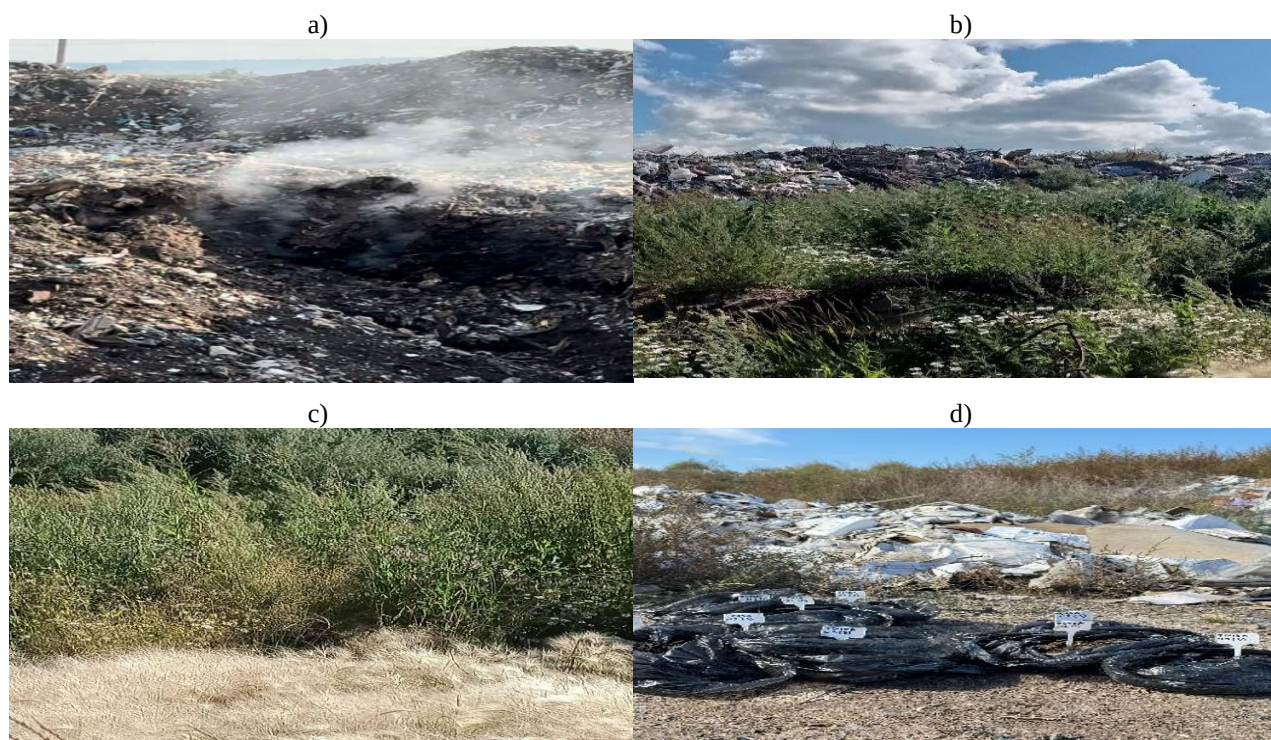


Figure 2. Closed municipal solid waste landfill in Kokshetau (53.320833° N; 69.478333° E):

(a) central part of the landfill body; (b) middle zone; (c) marginal zone;
(d) collected soil samples stored in polyethylene bags for subsequent laboratory analysis

A complete description of the vegetation cover was carried out at each site, with registration of all types of vascular plants. Taxonomic affiliation, life form, ecological group, and relative abundance were determined for each species; the projective coverage was assessed on the Brown–Blanke scale.

The interpretation of geobotanical data was carried out in comparison with concentrations of heavy metals and integrated pollution indicators (Igeo, phytotoxic index), which made it possible to assess the impact of anthropogenic soil pollution on the structure and composition of plant communities.

Statistical data processing included the calculation of descriptive indicators, analysis and geoaccumulation indices. The geoaccumulation index (Igeo) was calculated using a background control sample. The geoaccumulation index for each element was calculated using the formula:

$$I_{geo,i} = \log_2 \left(\frac{C_i}{1.5 \cdot C_{i, fon}} \right) \quad I_{geo,i} = \log_2 \left(\frac{C_i}{1.5 \cdot C_{i, fon}} \right) \quad (1)$$

where C_i is the concentration of the element in the soil, mg/kg; $C_{i, fon}$ is the background concentration in the control sample, mg/kg; the coefficient 1.5 takes into account the natural variability of background concentrations.

The phytotoxic index (FTI) was calculated as the average value of the multiplicities exceeding the maximum permissible concentration for Zn, Cu, Pb, As and Ni, after which the values obtained were averaged over the functional zones of the landfill to assess the spatial variability of soil phytotoxicity.

Results and Discussion

The results of the analysis of soil samples showed pronounced anthropogenic contamination of the territory of the closed landfill with heavy metals (Tab. 2). The maximum concentrations of zinc reached 4230 mg/kg, which exceeds the maximum permissible concentration by 42.3 times and the background values by 48.1 times. Significant exceedances were also recorded for arsenic (up to 29 MPC), copper (up to 15.8 MPC) and lead (up to 9.3 MPC). Nickel was characterized by more moderate but steady exceedances of standards (up to 3.6 MPC).

Table 2

Multiplicity of exceeding the maximum permissible concentration and background (maximum values)

Element	max C, mg/kg	C/MPC mg/kg	C/background mg/kg
Zn	4230	42,3	48,1
Cu	870	15,8	8,5
Pb	299	9,3	19,9
As	58	29,0	4,1
Ni	145	3,6	3,2

The data indicate the dominant role of Zn and As in forming the phytotoxic background of the landfill, due to their high biological activity and inhibitory effects on plant growth even at relatively low concentrations [13]. Elevated background exceedances of Pb and Cu reflect their long-term accumulation during landfill operation [14].

