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Accumulation of heavy metals in soil and litter of roadside plantations in Western Polissia of Ukraine

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Abstract

The article presents the results of a study on the influence of roadside forest belts of different species composition on the accumulation of heavy metals in soil and litter along roads of international and national importance in the conditions of Western Polissia of Ukraine. Mobile forms of Cd, Cu, Pb and Zn in soil and forest litter samples were determined in ammonium acetate extract buffer by atomic absorption spectrometry. The analysis of the content of heavy metals, their comparison with the maximum allowable concentrations depending on the composition of plantations and the category of the highway have been done. It is confirmed that roadside forest belts perform important functions in the accumulation of heavy metals in soil and forest litter. It is confirmed that roadside forest belts perform important functions in the accumulation of heavy metals in soil and forest litter. Among all the pollutants studied, the concentration of cadmium was the lowest and that of zinc the highest (especially in forest litter). Lead and copper in this indicator occupied an intermediate position. Despite the different species composition of plantations, the coefficient of concentration of heavy metals in the soil did not exceed the maximum allowable concentrations and was on average in the range of 0.10–0.20 of these indicators. The greatest effect of delaying the migration of heavy metals was observed in forest litter. Therefore, in order to effectively use the biological barrier along the roads, it is necessary to create linear protective belts of deciduous species with *Acer platanoides*, *Betula pendula*, *Carpinus betulus* and *Tilia cordata*, which give a rich annual litterfall.

Key words

coefficient of concentration, forest belt, highway, maximum allowable concentration, belt composition, pollutants

Introduction

Environmental pollution by harmful emissions from road transport is currently a global problem. The usage of road transport for various purposes is growing every year all over the world, which has a corresponding effect on the level of environmental pollution, especially air pollution. This problem is especially relevant in densely populated cities, where congestion is much higher compared to suburban areas (Arkhipova et al. 2009).

The transport and road complex of Ukraine is one of the largest sources of environmental pollution (noise pollution and heat are the most common). There is also a steady increase in the usage of road transport for various purposes despite the crisis and the declining population in the country. This leads to congestion of the

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road network of urban areas and exacerbates the socio-economic, sanitary and technical problems associated with human health and traffic organisation (Baliuk et al. 2004). The vast majority of highways pass through settlements, which lead to restrictions the speed of road transport and they do not meet the requirements for international transport corridors.

The impact of road transport on the sanitary condition of soils along the roads is significant and determined by the increased content of heavy metals on the soils adjacent to the roads. In particular, French scientists have proposed, based on the operation of roads that have undergone a 20-year service cycle, a set of specific indicators to assess the impact of road transport (Jullien and François 2006).

Quality control of areas adjacent to highways and the environment is an extremely important task, as urban areas, fields and many other facilities are vulnerable to pollution. There are more than 100 different components in the harmful emissions (exhaust gases) of automobile engines, the vast majority of which are toxic (Jovic et al. 2012). These include soot and carcinogens, aerosols, nitrogen oxides, sulphur and lead compounds and many others. The consequences of the impact of such emissions are pollution of the atmosphere and water bodies, changes in the chemical composition of soils, creation of high levels of noise and vibration, increased morbidity of humans and animals, and so on.

Heavy metals formed by traffic and road maintenance cause chronic pollution in water runoff and roadside soil. Some of the pollutants can be sprayed into the atmosphere or deposited on the soil by wind. Sediments affect the quality of roadside soil and their content in the soil gradually decreases, reaching the background level at a distance of up to 25 m from the road. Galvanised road barriers can be a source of pollution, in addition to cars (Legret and Pagotto 2006).

Heavy metals are given considerable attention in the research of various components of harmful emissions from road transport. It should be noted that heavy metals include elements of the periodic table with metallic properties, which have an atomic mass of more than 40 atomic units and do not belong to the radioactive elements. As trace elements, they are actively involved in important biochemical and physiological processes in plants and their high concentrations can cause toxic effects.

Heavy metals are characterised by high toxicity, the ability to accumulate, sedentary nature and high stability in the environment in comparison with other pollutants. Harmful effects of such substances reduce the natural stability of biological objects (Deurer and Bottche 2007; Olaniran et al. 2013). The accumulation of heavy metals in living organisms can lead to activation of various chemical processes and can cause damage to cells, tissues or individual organs and parts of the plant, which can adversely affect the state of the whole organism (Hazrat et al. 2019).

Heavy metals are also considered in the agro-ecological aspect because under the action of air currents, pollutants fall on the adjacent field lands and are characterised by the property to accumulate in crops. Consumption of such crops by humans can lead to various diseases (Foy et al. 1978; Reimers 1992; Grigalavicienė et al. 2005). Numerous studies have shown that due to accumulation in the environment, chemical elements such as lead (Pb), cadmium (Cd), zinc (Zn) and copper (Cu) pose a significant danger based on their high biological activity and toxic properties (Khan et al. 2004; Almeida et al. 2007).

It should be also noted that copper and zinc are biogenic metals (bimetals) and they are necessary to ensure the viability of plants. Such elements are concentrated in the chloroplasts of plant leaves and are directly related to the process of photosynthesis. Normal amounts of copper and zinc have a positive effect on the biological resistance of plants to low and high temperatures and soil salinity. Copper can, to some extent, affect the uptake of nitrogen by plants, and zinc enhances the growth and development of the root system and is important for plant fruiting processes (Skarlyna-Ufimtseva 1980; Barbieri 2016; Iacoban et al. 2019).

