

Technologies for optimization of ecosystem services and functions of soils under anthropogenic impact in urban areas

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Abstract. The article presents the data of ecological monitoring and assessment of soils of the ecosystems represented in Kursk. On the basis of the description of the structure of 17 soil profile cuts laid out in different functional zones and geomorphological elements of urban landscapes, 7 main types of soils mainly represented in the ecosystems of Kursk were identified and depicted on the map-scheme. According to the monitoring of heavy metals, a tendency to the increase of the concentration of their gross forms in soils has been noted. The increase in their content reaches up to 48.9 % per year. Changes in the concentrations of mobile forms are determined by the dynamics of soil processes and, consequently, they do not always have increasing tendency. The soil remediation technologies, adapted for urban environment, are proposed. Phytoremediation technology and sorption method of detoxification helps to increase the environmental comfort in cities significantly.

1. Introduction

The effectiveness of the state policy in the sphere of ecology can be achieved only through the analysis of the full-fledged data on environmental objects and their integrated assessment. The necessity to evaluate all the components of natural and natural-anthropogenic objects of the environment is obvious. However, soil ecological monitoring in order to assess the quality of the soil cover is essential. Due to their natural specifics, the soils serve as a kind of depot that accumulates, stabilizes and neutralizes numerous products of anthropogenic emissions, fulfilling the role of a barrier on the way of migration of toxicants to adjacent environmental components. These characteristics of soils, as one of the most important components of the environment, determine the stability of ecosystems to anthropogenic impact and ensure their stability and comfort for humans [1].

Preservation of ecosystem functions of soils is a key priority for modern ecologists [2]. This is an integral component when forming an environmentally friendly zones in the cities. The urban soils fulfill a number of important ecological functions and are the basis of the ecological framework [1, 3]. Soils of modern cities are under powerful anthropogenic pressure, leading to their degradation [3]. Technogenesis supports numerous soil damages that results in the formation of various types of urban soils. Basic characteristics and development strategies of urban soils differ greatly from their background analogues [2–4].

Heavy metals (HM) pollution of the soils is one of the main environmental problems that limits a number of ecosystem services of soils. An important practical task of urboecology is the development and introduction of effective methods for the detoxification of soils with heavy metals pollution.



Various selective treatment methods are currently proposed. However, their adaptation to the spatial heterogeneity and excessive anthropogenic changes of the environment requires a large number of studies and their approbation within the conditions of urban environment. For example, an environmentally safe and adequate phytoremediation method of treatment can be successfully applied to reduce toxic concentrations of HM in soils. It is sufficient to select the plants-hyperaccumulators of HM the use of which is not limited by the bioclimatic conditions, the level of soil pollution and metal specificity of a particular plant [5–7].

Sorption treatment methods, based on the ability of materials and fertilizers applied on the polluted soils to immobilize heavy metals in surface horizons, preventing their transfer into adjacent environments and trophic chains, are highly effective. Sorbents can save a significant amount of natural and financial resources required for ecological function recovery of urban soils.

The aim of the work was an environmental assessment of the soils polluted by the heavy metals in Kursk and testing of selective methods for their remediation.

2. Objects and methods of research

When choosing the key areas of the research and sampling sites, such factors as land-use category and topographic effect were taken into consideration. The study of soils and their diagnostics were carried out by laying soil profile cuts and bore holes in various functional zones of the city, as well as in various elementary geomorphological units of urbolandscapes. 17 soil profile cuts that characterize the up-to-date soil cover of Kursk were analyzed. Diagnosis and classification were carried out in accordance with the modern approaches to the classification of urban soils [8, 9]. The selection of soil samples in the profile cuts was carried out from each genetic horizon.

