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The Influence of Industrial Emissions from a Zinc Factory on the Properties of Chernozem Soil

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Abstract

This article describes the influence of zinc factory emissions on soil cover and vegetation cover of the lands of East Kazakhstan. It is shown how the physical properties of water affect soil moisture. The authors consider how heavy metals destroy the composition of organic acids and how it affects the aggregate state of the soil cover.

Keywords: *agrochemical properties, collembolans, erosion, heavy metals, oribatid mites, physical properties of water.*

INTRODUCTION

The sustainable growth of the main economic indicators of Kazakhstan over recent years is largely ensured by the development of mining and processing industries. Further increase in business activity, associated with exploration, production, processing and transportation of mineral resources, inevitably leads to an increased negative impact on the soil cover, atmosphere, surface and groundwater, flora, fauna, and public health.

It is known that there is no other branch of the economy in the world that can be compared with the mining industry in terms of the negative impact on natural resources.

Rich mineral resources of the Republic of Kazakhstan are developed in all regions by shaft method or open-pit method. Due to the historical development, East Kazakhstan region is associated with the predominance of the mining industry and nonferrous metallurgy, and it is one of the most depressed regions in the country. The main enterprises of the mining and metallurgical complex are located in the zone of the densest river network. Due to the technical need, the largest thermal power plants are located here as well. Such an arrangement means that all pollutants with gaseous, liquid, and solid waste from industrial enterprises inevitably fall into the river network and soil, causing environmental damage to both biocenoses and the population of the region. In this case, the soil and vegetation cover of the territories are violated, and sometimes they are completely destructed. These areas are barren, often toxic, do not overgrow for a long time, are subjected to erosion and degradation processes resulting in environmental degradation, causing significant damage to human health. This causes an imbalance in the functioning of the biosphere as the main component of the existence of life on Earth.

In the East Kazakhstan region, in early 2015, technologically disturbed and polluted lands amounted to 12602 thous. ha, while depleted lands – to 5120 ha. At the end of 2015, the area of technologically disturbed lands increased by 182 thousand ha and amounted to 12784 thous. ha, while depleted lands increased by 14 ha and amounted to 5134 ha [1].

One of the main and purposeful measures for the rehabilitation of disturbed lands and their return to agricultural circulation, improving the habitat of industrial regions aimed at protecting the environment and ensuring full functioning of the biosphere, is their recultivation. The study of soil formation processes and ecosystems of disturbed lands is of scientific interest in terms of theory and practice. Under the influence of mining and processing industry, soil cover is subjected to pollution. Pollution has already affected the qualitative and quantitative composition of soil biota.

The purpose of the present research is to study the impact of mining, metallurgical, and processing industries on the environment, and to develop theoretical foundations for the rehabilitation of polluted landscapes.

MATERIALS AND METHODS

The research object is the territory subjected to the impact of emissions of processing mining enterprises in East Kazakhstan region. The article studies also the influence of zinc factory on the surrounding landscapes.

The research was conducted using the following methods: reconnaissance detour of the territory, the definition of pollution sources, and manifestations of erosion processes; comparative soil-ecological control method; field methods based on laying soil sections and soil sampling for laboratory analytical analysis. Determination of soil physical and chemical properties was performed by conventional methods. The extraction of microarthropods was carried out in the field environment using Berlese-Tullgren extractor. Determination of soil mites and collembolans was conducted using the determinants of the USSR fauna.

The scientific novelty of the research is substantiated by an integrated ecosystem-based approach in the study of landscapes polluted with anthropogenic emissions of industrial enterprises; the laying of experimental field tests using carbonized bio-coal from rice husks as a sorbent of soil pollutant elements; the development of theoretical foundations for the rehabilitation of polluted landscapes. The article presents the assessment of soil ecological functions in terms of pollution and after rehabilitation in comparison with nonpolluted objects.