Thus, copper and zinc are part of living organisms and are directly involved in metabolic processes, but excess amounts of these cause toxic reactions and may increase the impact of other harmful substances (Titov et al. 2007). Zinc is characterised by low toxicity, but becomes toxic with increasing concentrations, which manifests itself in the form of interveinal chlorosis, marginal chlorosis and leaf necrosis. Excess copper inhibits the growth processes of the root system and the formation of shoots, and the leaf surface becomes dark green (Akpor and Muchie 2010).

Lead and cadmium have carcinogenic properties and are among the most toxic pollutants (Seregin and Ivanov 2001). They are among the most dangerous pollutants due to intensive and widespread use in industry and transport, and their half-life is 10–30 years.

The presence of lead compounds in the air and soil along the roads is due to harmful emissions from gasoline engines running on leaded gasoline. Ethyl liquid is burned in the combustion chambers of engines and inorganic compounds such as oxides and salts are formed, which are released into the atmosphere in the form of aerosols. Suspended particles are sprayed into the environment. The vast majority of lead compounds settle on the surface near highways. Aerosols can enter the human body during respiration, through the skin or with food. They lead to dysfunction of the digestive system, neuromuscular system and brain. In plants, excess lead causes inhibition of growth processes, reduced intensity of photosynthesis, physical deformation of leaves and brown colouration of root systems. Excess cadmium causes development of chlorosis in plants, deformation and discolouration of leaves and inhibition of root growth (Arkhipova et al. 2009; Fateeva and Pashchenko 2003).

In order to protect the areas adjacent to the roads from harmful phenomena, as well as for the aesthetic design of the area, roadside forest plantations are created. In this context, the harmful phenomena include the following: snow and soil during snowstorms and strong winds, water erosion of the soil and contamination of the territory with heavy metals, dust, weathering products, acoustic impact, etc. (Agroforestry 2010). Such plantations should be formed from biologically stable and durable species of woody plants; they resist

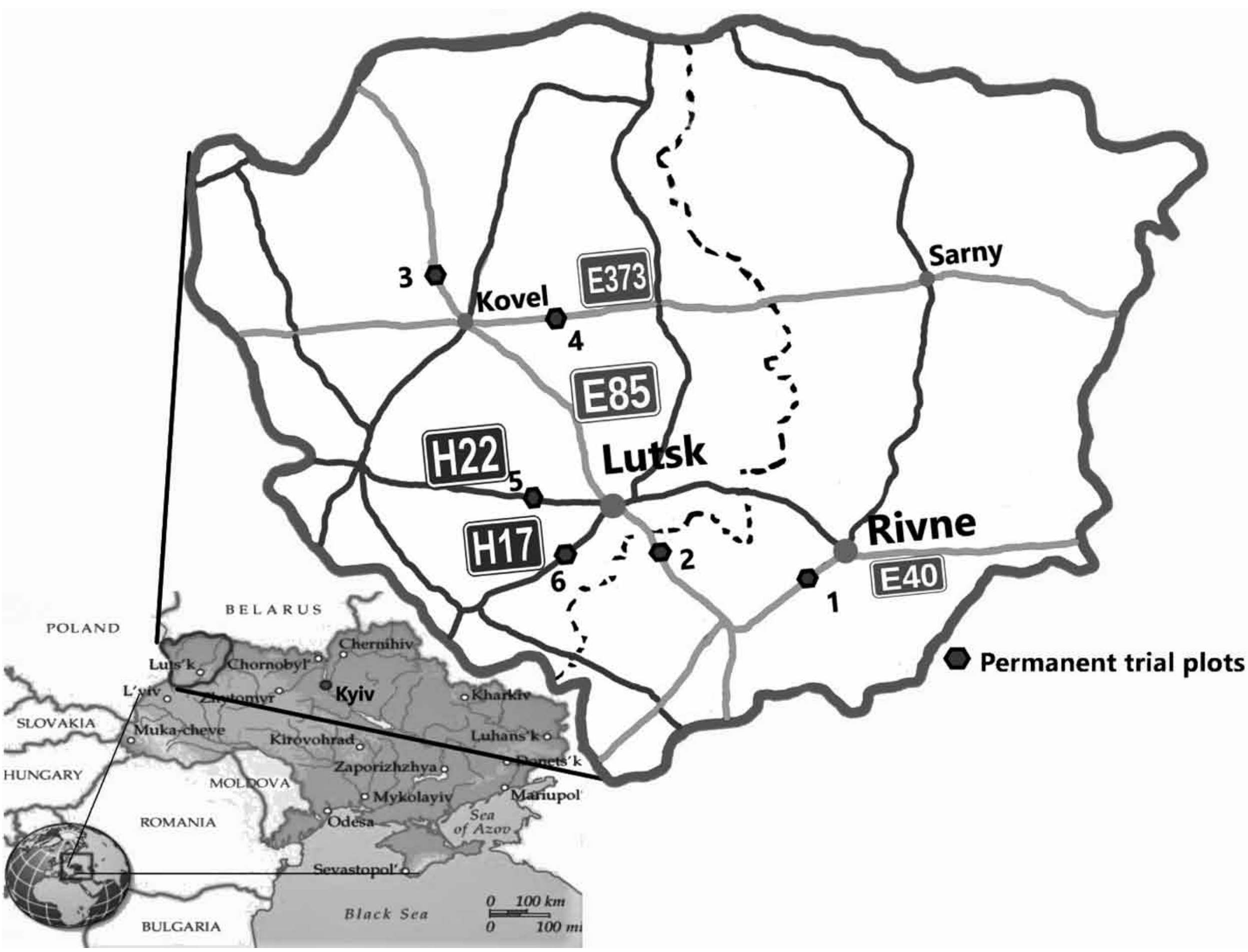

Figure 1. Road transport network of Western Polissia of Ukraine and locations of permanent test plots

