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The influence of *Robinia pseudoacacia* plantations on soil in the park areas of Dnipro city contaminated with heavy metals

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Abstract. The aim of this study was to investigate the soil condition of recreational park areas in Dnipro city on chromium, nickel and cobalt contents and the ability of various components of black locust's aboveground biomass to accumulate these contaminants. An excess of the maximum permissible concentration (MPC) of chromium (2.1-4.3) and nickel (1.5-3.5) was recorded in the studied soils of recreational plantings in all experimental sites. Cobalt concentrations exceeded MPC only in two experimental sites: Oles Honchar Dnipro National University Botanical Garden and Green Grove Park (1.4-1.5). It was compared the metal concentrations in the vegetative (leaves, trunk) and generative (fruits) organs of *R. pseudoacacia* and in the soil beneath a tree canopy of the plantings. Chromium concentrations in aboveground biomass corresponded to the range of 0.10-11.67 $mg \cdot kg^{-1}$, the highest concentration of this metal occurred in assimilation fraction. The highest accumulation of nickel was recorded in fruits, where its highest concentration was equal to 8.46 $mg \cdot kg^{-1}$. Cobalt had the lowest concentration values among the metals studied; the range of its content was 0.09-0.21 $mg \cdot kg^{-1}$, and it had almost the same concentration level in the biomass of trunk wood, leaves and fruits. The biological accumulation factor (BAF) was calculated to determine the deposit potential of *R. pseudoacacia*. According to the obtained values of BAF, it should be noted that bioconcentration was not occurred for all the studied metals. *R. pseudoacacia* is able to function optimally in urban soils of park areas with a rather wide ranges of chromium, nickel and cobalt concentrations. Due to low values of BAF, this tree species is not susceptible to accumulate the metals in such concentrations that can pose a risk for the use of this species in recreational plantings of industrial city parks

Keywords: soil pollution; chromium; nickel; cobalt; biological accumulation factor

Introduction

Due to the increasing anthropogenic pressure on urban ecosystems, which leads to the accumulation of toxic substances in soils, particularly heavy metals such as chromium, nickel, and cobalt. These contaminants pose serious environmental and health risks, as they are persistent, non-biodegradable, and capable of entering the food chain. Today, various approaches and effective technologies are used, which both directly and indirectly affect the intensity of accumulation of heavy metals by reducing their mobility and availability to plants (Kharytonov *et al.*, 2021).

Park zones, serving as critical recreational spaces in cities, often experience significant exposure to pollution from surrounding industrial activities, transport emissions, and urban runoff. Certain tree species are capable of absorbing, translocating, and accumulating heavy metals in their biomass, thus acting as natural phytoremediators that reduce the bioavailability of pollutants in the soil. Understanding these processes contributes to the creation of sustainable and safe recreational environments, enhances the ecological functions of urban green spaces, and informs the design of planting schemes aimed at restoring the physical and chemical properties of degraded soils.

The most common transformation of environment is soil contamination with heavy metals, acidification and, in extreme cases, destruction of the soil cover. Metal elements are considered to be actual and widespread soil pollutants. According to V. Zverkovskyy *et al.* (2018), the annual volume of heavy metal emissions in the Dnipro region has been in the range (tons · $year^{-1}$) 774.9-618.6, of which

Cr was 4.9-11.4 and Ni was 3.0-7.6. When metal-containing aerosols fall out onto the land and plant surfaces, the degree of their ability to be incorporated in the trophic links of ecosystems depends on a significant number of factors. Therefore, systematic environmental monitoring, assessment of soil condition in urbanised and recreational areas of industrial cities should serve as the basis for the development of an action plan aimed at optimisation of the soil properties (namely granulometric composition, physico-chemical, biological properties) (Bobunov *et al.*, 2023).

The technology of creating a net of plantings which will have remediation properties is one of the methods most appropriate to restore the corresponding fertility characteristics to contaminated soils. Native and non-native plant species that are used in plantings of recreational areas of industrial cities should have broad environmental tolerance in order to function and realise self-remediation potential. Plantings of tree species are particularly valuable, as they have a long-life cycle, and their significantly developed crown biomass can serve as a place of deposition of pollutants that remain in the aboveground biomass for a long time. *Robinia pseudoacacia* L. is one of the most suitable species with broad ecological valence and remediation potential. An urgent issue is the research of its ability to absorb inorganic metal contaminants from the soil and retain them in the biomass of different tissues, since plant body tissues, being different compartments of biomass, have different degrees of potential ability to absorb and accumulate pollutants (Kunakh *et al.*, 2024).

