Ecological assessment of the content of heavy metals and arsenic in the soils of the forest-steppe zone of the Omsk region, Russia

Natalya Zharkova[1*] and *Dilyara* Dolgova[1]

[1]Omsk State Agrarian University named After p. A. Stolypin, 644008, 1, Institute sq, Omsk, Russia

Abstract. The accumulation of heavy metals (HMs) and arsenic in soils poses a direct threat to soil biota and ecosystem health due to their toxicity and potential for transfer through the food chain. In this study, an ecological risk assessment was conducted for biota in forest-steppe soils of Western Siberia. Engineering-ecological surveys allow estimating the current state and making a forecast of possible changes of environmental objects to prevent, minimize or eliminate harmful and undesirable environmental and other consequences. The purpose of this study is to conduct an environmental assessment of the content of heavy metals and arsenic in the soils of Tyukalinsky, Zyvaevsky and Omsk districts of the Omsk region. The research was conducted during 2019-2024. The soil samples were used to determine the gross content of Cu, Zn, Cd, Pb, and Ni by the atomic absorption method, Hg – flameless atomic absorption method, As – photometric method. The degree of contamination of soils with heavy metals was determined by comparing the concentrations of the elements under study with regulatory and background values. Comprehensive assessment of the degree of contamination of soils with heavy metals was carried out with the help of Zc (total soil contamination index). It was established that soil samples taken in the areas where the research was conducted meet the requirements of hygienic standards. The value of the total pollution index Zc soils < 16, which indicates an acceptable level of contamination and the possibility of using these soils without restrictions, excluding objects of high risk. Thus, during the course of the conducted research, recommendations were given for the first time on the use of soil cover in developed areas in order to reduce the negative impact. The study results provide a crucial baseline for monitoring the biological integrity of this vital ecosystem.

1 Introduction

In the modern world, the agricultural sector and industrial enterprises have a significant anthropogenic impact on soils [1-2]. In this regard, within the framework of engineering

* Corresponding author: nn.zharkova@omgau.org

and environmental surveys, it is necessary to assess soil contamination in order to identify the level of pollution, determine its source and develop measures to minimize harmful effects on the environment and human health. Soil analysis is an important element of engineering and environmental surveys, necessary to assess the condition of the surveyed area [3-4].

At the design stage, engineering and environmental studies provide an opportunity to obtain data on the state of the components of the natural environment in order to reduce the negative impact of planned economic activities and comply with all requirements in the field of environmental legislation.

Soil analysis is an important element of engineering and environmental surveys, necessary to assess the condition of the surveyed area. Understanding the condition of the soils helps to prevent problems related to pollution, sustainability and other factors that may affect future work [5-6].

When planning business facilities in cities, on production sites, in the agricultural sector, and in areas of geochemical anomalies, an essential point is to assess the presence of heavy metals in the soil. The risk of high levels of soil contamination demonstrates a significant effect on its subsequent use. For example, it is impossible to cut a fertile layer if it belongs to the category of "polluted". Erroneous categorization of soil pollution based on the results of engineering and environmental surveys may lead to questionable design decisions regarding land reclamation. For example, if the pollution category is mistakenly defined as low, insufficient measures will be taken, which will not solve the pollution problem and may lead to further deterioration of the environmental situation [7-9].

In connection with all of the above, the key stage in engineering and environmental surveys is the identification of soil contamination and the establishment of their category.

The purpose of the presented work is to determine the category of soil pollution in the forest–steppe zone of the Omsk region with heavy metals.

2 Materials and methods

The paper presents the results of engineering and environmental surveys conducted by CJSC Design Institute for Reconstruction and Construction of Oil and Gas Facilities (CJSC DIRC) in Tyukalinsky, Zyvaevsky and Omsk districts of the Omsk region in 2019-2024. Soil studies included ecotoxicological assessment of soil contamination and determination of their suitability for construction.

Soil samples were taken according to the normative documents GOST 17.4.3.01-2017 and GOST 17.4.4.02-2017.

Soil sampling was carried out according to clause 4.19 of SP 11-102-97 "Engineering and environmental surveys for construction" from the surface soil layer (0-30 cm) using the "envelope" method. Point samples were mixed to obtain a combined sample weighing at least 1 kg.