RESULTS AND DISCUSSION

The object under study is characterized by dominant leached and podzolized chernozems. Emissions from the zinc factory have a negative impact on the environment. The impact of zinc factory emissions extends over long distances. The distribution area of the factory emissions in the circumference is 2 km, with a special effect of the wind rose eastward from the plant towards the city and the hilly mountain which is devoid of vegetation and is cut by erosive furrows and gullies. A strong influence of factory emissions on the soil and vegetation cover was revealed within a radius of 2 km. Thus, the territory subjected to the impact of factory emissions is characterized by formed rill channels, grooves, and irrigation ditches. The top layers of chernozem soil are completely washed-off. Due to pollution, soil cover of the territory around the enrichment factory is deprived of vegetation.

Studies of physical, physicochemical, chemical, and biological properties of the soil showed the negative impact of factory emissions on the basic parameters of soil fertility. Thus, the granulometric composition of soil changes due to the accumulation of fine silty clay fractions resulting in the formation of more indurated illuvial B horizon. The volume mass of degraded polluted soils is higher than in chernozem soils of undisturbed landscapes.

Leached chernozem of the test area is characterized by deep erosion processes and partial wash-off of the humus horizon. The soil of the test area contains just 4.7% of humus in comparison with nonpolluted leached chernozem (8.1%) (Figure 1). In consequence of soil pollution and degradation, the proportion of total humus in the soil of the test area has decreased by 38%.

The increase in mobile organomineral compounds as well as in the proportion of fulvic acids in the humus of chernozem soils can lead to soil degradation. In chernozem, humus is considered a relatively stable system. Minkina T.M. et al., noted about the influence of heavy metals on the properties of polluted soils [2, 3]. Thus, heavy metals exert an impact on the acid composition of humus substances; cations of soil adsorption complex are displaced by heavy metal ions. In terms of the bond strength between absorbed cations and soil adsorption complex, metals constitute a decreasing series: Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}>H^{+}. Based on the conducted research, we can conclude that in ordinary chernozem the pH level decreases along with nitrate nitrogen and mobile phosphorus.

The sum of absorbed bases in the soil of the test plot amounts to 18.4 mg/kg. The composition of absorbed bases is dominated by calcium. The sum of the absorbed basis of soil section 1 equals 12.0-25.81 mg/kg (Figures 2 and 3). The decrease in the sum of absorbed bases should be explained by the manifestations of erosion processes (the upper horizon losses) and the influence of heavy metals, as well as complex formation and displacement of the absorbed bases.

In the soil-absorbing complex of the soils of the experimental site, certain transformation processes took place. Thus, in the conditions of pollution by emissions from zinc factory, the amount of absorbed calcium basic ion decreased in the upper horizons. There was a decrease in the sum of absorbed bases.

Provision of soils with available forms of nitrogen and mobile phosphorus is low. The content of mobile potassium in 0-20 cm layer is 423.0 mg/kg. A decrease in the content of mobile potassium is observed along the soil profile (Figures 4 and 5).

It has been established that the greatest variability in the 0-20 cm horizon is observed in the content of mobile phosphorus (V% - 10.88) and mobile potassium (V% - 4.76). The coefficient of variation in the content of easily hydrolyzed nitrogen in the 0-20 cm soil horizon is V% = 4.56.

In many mining areas, scientists distinguish three or four landscape-functional zones of anthropogenic transformation of natural habitats. The first zone is mining and quarrying dump landscapes with almost complete degradation of soil and vegetation cover, and high concentrations of heavy metals in the dust, anthropogenic depositions, waters, and plants. The allocation of this zone is not a problem, and its boundaries can be easily mapped by decoding aerial or space imagery. The second zone is represented by mining landscapes. This zone is directly influenced by quarries, mining and processing plants, or concentrating plants. In this zone, the content of dust and heavy metals in the air and soil within the area of 2-3 km exceeds the maximum allowable concentration (MAC) by 10 or more times and decreases with increasing distance in accordance with an exponential law [4, 5].

According to [6], metallurgic plants affect the environment within a radius of 5-10 km. In this zone, the association of pollutants reduces, while most often Zn and Pb form most extensive areolas. This area can be allocated to the third zone with quite strong soil pollution. According to A.I. Perelman and N.S. Kasimova, background landscapes are usually located no closer than 15-20 km from the pollution sources, representing the fourth zone, which is characterized by moderate area pollution, strongly dependent on the terrain conditions and climatic characteristics [4]. The long duration of the factory operation (more than half a century) and increased geochemical background necessitate constant monitoring of the surrounding soil conditions.