The data of ecological monitoring of heavy metals pollution in soils are obtained from three observation stations, located in the industrial and residential areas of the southern part of Kursk. Samples of wood and leaves of *Tilia platyphyllos*, *Aesculus hippocastanum* and *Acer platanoides* were also taken in the industrial and residential areas of the city in the autumn period. This approach allowed us to determine the maximum accumulation of heavy metals during the growing season. Based on the experimental data, the composition of the studied tree species of the remediation park was modeled, and practical recommendations were also made to introduce this method of remediation into the urban environment.

The detoxification capacity of the sorbent on basis of natural lime and sapropel was studied in laboratory experiments with model pollution of gray forest middle loamy soil with Plumbum ions.

The laboratory experience was laid in plastic vegetation vessels, where 2 kg of gray forest soil were placed. In each vessel, a pollutant element was introduced – Plumbum in the form of its oxide in a dose of 10 MPC (320 mg/kg). After soil system stabilization (after 20 days), four variants of the laboratory experiment were put into the vessels in 6-fold replication according to the scheme:

- 1) Test sample (background – 10 MPC for Plumbum, 640 mg/vessel);
- 2) Background + sapropel + lime – 5 g of mixture/vessel (ratio of components 1:5 by weight);
- 3) Background + sapropel + lime – 10 g of mixture/vessel (ratio of components 1:5 by weight);
- 4) Background + sapropel + lime – 15 g mixture/vessel (ratio of components 1:5 by weight).

The experiment lasted for 40 days. Every 5 days the actual soil acidity (pH) was measured by the ionometric method. Artificial watering, corresponding to the average annual rainfall for the Kursk region, was applied. Quantitative analysis of heavy metals in soils was carried out using atomic absorption spectrometry. Movable forms of heavy metals were extracted with ammonium acetate buffer (pH = 4.8).

3. Geo-information modeling of the soil cover of Kursk

Carrying out an ecological and geochemical survey of the soil cover of Kursk resulted in constructing a map-scheme of the city soils (Fig. 1).