The observed contamination levels are consistent with those reported for MSW landfills worldwide, where elevated concentrations of Zn, Pb, Cu, and As and their accumulation in topsoil are commonly observed. Similar exceedance ranges and radial contamination gradients have been documented in Europe, China, and Central Asia [10, 11, 15], indicating the universal nature of heavy metal accumulation and migration in technogenically disturbed ecosystems.

Analysis of average metal concentrations across functional zones revealed a pronounced spatial gradient (Tab. 3). The highest levels were recorded in the landfill core (Zn — 2753, Cu — 780, Pb — 280 mg/kg), with decreasing concentrations toward the middle and marginal zones; however, even peripheral areas remained above background levels.

Table 3

Average concentrations by functional zones, mg/kg

The zone	Zn	Cu	Mn	Sr	Pb	As	Ni
Core (1-3)	2753	780	1610	339	280	51	124
Average (4-6)	1467	539	1037	250	154	39	124
Regional (7-10)	424	200	695	163	88	25	73

This pattern reflects the peculiarities of the landfill's functioning as a source of long-term anthropogenic impact: the central part is characterized by maximum accumulation of waste and filtrate, while partial dispersion of pollutants occurs as it moves away from it. Nevertheless, even the peripheral areas retain signs of sustained anthropogenic pollution, which underlines the long-term nature of the landfill's impact on the soil cover (Tab. 4) [14].

Table 4

Phytotoxic index (FTI) by zone

The zone	FTI	Evaluation
The core	15.81	Very high phytotoxicity
The middle part	10.38	High
The edge part	4.99	Moderate

The calculation of the geoaccumulation index made it possible to quantify the degree of soil contamination by individual elements (Tab. 5). For zinc, Igeo values in the central part of the landfill reached 5.0, which correspond to the class of extremely polluted soils. For lead, Igeo values at points 1–4 were in the range of 3.21–3.73, which also indicates severe and extreme contamination. Copper was characterized by Igeo values ranging from moderate to severe contamination, while arsenic corresponded to a moderate level of contamination at most points.

Table 5

Geoaccumulation Index (Igeo) for key elements

Point	Zn	Cu	Pb	As
1.0	5.0	2.31	3.46	1.25
2.0	4.19	2.21	3.73	1.1
3.0	3.62	2.51	3.7	1.47
4.0	3.64	2.0	3.21	1.13
5.0	3.65	1.89	2.75	1.0
6.0	3.06	1.52	2.21	0.47
7.0	0.92	0.63	2.51	0.47
8.0	1.95	0.27	2.0	0.31
9.0	0.83	-0.09	1.66	0.19
10.0	2.41	0.61	1.51	0.0

Igeo values decreased in the marginal zone of the polygon body, however, levels corresponding to moderate and severe pollution remained for a number of elements (Zn and Pb). This indicates that the anthropogenic impact of the landfill extends beyond its central part and forms a sustainably disturbed anthropogenic territory.

Such geoaccumulation index values are typical of areas with long-term waste accumulation and the absence of engineered barriers, which is confirmed by similar studies on closed landfills, where Igeo values for Zn and Pb often reach categories of strong to extreme contamination [11, 14].

An analysis of the spatial profile of the distribution of concentrations of heavy metals (Zn, Cu, Pb and As), shown in Figure 3, revealed a pronounced gradient of soil pollution from the central part of the closed landfill to its periphery. The maximum concentrations of all the studied elements were recorded in the central zone of the landfill body, reflecting the long-term accumulation of pollutants in the zone of maximum waste deposition [15].

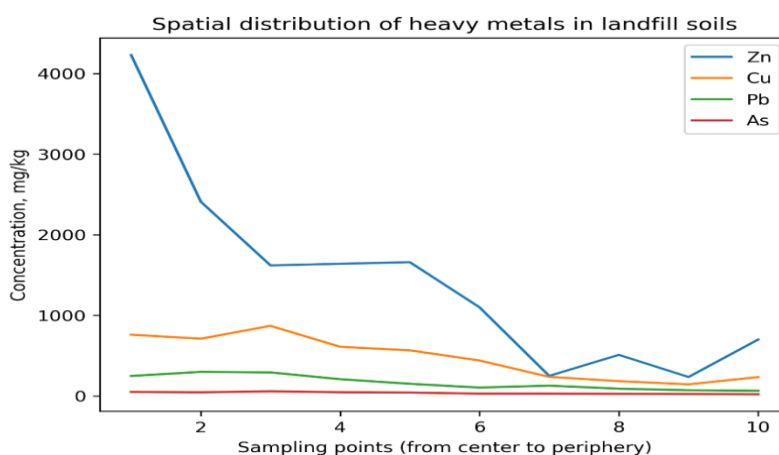


Figure 3. Spatial profile of the distribution of concentrations of heavy metals (Zn, Cu, Pb, As) from the center of the landfill to the periphery

The sharpest contrast is observed for zinc, whose concentrations in the central points exceed the values in the marginal zone by several times. A similar, though less pronounced, trend is observed for copper and lead, indicating similar mechanisms governing their input and migration within the landfill body. For arsenic,

concentrations also decrease with distance from the center, but its distribution profile is more smoothed, which may indicate increased mobility of this element and its redistribution with the filtrate [15].

The revealed pattern of distribution of heavy metals confirms that the central part of the landfill is the main zone of phytotoxic background formation. As they move away from the center, metal concentrations decrease, but even in the peripheral zone their levels remain above the background values, which indicates a stable anthropogenic impact and long-term persistence of pollution in the soil cover after the closure of the landfill [13].