snowbreaks, should fully retain within the calculated width of the land strip blizzard, retain soil and dust during strong winds and dust storms, accumulate harmful emissions from road transport and reduce noise pressure (Spiegel 2002).

In this context, the sanitary-ecological function of roadside forest plantations is important, which is, first of all, retention and absorption of hazardous substances by tree species as well as prevention of their further spread. Such plantations perform the functions of chemical pollution accumulators and have high phytomeliorative properties in the conditions of heavy metal pollution (Järup 2003; Ali et al. 2013).

The purpose of the research was to determine the level of soil and forest litter contamination with heavy metals, which is mainly due to the harmful emissions from road transport in the area protected by roadside forest plantations of different species composition.

Material and methods

Description of the study area

The research was performed in forest belts that grow along the roads of international and national importance in the conditions of Western Polissia, Ukraine. The plantations are subordinated to the Road Service in Rivne and Volyn regions, namely:

- M-06 – highway of international importance Kyiv–Chop (state border with Hungary), coincides with part of the European highway E40;
- M-07 – highway of international importance Kyiv–Kovel – checkpoint ‘Yagodyn’ (state border with Poland), coincides with part of the European highway E373;
- M-19 – highway of international importance, running from the crossing Domanove (Volyn region) to the road border crossing Porubne (Chernivtsi region), coincides with part of the European road route E85;
- H-17 – highway of national importance Lviv–Radekhiv–Lutsk, passes through the territory of Lviv and Volyn regions and
- H-22 – highway of national importance Ustyluh–Lutsk–Rivne, passes through the territory of Volyn and Rivne regions.

The transport network of the studied region is shown in Figure 1, and the characteristics of roadside forest belts according to the six test plots are given in Table 1.

Data collection

Pure plantations aged 25–45 years formed the subject of the study. Maple, linden, birch, hornbeam and poplar had been planted as roadside plantations. The number of rows in forest belts along roads of international importance was three to four, the width of such belts between the extreme rows was 10–15 m, and the distance from the belt to the road varied between 10 and 12 m. Studies were conducted in two plantations along the roads of national importance as well.

The experimental plots were selected taking into account the high intensity of road traffic. Soil samples

Table 1. Characteristics of roadside forest belts

Plot number	Plantation composition*	Road number	Location GPS		Age [years]	Number rows in the belt [pc.]	Width of the belt between extreme rows [m]	Distance from the belt to the road [m]
			N latitude	E longitude				
Roads of international importance								
1	10Cb	M-06	50.551694	26.078739	25	3	10	12
2	10Ap	M-19	50.629913	25.498699	35	4	15	12
3	10Tc	M-19	51.327933	24.658482	48	4	15	12
4	10Bp	M-07	51.250750	25.234465	25	3	10	10
Roads of national importance								
5	10Ap	H-22	50.764138	25.107012	41	5	20	10
6	10Pn	H-17	50.641977	25.177108	45	2	5	8

* Latin names of species: Bp – *Betula pendula* Roth., Ap – *Acer platanoides* L., Cb – *Carpinus betulus* L., Tc – *Tilia cordata* Mill., Pn – *Populus nigra* L.

were taken in accordance with the requirements of the state standard (Soil quality 2004) by the method of envelope, and one representative sample weighing at least 1 kg was collected from 5 samples. Sampling was performed in the following places: at the edge of the belt on the side of the road, in the middle part of the belt and on the opposite edge. The depth of soil sampling was 0–5 cm. Samples of forest litter were taken from the soil surface in these places previously.

Data analysis

Mobile forms of Cd, Cu, Pb and Zn were determined in ammonium acetate buffer extract by atomic absorption spectrometry (Uyguner and Bekbolet 2005). In this method, the mobile forms of copper, zinc, cadmium and lead ions are extracted from the soil and forest litter with ammonium acetate buffer solution of pH = 4.8. Part of the exchange cations is transferred to the solution and the compounds are hydrolysed, which forms acetate or ammonium complex compounds. Due to the high buffering capacity of this solution, the medium remains stable during the extraction of heavy metals from different soils. The content of heavy metals was studied using atomic absorption type spectrometers. The specific property of atoms to absorb a certain wavelength of light from the combustion of an air–acetylene flame made it possible to determine the content of pollutants in the samples. Spectrometer KVANT-2AT was used for the analysis of soil samples. The content of heavy metals in the litter was determined with the spectrometer C-115-M1 (San PiN 1988; Baliuk et al. 2004). The lab research was done at the State Institution 'Institute of Soil Protection of Ukraine'.

