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Original Article

Assessment of potential ecological risk of heavy metal contamination of agricultural soils in Kazakhstan

Avaliação do potencial risco ecológico de contaminação de solos agrícolas por metais pesados no Cazaquistão

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Abstract

Accumulation of heavy metals in soil can lead to the deterioration of soil quality, reduce soil fertility and crop yields, and thus threaten human and animal health. The study aimed to assess the potential ecological risk of heavy metal contamination of agricultural soils in Kazakhstan. The study was carried out in 2021 on the soils of the Zhdanovskoye owner-operated farm in the Sokolovsko-Sarybai district of the Kostanay region. The quantitative content of heavy metals, such as lead (Pb), mercury (Hg), arsenic (As), and cadmium (Cd), was determined, and concentrations of trace elements, such as zinc (Zn), copper (Cu), iron (Fe), and manganese (Mn), were calculated for the considered contaminated lands. The potential ecological risk index (*RI*) proposed by L. Hakanson was used in the study concerning heavy metal contamination of soil. As a result, the presence of trace elements and heavy metals in the considered areas of the Kostanay region was shown. The *RI* values for all sites ranged from 137 to 447, corresponding to the level of ecological risk grading from low to high. The average *RI* for As, Cd, Hg, Pb, Zn, Ni, and Cu amounted to 328, which indicates a high ecological risk. Detected levels of As, Cd, Zn, and Pb in long-term abandoned mining areas were well above national thresholds, indicating the impending need to fully investigate and assess the suitability of the land for further agricultural use. The availability of such data will allow predicting cluster-based development of processing infrastructures in the vicinity of agricultural lands.

Keywords: agricultural soils, ecological risk, heavy metal contamination, toxicity coefficient.

Resumo

A acumulação de metais pesados no solo pode levar à deterioração da qualidade do solo, reduzir a fertilidade do solo e o rendimento das colheitas, ameaçando assim a saúde humana e animal. O conteúdo quantitativo de metais pesados, como chumbo (Pb), mercúrio (Hg), arsênio (As) e cádmio (Cd), foi determinado, e as concentrações de oligoelementos, como zinco (Zn), cobre (Cu), ferro (Fe) e manganês (Mn), foram calculadas para as terras consideradas contaminadas. O índice de risco ecológico potencial (IR) proposto por L. Hakanson foi utilizado no estudo de contaminação do solo por metais pesados. Como resultado, foi demonstrada a presença de oligoelementos e metais pesados nas áreas consideradas da região de Kostanay. Os valores de IR para todos os locais variaram de 137 a 447, correspondendo ao nível de classificação de risco ecológico de baixo a alto. O IR médio para As, Cd, Hg, Pb, Zn, Ni e Cu foi de 328, o que indica um alto risco ecológico. Os níveis detectados de As, Cd, Zn e Pb em áreas mineiras abandonadas há muito tempo estavam bem acima dos limites nacionais, indicando a necessidade iminente de investigar e avaliar exaustivamente a adequação da terra para posterior utilização agrícola. A disponibilidade de tais dados permitirá prever o desenvolvimento baseado em clusters de infraestruturas de processamento nas proximidades de terras agrícolas.

Palavras-chave: solos agrícolas, risco ecológico, contaminação por metais pesados, coeficiente de toxicidade.

1. Introduction

1.1. Research problem

For many years, the attention of scientists has been focused on areas with minerals, arable areas (Kalashnikov et al., 2023), or areas reclaimed after mining (Kuandykova et al., 2023). Less attention has been paid to soil actively exposed to technogenic activities (Nardin and Nardina, 2021; Bugubaeva et al., 2023) and contamination (Nasiyev et al., 2021, 2022a). In the 1920s, the scale of technogenic transformations of the biosphere enormously increased due to the development of technology (Dudal, 2005).

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According to the Sustainable Development Goals defined by the UN General Assembly in 2015 (UN, 2015), the goal of protecting and restoring terrestrial ecosystems and promoting their rational use in agriculture increases the importance of the research problem and outlines future research trends in this area, creating conditions for improving the level and quality of human life and improving the environmental situation and efficient use of natural resources (Bagratuni et al., 2023; Yessimbek et al., 2022).

Kazakhstan's significant land resources (Mukhomedyarova et al., 2023) and a large number of state and owner-operated farms, pasture lands (Shayakhmetova et al., 2023), and agricultural enterprises confirm the relevance of the issue for the development of agriculture in the country within the concept of sustainable development of territories (Nuralina et al., 2023).

1.2. Literature review

Technogenic soils, i.e., soils created or significantly transformed by humans in industrial and urbanized areas, are among the most intensively studied soil groups (Kabała et al., 2020). The majority of the population lives in areas dominated by technogenic soils (Uzarowicz et al., 2000). Such areas can pose a danger to human health, flora, and fauna (Kondratenko et al., 2022; Shayakhmetova et al., 2023). Thus, they require special attention and monitoring (Warchulski et al., 2019; Sutkowska and Teper, 2015; Karczewska and Kabała, 2017; Józefowska et al., 2020).