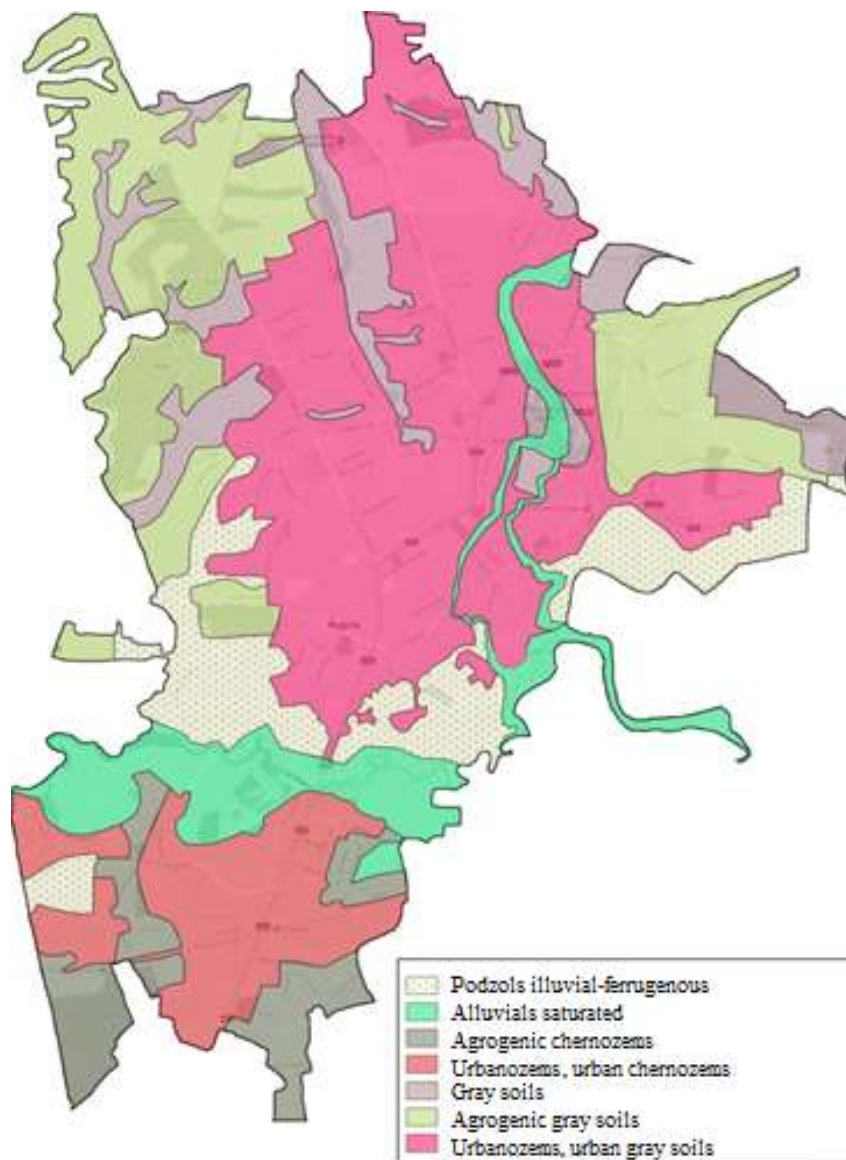


Figure 1. The map-scheme of the city soils of Kursk

The territory of the city is represented by four types of initial native soils historically formed during the Holocene – leached chernozems and gray forest soils on loess loams, alluvial soils of overflow lands on ancient alluvial sediments and sandy podzols formed on ancient alluvial and fluvio-glacial sandy sediments in the terrace above the floodplain of the Seym River. During steps of the morphological description of soil profile cuts and the analysis of the physicochemical characteristics of the soils of the chosen sites, with reference to the cadastral schemes and the functional zoning of the territories, seven main soil groups have been identified. These 7 groups include soils of different nature and degree of anthropogenic transformation (Figure 1). The soils of industrial zones are highly fragmented. Disturbed soil profiles formed as a result of the functioning and construction of industrial sites of various purposes can be found there. Urbanozem with depth of urban horizons of more than 50 cm is the most presented type of soil. In such soils, the amount of anthropogenic inclusions in the Urbik horizons reaches up to 30–35 %. Heavy metals pollution that reaches the depth of 1 m is recorded.

Residential zones of the city have a great variety of anthropogenic changes in the soil cover. Along with urbanozems in urban wastelands urbogray forest soils and urbodark-gray soils are presented,

characterized by the gradual intake and processing of urbotechnogenic sediments. Depth of profile transformation is less than 50 cm.

The soils of sanitary protection and recreational zones of the key sites under research have undisturbed profiles with a classical order of genetic horizons. The soils of sanitary protection zones adjacent to the industrial-active zones are polluted with HM. The soils have frank elements of physical degradation: soil consolidation and erosion, in the areas that are relatively distant from pollutant emission sources

4. Ecological monitoring and assessment of soils in different functional areas of Kursk

When analyzing the results of environmental monitoring obtained from observation stations in the southern part of Kursk, the increase in the gross form of Plumbum for 5 years was noted and totalled 47 mg/kg (Table 1).

Table 1. The average content of gross and mobile forms of heavy metal ions in the soils of Kursk in the period from 2012–2017 year

Element	Content 2012 (mg/kg)	Content 2015 (mg/kg)	Content 2017 (mg/kg)	Reproportion, (%) 2012–2015 year	Reproportion, (%) 2015–2017 year	MPC (mg/kg)
Zn _{gross}	86.3±5.1	98.2±9.1	79.7±8.4	13.7	-18.8	100
Zn _{mob.}	25.2±3.9	28.6±3.4	6.3±1.2	9.5	-77.8	23
Pb _{gross}	80.4±8.2	98.2±13.1	127.4±5.6	21.2	29.7	32
Pb _{mob.}	14.3±2.6	27.6±4.3	23.0±2.1	93.0	-	6
Ni _{gross}	24.1±5.2	27.5±3.4	54.4±4.2	14.1	97.8	40
Ni _{mob.}	1.6±0.4	1.6±0.4	2.2±0.3	-	39.3	4
Cd _{gross}	2.1±1.3	2.1±1.1	2.7±0.9	-	32.8	1
Cd _{mob}	0.6±0.07	0.9±0.2	0.5±0.1	50.0	-44.4	0.1
Cu _{gross}	16.1±3.8	21.7±1.7	65.2±1.9	34.7	200.0	55
Cu _{mob}	0.9±0.1	1.4±0.1	1.1±0.2	55.5	-	6