Based on the analysis of selected soil samples and forest litter, the intensity of contamination of these components of the forest stands with ions of lead, copper, zinc and cadmium was determined for performing a comparative analysis with their maximum allowable concentrations (Csuros and Csuros 2002).

The lands on which the research was conducted have not been subjected to any impact and mechanical cultivation for the last 30 years. The natural background was taken as the level of maximum permissible concentrations in the study area.

Results and discussion

It is known that the entry of heavy metals into the soil determines the possibility of their further migration into groundwater and availability to plants, and it poses a potential threat to living organisms. At the same time, soil is one of the important protective biochemical barriers for a number of compounds during their migration to groundwater and plants. The content of mobile forms of heavy metals in the soil, depending on the composition of roadside belt plantations and the place of sampling is given. The concentrations of heavy metals in terms of test areas are shown in Figure 2.

The data of Figure 2(A) and (B) show that linden plantations accumulated lead and cadmium the most and maple forest belt retained the least. At the same time, hornbeam plantation most effectively retained zinc and copper, as evidenced by the data of Figure 2(C) and (D), respectively. The same metals were accumulated less by the birch forest belt on the E373 highway. Figure 2(C) and (D) shows that there was a significant increase in the concentration of heavy metals in birch plantation (test area 4) compared to other plantings, but the permissible level was not exceeded. It can be assumed that this trend was caused directly by the functioning of linear plantations themselves.

Based on the data shown in Figure 2, there is a dependence on the fact that the content of heavy metals from the edge of the belt on the side of the road to the opposite edge decreased in most measurements. This dependence is explained by the partial influence of the distance factor from the source of pollution, as well as the direct influence of protective forest belts.

The content of heavy metals was higher on the highways of international importance than on the national roads, which is associated with a decrease in traffic on the latter. This trend is confirmed by the studies of Degórski and Zawiska (2015), Clemens (2006) and others.

Polish researchers studied the content of heavy metals (Ni, Pb, Cu, Zn, Cd and Cr) in soils at the places along roads with different traffic intensity, different capacity and smoothness of road transport. Samples were taken along transects perpendicular to the road edge, at a distance of 1, 3, 5, 10, 20, 50 and 100 m from the road edge. Scientists have determined that the content of heavy metals in soils between the individual analysed segments can reach a ratio of more

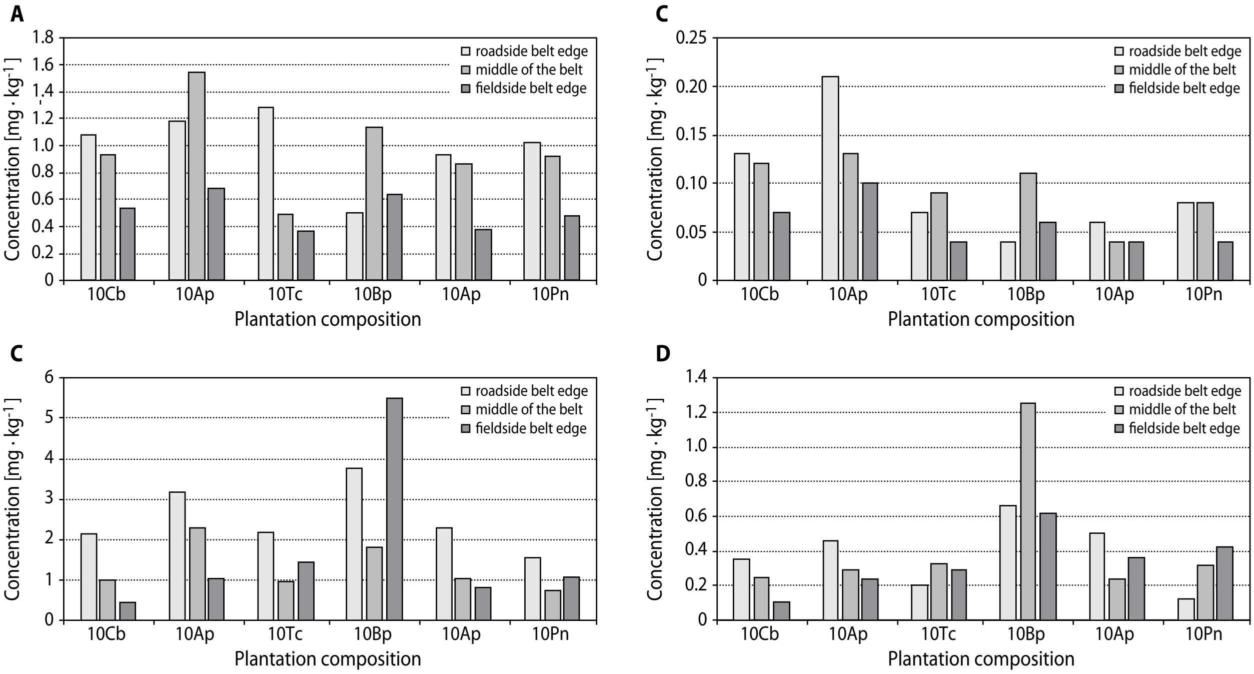

Figure 2. Concentration of heavy metals in the soil of roadside belts of different species composition: (A) Pb, (B) Cd, (C) Zn and (D) Cu