The soils of the experimental site in the upper horizons contain heavy metals that exceed the MACby 2-10 times. The main pollutants are zinc, lead, and copper. Soil organic matter is able to form complexes with lead ions. In this case, lead absorption occurs in whole or in part due to the displacement of other ions [7]. At pollution, copper and lead are most strongly fixed in the soil. Their fixation occurs due to complexes' formation with organic matter and to a lesser extent due to specific sorption by mineral components. Zinc and cadmium are less bound in the soil [8].

According to the analysis results, the content of all heavy metals in the studied leached chernozem soil exceeds the maximum permissible limits. At the test site, in the soil section 1 (0-25, 25-56 cm), an increased concentration of heavy metals is observed in the upper layers. The zinc factory releases polluting heavy metals, which negatively affect the soil and vegetation cover of the area around the zinc factory. This area is heavily polluted, especially the upper soil horizons. Pollution with zinc exceeds the MAC by 391.7 times. Such high pollution has a strong effect on the vegetation cover (Figures 6 and 7).

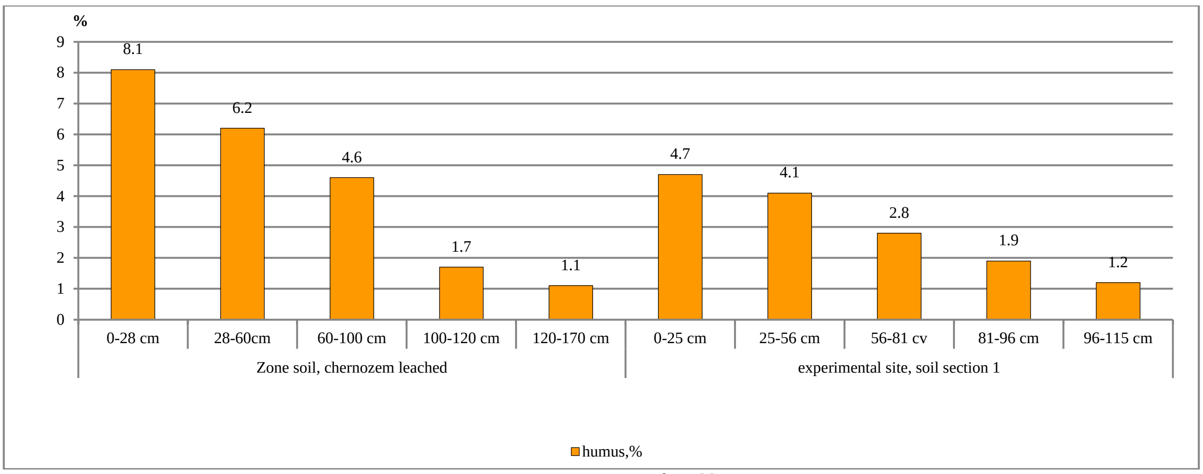
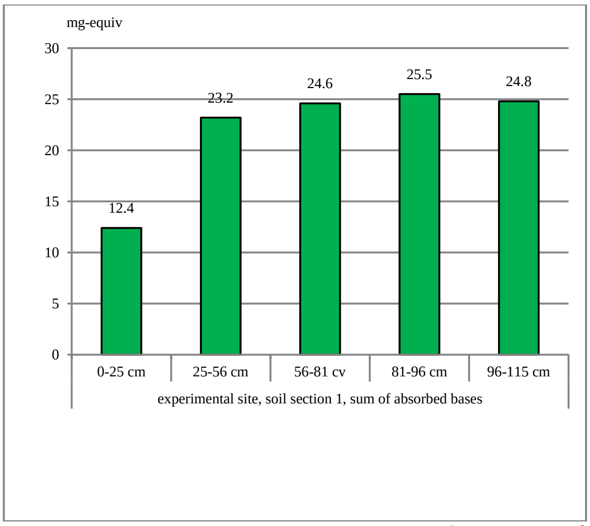
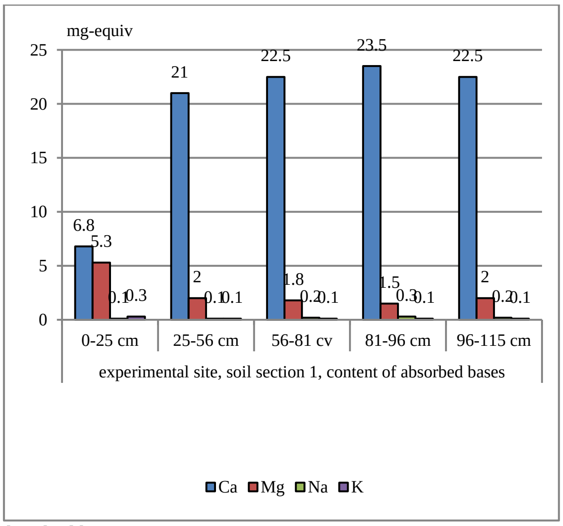
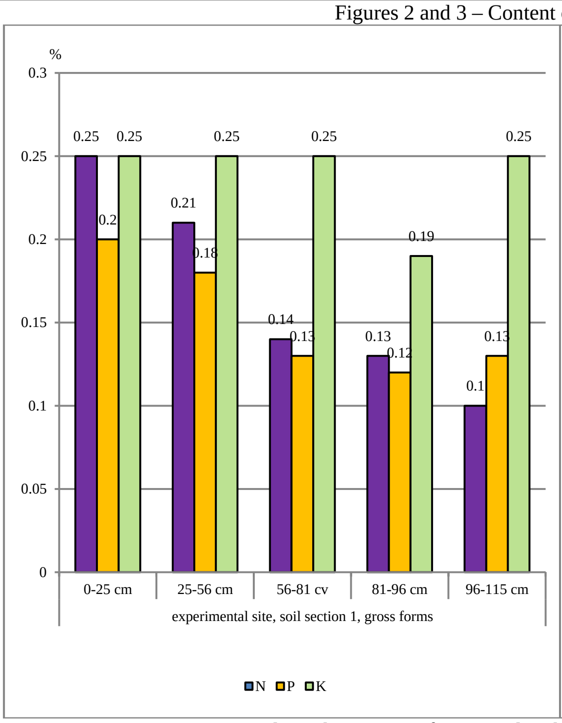