The greatest concerns are caused by heavy metal contamination of soil (Bekezhanov et al., 2021; Li et al., 2020), which explains the focus of our study. Technogenic soil contamination is caused by various heavy metals, especially copper (Cu), nickel (Ni), cadmium (Cd), zinc (Zn), chromium (Cr), and lead (Pb) (Hinojosa et al., 2004). Heavy metals represent a group of elements with metallic properties that include transition metals, metalloids, lanthanides, and actinoids (Singh et al., 2011). Concentrations of cobalt (Co), Cu, iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), and Zn trace elements are strictly regulated by interactions with binding proteins because they pose a potential risk to cell function (Theron et al., 2012). Arsenic (As), Cd, Pb, mercury (Hg), plutonium (Pu), tungsten (W), and vanadium (V) are non-essential heavy metals, which are potent toxins and penetrate tissue cells due to their physicochemical properties, such as ionic charge (Duce and Bush, 2010). Non-essential metals deserve special attention because they do not perform any essential function in living organisms, are highly toxic at low exposure levels, and are considered a major threat to life forms (Atobatele and Olutona, 2015). This is also confirmed by the environmental protection agencies, which indicate that As, Cd, Pb, and Hg are among the most toxic metals in the environment (Goyer, 2004). Moreover, the Agency for Toxic Substances and Disease Registry (ATSDR) lists more than 20 heavy metals with pronounced toxicity, among which four are of particular concern to human health: As, Pb, Cd, and Hg. Of these four elements, As is the most common cause of acute heavy metal poisoning and therefore ranks first in the ATSDR list; Pb ranks second, and Cd ranks seventh (Fay and Mumtaz, 1996; Flora et al., 2011).

The issue of heavy metal contamination is relevant for many countries (Yerezhepkyzy et al., 2017). The object of our study was Kazakhstan, where historically there has been a variety of industrial activities with an environmental impact (Makhmetova et al., 2023). Heavy metal contamination in Kazakhstan, being the ninth largest country in the world in terms of territory (Aytzhanova, 2019), is caused primarily by a combination of natural factors and technogenic activities (Bekezhanov et al., 2021). There are many hazardous areas (occupying more than 60 thousand ha) in Kazakhstan's industrial zones that contaminate the soil. These are drilling wells, mining wastes, quarries, and dumps. Only the activities of non-ferrous metallurgy enterprises resulted in waste accumulation of over 22 billion t, including about 4 billion t of mining waste, over 1.1 billion t of enrichment toxic waste, and 105 million t of metallurgical processing waste (Republic of Kazakhstan, 2021).

While focusing on the contamination sources in the country, the issue of environmental contamination is most acute concerning the ash dumps of the Troitskaya regional power station and the tailings dumps of the Sokolovsko-Sarbaisky mining and processing plant. Disposal, neutralization, burial, and transboundary transportation of wastes are among the most urgent problems in Kazakhstan. Toxic waste is still accumulated and stored in various tailings dumps, often without compliance with environmental standards and requirements (Baideldynov et al., 2019; Rzabay et al., 2018). As a result, soil and ground and surface waters (Malakhov et al., 2022) in many regions are subject to intensive contamination, including with heavy metals (Republic of Kazakhstan, 2021).

Reducing ecological risks is especially important for the development of agriculture (Nugmanov et al., 2022). Since agriculture occupies a significant sector in Kazakhstan's economy, the development potential of this industry is closely related to minimizing the consequences of technogenic activities, contamination, and environmental risks. Heavy metal accumulation in soil can result in the deterioration of soil quality, reduce soil fertility and crop yields, and thus threaten human and animal health (Zang et al., 2017; Fei et al., 2020).

The purpose of the present study was to assess the potential ecological risk of heavy metal contamination of agricultural soils in the Kostanay region.

Soils from the Zhdanovskoye owner-operated farm in the Sokolovsko-Sarybaisky district of the Kostanay region were selected as the study object. Soil sampling was conducted, and materials were collected to analyze the content of heavy metals and trace elements, such as Pb, Hg, As, Cd, Zn, Cu, Fe, and Mn. Based on the data analysis, we concluded the presence of heavy metals and trace elements in the Kostanay region. It was determined that heavy metals are toxic even in very low concentrations. Thus, for the development of organic agriculture in the region, it is important to predict the potential risks of soil contamination. Finally, the main conclusions were drawn, limitations of the conducted study were determined, and further prospects were outlined.

2. Materials and Methods

2.1. Research area

The research object was the soil of the Zhdanovskoye owner-operated farm in the Sokolovsko-Sarybaisky district of the Kostanay region. Tests were conducted from May 3 to May 17, 2021.

Contaminated and disturbed lands are widespread in industrial urban zones and mining and material processing sites. Mining of minerals using the open-pit method in large territories leads to the alienation of lands for non-agricultural purposes, such as quarries, dumps, tailings dumps, and mine and domestic water accumulators.

In the Kostanay region, at the end of 2021, the total land area taken out from turnover due to contamination and land disturbance amounted to 37,773.6 ha, including about 27 thousand ha occupied by mining enterprises. Activities of seven large mining enterprises in the region are associated with land disturbance. These are the Aluminum of Kazakhstan JSC (Lisakovsk (Krasnooktyabrskoye Bauxite Ore Mining Plant Administration, KBRU) and Arkalyk (Torgai Bauxite Ore Mining Plant Administration, TBRU)), Kostanay Minerals JSC (Zhitikara), Varvarinskoye JSC (B. Mailin district), Sokolovsko-Sarbayskoye Mining and Processing Production Association (SSGPO) JSC (Rudnyi), Lisakovsky branch of the Orken LLP, and Komarovskoye Mining Enterprise LLP (Zhitikara) (Figure 1) (Republic of Kazakhstan, 2022).

The mining industry of the region is represented by large enterprises involved in iron ore extraction and production of iron ore pellets. These are the Sokolovsko-Sarbai Mining and Processing Production Association JSC (Rudniy) and the Lisakovskiy Mining and Processing Plant, which is the Lisakovskiy branch of the Orken LLP. Non-ferrous metallurgy enterprises include Aluminum of Kazakhstan KBRU JSC, Shaimerden JSC in the Kamystinsky district (Zn, Ni), Komarovskoye Mining Enterprise LLP (Zhitikara), Varvarinskoye JSC in the Taranovsky district (gold (Au), Cu), and others.

According to the Bureau of National Statistics of the Republic of Kazakhstan (2022), the number of stationary emission sources in the Kostanay region in 2021 amounted to 18,976 units (Table 1).