Table 2. The average content of heavy metals in the soil

Plot number	Plantation composition	Road number	The average content of heavy metals, mg · kg^{-1}			
			Pb	Cd	Zn	Cu
Roads of international importance						
1	10Cb	M-06	0.85 ± 0.22	0.11 ± 0.02	1.20 ± 0.75	0.24 ± 0.08
2	10Ap	M-19	1.14 ± 0.27	0.15 ± 0.04	2.17 ± 0.80	0.33 ± 0.10
3	10Tc	M-19	0.72 ± 0.37	0.07 ± 0.03	1.53 ± 0.66	0.28 ± 0.05
4	10Bp	M-07	0.76 ± 0.28	0.07 ± 0.02	3.70 ± 1.80	0.85 ± 0.26
Roads of national importance						
5	10Ap	H-22	0.73 ± 0.23	0.05 ± 0.01	1.39 ± 0.60	0.37 ± 0.01
6	10Pn	H-17	0.81 ± 0.22	0.07 ± 0.01	1.12 ± 0.32	0.29 ± 0.12

than 100 times. It was found that the content of heavy metals in soils decreased with distance from the road and was characterised by a more regular distribution on the sections along national roads and a less regular distribution on the sections along highways (Degórski and Zawiska 2015).

Since soil is a multicomponent system and can be considered from different points of view, regulation of the content of pollutants in it and plants is quite a difficult task. This is due to the inability to fully take into account all the environmental factors that directly affect the migration and accumulation of pollutants. In particular, the issue of rationing the content of heavy metals in the soil is quite difficult to solve, and the basis of this problem should be recognition of the diverse functions of soil ecosystems.

The establishment of levels of man-made contamination of soils and forest litter with heavy metals and comparison of the results can also be influenced by a number of objective factors, namely, local background content of individual elements, traffic intensity, climatic conditions, vegetation period, etc. (Fateeva and Pashchenko 2003).

To assess the degree of danger of the pollutant element in the research, we used the concentration coefficient – the ratio of pollutant content in the soil (average of all sampling sites) to its maximum allowable concentration. The following values of the maximum allowable concentrations of mobile forms of heavy metals in the soil were taken according to the general sanitary limiting indicator: Cu – 3.0 mg · kg^{-1}, Pb – 6.0 mg · kg^{-1}, Cd – 0.7 mg · kg^{-1} and Zn – 23.0 mg · kg^{-1} (Fateeva and Pashchenko 2003). The average content of heavy metals and the coefficient of their concentration in the context of the experimental plots are given in Table 2.

The obtained values of the coefficient of concentration of heavy metals in the soil of roadside forest belts are given in Figures 3 and 4.

The average content of heavy metals in soil samples selected in roadside plantations along roads of international importance showed the accumulation of zinc (3.70 mg · kg^{-1}) and copper (0.85 mg · kg^{-1}) in birch belts. The greater concentrations of lead (1.14 mg · kg^{-1}) and cadmium (0.15 mg · kg^{-1}) were fixed in maple plantations. In other roadside belts, the pollutant concentrations occupied an intermediate position.

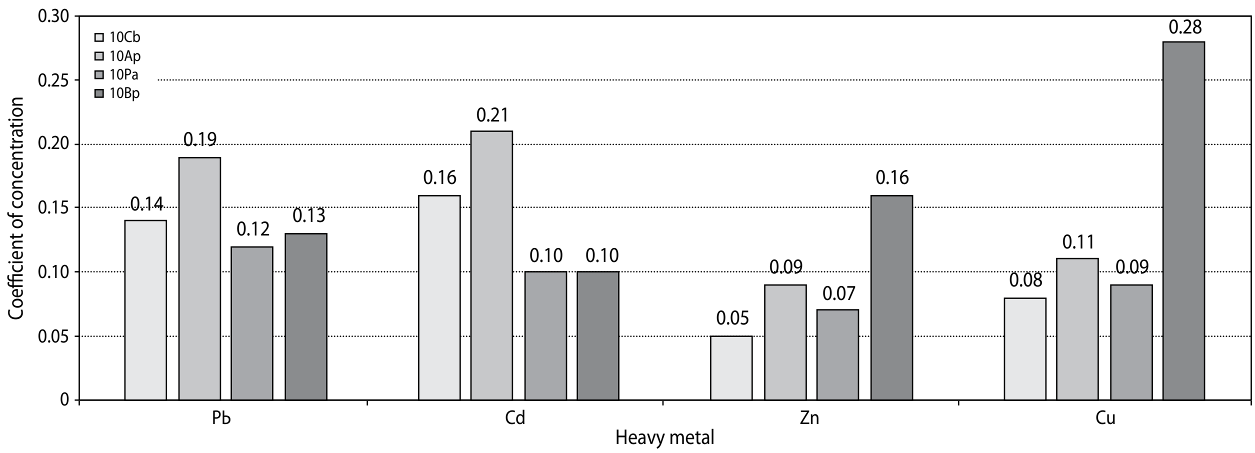

Figure 3. Coefficient of concentration of heavy metals in the soil of roadside forest belts along highways of international importance

