

Agroecological peculiarities of technogenic pollution of soils and vegetation in the impact zone of Lebedinsky mining and processing enterprise

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Abstract. Soil contaminated with heavy metals is of little or no use to most living organisms. Even if the soil does not become lifeless, the biocenoses formed on it are characterised by small biomass volume, low speed of biological processes, narrow species composition (biodiversity), weak stability, etc. In addition, agricultural products obtained on contaminated soils are often simply toxic, due to the increased content of heavy metals. We have investigated the impact of Lebedinsky mining and processing plant on the state of soil and vegetation in the zone of its operation. On the large factual material, the regularities of spatial variation are revealed and the character of statistical distribution of heavy metals content in soils and plants of agricultural crops in the technogenic landscape is established.

1 Introduction

With the growth of production, development of machinery and technology, the scale of human impact on the natural environment has increased significantly. The self-sufficiency of nature in self-purification and self-recovery under such conditions becomes practically impossible. This is especially true for large industrial enterprises, whose operation necessitates environmental regulation of the territory, taking into account the natural conditions of the region and its functional purpose.

Lebedinsky Mining and Processing Plant is one of the largest enterprises producing iron ore raw materials. The open-pit mining method is always accompanied by an anthropogenic impact on the environment and disturbance of the natural balance. There is a need to occupy large land areas for the disposal of overburden, ore dressing waste, and sludge. Negative results of the impact of mining are also changes in hydrogeological conditions, air pollution by emissions from various sources (quarries, processing plants, tailings dumps).

The basis of technogenic emissions from mining and processing plants is iron silicate dust, sulphur dioxide, carbon monoxide and nitrogen oxides. Dust, which accounts for up to

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60% of all emissions, contains many trace elements: iron, chromium, cobalt, titanium, vanadium, sulphur, zinc, nickel and others, which to a greater or lesser extent adversely affect plant and animal life, as well as human life. Gas and dust emissions are sources of large amounts of solid substances and chemical elements into the environment. The main mass of technogenically dispersed metals, although emitted into the air, very quickly reaches the soil surface. It is in the soil that pollutant metals accumulate and here their differentiation begins. A significant part of metals is included in the soil-forming process, and some part is absorbed by vegetation and carried away with surface and ground runoff. As a result, technogenic geochemical anomalies of heavy metals are formed [1]. Their characteristic feature is a rapid decrease in the concentration of pollutants from the source to the periphery. Emissions of harmful substances are deposited on the soil, partially included in the cyclic exchange between the land surface and the surface layer of the atmosphere and thus redistributed further from the source of emission (at a distance of up to 40-50 kilometres, in accordance with the wind rose). As a result, regional pollution is formed, spreading over significant areas [2]. The size of these areas depends on many factors, both technogenic - productivity and duration of exposure to dispersion of harmful substances (in particular, metals), and natural climatic factors.

At the same time, soil is an indicator of pollution, as it preserves long-term information about the environment and reflects stable long-term accumulation of pollutants. Accordingly, the vegetation cover of both agro-landscapes and natural phytocenoses is also polluted.

In this connection, it is important to study the ways of chemical elements entering the natural environment, accumulation in soil and migration in the system soil-plant-animal organism.

One of the ways to detect and prevent undesirable consequences of anthropogenic changes in soils can be the organisation of soil pollution monitoring, which is an important part of monitoring of pollution of the natural environment. Soil pollution monitoring, or pollution control system allows to identify the most dangerous sources of toxic substances emissions, the area's most strongly exposed to anthropogenic impact, and promotes rational use of material resources in the fight against negative consequences of actual and predictive levels of soil pollution. Currently, there is very limited information on the areas of soils contaminated with heavy metals. This is largely due to the fact that determination of the areas of contaminated soils requires land inventory and is a very expensive activity.

It has been established that the main sources of pollution of agro-landscapes in Gubkin Urban District are Lebedinsky and Stoilensky mining and processing plants and JSC "Kombinat KMaruda", which account for 53% of all emissions.

The purpose of this work is to assess the ecological condition of soil and vegetation in the area of operation of Lebedinsky Mining and Processing Plant and to determine the content of heavy metals in plants at the tailings dump depending on the thickness of the reclamation layer or its absence.

The objects of research of the present work are agrolandscapes of natural environment (soil cover and vegetation) located in Gubkinsky district of Belgorod region. The objectives of the work were to study the content of heavy metals in soils and plants taking into account possible contamination by industrial wastes and dust and gas emissions, as well as to find ways to prevent the accumulation of chemical elements in them and to provide conditions for normal plant life.