The spatial distribution of heavy metals within the landfill is controlled by a combination of interrelated migration processes in a technogenically disturbed environment. A key mechanism is the infiltration of atmospheric precipitation through the landfill body: in the absence of impermeable liners and leachate collection systems, contaminated leachate is formed, promoting the vertical migration of dissolved and suspended metal forms, particularly in the central zone with maximum waste accumulation [16].

Surface runoff also plays a significant role by transporting fine contaminated material to lower relief areas and peripheral zones, explaining the persistence of elevated concentrations even at a distance from the landfill center [14]. Under conditions of sparse vegetation and a continental climate, aeolian transport further contributes to the dispersal of contaminated dust and secondary pollution of surrounding areas [15].

Microrelief additionally influences spatial differentiation: depressions act as accumulation zones for moisture, leachate, and fine particles, enhancing local metal concentrations and mobility, especially for arsenic [16].

Thus, the radial gradient of contamination results from the combined effects of infiltration, surface runoff, aeolian transport, and local accumulation, ensuring both vertical and horizontal migration of metals and their long-term persistence after landfill closure [10, 11].

The distribution of Zn, Cu, Pb, and As concentrations across the functional zones of the landfill body, shown in Figure 4, reflects significant differences in the environmental conditions of vegetation cover formation.

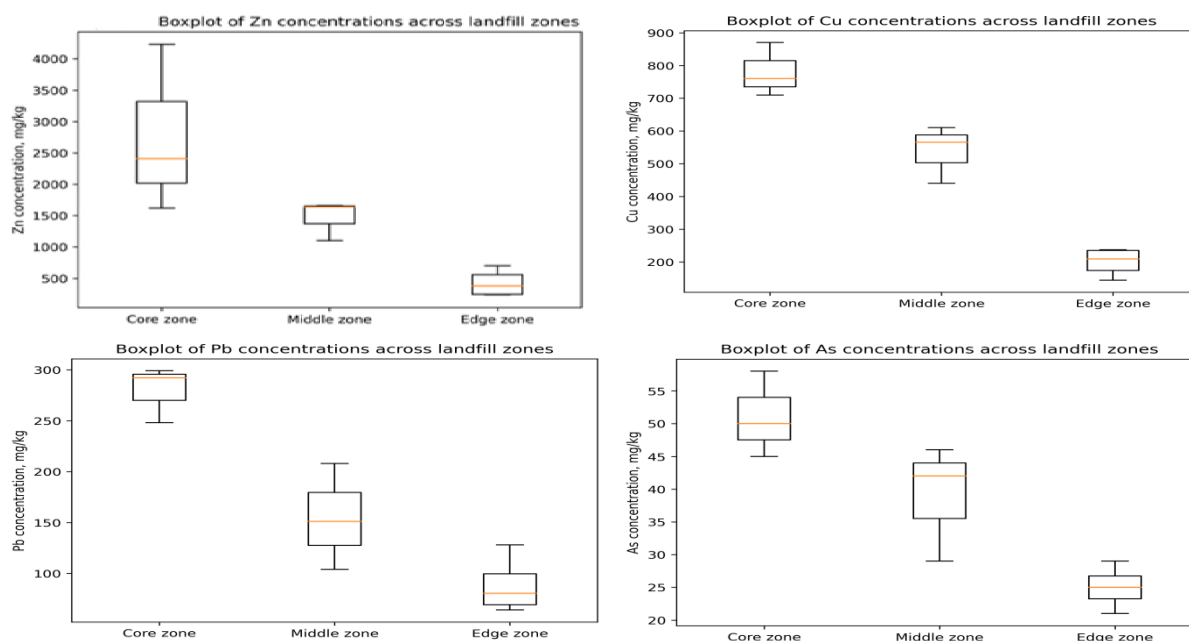


Figure 4. Boxplot of the distribution of Zn, Cu, Pb, and As concentrations by functional zones of the polygon body

The core of the landfill is characterized by the highest median values and significant variability in heavy metal concentrations, which indicates the formation of a pronounced phytotoxic background. Under these conditions, the development of zonal steppe phytocenoses is significantly limited, and the vegetation cover is mainly represented by ruderal and stress-tolerant species with a short life cycle [14].

In the middle part of the landfill, a decrease in pollution levels is accompanied by a partial increase in floral diversity, but persistent elevated concentrations of heavy metals continue to exert selective pressure on vegetation. In the marginal zone, where the median concentrations are minimal, there are signs of restoration

of zonal vegetation elements, but their sustainable development is hindered by residual soil pollution. Thus, the spatial differentiation of the heavy metal content is directly reflected in the structure and composition of the flora and determines the formation of specific anthropogenic phytocenoses on the territory of a closed landfill (Fig. 5).

The revealed high concentrations of heavy metals in the soils of a closed landfill have a decisive effect on the formation and spatial structure of vegetation cover. The recorded dominance of individual taxonomic groups and plant life forms reflects the adaptation of the flora to conditions of sustained anthropogenic and phytotoxic effects.

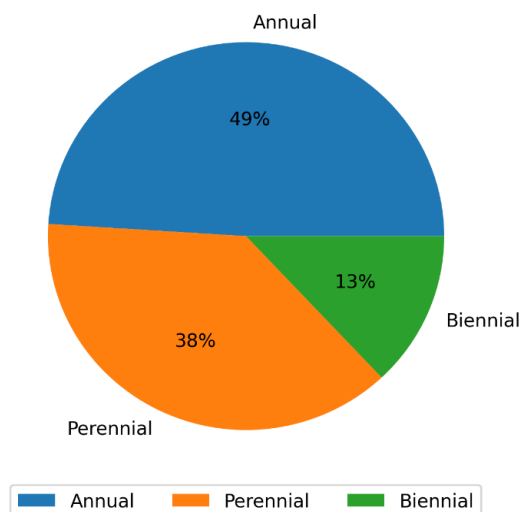


Figure 5. Distribution of plant life forms at the closed MSW landfill in Kokshetau

The found predominance of representatives of the *Asteraceae* (more than 25% of species), *Poaceae*, *Brassicaceae*, and *Chenopodiaceae* families is characteristic of anthropogenic disturbed ecosystems and is consistent with an increased content of Zn, Cu, Pb, and As in soils (Fig. 6). Many species of these families have high ecological plasticity, a short life cycle, and the ability to tolerate chemical stress, including heavy metal pollution. This is confirmed by the high participation of annual species (49%), while the share of perennials and biennials is 38% and 13%, respectively, which is typical for disturbed and technogenically transformed territories [12].