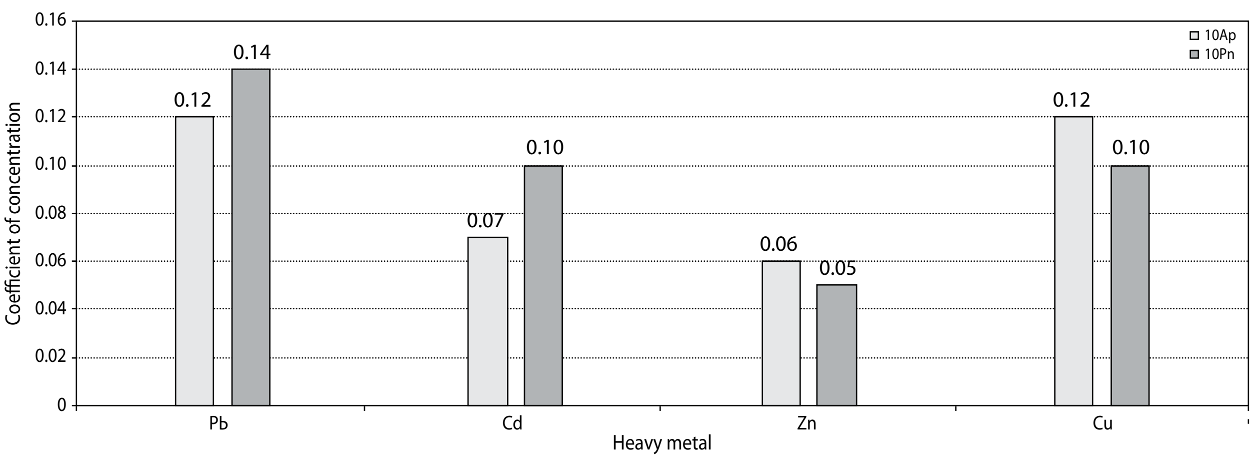

Figure 4. Coefficient of concentration of heavy metals in the soil of roadside forest belts along highways of national importance

Studying the content of heavy metals in soil from the roadside forest belts of the Vilnius–Klaipeda highway, Grigalavicienė et al. (2005) found that the content of Pb, Cu and Cd in the soil behind the forest belt was 7.9, 1.32 and 1.19 mg · kg^{-1}, respectively. Such high concentrations of heavy metals are due to heavy traffic on the highway.

The content of heavy metals in the soil under roadside forest belts along the roads of national importance had the following values: lead – 0.73–0.81 mg · kg^{-1}, cadmium – 0.05–0.07 mg · kg^{-1}, zinc – 1.12–1.39 mg · kg^{-1} and copper – 0.29–0.37 mg · kg^{-1}. We did not find a clear relationship between the composition of plantations and the content of pollutants. Thus, in the soil of maple plantations, there was a higher content of zinc and copper, and in the soil of poplar plantations, lead and cadmium were high in content.

General analysis of the coefficient of concentration of heavy metals in the soil of roadside forest belts of different species composition along roads of international importance showed that its value did not exceed the maximum allowable concentrations and was on average within 0.10–0.20 of these indicators.

The coefficient of lead concentration had approximately the same value (0.12–0.14) for roadside forest belts of hornbeam, linden and birch.

The concentration coefficient in the soil of cadmium was characterised by a value of 0.10 for roadside belts of linden and birch and 0.16 for roadside belts of hornbeam. A slight increase in the concentration coefficient in the maple plantation to 0.21 was also observed.

The zinc concentration coefficient was lower than that of other metals. Its value was in the range of 0.05–0.09, and in the conditions of the roadside belt of birch, it was 0.16. An almost similar pattern could be traced for the coefficient of copper concentration. Mainly, this indicator was 0.08–0.11, and in the conditions of the birch belt, it was 0.28.

As mentioned above, roads of national importance are characterized by lower traffic intensity, which in turn leads to a slight decrease in the concentration of heavy metals in the soil of roadside forest belts. The belts of maple and poplar were selected for comparative analysis. The distance from the road to the first row of belts was 8–10 m (Table 1). The results of the research show that the coefficient of lead concentration was in the range of 0.12–0.14, cadmium – 0.07–0.10, zinc – 0.05–0.06 and copper – 0.10–0.12. Based on the obtained data, it can be noted that the composition of roadside plantations, their width and structural features do not have a significant impact on the value of the studied indicator.

Forest litter is known to be formed as a result of accumulation of a layer of vegetation and litterfall on the soil surface, which is at different stages of decomposition. In the process of annual accumulation of plant litterfall and its gradual decomposition, the litter forms a layered structure. Since the maximum permissible concentrations of chemicals have not been set for forest litter, we will limit ourselves only to the analysis of heavy metal content in this element of forest plantations (Tab. 3).