2 Materials and research methods

Currently, one of the urgent issues of ecology and nature protection is the study of the consequences of pollution of environmental facilities and the greening of production. The directions and tools of the strategy of transition to sustainable development are presented

directly in the publications: Klein B.C., Scheidemantle B., Hanes R.J., Davison B.H., Cai C.M. [3], Wang J., Lyu Y., Zeng R., Mao J., Guo Z. [4], Aghbashlo M., Hosseinzadeh-Bandbafha H., Shahbeik H., Tabatabaei M. [5], Dinesha P., Kumar S., Rosen M.A. [6], Onifade S.T., Alola A.A. [7], Napathorn C. [8], Amirshenava S., Osanloo M. [9].

The actual problems of modern development include the study of anthropogenic impacts on the soil, in particular, soil pollution with heavy metals. The environmental consequences of this phenomenon have two negative sides at once. Firstly, heavy metals cause serious diseases in animals and humans by entering excessive amounts through food chains from the soil into plants, and from there into the body of animals and humans. Secondly, accumulating in large quantities in the soil, heavy metals can change many of its properties: the number of microorganisms decreases, the intensity of the main microbiological processes and the activity of soil enzymes decreases, etc. The result of all this is a partial, and in some cases, complete loss of soil fertility.

Since the main share of pollutants enters the air from smokestacks of plants and ventilation ducts, dusting of magnetic separation tailings, explosions in quarries and wind transport of already deposited particles, most of them are deposited near the enterprise at its industrial site and within the sanitary protection zone. The smaller part of heavy metals is transported by atmospheric streams to a greater distance and deposited within 3 to 8 km from the emission site, and in case of strong wind - up to 30 km. In addition to emissions from the Lebedinsky and Stoilensky mining and processing plants, the territory is polluted by toxicants released into the atmosphere from motor vehicle exhaust pipes, which are deposited, as a rule, near motorways and towns.

On the basis of a large amount of factual material the regularities of spatial variation were revealed and the character of statistical distribution of heavy metal content in soils and plants of agricultural crops in the anthropogenic landscape was established.

To determine the assessment of contamination of agrolandscapes of Gubkinsky district, samples of soils and agricultural products (crops) were taken: 1) soil cover represented mainly by typical chernozems and leached chernozems; 2) agricultural crops (cereals and vegetable crops) falling within the zone of technogenic influence. Samples were taken taking into account the direction of winds that prevail in the study area: the prevailing winds are east, west and south-west (average annual value).

Main research methods: field collection of soil and plant samples at different distances from the pollution source and chemical analysis method. The content of gross forms of heavy metals was determined by X-ray fluorescence spectrometry. Concentrations of the following elements were determined in the samples: copper, iron, zinc, manganese, lead, cadmium, chromium, nickel. The background content of heavy metals in soil samples was determined at a distance of 40 km to the west of the pollution source.

3 Results and discussion

Soil fulfils a number of ecological functions, both biocenotic and global (biosphere-wide), which ensure the stability of both individual biogeocenoses and the biosphere as a whole, and, consequently, the very possibility of existence of life on Earth. In addition, the specific function performed by soil in relation to humans should be emphasised. Soil is the most important irreplaceable natural resource - the main means of agricultural production.

Soil contaminated with heavy metals is of little or no use to most living organisms. Even if the soil does not become lifeless, biocenoses formed on it are characterised by low biomass, low speed of biological processes, narrow species composition (biodiversity), weak stability, etc.

In addition, agricultural products obtained on contaminated soils are often simply toxic, due to the increased content of heavy metals.

We have investigated the impact of Lebedinsky mining and processing plant on the state of soil and vegetation in the zone of its operation.

The results of statistical processing of monitoring data on the content of heavy metals in soils at different distances from the source of pollution are presented in Table 1.

Table 1. Gross metal content in soils (mg/kg dry weight).

Distance from pollution source, km	Chemical element content					
	Cu	Fe	Zn	Mn	Pb	Cd
6.0	19	30700	59	522	18	0.33
6.5	23	33500	60	499	22	0.49
7.5	22	32900	63	553	9	0.28
8.0	18	28000	58	585	18	0.21
9.0	12	29200	58	467	11	0.33
16.0	26	28700	61	519	23	0.19
IPC (indicative permissible concentration)	55	-	100	1500	32	3
NBC (natural background concentration)	9	30000	48	480	7	0.35

The arable layer of zonal chernozems experiencing low anthropogenic impact contains 4.3% of iron-containing minerals. Around the centre of the industrial hub the iron content in the arable layer of chernozem soils increases in some samples up to 6%.

Long-term analysis shows that concentrations of most heavy metals in the soil cover do not exceed the background concentrations in the area and tentatively permissible. In this regard, it is inappropriate to speak about heavy metal pollution of the territory as a result of dust emissions exclusively from the mining complex.