The list of pollutants was established in accordance with the requirements of GOST R 58486-2019 "Nature protection. Soils. The nomenclature of indicators of sanitary condition".

In-house sample processing was carried out at JSC " DIRC". The content of heavy metals and arsenic was determined in the laboratory of the Omsk branch of the Federal State Budgetary Institution Agrochemical Service of Russia. n soil samples, the gross forms of Zn, Cu, Cd, Pb, Ni were determined by inductively coupled plasma spectrometry according to HDPE F 16.1:2.3:3.11-98, Hg by flame-free atomic absorption in accordance with M–MVI-80-2008, As by atomic absorption spectroscopy of "cold steam" according to RD 52.18.827-2016.

Background samples were taken at a distance of at least 500 m from the nearest man-

made object in order to determine the local geochemical background.

The assessment of the danger of soil pollution was carried out using sanitary and hygienic standards established in Russia – the maximum permissible and approximate permissible concentration (MPC, APC) according to SanPiN 1.2.3685–21 "Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans".

The assessment of the environmental hazard of contamination of the surface layer of soils with individual heavy metals was carried out by calculating the safety according to MU 2.1.7.730-99 "Hygienic assessment of soil quality in populated areas":

$$K_{hazard} = C_i / C_{ПДК}, \quad (1)$$

where C_i – is the concentration of heavy metal in the surface layer of the soil, mg/kg;

$C_{ПДК}$ – sanitary and hygienic standards for a specific heavy metal.

The degree of pollution by heavy metals was determined by comparing their concentrations in the studied material with local geochemical background, as well as with the established MPC and APC [9; SanPIN 1.2.3685-21]. Integral assessment of the degree of pollution by heavy metals was performed on the total pollution index according to SP 11-102-97 "Engineering and environmental surveys for construction".

The higher the risk of chemical contamination of soils, the more the actual content exceeds the maximum permissible concentration.

Assessment of chemical contamination of soils and soils is carried out according to indicators developed as a result of geochemical and hygienic studies, according to SP 11-102-97. Thus, the total soil pollution index (Zc) is used to comprehensively assess the level of soil contamination with several heavy metals simultaneously:

$$Zc=\sum K_{ci} – (n – 1), \quad (2)$$

Where: n – is the number of detectable elements in the soil cover;

K_{ci} – is the concentration coefficient of pollutants, calculated by dividing the concentration of a pollutant in the soil cover by the background content of this element:

$$K_{ci} = C_i / C_{фi} \quad (3)$$

where C_i – is the actual concentration of heavy metal in the soil, mg/kg;

$C_{фi}$ – is the regional background concentration of heavy metal in the soil, mg/kg.

Depending on the value of the total soil pollution index, the following pollution levels are set: Zc < 16 – acceptable, Zc 16-32 – moderately dangerous, Zc 32-128 – dangerous, Zc > 128 – extremely dangerous.

3 Results

Heavy metals (Zn, Cu, Cd, Ni, Pb, Hg) and As are classified as priority pollutants. They can accumulate in the soil, move through food chains, enter the human body and cause various diseases (cardiovascular, allergic, oncological). The greatest contamination of soils with heavy metals is observed in the impact zones of industrial enterprises and near highways.

To assess the ecological state of the soils of three districts of the Omsk region, soil samples were selected to determine the content of basic heavy metals.

Soil sampling in the Tyukalinsky district of the Omsk region was carried out at two survey sites. In the studied areas, the soils were represented by loams with acidity varying

from slightly acidic to slightly alkaline (5.3–7.4). The gross content of Zn in soils varied depending on isolation from 56.0 to 59.2, Cu from 35.6 to 36.6, Pb from 12.77 to 12.82, Cd from 0.54 to 0.58, Hg from 0.018 to 0.023, Ni from 45.5 to 51.2 and As from 7.11 to 9.60 mg/kg (Table 1).

Table 1. Average content of gross forms of heavy metals and arsenic in soils of Tyukalinsky district in 2019-2024, mg/kg.