Table 3. The average content of heavy metals in forest litter

Plot number	Plantation composition	Road number	The average content of heavy metals [mg · kg^{-1}]			
			Pb	Cd	Zn	Cu
Roads of international importance						
1	10Cb	M-06	0.35 ± 0.03	0.02 ± 0.003	15.09 ± 0.43	2.24 ± 0.09
2	10Ap	M-19	0.77 ± 0.02	0.03 ± 0.003	13.29 ± 0.95	2.64 ± 0.28
3	10Tc	M-19	0.71 ± 0.02	0.03 ± 0.001	13.20 ± 0.26	3.00 ± 0.10
4	10Bp	M-07	0.97 ± 0.02	0.04 ± 0.003	13.48 ± 0.14	3.62 ± 0.08
Roads of national importance						
5	10Ap	H-22	0.65 ± 0.05	0.02 ± 0.001	14.01 ± 0.05	2.38 ± 0.02
6	10Pn	H-17	0.85 ± 0.05	0.03 ± 0.003	13.15 ± 0.15	2.66 ± 0.24

Analysis of the content of heavy metals in the forest litter of roadside forest belts along highways of international importance showed a very significant difference in their values compared to the soil. Thus, the concentration of zinc was at the level of 13.20–15.09 mg · kg^{-1}, copper – 2.24–3.62 mg · kg^{-1}, lead – 0.35–0.97 mg · kg^{-1} and cadmium – 0.02–0.04 mg · kg^{-1}. Forest litter of birch stands was characterised by a higher content of lead, cadmium and copper and that of hornbeam by zinc.

This difference in performance that depends upon the composition of plantations is quite significant. For example, the lead content in the forest litter of the roadside belt of hornbeam and birch was 0.35 and 0.97 mg · kg^{-1}, respectively. A similar pattern, but in a smaller ratio, was observed for the content of copper (in hornbeam plantations 2.24 mg · kg^{-1} and in birch 3.62 mg · kg^{-1}) and cadmium (0.02 and 0.04 mg · kg^{-1}, respectively). Forest litter of roadside belts of maple and linden occupied an intermediate place according to these indicators.

Since forest litter is formed mainly from the leaf litter of woody plant species, it can be assumed that the leaves of birch have a greater ability to accumulate heavy metals compared to other species. Hornbeam leaves were found to have the lowest accumulative capacity in this respect. The results of the analysis allow us to conclude that the content of heavy metals in forest litter largely depends on the species composition of roadside forest belts.

The content of heavy metals in the forest floor of roadside forest belts along the roads of national importance has the following values: lead – 0.65–0.85 mg · kg^{-1}, cadmium – 0.02–0.03 mg · kg^{-1}, zinc – 13.15–14.01 mg · kg^{-1} and copper – 2.38–2.66 mg · kg^{-1} (Tab. 3). It should be noted that the forest litter of gray poplar is characterised by a slightly higher content of lead, cadmium and copper and of maple by zinc.

Comparative analysis of the content of heavy metals in these components of the plantation is important from the point of view of the interaction of soil and forest litter. Thus, there is no clear dependence on the lead content: in some plantations (hornbeam, maple), its content is higher in the soil, and in others, it is almost the same. The content of cadmium is 2–5 times higher than in forest litter. The content of zinc and copper is inversely related. The content of zinc in 4–12 times and copper is 4–10 times more in forest litter, compared to soil. One of the reasons for this ratio, in our opinion, is fixation of heavy metals in the organic matter of this substrate due to the formation of complex organomineral compounds – chelates.

Thus, it can be stated that the studied roadside forest belts in the conditions of Western Polissia of Ukraine perform important functions regarding the accumulation of heavy metals in the soil and forest litter. Cadmium has the lowest concentration and zinc the highest (especially in forest litter), of all the pollutants studied. Lead and copper occupy an intermediate position in this indicator. Despite the different species composition of plantations, the coefficient of concentration of heavy metals in the soil does not exceed the maximum allowable concentrations and is on average in the range of 0.10–0.20 of these indicators.

Conclusions

The sanitary-ecological function of roadside forest plantations is important, which consists, first of all, of retention and absorption of hazardous substances by the tree species of plants, as well as preventing their further spread. Such plantations perform the functions of accumulators of chemical pollution and have high phytomeliorative properties in conditions of environmental pollution by heavy metals.

In most measurements, there is a dependence on the fact that the content of heavy metals from the edge of the belt from the side of the road to the opposite edge decreases. This dependence is explained by the partial influence of the distance factor from the source of pollution, as well as the direct influence of protective forest belts. At the same time, the content of heavy metals decreases accordingly in terms of the values of highways, which is caused by the higher intensity of traffic on roads of international importance.

General analysis of the coefficient of concentration of heavy metals in the soil of roadside forest belts of different species composition along roads of international importance showed that its value does not exceed the maximum allowable concentrations and is on average within 0.10–0.20.

The content of heavy metals in the forest litter of roadside forest belts along highways of international importance showed a significant difference in values. Thus, the concentration of zinc was at the level of 13.20–15.09 mg · kg^{-1}, copper – 2.24–3.62 mg · kg^{-1}, lead – 0.35–0.97 mg · kg^{-1} and cadmium – 0.02–0.04 mg · kg^{-1}. Forest litter of birch plantations was characterised by a higher content of lead, cadmium and copper and hornbeam plantations by zinc.

References

Agroforestry. Terms and definitions: ISO 4874:2007. 2010. Effective from 01.01.2009. K. State standard of Ukraine (in Ukrainian).