Other circumstances may also be the reasons for the absence of soil pollution with heavy metals in the zone of influence of the mining complex. Thus, simultaneously with accumulation of metals in the soil layer their removal in the process of surface water erosion occurs. In the process of infiltration heavy metals move to deeper soil layers, there is a concentration in agricultural products.

In addition, none of the elements forms intensive pollution around the enterprise, but it is possible to identify some patterns. Thus, there is an area of high lead content, which runs from the north-east to the south-west of the study area, along the federal motorway with a large flow of motor vehicles.

There is practically no direct correlation between the level of heavy metals content in soil and their uptake by plants. A number of geochemical barriers and, first of all, the soil, stand in the way of penetration of heavy metals into plants. The level of toxicity of heavy metals depends on the mechanical composition of soil, its acidity, moisture, humus content, biological activity.

To determine the content of heavy metals in plants of different crops, samples of grain, spring barley straw and fodder beet root crops were taken at agro-enterprises, as well as samples of fruit and vegetable crops in settlements located in the zone of influence of Lebedinsky mining and processing plant (depending on the distance from the source of pollution). The results of the studies are given in Tables 2 and 3.

Table 2. Content of chemical elements in crop plants (mg/kg).

Distance from pollution source, km	Culture	Chemical element content				
		Cu	Fe	Zn	Pb	Mn
MPL (maximum permissible level)		20-40	250	60-100	1-5	60-70
1.0	Barley (grain)	2.4	117	11.7	23.6	14.3
	Barley (straw)	7.3	500	27.3	13.5	13.7
	Fodder beet (root crops)	5.9	310	31.1	2.8	44.9
2.0 – 7.0	Barley (grain)	13.1	123	13.8	9.5	13.8
	Barley (straw)	7.3	252	27.3	3.2	15.2
	Fodder beet (root crops)	6.1	238	23.8	2.2	37.4
7.0 – 15.0	Barley (grain)	2.5	126	12.6	5.8	15.4
	Barley (straw)	7.0	100	15.0	0.6	15.0
	Fodder beet (root crops)	4.5	154	6.6	0.8	28.5

It follows from the data in Table 2 that the content of heavy metals in grain products does not exceed the maximum permissible level for most elements, with the exception of lead: in spring barley grain there was an excess of lead concentration in the harvest obtained at a distance of 1-7 km. Iron content in root crops of fodder beetroot and in straw of fodder barley from the harvest obtained at a distance of up to 7 km from Lebedinsky Mining and Processing Plant exceeds the maximum permissible level by 1.5-2 times. At a distance from the source of pollution over 7 km the concentration of heavy metals in the studied crops did not exceed the maximum permissible level.

Table 3. Content of chemical elements in fruit and vegetable crops (mg/kg).

Distance from the pollution source 6 km and from the motorway 1 km	Culture	Chemical element content				
		Cu	Fe	Zn	Pb	Mn
Distance from the pollution source 6 km and from the motorway 1 km	Potatoes	0.43	4.42	1.22	0.229	0.883
	Carrots	0.521	5.43	0.87	0.179	1.601
	Onions	0.68	5.05	0.84	0.179	44.9
	Cucumbers	0.15	1.87	0.265	0.12	0.32
	Tomatoes	0.005	0.014	0.005	0.03	0.002
	Apples	0.657	2.038	0.521	0.111	0.432
	MPC (maximum permissible concentration)	5.0	50.0	10.0	0.5	-

Most chemical elements play an important role in plant life. However, when they are contained in concentrations exceeding the maximum permissible concentrations (MPC), they become toxic to plants and, consequently, animals and humans. As can be seen from the results of the study shown in Table 3, the content of trace elements (copper, iron, zinc, lead, manganese) in fruit and vegetable crops did not exceed the maximum permissible concentrations.

The next stage of our work was to assess the content of heavy metals in plants at the tailings dump depending on the thickness of the reclamation layer or its absence.

Due to the existing type of metabolism, plants selectively absorb mainly necessary elements in amounts corresponding to their physiological and biochemical needs. However,

there may be cases of forced intake of necessary elements in quantities toxic for their development. This results in various kinds of changes in plant appearance up to symptoms of endemic disease. Threshold concentrations can vary considerably for each element. This is due to the biological peculiarities of the plant species and its growing conditions. For example, cereal grains have at least three protective barriers at the soil-root, root-stem, and stem-grain boundaries. Other plants have no defence barriers. However, even for species of the same crop the levels of threshold concentrations are not constant, moreover, they can change under the influence of climatic, soil-geochemical and other conditions.