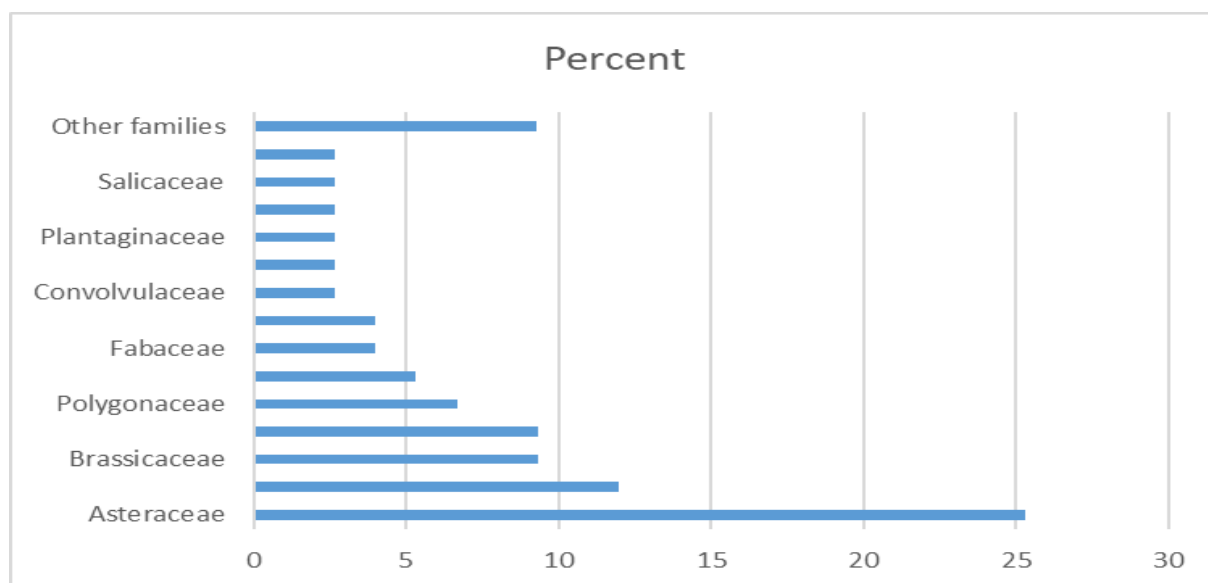


Figure 6. Floristic spectrum of plant species at the closed MSW landfill in Kokshetau (% of total species)

The low representation of woody plants and the predominance of herbaceous vegetation indicate unfavorable edaphic conditions for the formation of stable multi-tiered phytocenoses. Heavy metals, accumulating in the upper technogenically transformed horizon, limit the development of the deep root system and prevent the consolidation of tree species, which explains their sporadic presence in the form of single seedlings [13].

Geobotanical analysis showed that a substantial part of the flora is represented by meadow-steppe species typical of the regional vegetation. However, classical turf-grass steppes of the *Festuco-Brometea* class are largely degraded or only fragmentarily preserved. Their replacement by ruderal and stress-tolerant species indicates a profound transformation of natural phytocenoses under prolonged soil contamination.

The vegetation includes numerous ruderal and stress-tolerant species such as *Bassia scoparia*, *Atriplex patula*, *Chenopodium album*, *Artemisia* spp., and *Plantago major*, which are characteristic of technogenically disturbed environments. These species exhibit high tolerance to salinity, moisture deficit, and elevated heavy metal concentrations, forming the basis of secondary plant communities.

Particular importance is attached to wetland and halophytic species (*Phragmites australis*, *Suaeda prostrata*, *Atriplex patula*, *Persicaria hydropiper*) associated with moist areas and leachate accumulation zones. These habitats are characterized by altered hydrological conditions and increased metal mobility, enhancing selective pressure on vegetation and promoting the formation of specific local phytocenoses [16].

Several species can be considered ecological indicators. In particular, *Bassia scoparia*, *Atriplex patula*, and *Suaeda prostrata* indicate saline and technogenically disturbed soils, while *Phragmites australis* reflects zones of increased moisture and leachate accumulation. Their distribution highlights spatial heterogeneity and the degree of ecosystem transformation.

No widespread occurrence of aggressive invasive species was recorded; however, the presence of synanthropic plants indicates a high level of anthropogenic transformation of the vegetation cover.

The dominance of *Bassia scoparia* (average coverage 21.92%, frequency 50%) with high average projective coverage and frequency of occurrence is indicative from a geobotanical point of view. This species is known as a typical ruderal and halophytic element, resistant to salinity, moisture deficiency, and elevated concentrations of heavy metals. Its wide distribution and the formation of dense thickets in the most polluted areas of the landfill allow us to consider *Bassia scoparia* as a bioindicator of technogenically disturbed and phytotoxic substrates [17, 18].

Thus, the spatial structure of vegetation and its taxonomic composition in a closed landfill directly reflect the level and nature of soil contamination with heavy metals. The formed plant communities are stable anthropogenic phytocenoses dominated by species adapted to chemical stress and disturbed water-soil regime, which confirms the long-term and persistent impact of the landfill on the ecosystem.