№ of the geo-environmental sampling object	Hg	As	Pb	Cd	Cu	Zn	Ni
Object № 1	0.023 * / 0.01 **	9.6 / 0.96	12.82 / 0.09	0.58 / 0.28	36.6 / 0.28	59.2 / 0.27	51.2 / 0.64
Object № 2	0.018 / 0.009	7.11 / 0.71	12.77 / 0.09	0,54 / 0,27	35.6 / 0.27	56.0 / 0.25	45.5 / 0.57
MPC	2.1	-	-	-	-	-	-
APC [1]	-	10	130	2,0	132	220	80
Background	0.1	2.2	15	0,12	15	45	30
GK[2]	0.083	1.7	16	0,13	47	83	58

Source: Compiled by the authors. * – average content of the element in the soil; ** – hazard coefficient relative to the maximum permissible concentration (MPC); 1 – approximately allowable concentration; 2 – geochemical clark of the solid earth crust according to A.P. Vinogradov.

At the studied objects of geoecological testing in the Tyukalinsky district of the Omsk region, the content of heavy metals did not exceed sanitary and hygienic standards (Table 1). For all the elements being determined, the hazard coefficients were below one.

Due to the lack of actual data on the regional background content of controlled chemical elements in the soil, the approximate values given in Table 4.1 of SP 11-102-97 for sod-podzolic loamy soils were taken as background values. The actual concentrations of pollutants exceeded the background values for arsenic by 3.2-4.4 times, cadmium by 4.5-4.8 times, copper by 2.4 times, zinc by 1.24-1.32 times and nickel by 1.52-1.71 times.

In the Omsk region, sampling was carried out at one facility, the number of samples taken was four (Table 2).

Table 2 Average content of gross forms of heavy metals and arsenic in soils of Omsk region in 2019-2024, mg/kg.

№ of the geo-environmental sampling object	Hg	As	Pb	Cd	Cu	Zn	Ni
Object № 1	0.10 / 0.05	3.55 / 0.36	16.25 / 0.13	0.20 / 0.10	13.48 / 0.10	43.13 / 0.20	21.75 / 0.27
MPC	2.1	-	-	-	-	-	-
APC [1]	-	10	130	2,0	132	220	80
Background	0.1	2.2	15	0,12	15	45	30
GK[2]	0.083	1.7	16	0,13	47	83	58

Source: Compiled by the authors. * – average content of the element in the soil; ** – hazard coefficient relative to the maximum permissible concentration (MPC); 1 – approximately allowable concentration; 2 – geochemical clark of the solid earth crust according to A.P. Vinogradov.

Soils of Omsk region had loamy and sandy loam granulometric composition, pH values varied from 5.9 to 6.7 (slightly acidic and neutral). Comparing the content of heavy metals with the background, excesses were noted for arsenic (1.6 times) and cadmium (1.7 times). There were no exceedances of MPC and APC in soil samples of Omsk district (Table 2).

In the Nazyvaevsky district of the Omsk region, sampling was carried out at two geoecological testing facilities. A total of 15 samples were taken (Table 3). The soil samples had a loamy grain composition, the pH values varied from 3.92 to 8.28. The concentrations of heavy metals at sites 1-2 varied slightly. Thus, the concentration of Zn is 47.0–56.0, Cu – 28.8–35.6, Ni – 41.0–45.5, Cd – 0.54–0.55, Pb – 10.46–12.77, Hg – 0.018–0.025, As – 6.64–7.11 mg/kg. In the studied samples, there were no exceedances of the standard values (MPC and APC). The hazard coefficients relative to the APC (MPC) were < 1. At the same time, the regional background level was found to be exceeded for Zn, Cu, Cd, Ni, and As.

Table 3 Average content of gross forms of heavy metals in the soils of Nazyvaevsky district in 2019-2024, mg/kg.