The stable increase in concentration of Plumbum in soils is fed by to aerosol deposition of the polluted atmosphere and a constant input of accumulating urbosediment. An increase in the content of gross cadmium has been observed only for the last two years and is 32.8 % (0.34 mg/kg per year) (Table 1).

The maximum accumulation in the period from 2015 to 2017 was recorded in gross forms of cuprum and nickel, it figures up to 97.8 and 200 % respectively. Such an increase in the content of the pollutants could have occurred as a result of peak industrial emissions. The content of the gross form of zinc has decreased noteworthy, apparently due to translocation into plants and deposition in wood, due to subsurface leaching. This is proved by a decrease in the concentration of the mobile form of the metal.

Concentrations of mobile plumbum and cuprum have been stable for the past two years, and the concentration of mobile cadmium has decreased by 0.4 mg/kg. This process goes on despite of the high rate of growth of its gross forms, that shows a high degree of their affinity for sorption on geochemical barriers (organic matter, clay minerals, magnetic phase of the soil) and high capacity of the soil absorbing complex with respect to these elements. However, the amount of mobile nickel is increasing (39.3 %). It seems that nickel in comparison with other metals under analysis has the lowest affinity for sorption on geochemical barriers and a considerable part of it stays in the soil solution.

Figure 2 shows the data of the total soil pollution of the main catenas in industrial, residential and sanitary protection zones in the southern part of Kursk, obtained from the analysis of six lots located in the eluvial and transsuperaqual geomorphological elements of the landscape. Urbanozems of lot No. 1 and No. 2 have a very high very dangerous level of pollution, the alluvial soil of lot No. 3 has high,

dangerous level. The soils of lots No. 4–6 (alluvial soil, soddy-podzol sandy illuvial-ferruginous, urban soil) refer to low level of pollution. In general, it is possible to notice a decrease in the total pollution moving away from the active source of pollution to the Seim River (Figure 3). And a slight increase in the total soiling index (Z_c) in urbanozems in the territory of the former machinery plant.