Conclusion

The closed municipal solid waste landfill in Kokshetau is characterized by a high level of technogenic soil contamination with heavy metals, formed as a result of the long-term operation of the facility (1960–2017) and the lack of engineering protection systems. The maximum concentrations of zinc, copper, lead and arsenic are many times higher than the maximum permissible and background values, which indicates the persistent nature of soil contamination.

An analysis of the spatial distribution of pollutants revealed a pronounced radial-gradient nature of pollution: the highest levels of concentrations and multiplicity of excess standards were recorded in the central part of the landfill body, while as they move away to the periphery, their consistent decrease is noted. At the same time, concentrations of heavy metals exceeding the background values remain even in the marginal zone, which indicates a long-term preservation of anthropogenic impact after the closure of the landfill.

The calculation of the geoaccumulation index (Igeo) showed that the soils of the central part of the landfill belong to the categories of highly and extremely polluted, primarily by Zn and Pb. Igeo values decrease in the middle and marginal parts, however, levels corresponding to moderate and severe pollution remain for individual elements, which confirms the functional heterogeneity of the polygon body.

The values of the phytotoxic index (FTI) by functional zones indicate the formation of a pronounced phytotoxic background in the central and middle parts of the landfill. The decrease in FTI to the periphery reflects a decrease in chemical stress, but its levels remain sufficient to limit the development of zonal plant communities and maintain conditions of selective pressure on the flora.

Geobotanical studies have shown that soil pollution with heavy metals has a decisive effect on the structure and composition of vegetation cover. The flora of the landfill is mainly represented by herbaceous

and short-lived species, while the proportion of annual plants reaches 49%, which is typical for ecosystems with unstable and phytotoxic edaphic conditions.

The taxonomic structure of vegetation is characterized by the dominance of the *Asteraceae*, *Poaceae*, *Brassicaceae* and *Chenopodiaceae* families, typical of anthropogenic disturbed areas and resistant to chemical stress. The low representation of tree species indicates unfavorable soil conditions for the formation of stable multi-tiered phytocenoses.

The spatial distribution of plant communities is consistent with the soil pollution gradient: ruderal and stress-tolerant phytocenoses are formed in the central zones, while only partially preserved elements of zonal meadow-steppe vegetation are noted in the marginal part. The dominance of *Bassia scoparia* in the most polluted areas allows us to consider this species as a potential bioindicator of technogenically disturbed and phytotoxic substrates.

Considering the identified level of contamination and its spatial heterogeneity, a key priority for future work is the establishment of a systematic environmental monitoring program. Monitoring should include regular assessment of heavy metal concentrations in soils and vegetation, evaluation of phytotoxicity dynamics, and the use of geobotanical and bioindication methods to track ecosystem recovery processes.

A promising and environmentally sound approach to reclamation is phytoremediation, based on the use of pollution-tolerant plant species. Species selection should account for their ability to withstand high concentrations of heavy metals, accumulate them in biomass, stabilize the soil cover, and reduce contaminant mobility. The establishment of a stable vegetation cover will not only limit metal migration but also enhance the ecological resilience of the territory.

In general, a closed MSW landfill should be considered as a sustainably transformed anthropogenic ecosystem in which soil contamination with heavy metals continues to determine environmental conditions and biological processes even after the facility is discontinued. The results obtained emphasize the need to take into account accumulated anthropogenic pollution when assessing the ecological status and developing measures for the reclamation of such territories.

Funding

The research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan. It is supported through grant funding for scientific and/or scientific-technical projects for the years 2024–2026, with project duration of 36 months. Project title: Development of technology for reclamation of a closed solid waste landfill in the Akmola region by creating a model of artificial phytocenoses. Project IRN: AP23487981.

Author contribution

The manuscript was written through contributions of all authors. All authors have given approval to the final version of the manuscript. CRediT: **Bayazitova Z.E.** — attracting financing, research, writing a draft, editing, **Kurmanbayeva A.S.** — collecting samples, editing, conceptualization, data processing, methodology; **Safronova N.M.** — data processing, methodology, formal analysis, editing; **Japarova S.B.** — collecting samples, methodology, preparation of drawings.

Conflict of Interest

The authors declare no conflict of interest.

References

- 1 Štrbac S. Heavy metal concentrations in soil near illegal landfills: Ecological implications and ANN hazard prediction / S. Štrbac, L. Mandić, B. Škrbić, M. Marković // *Journal of Soils and Sediments*. — 2024. — Vol. 24(1). — P. 1–17. <https://doi.org/10.1007/s11368-023-03637-1>
- 2 Агаркова С.В. Проблемы утилизации твердых бытовых отходов / С.В. Агаркова // *Вестник науки*. — 2020. — Т. 2, № 3 (24). — С. 71–74.
- 3 Glazyrin S.A. Analysis of the efficiency and environmental impact of municipal solid waste incineration as a tool for sustainability development in Kazakhstan / S.A. Glazyrin, E.E. Kopishev, M.G. Zhumagulov, Z.A. Bimurzina, Y.K. Aibuldinov // *Sustainability*. — 2025. — Vol. 17(19). — Article ID 8696. <https://doi.org/10.3390/su17198696>
- 4 Kurmanbayeva A. Waste accumulation and geoecological assessment of the territories around the landfills in Kokshetau / A. Kurmanbayeva, Z. Bayazitova, A. Talal, A. Kakabayev, S. Zhaparova // *International Journal of GEOMATE*. — 2022. — Vol. 23, Iss. 96. — P. 179–185. <https://doi.org/10.21660/2022.96.j2384>