№ of the geo-environmental sampling object	Hg	As	Pb	Cd	Cu	Zn	Ni
Object № 1	0.018 / 0.01	7.11 / 0.71	12.77 / 0.09	0.54 / 0.27	35.6 / 0.27	56.0 / 0.25	45.5 / 0.57
Object № 2	0,025 / 0,01	6,64 / 0,66	10.46 / 0.08	0.55 / 0.28	28.8 / 0.22	47.0 / 0.21	41.0 / 0.51
MPC	2.1	-	-	-	-	-	-
APC [1]	-	10	130	2,0	132	220	80
Background	0.1	2.2	15	0.12	15	45	30
GK[2]	0.083	1.7	16	0.13	47	83	58

Source: Compiled by the authors. *– average content of the element in the soil; ** – hazard coefficient relative to the maximum permissible concentration (MPC); 1 – approximately allowable concentration; 2 – geochemical clark of the solid earth crust according to A.P. Vinogradov.

Thus, as a result of the conducted engineering and environmental surveys, it was established that there were no exceedances of sanitary and hygienic standards at all geoecological testing facilities.

Table 4 shows the concentration coefficients (K_{Ci}) of heavy metals in soils, reflecting the excess of their actual content over the background, as well as the total pollution index (Zc), which is a complex indicator of the degree of soil pollution.

Table 4 The total pollution index of soils in the forest-steppe zone of the Omsk region.

Geo-ecological sampling site	Concentration coefficient (K_{ci})							Zc	Pollution category (according to SanPiN 2.1.3684-21)
	Hazard class 1					Hazard class 2			
	Hg	As	Pb	Cd	Zn	Cu	Ni		
Tyukalinsky district, Object №1	0.23	**4.36**	0.85	**4.83**	**1.32**	**2.44**	**1.71**	9.66	permissible
Tyukalinsky district, Object №2	0.18	**3.23**	0.85	**4.50**	**1.24**	**2.37**	**1.52**	7.86	permissible
Omsk district, Object №1	1.00	**1.61**	**1.08**	**1.67**	0.90	0.96	0.73	1.36	permissible
Nazyvaevsky district, Object №1	0.18	**3.23**	0.85	**4.50**	**2.37**	**1.24**	**1.52**	7.86	permissible
Nazyvaevsky district, Object №2	0.25	**3.02**	0.70	**4.58**	**1.92**	**1.04**	**1.37**	6.93	permissible

Source: Compiled by the authors.

The concentration coefficients shown in Table 4 indicate that in the surveyed territories there was an excess of the background level for As and Cd in all the studied areas of the Omsk region, for Zn, Cu and Ni – in Tyukalinsky and Zyvaevsky districts, for Pb the excess was insignificant and was noted only in the Omsk region.

At the survey sites, in all selected soil samples, the total pollution index was < 16 (Table 4), which indicates a low level of contamination (category "acceptable"). According to Appendix 9 of SanPiN 1.2.3685-21, these soils can be used without restrictions, since the content of chemicals in the soil exceeds the background, but not above the maximum permissible concentrations.

4 Discussion

The results of the conducted research within the framework of engineering-ecological surveys are consistent with the data of a detailed survey of soils of the Omsk region for the content of gross forms of heavy metals [7, 10]. The generalized scientific data on the West Siberian region indicate a favorable agroecological situation regarding the content of heavy metals in soils.

In the work of V.M. Krasnitsky and A.G. Schmidt (2018), it was found that the soils of the Omsk region annually receive Pb – 0.018%, Cd – 0.036%, Cu – 0.019%, Zn – 0.028% (relative to their actual content). At the current level of anthropogenic load, it will take many years for heavy metal concentrations in the soil to reach regulatory values.

5 Conclusion

According to the data of the 2019-2024 engineering and environmental surveys, it was found that soil samples taken at the studied sites comply with the requirements of hygienic standards (MPC and APC). The value of the total pollution index Zc is less than 16, which indicates an acceptable level of soil contamination.

To reduce the negative impact on the surveyed areas, it is necessary to observe the boundaries of the territories allocated for construction, install containers for waste collection, as well as to carry out their timely removal to specially designated locations; drainage of waste oil should be made in special containers, not allowing them to fall on the ground surface.

It is recommended that disturbed areas be reclaimed after the work has been performed. At the same time, land plots disturbed during the works should be reclaimed to their original state.

The prospect of further research is related to the need for ongoing monitoring of heavy metals and arsenic in the soils of excavated areas, in order to prevent undesirable environmental effects during construction.

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