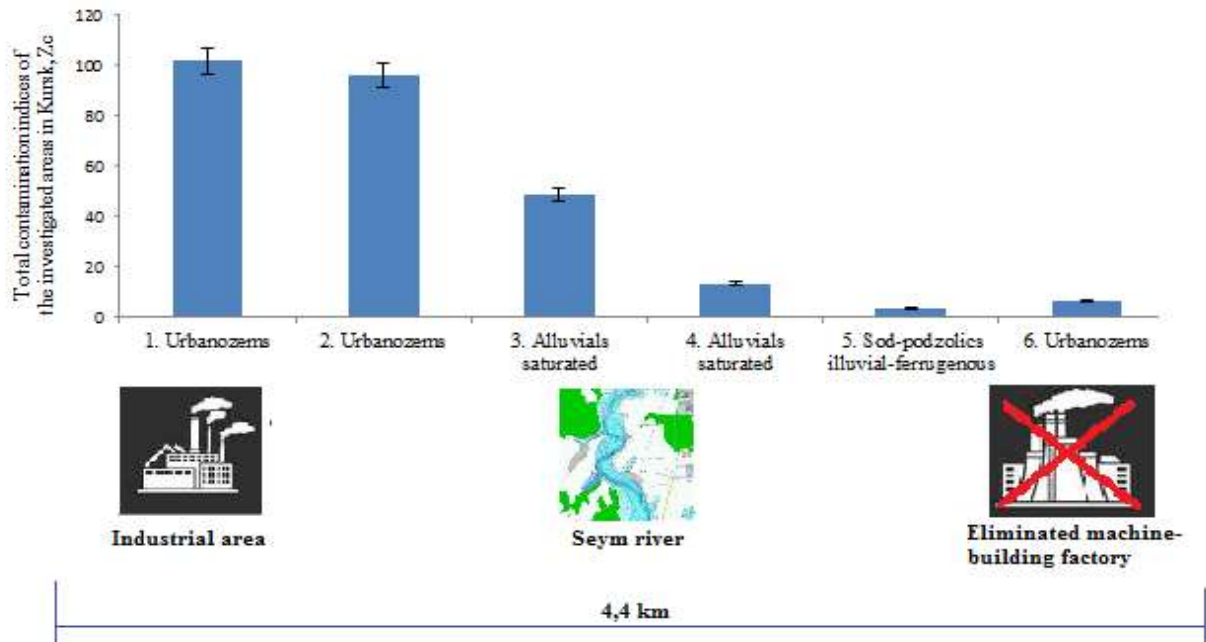


Figure 2. Distribution of total pollution in the soils of the catena under analysis

This can be explained by the prevailing wind and lateral migrations of HM in the soil catena from the alluvial elements (lots No. 1 and No. 2) to transsuperaqual (plot No. 3). Natural barriers for the further distribution of HM are the river and the forest range situated on its right bank. As a result, the transported pollutants produce a high level of pollution on the left bank of the river, and on the right a low level is observed. The territory of the former machinery plant were subject to reorganization (plot No. 6), the polluted soil was removed. This explains the low level of urban pollution at the moment.

5. Selective technologies for urban soils remediation with heavy metals pollution

Environmental comfort level increase in the cities can be achieved by reducing the toxicity of soils with heavy metals pollution. Figure 3 shows the proprietary model of urban microlandscape remediation.

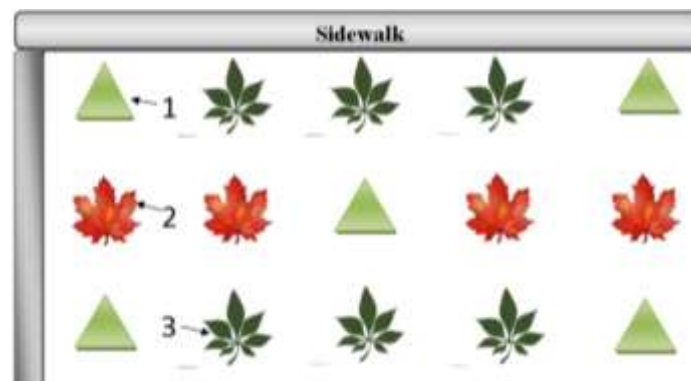


Figure 3. The proprietary model of tree planting that forms a single unit of remediating urban microlandscape [10]
1 – *Tilia platyphyllos*, 2 – *Acer platanoides*, 3 – *Aesculus hippocastanum*

An important aspect of the patent is the composition of wood species, selected not only by the HM accumulation characteristics, but also by the period of their leaf abscission. A set of remediation species allows to prevent the transfer of HM to the soil during the leaf abscission of *Aesculus hippocastanum* and *Acer platanoides*, and also to ensure the supply of organic substance and the progress of the soil-forming processes due to the later leaf abscission of *Tilia platyphyllos*.

The proposed technology of trees-remediators planting enhanced the aesthetics and facilitated to increase the pollution export of heavy metals not only from the surface horizons, but also from deep layers due to the rooting depth. The volumes of produced wood of all trees-remediators will allow to reduce the concentrations of HM in the soil by depositing them in wood. The location of *Tilia platyphyllos* at the corners and in the center of the area allows the distribution of leaf abscission throughout the soil surface. The distance between the trees facilitates the collection of leaves and lawn care with the use of compact agricultural vehicles. The grass lawns will give a picturesque look to the remediation park and will prevent the migration of heavy metals deeper into the soil profile. This model will be a single unit of sustainable urban microlandscapes. The area of this unit is 1.76 Are (52×34 m). The number of the units will depend on the area of the site planned for remediation.