- 5 Inglezakis V.J. Municipal solid waste management in Kazakhstan: Astana and Almaty case studies / V.J. Inglezakis, K. Moustakas, G. Khamitovac, D. Tokmurzin, R. Rakhmatulina, B. Serik, Y. Abikak // *Chemical Engineering Transactions*. — 2017. — Vol. 56. — P. 565–570. <https://doi.org/10.3303/CET1756095>
- 6 Aibuldinov Y. K. Analysis of the composition and properties of municipal solid waste in various cities of Kazakhstan / Y.K. Aibuldinov, S.A. Glazyrin, E.E. Kopishev, M.G. Zhumagulov, Z.A. Bimurzina // *Energies*. — 2024. — Vol. 17(24). — Article ID 6426. <https://doi.org/10.3390/en17246426>
- 7 Kaliaskarova Z.K. Soil pollution with heavy metals on the land of the Karasai landfill of municipal solid waste in Almaty city / Z.K. Kaliaskarova, Zh.N. Aliyeva, A.S. Ikanova, E.S.M. Negim // *News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences*. — 2019. — Vol. 6(438). — P. 256–267. <https://doi.org/10.32014/2019.2518-170X.177>
- 8 Bayazitova Z.E. Assessment of ecological danger of seepage water solid waste landfill of Kokshetau / Z.E. Bayazitova, A.S. Kurmanbayeva, A.A. Kakabayev, S.B. Zhaparova, G.S. Baituk, A. Zandybay, G.E. Baikenova // *Bulletin of Kazakh National University. Ecological series*. — 2022. — Vol. 70(1). — P. 46–55. <https://doi.org/10.26577/EJE.2022.v70.i1.05>
- 9 Курманбаева А.С. Биорекультивация полигонов твёрдых бытовых отходов / А.С. Курманбаева, З.Е. Баязитова, Н.М. Сафронова // *Eurasian Journal of Applied Biotechnology*. — 2024. — № 3S.
- 10 Akter S. Heavy metal contamination of surface soils: concentrations, sources, and ecological risks / S. Akter, A. Huq, M. Uddin // *Environmental Geochemistry & Health*. — 2025. — Vol. 198. — Article ID 165. <https://doi.org/10.1080/03067319.2023.2280180>
- 11 Qi J. Heavy metal contamination in soil and ecological risk assessment near waste disposal sites / J. Qi, Y. Zhang, X. Chen // *PeerJ*. — 2024. — Vol. 12. — e18510. <https://doi.org/10.7717/peerj.18510>
- 12 Гигиенические нормативы ПДК химических веществ в почве. — [Электронный ресурс]. — Режим доступа: https://adilet.zan.kz/rus/docs/V2100022595?utm_source=chatgpt.com
- 13 Broadley M. R. Zinc in plants / M. R. Broadley, P.J. White, J.P. Hammond, I. Zelko, A. Lux // *New Phytologist*. — 2007. — Vol. 173(4). — P. 677–702. <https://doi.org/10.1111/j.1469-8137.2007.01996.x>
- 14 Finnegan P. M. Arsenic toxicity: the effects on plant metabolism / P.M. Finnegan, W. Chen // *Frontiers in Physiology*. — 2012. — Vol. 3. — Article ID 182. <https://doi.org/10.3389/fphys.2012.00182>
- 15 Cai S. Assessment of metal pollution and effects of physicochemical factors on soil microbial communities around a landfill / S. Cai, S. Zhou, Q. Wang, J. Cheng, B. Zeng // *Ecotoxicology and Environmental Safety*. — 2024. — Vol. 271. — Article ID 115968. <https://doi.org/10.1016/j.ecoenv.2024.115968>
- 16 Khan S. Global soil pollution by toxic elements: Current status and future perspectives / S. Khan, M. Naushad, E.C. Lima, et al. // *Science of the Total Environment*. — 2021. — Vol. 778. — P. 146–171. <https://doi.org/10.1016/j.scitotenv.2021.146171>
- 17 Nagajyoti P. C. Heavy metals, occurrence and toxicity for plants / P.C. Nagajyoti, K.D. Lee, T.V.M. Sreekanth // *Environmental Chemistry Letters*. — 2010. — Vol. 8. — P. 199–216. <https://doi.org/10.1007/s10311-010-0297-8>
- 18 Prach K. Four opportunities for studies of ecological succession / K. Prach, L. R. Walker // *Trends in Ecology & Evolution*. — 2011. — No. 26. — P. 119–123. <https://doi.org/10.1016/j.tree.2010.12.007>

З.Е. Баязитова, А.С. Құрманбаева, Н.М. Сафронова, С.Б. Жапарова

Көкшетау қаласындағы қатты тұрмыстық қалдықтар жабық полигонының топырақ пен өсімдік жамылғысының жағдайын экологиялық және биологиялық бағалау

Көкшетау қаласындағы 1960–2017 жылдары пайдаланылған, инженерлік қорғаныс жүйелерімен жабдықталмаған жабық қатты тұрмыстық қалдықтар (ҚТҚ) полигонының экологиялық жағдайы ауыр металдармен ластану және оның өсімдік жамылғысына әсері тұрғысынан бағаланды. Топырақ талдауы Zn, Cu, Pb және As элементтері бойынша шекті рұқсат етілген және фондық концентрациялардың бірнеше есе артқанын көрсетті. Максималды концентрациялар келесідей болды: Zn — 4230 мг/кг, Cu — 870 мг/кг, Pb — 299 мг/кг, As — 58 мг/кг және Ni — 145 мг/кг, бұл шекті рұқсат етілген концентрациялардан тиісінше 42,3; 15,8; 9,3; 29,0 және 3,6 есе жоғары. Фондық мәндермен салыстырғанда элементтердің мөлшері Zn үшін 48,1 есе, Cu үшін 8,5 есе, Pb үшін 19,9 есе, As үшін 4,1 есе және Ni үшін 3,2 есе артқан. Ластанудың айқын радиалды-градиенттік сипаты анықталды: ең жоғары концентрациялар мен нормативтік көрсеткіштердің артуы полигонның орталық бөлігінде тіркеліп, шеткі аймақтарға қарай біртіндеп төмендеген. Алайда шеткі учаскелердің өзінде фондық деңгейден жоғары концентрациялар сақталып, полигон жабылғаннан кейін де антропогендік әсердің тұрақты екенін көрсетті. Геоаккумуляция индексі (Igeo) бойынша орталық аймақ топырақтары, әсіресе Zn және Pb элементтері тұрғысынан, күшті және аса күшті ластанған санатқа жатқызылды. Фитоуыттылық индексі (FTI) орталық және ортаңғы аймақтарда айқын фитоуытты фонның қалыптасқанын растады. Геоботаникалық зерттеулер өсімдік қауымдастықтарының елеулі трансформацияға ұшырағанын көрсетті. Флора негізінен шөптесін және қысқа өмірлі түрлермен сипатталады, біржылдық өсімдіктердің үлесі 49 %-ды құрайды. Таксономиялық құрылымында *Asteraceae*, *Poaceae*,