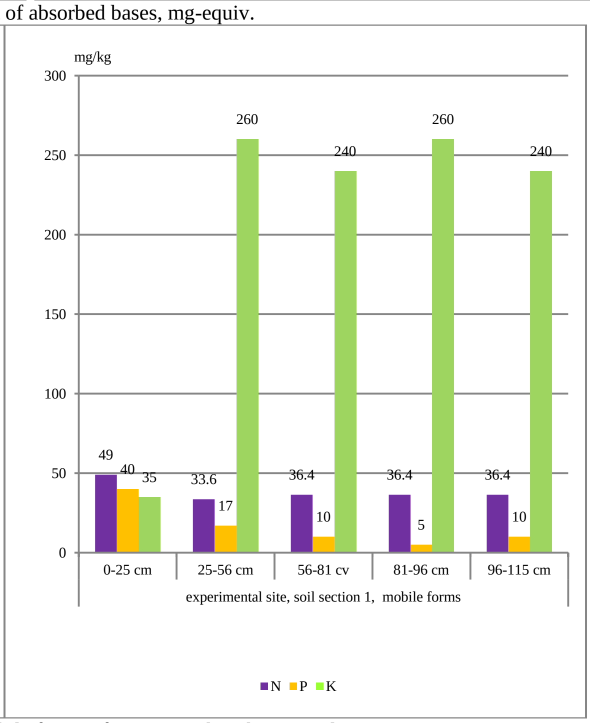
Figure 1 – Content of total humus, %



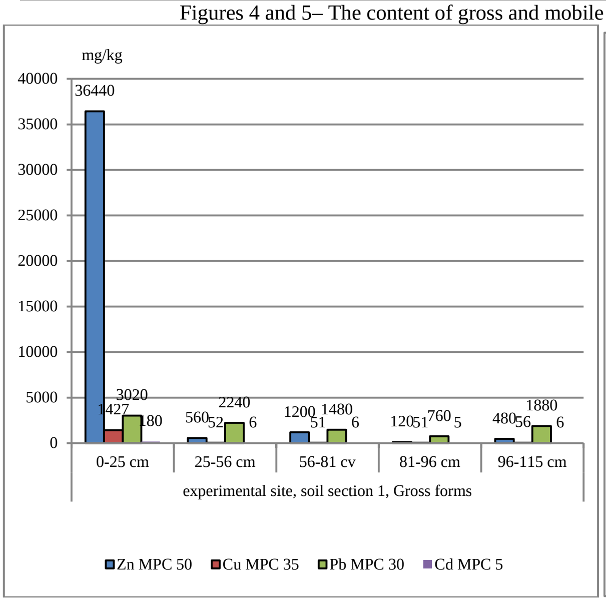


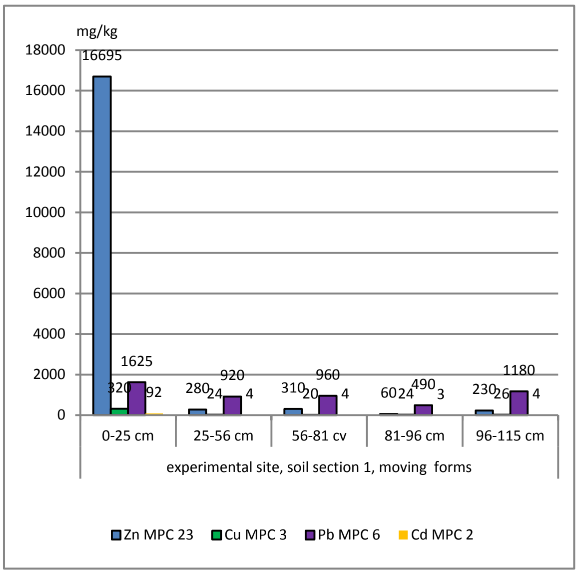
Figures 2 and 3 – Content of absorbed bases, mg-equiv.





Figures 4 and 5– The content of gross and mobile forms