Akpor, O.B., Muchie, M. 2010. Remediation of heavy metals in drinking water and wastewater treatment systems: Processes and applications. *International Journal of Physical Sciences,* 5 (12), 1807–1817. DOI: 10.5897/IJPS.9000482

Ali, H., Khan, E., Sajad, M. 2013. Phytoremediation of heavy metals-Concepts and applications. *Chemosphere*, 91 (7), 869–881. DOI: 10.1016/j.chemosphere.2013.01.075

Almeida, A., Valle, R., Mielke, M., Gomes, F. 2007. Tolerance and prospection of phytoremediator woody species of Cd, Pb, Cu and Cr. *Brazilian Journal of Plant Physiology*, 19 (2), 83–98. DOI: 10.1590/S1677-04202007000200001

Arkhipova, H., Tkachuk, I., Hlushkov, E. 2009. Analysis of the impact of exhaust gases on the state of atmospheric air in densely populated areas (in Ukrainian). *Scientific Bulletin of the National Aviation University*, 1, 78–83.

Baliuk, S., Fadeev, S., Myroshnichenko, M. 2004. Soil and geochemical survey of urban areas. Guidelines (in Ukrainian). Institute of Soil Science and Agrochemistry named after O. Sokolovskyi, Kharkiv.

Barbieri, M. 2016. The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. *Journal of Geology and Geophysics*, 5 (1), 237. DOI: 10.4172/2381-8719.1000237

Clemens, S. 2006. Toxic metal accumulation, response to exposure and mechanisms of tolerance in plant. *Biochemie*, 88, 1707–1719. DOI: 10.1016/j.biochi.2006.07.003

Csuros, M., Csuros, C. 2002. Environmental sampling and analysis for metals. Lewis Publishers, Boca Raton, USA.

Degórski, M., Zawiska, I. 2015. The influence of car traffic on the sanitary state of the soils. *Europa XXI*, 28, 142–155. DOI: 10.7163/Eu21.2015.28.7

Deurer, M., Bottcher, J. 2007. Evaluation of models to upscale the small scale variability of Cd sorption in a case study. *Geoderma*, 137, 269–278.

Fateeva, A., Pashchenko, Ya. 2003. Background content of microelements in the soils of Ukraine (in Ukrainian). Kharkiv.

Foy, C., Chaney, R., White, M. 1978. The physiology of metal toxicity in plants. *Annual Review of Plant Physiology*, 29 (1), 511–566.

Grigalavicienė, I., Rutkovienė, V., Marozas, V. 2005. The accumulation of heavy metals Pb, Cu and Cd at roadside forest soil. *Polish Journal of Environmental Studies*, 14 (1), 109–115.

Hazrat, A., Ezzat, K., Ikram, I. 2019. Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, ID 6730305. DOI: 10.1155/2019/6730305

Iacoban, C. et al. 2019. Tarnita polluted area: accumulation of metals and nutrients from the soil by woody species. *Revista de Chimie*, 70 (3), 753–758. DOI: 10.37358/RC.19.3.7001

Järup, L. 2003. Hazards of heavy metal contamination. *British Medical Bulletin*, 68 (1), 167– 182. DOI: 10.1093/bmb/ldg032

Jovic, M., Onjia, A., Stanković, S. 2012. Toxic metal health risk by mussel consumption. *Environmental Chemistry Letters*, 10 (1), 69–77.

Jullien, A., François, D. 2006. Soil indicators used in road environmental impact assessments. *Resources, Conservation and Recycling*, 48 (2), 101–124. DOI: 10.1016/j.resconrec.2005.12.006

Khan, F., Rahman, A., Jan, A., Riaz, M. 2004. Toxic and trace metals (Pb, Cd, Zn, Cu, Mn, Ni, Co and Cr) in dust, dustfall/soil. *Journal of the Chemical Society of Pakistan*, 26 (4), 453–456.

Legret, M., Pagotto, C. 2006. Heavy metal deposition and soil pollution along two major rural highways. *Environmental Technology*, 27, 247–254. DOI: 10.1080/09593332708618641

Olaniran, A., Balgobind, A., Pillay, B. 2013. Bioavailability of heavy metals in soil: impact on microbial biodegradation of organic compounds and possible improvement strategies. *International Journal of Molecular Sciences*, 14, 10197–10228.

Reimers, N. 1992. Protection of nature and the environment (in Russian). Education.

San PiN 42-128-4433-87. 1988. Sanitary standards of permissible concentrations of chemical substances in soil. Ministry of Health of the USSR, Moscow (in Russian).

Seregin, I.V., Ivanov, V.B. 2001. Physiological aspects of the toxic effect of cadmium and lead on higher plants (in Russian). *Plants Physiology*, 48 (4), 606–630.

Skarlyna-Ufimtseva, M. 1980. Technogenic pollution of plants with heavy metals and its ecological and biological effect (in Russian). *Heavy Metals in the Environment*, 85–88.

Soil quality. Sampling: ISO 4287: 2004. Effective from 2005-01-01. State Committee of Ukraine, Kyiv (in Ukrainian).

Spiegel, H. 2002. Trace element accumulation in selected bioindicators exposed to emissions along the industrial facilities of Danube Lowland. *Turkish Journal of Chemistry*, 26 (6), 815–823.

Titov, A., Talanova, V., Kaznina, N, Laidinen, G. 2007. Plant resistance to heavy metals (in Russian). Center of RAS, Petrozavodsk, Karelian scientific.

Uyguner, C.S., Bekbolet, M. 2005. Implementation of spectroscopic parameters for practical monitoring of natural organic matter. *Desalination*, 176 (1/3), 47–55. DOI: 10.1016/j.desal.2004.10.027