Brassicaceae және *Chenopodiaceae* тұқымдастары басым, бұл антропогендік бұзылған және химиялық стресс жағдайларына тән. Жоғары деңгейде ластанған учаскелерде *Bassia scoparia* түрінің басымдығы оны техногендік бұзылған субстраттардың әлеуетті биоиндикаторы ретінде қарастыруға мүмкіндік береді. Жалпы алғанда, жабық ҚТҚ полигоны ауыр металдардың жинақталған ластануы экологиялық жағдай мен биологиялық үдерістерді айқындауды жалғастырып отырған тұрақты трансформацияланған антропогендік экожүйе. Бұл жағдай кешенді мониторинг пен рекультивация стратегияларын әзірлеудің қажеттілігін көрсетеді.

Кілт сөздер: қатты тұрмыстық қалдықтар полигоны, топырақтың ластануы, фитоуыттылық, антропогендік әсер, ауыр металдар, экожүйенің бұзылуы.

З.Е. Баязитова, А.С. Курманбаева, Н.М. Сафронова, С.Б. Жапарова

Эколого - биологическая оценка состояния почв и растительного покрова закрытого полигона твёрдых бытовых отходов в г. Кокшетау

Проведена оценка экологического состояния закрытого полигона твёрдых бытовых отходов (ТБО) в г. Кокшетау, эксплуатировавшегося в 1960–2017 гг. и не оснащённого инженерными защитными системами, с акцентом на загрязнение тяжёлыми металлами и его влияние на растительный покров. Анализ почв выявил многократные превышения предельно допустимых и фоновых концентраций Zn, Cu, Pb и As. Максимальные концентрации составили: Zn — 4230 мг/кг, Cu — 870 мг/кг, Pb — 299 мг/кг, As — 58 мг/кг и Ni — 145 мг/кг, что превышает предельно допустимые концентрации соответственно в 42,3; 15,8; 9,3; 29,0 и 3,6 раза. По сравнению с фоновыми значениями содержание элементов увеличено в 48,1 раза для Zn, в 8,5 раза для Cu, в 19,9 раза для Pb, в 4,1 раза для As и в 3,2 раза для Ni. Установлен выраженный радиально-градиентный характер загрязнения: максимальные концентрации и кратность превышения нормативов зафиксированы в центральной части тела полигона с последующим постепенным снижением к периферии. Однако даже в краевых зонах отмечаются значения выше фоновых уровней, что свидетельствует о сохранении устойчивого антропогенного воздействия после закрытия объекта. Расчёт индекса геоаккумуляции (Igeo) показал, что почвы центральной части относятся к категории сильно и экстремально загрязнённых, прежде всего по Zn и Pb. Значения фитотоксического индекса (FTI) подтвердили формирование выраженного фитотоксического фона в центральной и средней зонах полигона. Геоботанические исследования выявили существенную трансформацию растительных сообществ. Флора представлена преимущественно травянистыми и короткоживущими видами; доля однолетних растений составляет 49 %. Таксономическая структура характеризуется доминированием семейств *Asteraceae*, *Poaceae*, *Brassicaceae* и *Chenopodiaceae*, типичных для нарушенных и химически стрессированных местообитаний. Преобладание *Bassia scoparia* в наиболее загрязнённых участках позволяет рассматривать данный вид как потенциальный биоиндикатор техногенно нарушенных субстратов. В целом закрытый полигон ТБО представляет собой устойчиво трансформированную антропогенную экосистему, в которой накопленное загрязнение тяжёлыми металлами продолжает определять экологические условия и биологические процессы, что подчёркивает необходимость комплексного мониторинга и разработки мер рекультивации.

Ключевые слова: полигон твёрдых бытовых отходов, загрязнение почв, фитотоксичность, антропогенное воздействие, тяжёлые металлы, нарушение экосистемы.

References

- 1 Štrbac, S., Mandić, L., Škrbić, B., & Marković, M. (2024). Heavy metal concentrations in soil near illegal landfills: Ecological implications and ANN hazard prediction. *Journal of Soils and Sediments*, 24(1), 1–17. <https://doi.org/10.1007/s11368-023-03637-1>
- 2 Agarkova, S. V. (2020). Problemy utilizatsii tverdykh bytovykh otkhodov [Problems of municipal solid waste disposal]. *Vestnik nauki — Science Bulletin*, 2, 3(24), 71–74 [in Russian].
- 3 Glazyrin, S. A., Kopishev, E. E., Zhumagulov, M. G., Bimurzina, Z. A., & Aibuldinov, Y. K. (2025). Analysis of the efficiency and environmental impact of municipal solid waste incineration as a tool for sustainability development in Kazakhstan. *Sustainability*, 17(19), 8696. <https://doi.org/10.3390/su17198696>
- 4 Kurmanbayeva, A., Bayazitova, Z., Talal, A., Kakabayev, A., & Zhaparova, S. (2022). Waste accumulation and geoecological assessment of the territories around the landfills in Kokshetau. *International Journal of GEOMATE*, 23(96), 179–185. <https://doi.org/10.21660/2022.96.j2384>
- 5 Inglezakis, V. J., Moustakas, K., Khamitov, G., Tokmurzin, D., Rakhmatulina, R., Serik, B., & Abikak, Y. (2017). Municipal solid waste management in Kazakhstan: Astana and Almaty case studies. *Chemical Engineering Transactions*, 56, 565–570. <https://doi.org/10.3303/CET1756095>