At accumulation of heavy metals in plants they are concentrated, first of all, in vegetative mass of plants, and then in reproductive organs. The death of plants occurs at the content of elements in the soil above the maximum permissible concentrations.

Good condition of plants at high weight fraction of heavy metals in them can lead to false conclusion about possibility of using highly contaminated soils for fodder or vegetable crops, which is widely practiced near motorways and industrial enterprises. Therefore, the only criterion for the possibility of growing plants is the analysis of heavy metal content in vegetative and reproductive organs of plants. Plant products in the zone of influence of industrial emissions are contaminated not only by absorption of chemical elements from soils, but also by direct deposition of emission products on plant surfaces [10]. This is especially dangerous for those crops that use ground green mass.

Plant samples were collected and analysed in accordance with the methodology of the Central Research Institute of Agrochemical Service of Agriculture [11]. Table 4 shows the data on the content of chemical elements in plants grown on the tailing dump depending on the thickness of the reclamation layer.

Table 4. Content of chemical elements in plant crops grown on the reclaimed tailings dump.

Methods of reclamation	Plant culture	Chemical element content (mg/kg feed)					
		Fe	Mn	Cu	Zn	Pb	Cr
MPL (maximum permissible level)		250	60-70	20-40	60-100	-	-
enrichment tailings	blue-hybrid lucerne (hay)	2218	22.8	7.0	10.8	3.1	16.4
tailings + 0.2 m of black soil		1291	21.7	4.8	12.4	2.8	3.0
tailings + 0.4 m of black soil		1239	13.7	3.7	8.8	1.8	5.5
tailings + 0.5 m of loam		1200	14.2	6.0	13.0	2.1	11.0
tailings + 0.4 m loam + 0.1 m of black soil		988	14.7	6.0	12.0	2.0	10.0
tailings + 0.3 m of loam + 0.3 m of black soil		1410	13.8	5.0	8.8	1.2	26.9
tailings + 0.5 m loam + 0.4 m of black soil	lucerne (roots)	1974	136.6	5.4	15.0	2.4	60.5
	sainfoin (hay)	322	10.0	10.2	11.0	1.0	5.7
	clover (hay)	848	13.3	10.3	11.5	1.4	11.8
	yellow lucerne (hay)	513	8.8	12.2	11.1	1.4	4.4

It should be noted that the content of chemical elements depends on the plant species. Alfalfa blue-hybrid accumulates elements such as iron and lead in the vegetative mass the most. Clover hay contains a large amount of copper and chromium, and sainfoin contains the least amount of iron compared to other types of legume grasses. The roots of blue-hybrid alfalfa contain high amounts of manganese and chromium. This indicates the presence of a geochemical barrier in alfalfa at the root-stem boundary; however, this barrier does not work in relation to such elements as iron, copper, zinc, and lead.

4 Conclusion

Soil contaminated with heavy metals is unable to fulfil its ecological, including general biospheric, and agricultural functions fully. This poses a threat to the ecological and food security of mankind.

The study of soils and vegetation in the zone of functioning of Lebedinsky mining and processing plant has shown the following conclusions.

Production of fodder beet in a seven-kilometre zone from the source of pollution leads to the accumulation of iron in root crops and further transformation along trophic chains. The maximum accumulation of this element is observed in the two-kilometre zone.

High content of lead in grain products can be explained by intake of the element not only through soil, but also by aerosol pathway associated with motor transport emissions.

The degree of contamination of fruit and vegetable crops with such elements as copper, iron, zinc, lead and manganese did not exceed their maximum permissible concentrations in food products.

As a result of industrial emissions from mining enterprises, as well as dusting of tailings within a radius of 2 kilometres, a technogenic geochemical anomaly with increased content of iron, copper, zinc and lead is formed. However, they are also called "elements of life", emphasising the possibility of life and development of living organisms only in the presence of these mineral elements. It is important to improve the system of sanitary and hygienic monitoring of soil and sanitary and hygienic condition of crop products under conditions of anthropogenic impact on the environment.

On the reclaimed soils of tailing dumps the greatest amount of elements is accumulated in plants at low thickness of the reclamation layer or its absence. This is especially noticeable in the accumulation of iron in the ground mass of alfalfa, the content of which exceeds the maximum permissible by 10 times. In addition, alfalfa grown on enrichment tailings contains increased amounts of lead and manganese in the above-ground part. Increasing the reclamation layer to 0.5 m of loam for alfalfa reduces iron accumulation twofold, and to 0.9 m (0.5 m of loam + 0.4 m of bulk chernozem) - 4 times and 6 times for sainfoin. At the same time, the content of copper and lead decreases to a concentration close to normal.

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