According to the Bureau of National Statistics of the Republic of Kazakhstan (2022), the total volume of emissions in 2021 amounted to 137.9 thousand t (Figure 2).

The largest mining enterprise in the Kostanay region, the Sokolovsko-Sarbayskoye Mining and Processing Production Association JSC, accounts for about 77% of the total industrial emissions. Due to the increase in production volumes in 2021 compared to 2020, the actual emissions of the enterprises increased. Thus, the Sokolovsko-Sarbayskoye Mining and Processing Production Association JSC increased emissions by 1%, Kostanay Minerals JSC – by 4%, and Kostanay Heat and Power Company (KTEK Municipal Utility Service) – by 16%. In 2021, several enterprises in the region reduced the production volume and, accordingly, emissions into the environment. Thus, the Varvarinskoye JSC decreased emissions by 29% and the Lisakovskiy branch of the Orken LLP – by 13% (Republic of Kazakhstan, 2022).

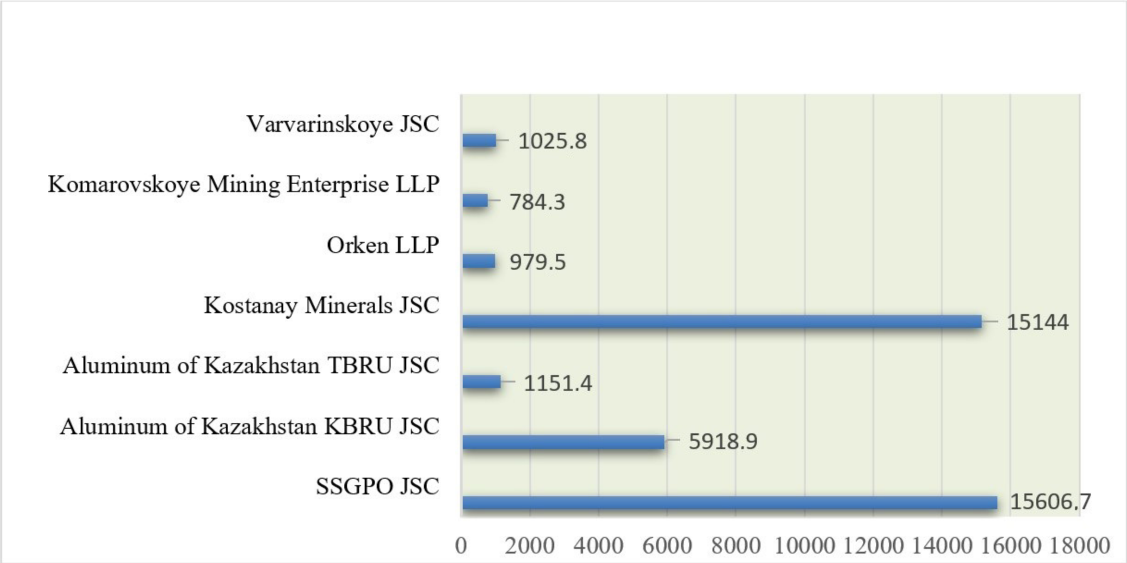

Figure 1. Information on disturbed lands in Kostanay region for 2021, thousand ha. **Source:** Local Administration of the Kostanay region.

Table 1. The number of stationary emission sources for 2019-2021.

Year	2019	2020	2021
Stationary emission sources, units	17,462	17,929	18,976

2.2. Sampling

Soil sampling was conducted in May 2021. A total of 47 soil samples 500 g each were collected. The samples were taken from an area located more than 25-30 km away from the mining area and sites little affected by anthropogenic activities. The material was collected manually and then analyzed by Kazagraks JSC specialists.

The sampling of fruit and vegetable products and soil was conducted pointwise (Nasiyev et al., 2021; Makarova et al., 2022). Potatoes from small and large farms were analyzed. The quantitative content of heavy metals, such as Pb, Hg, As, and Cd, and concentrations of the trace elements, such as Zn, Cu, Fe, and Mn, were considered ecological quality indicators of agricultural products in the contaminated areas. When assessing the trace element composition, the gross content of elements was analyzed. The maximum allowable concentrations (MAC) for As, Cd, Hg, and Pb were 0.2, 0.1, 0.03, and 0.5 mg/kg, respectively.

2.3. Data analysis

The method used to assess the potential ecological risk index (*RI*) was developed by Swedish scientist L. Hakanson (1980). According to this method, the potential ecological risk is calculated using E_r^i risk factors (Equations 1 to 3):

$$C_f^i = \frac{C_S^i}{C_n^i} \quad (1)$$

$$E_r^i = T_r^i \times C_f^i \quad (2)$$

$$RI = \sum_{i=1}^{n} E_r^i \quad (3)$$

where C_f^i is the contamination coefficient; C_S^i and C_n^i are the actual and background content of the *i*-th element in the soil. The toxicity coefficient T_r^i is presented in Table 2.

According to Hakanson, the following environmental risk rating was proposed depending on E_r^i values (Table 3).

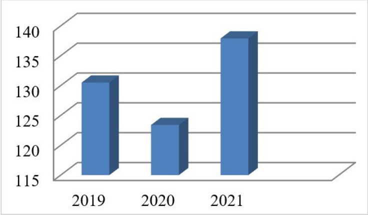

Figure 2. Pollutant emissions from stationary sources in the Kostanay region for 2019-2021, thousand t. **Source:** Bureau of National Statistics of the Republic of Kazakhstan (2022).

3. Results

The results of the ecological assessment of the soil landscape in the industrial area of the Kostanay region are presented in Figure 3 and Table 4.

3.1. Assessment of soil landscape

Based on the results, the average soil pH was 7.19, which indicates that the soil environment was slightly alkaline. The average humus content was 3.77%. The average nitrogen (N) (total) content was 0.56%.