- 6 Aibuldinov, Y. K., Glazyrin, S. A., Kopishev, E. E., Zhumagulov, M. G., & Bimurzina, Z. A. (2024). Analysis of the composition and properties of municipal solid waste in various cities of Kazakhstan. *Energies*, 17(24), 6426. <https://doi.org/10.3390/en17246426>
- 7 Kaliaskarova, Z. K., Aliyeva, Zh. N., Ikanova, A. S., & Negim, E. S. M. (2019). Soil pollution with heavy metals on the land of the Karasai landfill of municipal solid waste in Almaty city. *News of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences*, 6(438), 256–267. <https://doi.org/10.32014/2019.2518-170X.177>
- 8 Bayazitova, Z. E., Kurmanbayeva, A. S., Kakabayev, A. A., Zhaparova, S. B., Baituk, G. S., Zandybay, A., & Baikenova, G. E. (2022). Assessment of ecological danger of seepage water solid waste landfill of Kokshetau. *Bulletin of Kazakh National Universiteti, Ecological series*, 70(1), 46–55. <https://doi.org/10.26577/EJE.2022.v70.i1.05>
- 9 Kurmanbayeva, A. S., Bayazitova, Z. E., & Safronova, N. M. (2024). Biorekultivatsiia polygonov tverdykh bytovykh otkhodov [Biorecultivation of municipal solid waste landfills]. *Eurasian Journal of Applied Biotechnology*, 3(Suppl.).
- 10 Akter, S., Huq, A., & Uddin, M. (2025). Heavy metal contamination of surface soils: concentrations, sources, and ecological risks. *Environmental Geochemistry & Health*, 198, 165. <https://doi.org/10.1080/03067319.2023.2280180>
- 11 Qi, J., Zhang, Y., & Chen, X. (2024). Heavy metal contamination in soil and ecological risk assessment near waste disposal sites. *PeerJ*, 12, e18510. <https://doi.org/10.7717/peerj.18510>
- 12 (2026). Gigienicheskie normativy PDK khimicheskikh veshchestv v pochve [Hygienic standards for maximum permissible concentrations (MPC) of chemical substances in soil]. *adilet.zan.kz*. Retrieved from <https://adilet.zan.kz/rus/docs/V2100022595> [in Russian].
- 13 Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., & Lux, A. (2007). Zinc in plants. *New Phytologist*, 173(4), 677–702. <https://doi.org/10.1111/j.1469-8137.2007.01996.x>
- 14 Finnegan, P. M., & Chen, W. (2012). Arsenic toxicity: the effects on plant metabolism. *Frontiers in Physiology*, 3, 182. <https://doi.org/10.3389/fphys.2012.00182>
- 15 Cai, S., Zhou, S., Wang, Q., Cheng, J., & Zeng, B. (2024). Assessment of metal pollution and effects of physicochemical factors on soil microbial communities around a landfill. *Ecotoxicology and Environmental Safety*, 271, 115968. <https://doi.org/10.1016/j.ecoenv.2024.115968>
- 16 Khan, S., Naushad, M., Lima, E. C. et al. (2021). Global soil pollution by toxic elements: Current status and future perspectives. *Science of the Total Environment*, 778, 146–171. <https://doi.org/10.1016/j.scitotenv.2021.146171>
- 17 Nagajyoti, P. C., Lee, K. D., & Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants. *Environmental Chemistry Letters*, 8, 199–216. <https://doi.org/10.1007/s10311-010-0297-8>
- 18 Prach, K., & Walker, L. R. (2011). Four opportunities for studies of ecological succession. *Trends in Ecology & Evolution*, 26, 119–123. <https://doi.org/10.1016/j.tree.2010.12.007>

Information about the authors

Bayazitova Zulfiya Erzatovna (contact person) — Candidate of Biological Sciences, Professor, Department of Mining, Construction and Ecology, Sh. Ualikhanov Kokshetau University, Kokshetau, Kazakhstan; e-mail: z_bayazitova@mail.ru; ORCID: <https://orcid.org/0000-0002-1106-0573>

Kurmanbayeva Aigul Saparbekovna — Candidate of Biological Sciences, Professor, Department of Mining, Construction and Ecology, Sh. Ualikhanov Kokshetau University, Kokshetau, Kazakhstan; e-mail: akurmanbayeva@shokan.edu.kz; ORCID: <https://orcid.org/0000-0002-6133-3226>

Safronova Natalya Mikhailovna — Candidate of Biological Sciences, Professor, Department of Biology and Teaching Methods, Sh. Ualikhanov Kokshetau University, Kokshetau, Kazakhstan; e-mail: natalyasafonova@shokan.edu.kz; ORCID: <https://orcid.org/0000-0001-5176-4404>

Zhaparova Sayagul Beketovna — Candidate of Biological Sciences, Professor, Department of Mining, Construction and Ecology, Sh. Ualikhanov Kokshetau University, Kazakhstan; e-mail: zhaparova.saya77@gmail.com; ORCID: <https://orcid.org/0000-0002-5346-5528>