The effectiveness of the described phyto-landscape model in urban environment with increased spatially-nonhomogeneous technogenic burden is justified by the obtained empirical data on the accumulation of heavy metals by the vegetative organs of the species-remediators. The greatest accumulating capacity in relation to plumbum and cadmium has *Aesculus hippocastanum*, which deposits up to 856 mg/kg and 0.9 mg/kg of cadmium. Such remediator as *Acer platanoides* is highly effective in relation to zinc. The leaves of *Acer platanoides* can accumulate up to 1355 mg/kg of zinc (Table 2).

Table 2. Accumulating capacity of tree species in urban ecosystems (according to the research carried out in Kursk region), mg/kg

Element	<i>Aesculus hippocastanum</i>		<i>Acer platanoides</i>		<i>Tilia platyphyllos</i>	
	Leaves	Wood	Leaves	Wood	Leaves	Wood
Pb	732±2.4	856±6.7	122.2±1.3	124.1±1.8	22.7±0.1	23.4±0.2
Cd	0,6±0.1	0,9±0.1	0,29±0.01	0,32±0.02	0.12±0.01	0.18±0.01
Zn	878±7.6	956±8.4	1355.4±7.4	1687.5±8.7	137.2±1.4	143.4±1.7

Leaves of *Tilia platyphyllos* accumulate small amounts of the metals. This will limit the secondary soil pollution during the natural course of soil formation processes and the mineralization of leaf abscission.

Table 3 shows that the annual wood growth will allow the removal of a significant part of heavy metals from the soil cover. Thus *Aesculus hippocastanum* will accumulate up to 22.2 g of plumbum, 0.02 g of cadmium and 24.8 g of zinc per year.

Table 3. The dependence of the annual amount of accumulated heavy metals on the tree species and biomass production (according to research in Kursk region)

Tree species	Wood production by a unit of sustainable urban microlandscapes, m ³	Wood production dry weight, kg	The amount of HM, deposited in wood, g		
			Pb	Cd	Zn
<i>Aesculus hippocastanum</i>	0.04	26.0	22.24	0.023	24.86
<i>Tilia platyphyllos</i>	0.03	11.4	0.27	0.02	1.63
<i>Acer platanoides</i>	0.024	14.4	1.78	0.004	24.29

Thus, it was established that toxic concentrations of HM concentrated in the soil are transferred with leaf abscission of *Aesculus hippocastanum* and *Acer platanoides* and are "weakened" by migration and accumulation in wood.

Phytoremediation method can hardly be used in the epicenters of HM emission with "top-cut grade" of heavy metals. In such cases it is rational to use the means of physical and chemical recreation. The introduction of a sorbent based on natural lime and sapropel materials have a beneficial effect on the immobilization of plumbum by increasing the actual soil acidity and increasing the capacity of the soil absorbing complex. This method allows you fix plumbum in the humus-accumulative horizon of soils and prevents its subsoil migration.

Analyzing the results of the temporal dynamics of the acidity of the soil-water extract (monitoring the temporal changes in the pH (H₂O) of the soil solution in the soil-water extract) at 40 days' exposure, unstable changes of the index were observed during the first 25 days, but then the acidity became stable in the variants of the experiment with the introduced sorbent. In the test sample there was a high decrease in pH (H₂O) and on the 25th day it also stabilized. The highest pH value – 8 was noted in the experiment with a sorbent dose of 15 g/vessel, the lowest reaction of the medium (pH = 7.6) – in the test sample (Figure 4). The effect of the sorbent increases the alkalinity of gray forest soil, that definitely reduces the level of mobile forms of plumbum in it. It is known that in the alkaline environment the electric charges of ampholytoids are redistributed and the sorption of Pb²⁺ increases on mineral and organo-mineral soil colloids.