Our results showed that the exceedance of As concentration relative to the MAC was detected for all sampling sites. Sporadic concentration exceedance was noted for Hg, Zn, Ni, and Cu. The multiplicity of the exceedance over the MAC for As reached 4.6 times, for Hg – 2.2 times, for Zn – 2.5 times, for Ni – 1.4 times, and for Cu – 1.8 times.

3.2. Analysis of fruit and vegetable products

We found that all samples of fruit and vegetable products contained elevated Cd (Figures 4 and 5). The Cd content in potatoes differed in samples collected from small (0.18) and large (0.2) farms, exceeding MAC by 1.5-2.0 times.

Table 2. Toxicity coefficient of heavy metals (Xu et al., 2008; Guan et al., 2014).

Element	As	Cd	Cr	Cu	Pb	Ni	Zn	Hg
Magnitude	10	30	2	5	5	5	1	40

Table 3. Grading standards of potential environmental risk from heavy metals.

E_r^i	Individual potential ecological risk	*RI**	Sum of individual potential ecological risks
E_r^i <40	low potential ecological risk	RI <150	low potential ecological risk
40≤ E_r^i <80	moderate potential ecological risk	150≤ RI <300	moderate ecological risk
80≤ E_r^i <160	considerable potential ecological risk	300≤ RI <600	considerable ecological risk
160≤ E_r^i <320	high potential ecological risk	RI >600	very high ecological risk
E_r^i >320	very high ecological risk		

*RI: index of potential environmental risk.

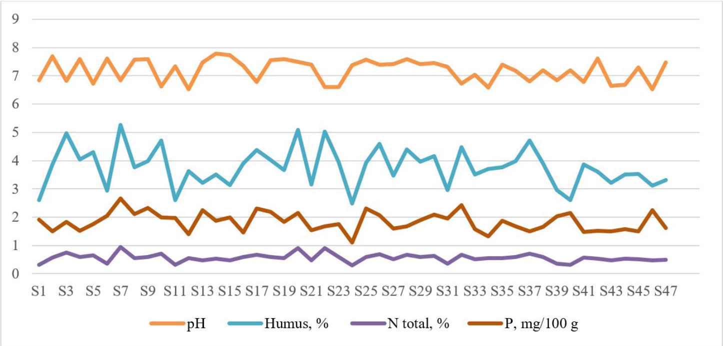

Figure 3. Soil sample analysis results.

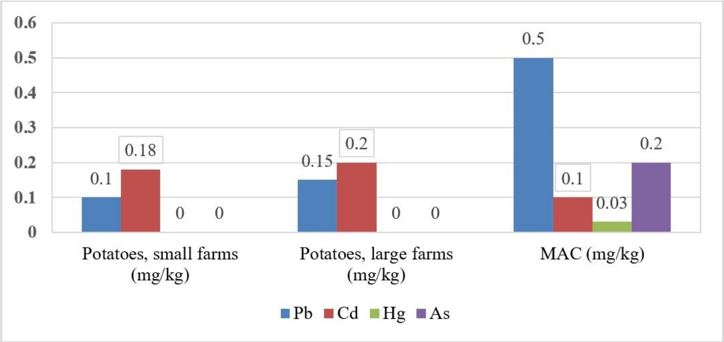

Figure 4. Analysis results of fruit and vegetable product samples from the Sokolovsko-Sarybaisky district.

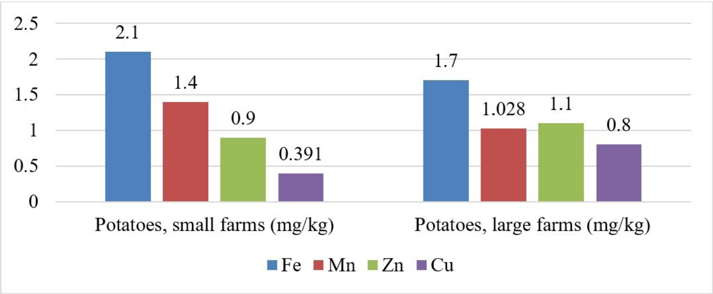

Figure 5. Content of trace elements in potatoes from small and large farms.

Table 4. Content of total forms of heavy metals and metalloids in the soil, mg/kg.

Element	Content, mg/kg			Background content, mg/kg
	Average	Minimum	Maximum	
Ni	17.1	5.1	28.1	6.2
Cu	32.5	10.8	58.0	12.1
As	3.2	1.1	8.9	1.2
Hg	1.1	1.1	4.8	4.1
Cd	0.4	0.07	0.6	0.07
Pb	7.6	6.0	9.7	9.6
Zn	85.7	27.0	138.5	29.0

Table 5. Assessment of potential risk of soil contamination with heavy metals.

Sample	E_r^i							RI*	Risk grading
	As	Cd	Hg	Pb	Zn	Ni	Cu		
S1	6.10	45.00	200.1	4.1	2.09	10.1	4.02	251	Moderate
S2	13.00	76.00	23.70	3.9	3.12	6.58	2.80	137	Low
S3	32.50	110.00	42.90	4.03	6.20	21.30	14.50	241	Moderate
S4	12.60	135.00	70.20	4.2	7.02	15.75	13.88	262	Moderate
S5	12.00	169.00	65.80	3.88	8.77	21.50	14.85	313	High
S6	13.10	201.00	89.96	3.55	11.10	22.66	15.55	358	High
S7	13.30	241.00	119.0	3.61	9.98	26.12	11.25	420	High
S8	13.20	254.00	128.5	3.34	9.36	26.75	10.03	452	High
S9	14.00	289.00	48.70	3.52	8.05	33.74	9.65	405	High
S10	14.70	310.00	50.1	4.01	6.58	32.65	9.01	447	High
Average	14.45	183.00	83.89	3.81	7.22	21.71	10.55	328.6	High

*RI: index of potential environmental risk.