of nitrogen, phosphorus, and potassium





Figures 6 and 7 – The content of heavy metals in chernozem leached soil in the area of Zinc factory, mg/kg

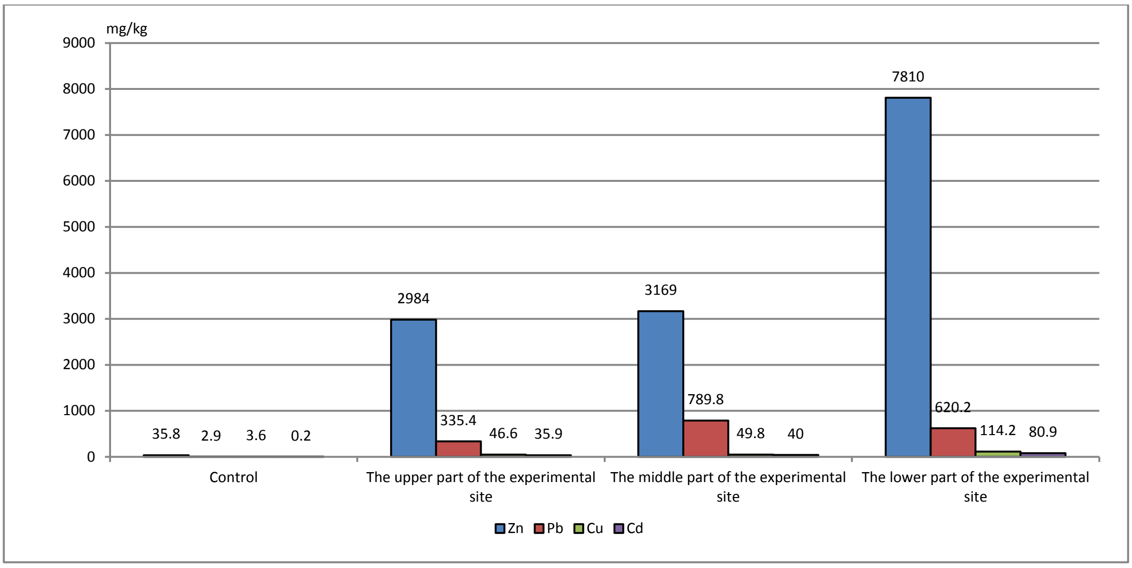


Figure 8 – The content of heavy metals in the plants of the experimental site, mg/kg