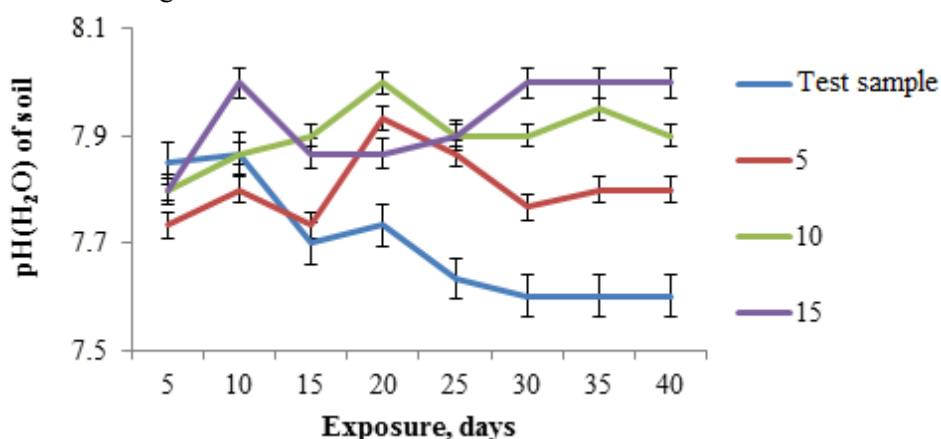


Figure 4. Dependence of (temporal) dynamics of soil acidity pH (H₂O) of gray forest soil on the dose of the sorbent introduced (g/vessel)

During the analysis of the obtained data on the mass concentrations of plumbum, it was found that the mobility of plumbum reduces significantly when the sorbent is introduced, by 82.5–89.8 % to test sample. This is explained by the composition of the introduced sapropel, which increases the capacity of the soil absorbing complex (organic matter, clay minerals) thus provides additional sorption of plumbum on mineral and organo-mineral colloids. The minimum proportion of mobile forms of plumbum was noted at the dose of the recultivant – 5 g/vessel (Table 4).

Table 4. The effect of the dose of the sorbent on the mobility of plumbum in gray forest soil

Dose of sorbent (g/vessel)	Test sample (without introduction)	5	10	15
The content of mobile form of Pb	226.2±26.6	23.1±5.7	39.7±9.2	34.7±8.6
Decrease of mobility, %	-	89.8	82.5	85.7

The results obtained during the experiments convincingly prove that the use of a sorbent based on lime and sapropel effectively reduces the concentrations of mobile forms of plumbum in polluted soils.

6. Conclusion

The mixed character of the soil cover of Kursk is determined by the intensive development and multi-functionality of the industrial, town-planning and transport complexes. The functioning of existing and construction of new industrial economic entities and residential estates of the city is accompanied by a powerful impact on the soil. Increased spatial heterogeneity of the environment and the anthropogenic impact lead to the limitation of ecosystem services of the vast majority of urban soils. This has irreversible effect on the ecological balance and courses a decrease in the environmental comfort level. The annual increase in plumbum is about 7–14.8 %, cadmium 16.4 %, nickel to 48.9 %. This tendency results in the extension of urban soils of with a very high and very dangerous level of pollution that can be ranked to environmental distress. The data obtained from soil monitoring indicate the worsening of the ecological situation in Kursk, which indicates the need to introduce the practice of remediation and restoration of the ecological functions of the urban soils. The use of selective methods of phytoremediation made it possible to transfer up to 22.2 g of plumbum, 0.02 g of cadmium and 24.8 g of zinc from polluted soils per year. The introduction of a sorbent based on lime and sapropel into polluted soils reduces the ratio of the mobile form of plumbum by 82.5–89.8 %. Ecologically safe methods of soil remediation allow forming a sustainable comfortable environment and have obvious resource potential and economic and financial advantages.

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