Figure 5 shows that the content of trace elements from the Sokolovsko-Sarybai polymetallic ore deposit was disordered.

3.3. Assessment of potential risk of soil contamination with heavy metals

The assessment results of potential ecological risk factors (E_r^i) and *RI* are presented in Table 5.

4. Discussion

When assessing the *RI* of heavy metal contamination, not only the content of heavy metals in the soil is considered but also the possible negative ecotoxicological consequences of contamination (Hakanson, 1980; Xu et al., 2008). The sequence of potential ecological risk factors of heavy metals in the conducted study is as follows: Cd>Hg>Ni>As>Cu>Zn>Pb. The ecological risk factors by elements varied from 2 to 310, which indicates the ecological risk grading categories from low to very high. As, Zn, Cu, and Ni belong to the low category of ecological risk. The highest variation in values was observed for Cd and Hg. The ecological risk category of elements increased from moderate to high. The average *RI* for As, Cd, Hg, Pb, Zn, Ni, and Cu was 328, indicating generally high ecological risk.

The *RI* values for all sites ranged from 137 to 447, corresponding to an overall ecological risk level from low to high. The detected levels of As, Cd, Zn, and Pb in long-term abandoned mining sites were well above the national thresholds. Changes in Pb, Zn, and Cd content showed a very similar pattern. Vertical distribution profiles in each sampling zone showed different patterns. The heavy metal content near the tailings pond tended to increase significantly with increasing soil depth. The research findings indicate the impending need to comprehensively investigate and assess the suitability of the land for further agricultural use. The need for such investigations is consistent with the findings of Xiao et al. (2017). Xiao et al. (2017) show that agriculture and industry significantly influence heavy metal contamination of agricultural soils and plants, especially soils near cement and electroplating plants. The soil surface is a fertile place to store heavy metals from where they penetrate plants by absorption along with water through roots and further by the vascular system (Budovich, 2021). The problem is aggravated by the fact that Kazakhstan is dominated by areas with intensive agriculture. Intensive agricultural activities associated with the use of pesticides, herbicides, and fertilizers, some of which may contain heavy metals, over time can lead to the accumulation of these metals in the soil (Nokusheva et al., 2023).

Researchers emphasize the need to develop organic agriculture (Nasiyev et al., 2022b; Khoruzhy et al., 2023) based on the use of organic fertilizers (Bayazitova et al., 2023; Nasiyev, 2013). Organic agriculture is a potentially more environmentally friendly alternative to conventional agricultural production and can play an important role in the sustainable development of ecosystems (Nokusheva et al., 2023). New opportunities for the Kazakh market of organic products are opened up by the country's participation in the integration processes taking place within the Eurasian Economic Union (EAEU) (Omarbakiyev et al., 2023).

Kazakhstan occupies 12.8% of agricultural production in EAEU. Over the past five years, the country has taken a leading position in the growth rate of cattle and poultry and the production of grain, sunflower seeds, vegetables, fruits, and berries (Liu, 2023). For further effective functioning and development of agriculture, it is important to consider ecological risks and take timely measures to mitigate them.

5. Conclusions

Our results showed that Pb, Cd, Hg, and As are toxic even in very low concentrations. The study showed the presence of trace elements and heavy metals in the territories of the Kostanay region.

The study was limited to the soils of the Zhdanovskoye owner-operated farm in the Sokolovsko-Sarybay district.

Further research should be aimed at studying heavy metal contamination of soils in other mining areas of Kazakhstan. Solving the issue of heavy metal contamination in Kazakhstan requires a multifaceted approach. Effective regulation, monitoring, environmental remediation efforts, and public awareness are essential components of any strategy aimed at mitigating the adverse effects of heavy metal contamination.

The obtained results allow prediction of cluster-based development of processing infrastructures in the vicinity of agricultural lands. The results of the forecast will be transferred to the local public administration authorities for use when planning works to reduce ecological risks in the region.

References

ATOBATELE, O.E. and OLUTONA, G.O., 2015. Distribution of three non-essential trace metals (cadmium, mercury and lead) in the organs of fish from Aiba reservoir, Iwo, Nigeria. *Toxicology Reports*, vol. 2, pp. 896-903. http://dx.doi.org/10.1016/j.toxrep.2015.06.003. PMid:28962427.

AYTZHANOVA, D.D., 2019. Sovremennaya geoekonomicheskaya situatsiya v Kazakhstane [Modern geo-economic situation in Kazakhstan]. *Vestnik Nauki*, vol. 2, no. 6(15), pp. 269-281.

BAGRATUNI, K., KASHINA, E., KLETSKOVA, E., KAPUSTINA, D., IVASHKIN, M., SINYUKOV, V., KARSHALOVA, A., HAJIYEV, H. and HAJIYEV, E., 2023. Impact of socially responsible business behavior on implementing the principles of sustainable development (experience of large business). *International Journal of Sustainable Development and Planning*, vol. 18, no. 8, pp. 2481-2488. http://dx.doi.org/10.18280/ijsdp.180819.

BAIDELDYNOV, D., JANGABULOVA, A., YEREZHEPKYZY, R., BERDIBAYEVA, A. and KHAMIT, A., 2019. Central Asian transboundary waters in the age of globalization: problems of legal regulation and international cooperation. *Journal of Environmental Management and Tourism*, vol. 10, no. 5, pp. 1060-1073. http://dx.doi.org/10.14505//jemt.10.5(37).13.

BAYAZITOVA, Z.E., KURMANBAYEVA, A.S., TLEUOVA, Z.O. and TEMIRBEKOVA, N.G., 2023. Application of the thermophilic fermentation method to obtain environmentally friendly organic fertilizer. *Journal of Ecological Engineering*, vol. 24, no. 4, pp. 202-216. http://dx.doi.org/10.12911/22998993/159647.