Anthropogenic soil pollution by chemical elements has a negative impact on vegetation. Getting into the plant, heavy metals suppress the normal course of metabolic processes, inhibit the plant development, reduce productivity, and make plant products unsuitable and dangerous for consumption by animals and humans.

VernadskyV.I. pointed to the close relationship between the chemical composition of the body and the chemical composition of Earth's crust [9]. At that, it is well known that the content of chemical elements in the same plants may differ. This depends on the different concentrations in the soil of their mobile compounds. Plants have a certain protective system to preserve the concentrations of elements favorable for vital activity. But, despite the presence of such a system, the plants degrade and die in case of the excessive intake of ions of chemical elements from the soil.

As already mentioned, emissions of the nonferrous metallurgy enterprises are transferred over long distances. The accumulation of heavy metals in the soil is noted at a distance of 10-15 km and even further from the source of pollution.

According to some data, the pollution of meadow vegetation by Pb and Zn was recorded at a distance of 12 km from the lead-zinc factory [10]. Near the factory (at a distance of 0-1 km) the accumulation of these metals in the soil is so great that the cultivation of any crops for animal feed or for taking them into food is dangerous for both human and animals. Consumption of plant and animal products obtained within a 3-km zone around the factory will lead to an excess of the standard rates of consumption of lead and cadmium recommended by the World Health Organization.

Analysis of heavy metals' content has shown that in plants, growing in the control areas located 25 km to the north of the factory, the excess in the content of heavy metals which would indicate their pollution, was not revealed. The exception is the content of nickel in the sown grass, which exceeds the limit of 1.0 mg/kg and amounts to 3.02 mg/kg.

Our data show that the most polluted plants grow in the lower part of the territory, which is closer to the factory and has a subordinate position (Figure 8). As exemplified by this territory, pollution of shrubby plants growing in this area exceeds that of shrubby plants growing in control plots by 351,56 times – for cadmium; by 218,09 times – for zinc; by 212,41 times – for the lead, etc.

External pollution is less dangerous for the plants than the pollution through the roots. Not always the negative impact of technogenic dust settled on plants is due to the chemical elements contained in it-pollutants. It can be associated with the reduced flow of solar energy to the cells, blockage of stomata, and chemical processes caused by acidic dust components. In our case, the plants on the studied sites are exposed to intense impacts both through the root system (to a greater extent) and through external pollution (to a lesser extent).

Thus, plants do not accumulate heavy metals, but on the contrary, heavy metals are accumulated in plants, because they penetrate plants. Any plant can accumulate chemical elements, necessary for metabolism, up to a certain limit even in case of their shortage in the environment. The main portion of the pollutants penetrated into plants is retained in the roots and returned back to the soil after their destruction. That is, even during the reclamation activities to clean the soil from heavy metals, the soil will be polluted for a long time (even after the termination of the impact caused by the factory).

Plants absorb almost all chemical elements from the environment. The ash composition of plants from technogenic landscapes shows that different parts of plants absorb and accumulate certain chemical elements. Thus, the plant litter and roots of herbaceous plants have the highest ash content. At that, the priority chemical elements in the ash are silicon, calcium, sulfur, phosphorus, potassium, and magnesium, as well as the minimal amount of nitrogen. Wood species have lower ash content. The ash composition depends on the environmental conditions of both herbaceous and woody plants [11].