BEKEZHANOV, D., KOPBASSAROVA, G., ZHUNISPAYEVA, A., URAZYMBETOV, T. and SEILKASSYMOVA, R., 2021. Environmental problems of international legal regulation of transboundary contamination. *Journal of Environmental Management and Tourism*, vol. 12, no. 2, pp. 392-405. http://dx.doi.org/10.14505//jemt.v12.2(50).08.

BUDOVICH, L.S., 2021. Effects of heavy metals in soil and plants on ecosystems and the economy. *Caspian Journal of Environmental Sciences*, vol. 19, no. 5, pp. 991-997.

BUGUBAEVA, A., KUPRIJANOV, A., CHASHKOV, V., KUANYSHBAEV, S., VALIEV, K., MAMIKHIN, S., SHCHEGLOV, A., NUGMANOV, A., BULAEV, A., SULTANGAZINA, G., KUNANBAYEV, K., CHERNYAVSKAYA, O., BAUBEKOVA, G., RUCHKINA, G., SAFRONOVA, O., UXIKBAYEVA, M. and SOKHAREV, Y., 2023. Productivity assessment of various plant communities at uranium mine sites in Central Kazakhstan. *SABRAO Journal of Breeding and Genetics*, vol. 55, no. 3, pp. 864-876. http://dx.doi.org/10.54910/sabrao2023.55.3.21.

DUCE, J.A. and BUSH, A.I., 2010. Biological metals and Alzheimer's disease: implications for therapeutics and diagnostics. *Progress in Neurobiology*, vol. 92, no. 1, pp. 1-18. http://dx.doi.org/10.1016/j.pneurobio.2010.04.003. PMid:20444428.

DUDAL, R., 2005. The sixth factor of soil formation. *Eurasian Soil Science*, vol. 38, no. 1, pp. 12-21.

FAY, R.M. and MUMTAZ, M.M., 1996. Development of a priority list of chemical mixtures occurring at 1188 hazardous waste sites, using the HazDat database. *Food and Chemical Toxicology*, vol. 34, no. 11-12, pp. 1163-1165. http://dx.doi.org/10.1016/S0278-6915(97)00090-2. PMid:9119332.

FEI, X., LOU, Z., XIAO, R., REN, Z. and LV, X., 2020. Contamination assessment and source apportionment of heavy metals in agricultural soil through the synthesis of PMF and GeogDetector Models. *The Science of the Total Environment*, vol. 747, pp. 141293. http://dx.doi.org/10.1016/j.scitotenv.2020.141293. PMid:32777512.

FLORA, S.J.S., PACHAURI, V. and SAXENA, G., 2011. *Arsenic, cadmium and lead: reproductive and developmental toxicology*. London: Academic Press.

GOYER, R., 2004. *Issue paper on the human health effects of metals*. Washington, DC: US Environmental Protection Agency.

GUAN, Y., SHAO, C. and JU, M., 2014. Heavy metal contamination assessment and partition for industrial and mining gathering areas. *International Journal of Environmental Research and Public Health*, vol. 11, no. 7, pp. 7286-7303. http://dx.doi.org/10.3390/ijerph110707286. PMid:25032743.

HAKANSON, L., 1980. An ecological risk index for aquatic contamination control: a sedimentological approach. *Water Research*, vol. 14, no. 8, pp. 975-1001. http://dx.doi.org/10.1016/0043-1354(80)90143-8.

HINOJOSA, M.B., CARREIRA, J.A., GARCÍA-RUÍZ, R. and DICK, R.P., 2004. Soil moisture pre-treatment effects on enzyme activities as indicators of heavy metal-contaminated and reclaimed soils. *Soil Biology & Biochemistry*, vol. 36, no. 10, pp. 1559-1568. http://dx.doi.org/10.1016/j.soilbio.2004.07.003.

JÓZEFOWSKA, A., WOŚ, B., PIETRZYKOWSKI, M. and SCHLAGHAMERSKÝ, J., 2020. Colonization by enchytraeids as a suitable indicator of successful biological reclamation of post-mining technosols using alders. *Applied Soil Ecology*, vol. 145, pp. 103300. http://dx.doi.org/10.1016/j.apsoil.2019.06.003.

KABAŁA, C., GREINERT, A., CHARZYŃSKI, P. and UZAROWICZ, L., 2020. Technogenic soils: a group soil of the year 2020 in Poland: concept, properties and classification of technogenic soils in Poland. *Soil Science Annual*, vol. 71, no. 4, pp. 267-280. http://dx.doi.org/10.37501/soilsa/131609.

KALASHNIKOV, P., KULANOV, A., NESIPBEKOV, E., KAISHATAYEVA, A. and KANTARBAYEVA, S., 2023. Impact of state and legal regulation on the sustainable development of agricultural territories and improving the standard of living of the population. *Journal of Environmental Management and Tourism*, vol. 14, no. 1, pp. 82-88. http://dx.doi.org/10.14505/jemt.v14.1(65).08.

KARCZEWSKA, A. and KABAŁA, C., 2017. Environmental risk assessment as a new basis for evaluation of soil contamination in Polish law. *Soil Science Annual*, vol. 68, no. 2, pp. 67-80. http://dx.doi.org/10.1515/ssa-2017-0008.

KHORUZHY, L., KATKOV, Y., KATKOVA, E., ROMANOVA, A. and DZHIKIYA, M., 2023. Sustainable development of agricultural enterprises with an active environmental stance: analysis of inter-organizational management accounting. *Journal of Law and Sustainable Development*, vol. 11, no. 3, pp. e386. http://dx.doi.org/10.55908/sdgs.v11i3.386.

KONDRATENKO, E.P., SOBOLEVA, O.M. and SERGEEVA, I.A., 2022. Influence of weather conditions and weediness on barley (*Hordeum vulgare*) yield. *Research on Crops*, vol. 23, no. 1, pp. 33-39.

KUANDYKOVA, M., AKPANOV, A., TLEUBAYEVA, S., BELGIBAYEV, A., MAKHMUDOV, A. and ATCHABAROVA, A., 2023. Attracting investment for rural development: introduction of organic agriculture and ESG principles in Kazakhstan. *Journal of Environmental Management And Tourism*, vol. 14, no. 1, pp. 2196-2206. http://dx.doi.org/10.14505/jemt.v14.5(69).04.

LI, X.Y., NING, S.Q., ZHANG, P. and YANG, W.L., 2020. Environmental contamination and health risks of heavy metals in the soil around a construction waste landfill. *International Journal of Design & Nature and Ecodynamics*, vol. 15, no. 3, pp. 393-399. http://dx.doi.org/10.18280/ijdne.150312.

LIU, Y., 2023. Effects of the EAEU's agricultural policy on the organic farming market of Kazakhstan. *Indian Journal of Economics and Development*, vol. 19, no. 1, pp. 80-90.

MAKAROVA, K.S., PETROV, A.F., PASTUKHOVA, A.V., GAZIZULINA, A.S., PETRUK, V.A. and GOTFRID, S.S., 2022. Introduction of large-fruited strawberry varieties on the territory of the Novosibirsk region in the conditions of Western Siberia. *Advancements in Life Sciences*, vol. 9, no. 3, pp. 328-333.

MAKHMETOVA, D., TLESSOVA, E., NURKENOVA, M., AUELBEKOVA, A. and ISSAYEVA, B., 2023. Waste management strategy of agricultural enterprises to improve the efficiency of rural development. *Journal of Environmental Management and Tourism*, vol. 14, no. 3, pp. 623-631. http://dx.doi.org/10.14505/jemt.v14.3(67).02.

MALAKHOV, D.V., TSKHAY, M., KALASHNIKOV, A.A., BEKMUKHAMEDOV, N.E., KALASHNIKOV, P.A. and BAIZAKOVA, A., 2022. Features of creating a system of space monitoring of water-supplied territories for irrigation in the South of Kazakhstan. *Journal of Ecological Engineering*, vol. 23, no. 11, pp. 202-216. http://dx.doi.org/10.12911/22998993/153398.

MUKHOMEDYAROVA, A.S., KUSHENBEKOVA, A.K., ELEKESHEVA, M.M., GUMAROVA, Z.M. and BULEKOVA, A.A., 2023. Influence of nitrogen mineral fertilizer application methods on the preservation and yield of winter wheat (*Triticum aestivum*). *Research on Crops*, vol. 24, pp. 241-249.

NARDIN, D. and NARDINA, S., 2021. Management of natural-anthropogenic complexes of rural territories in the context of the post-non-classical type of scientific rationality. *Journal of Environmental Management and Tourism*, vol. 12, no. 5, pp. 1242-1247. http://dx.doi.org/10.14505//jemt.v12.5(53).09.

NASIYEV, B., 2013. The role of organic fertilizers in increasing the fertility of West Kazakhstan soils. *Polish Journal of Soil Science*, vol. 46, no. 2, pp. 115-146.

NASIYEV, B., VASSILINA, T., ZHYLKYBAY, A., SHIBAIKIN, V. and SALYKOVA, A., 2021. Physicochemical and biological indicators of soils in an organic farming system. *TheScientificWorldJournal*, vol. 2021, pp. 9970957. http://dx.doi.org/10.1155/2021/9970957. PMid:34512205.

NASIYEV, B., SHIBAIKIN, V., BEKKALIYEV, A., ZHANATALAPOV, N.Z. and BEKKALIYEVA, A., 2022a. Changes in the quality of vegetation cover and soil of pastures in semi-deserts of West Kazakhstan, depending on the grazing methods. *Journal of Ecological Engineering*, vol. 23, no. 10, pp. 50-60. http://dx.doi.org/10.12911/22998993/152313.

NASIYEV, B., BEKKALIYEVA, A.K., VASSILINA, T.K., SHIBAIKIN, V.A. and ZHYLKYBAY, A.M., 2022b. Biologized technologies for cultivation of field crops in the organic farming system of West Kazakhstan. *Journal of Ecological Engineering*, vol. 23, no. 8, pp. 77-88. http://dx.doi.org/10.12911/22998993/150625.

NOKUSHEVA, Z.A., KANTARBAYEVA, E.Y., ORMANBETOV, M.B., YERMAGAMBET, B.T., KASSENOVA, Z.M. and KAZANKAPOVA, M.K., 2023. Development and implementation of effective schemes for the use of mineral fertilizers in the forest-steppe zone of the North Kazakhstan region. *Online Journal of Biological Sciences*, vol. 23, no. 3, pp. 313-322. http://dx.doi.org/10.3844/ojbsci.2023.313.322.

NUGMANOV, A.B., MAMIKHIN, S.V., VALIEV, K.K., BUGUBAEVA, A.U., TOKUSHEVA, A.S., TULKUBAEVA, S.A. and BULAEV, A.G., 2022. Poly-species phytocenoses for ecosystem restoration of degraded soil covers. *Online Journal of Biological Sciences*, vol. 22, no. 3, pp. 268-278. http://dx.doi.org/10.3844/ojbsci.2022.268.278.

NURALINA, K., BAIZHOLOVA, R., ABENOV, Y., MUKHIYAYEVA, D. and MOLDAKENOVA, Y., 2023. Development of a model of strategic priorities for sustainable development of rural areas in Kazakhstan until 2030. Example of the East Kazakhstan region. *Journal of Environmental Management and Tourism*, vol. 14, no. 5, pp. 2290-2299. http://dx.doi.org/10.14505/jemt.v14.5(69).10.