The importance of studying the population of soil invertebrates is due to their huge role in the life of the soil, where they not only inhabit, but also actively form the structure of soil horizons [12]. The state of soil fauna reflects the processes in the soil, while information about the soil population helps to understand the characteristics of soil formation in different types of soils. The intensity and direction of the processes in the soil block are the most important indicators of ecosystem dynamics. Bioindication of soil processes has been one of the priority research areas in ecology for many decades [13]. Combinations of anthropotechnogenic factors that affect the ecosystem condition are quite diverse, such as environmental pollution by emissions of industrial production, vehicles, exclusion of fertile land from nature management by mining waste, and many others. Anthropogenic stressors occur at such a rate that biological systems do not have time to adapt to them, however, their biological properties change under the impact of all these adverse factors [14].

Microarthropods include several large arthropod taxons. The criterion for the allocation of this group is the size of the animals (from fractions of a millimeter to several millimeters). The oribatid mites (*Oribatei*) and collembolans (*Collembol*a) are destructors of plant litter, and their role in the soil humification process is invaluable. They are the most active destroyers of plant residues among organisms of soil microfauna. The density of oribatid mites and collembolans reaches tens and hundreds of thousands, sometimes millions of zooid per 1 m^2 of the soil. It is not surprising that the role of these organisms in the life of the soil is difficult to overestimate. Moreover, collembolans are a group of organisms, which are the first to colonize barren soils and giving rise to the formation of pioneer communities. *Gamasid* mites lead a predatory life and are connected with the collembolans by food relationships. The rates of degradation and the character of organic substances' transformation are determined by the trophic activity of collembolans, community structure, and their total abundance. Eating bacteria, hyphae, and spores of fungi, many collembolans stimulate their growth and reproduction, contribute to the resettlement of microflora in soil and plant litter. *Collembolans* can be actively involved in the helminths' elimination mechanisms; helminths enter the soil in the course of their development. Soil microarthropods, due to their peculiarities (high mortality rate and rapid growth), are sensitive and quick to changes in the hydrothermal and chemical composition of soils. This makes them good indicators of soil ecological status [15-21].

Oribatid mites and collembolans, being representatives of microfauna, serve bioindicators of the soil medium. Their absence in the soil proves the high pollution of the soil, which is their natural habitat.

The experimental site was poor in terms of soil animals, including oribatid mites. Just a small amount of the genus *Subbelba* was revealed in the soil layer 0 - 5 cm thick.

For comparison, soil samples were taken from unpolluted areas. In samples collected from the zonal soil, 10 species of oribatid mites (*Oribatei*) were found. They belonged to 9 families, constituting 66.6% of all investigated mites. There were no representatives of the following genera: *Trhypochthonius, Subbelba, Parabelba, Suctobelba, Belba*. The dominant position was occupied by *Norhrus, Scheloribates, Acaris, Oppia, Zygoribatula*, and *Punctoribat*es genera. The number of oribatid mites in August amounted to 49200 pcs per 1 m^2 or 54.6% of the number of oribatid mites and collembolans in the given sample.

CONCLUSION

1. The conducted research has revealed that zinc factory is the main source of pollution of the experimental site. The distribution area of the factory emissions in the circumference is 2 km, with a special effect of the wind rose eastward from the plant towards the city. The soil cover of the territory is devoid of vegetation and subjected to deep erosion processes.
2. Heavy metal emissions have affected soil physical properties. As a result of the destruction of soil aggregates in granulometric composition and displacement of calcium cations from the soil-absorbing complex, a thin dusty fraction has increased, which in turn caused compaction of soil horizons.
3. In polluted leached chernozem, the content of total humus has decreased due to erosion processes and the wash-off of the soil surface by almost 40% as compared to the unpolluted soil of the control option.
4. Polluted soils are poorly provided with fertility elements (N, P, and K).
5. Heavy metal emissions and soil pollution have affected the soil adsorption complex. The sum of absorbed bases is quite low. Base cations were displaced from the soil-absorbing complex that led to the formation of organomineral compounds with heavy metal cations.
6. The content of heavy metals in the soil due to pollution exceeds the maximum permissible concentrations in tens and hundreds of times.
7. The accumulation of heavy metals in plants occurs in the plant litter and roots.
8. The soil in the polluted area is impoverished by soil microfauna.

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