OMARBAKIYEV, L.A., KANTARBAYEVA, S.M., NIZAMDINOVA, A.K., ZHUMASHEVA, S.T., SEITKHAMZINA, G.Zh., and SAULEMBEKOVA, A., 2023. Consequences of changing regional integration on environmental development, agricultural markets, and food security. *Global Journal of Environmental Science and Management*, vol. 9, no. 4, pp. 951-966.

REPUBLIC OF KAZAKHSTAN. Ministry of Agriculture of the Republic of Kazakhstan Land Management Committee, 2021 [viewed 1 December 2022]. *Summary analytical report on the state and use of the lands of the Republic of Kazakhstan for 2021* [online]. Nur-Sultan. Available from: https://www.gov.kz/uploads/2022/4/11/b09469de9be9cc54d2cc0e9cc7a77e84_original.7131188.pdf

REPUBLIC OF KAZAKHSTAN. Bureau of National Statistics of the Republic of Kazakhstan [online], 2022 [viewed 1 December 2022]. Available from: https://www.gov.kz/memleket/entities/stat?lang=ru

RZABAY, A., TELEUYEV, G., ABDUKARIMOVA, Z., KURMANBETOV, K., NESSIPBAYEVA, I. and ADYLGAZY, S., 2018. Some theoretical issues on the sources of environmental law in the republic of Kazakhstan. *Journal of Environmental Management and Tourism*, vol. 9, no. 7, pp. 1421-1427. http://dx.doi.org/10.14505//jemt.v9.7(31).07.

SHAYAKHMETOVA, A., SAVENKOVA, I., NASIYEV, B., AKHMETOV, M., USEINOV, A., TASKULOVA, A. and TEMIRBULATOVA, A., 2023. Agrotechnology for feed cultivation and creation of hayfields and pastures in the forest and steppe zone of Northern Kazakhstan. *SABRAO Journal of Breeding and Genetics*, vol. 55, no. 4, pp. 1245-1258. http://dx.doi.org/10.54910/sabrao2023.55.4.18.

SINGH, R., GAUTAM, N., MISHRA, A. and GUPTA, R., 2011. Heavy metals and living systems: an overview. *Indian Journal of Pharmacology*, vol. 43, no. 3, pp. 246-253. http://dx.doi.org/10.4103/0253-7613.81505. PMid:21713085.

SUTKOWSKA, K. and TEPER, L., 2015. Impact of Solvay waste alkalinity on the leaching of heavy metals in a 100 year-old landfill. In: *Proceedings of the World Congress on New Technologies (NewTech 2015)*, 2015, Barcelona, Spain. Orléans: International ASET Inc. Paper, no. 169.

THERON, A.J., TINTINGER, G.R. and ANDERSON, R., 2012. Harmful interactions of non-essential heavy metals with cells of the innate immune system. *Journal of Clinical Toxicology*, vol. S3, pp. 005.

UNITED NATIONS – UN, 2015 [viewed 19 November 2023]. *Sustainable development goals* [online]. Available from: https://www.un.org/sustainabledevelopment/ru/sustainable-development-goals/

UZAROWICZ, Ł., CHARZYŃSKI, P., GREINERT, A., HULISZ, P., KABAŁA, C., KUSZA, G., KWASOWSKI, W. and PĘDZIWIATR, A., 2000. Studies of technogenic soils in Poland: past, present, and future perspectives. *Soil Science Annual*, vol. 71, no. 4, pp. 281-299. http://dx.doi.org/10.37501/soilsa/131615.

WARCHULSKI, R., MENDECKI, M., GAWĘDA, A., SOŁTYSIAK, M. and GADOWSKI, M., 2019. Rainwater-induced migration of potentially toxic elements from a Zn–Pb slag dump in Ruda Śląska in light of mineralogical, geochemical and geophysical investigations. *Applied Geochemistry*, vol. 109, pp. 104396. http://dx.doi.org/10.1016/j.apgeochem.2019.104396.

XIAO, R., WANG, S., LI, R., WANG, J.J. and ZHANG, Z., 2017. Soil heavy metal contamination and health risks associated with artisanal gold mining in Tongguan, Shaanxi, China. *Ecotoxicology and Environmental Safety*, vol. 141, pp. 17-24. http://dx.doi.org/10.1016/j.ecoenv.2017.03.002. PMid:28285205.

XU, Z., NI, S., TUO, X. and ZHANG, C., 2008. Calculation of heavy metals' toxicity coefficient in the evaluation of potential ecological risk index. *Environmental Science & Technology*, vol. 31, pp. 112-115.

YEREZHEPKYZY, R., KARATAYEVA, A., KUANALIEVA, G.A., KONYSBAI, B.M. and AZHINURINA, D.A., 2017. Legal regulation of public access to information in the field of environmental protection and use of natural resources. *Journal of Legal. Ethical and Regulatory Issues*, vol. 20, no. 2, pp. 1-6.

YESSIMBEK, B., MAMBETOV, B., AKHMETOV, R., DOSMANBETOV, D., ABAYEVA, K., KOZHABEKOVA, A., ORAIKHANOVA, A. and BAIBATSHANOV, M., 2022. Prevention of desertification and land degradation using black saxaul in arid conditions. *Online Journal of Biological Sciences*, vol. 22, no. 4, pp. 484-491. http://dx.doi.org/10.3844/ojbsci.2022.484.491.

ZANG, F., WANG, S., NAN, Z., MA, J., ZHANG, Q., CHEN, Y. and LI, Y., 2017. Accumulation, spatio-temporal distribution, and risk assessment of heavy metals in the soil corn system around a polymetallic mining area from the Loess Plateau, Northwest China. *Geoderma*, vol. 305, pp. 188-196. http://dx.doi.org/10.1016/j.geoderma.2017.06.008.