Z.F. Wang *et al.* (2023) noted that along with other tree species, *R. pseudoacacia* is widely used for urban green spaces, mainly because of its high adaptive potential and ecosystem services. In particular, studies have shown that *R. pseudoacacia* demonstrates a fairly high resistance in the urban environment. However, in general, and in the context of creating green landscaped areas, in particular, Robinia is widely used as a soil improver, with nutrients such as magnesium, calcium. According to N. Yiğit (2024), this plant can reduce soil contamination with tin and molybdenum, as well as copper and lead (Băbău *et al.*, 2024). H.A. Ergül & I.S.K. Kuşçu (2024) found that *R. pseudoacacia* is the best phytoremediator of strontium from soils in copper mining areas compared to other species studied.

An important issue is the degree of accumulation of potentially toxic compounds and their further translocation due to the aboveground biomass production, part of which (trunk, crown) performs a long-lasting binding of pollutants, and other fraction (leaves, fruits) is able to enter the soil and thereby partially return potentially toxic compounds. V. Lovynska *et al.* (2023) presented the studies on the level of soil contamination with heavy metals (Zn, Cu, Cd, Pb) and the processes of their accumulation by native and non-native tree species in green spaces of Dnipro city. The ranges of average heavy metal concentrations in the various experimental sites of the city's green infrastructure were as follows ($mg \cdot kg^{-1}$) 30.7-185.5 for Zn, 5.7-22.4 for Cu, 9.0-31.3 for Pb, and 0.213-0.598 for Cd. Heavy metal accumulation in the leaf fraction of R. *pseudoacacia* was noted to be occurred in the following descending order: Zn > Cu > Pb > Cd. Authors noted determination of relationships between concentrations of potentially toxic metal elements in atmospheric air of Dnipro city and in the assimilation organs of *R. pseudoacacia* trees. Among the studied pollutants, the maximum concentration in the assimilation organs was found for Zn, the range of which was 15-30 $mg \cdot kg^{-1}$. Almost the same accumulation level was recorded for Cu and Pb: 3.9-17.2 $mg \cdot kg^{-1}$ and 8.6-10.8 $mg \cdot kg^{-1}$ respectively. The presence of Cd, as a non-essential element for plants, allows us to consider

R. pseudoacacia plantings as a potential depositor of this metal in the conditions of industrial cities where polyelement pollution occurs.

C. Zou *et al.* (2024) demonstrated that in urban green spaces the average soil organic carbon was 8.47 mg · ha^{-1} and concurrent with moderate heavy metals pollution with Ni 32.03-33.50 mg · kg^{-1}; Pb 27.93-29.65 mg · kg^{-1}; Cu 26.97-41.20 mg · kg^{-1}. The concentration of heavy metals in urban green spaces determined by the historical usage of the land, with escalation correlating with the duration of land utilisation history. D.L. Brkovic *et al.* (2021) determined the concentrations of metals (Mn, Ni, Ca, Mg, Fe, Zn, Cr, Pb, Cd, Cu) in the soil of fast-growing plant species (*Populus nigra* L., *Fraxinus ornus* L., *Salix alba* L., *Salix caprea* L.) (Serbia). The *F. ornus* species exhibits the ability to phytoextract Ca, the *P. nigra* species – Zn, Ca and Cd, while both *Salix* species have the ability to phytorecover Zn and Ca. As summarised the authors, S. alba is an effective bioaccumulator of Mn, Fe, Cr, Pb, Zn and Ca, *S. caprea* – Fe, Cu, Cr, Mg and Pb, and *P. nigra* – Mn and Cd. The authors recommend taking this into account when selecting plant species suitable for remediation.

Taking into account the significant remediation potential, wide distribution of *R. pseudoacacia* in recreational plantings of park areas of Dnipro city, the growth of this tree species in soils with varying degrees of pollution, the issue of the ability to absorb and accumulate metal elements in various components of aboveground biomass is relevant and requires further development.

The main objective of this research was to establish the ability of *R. pseudoacacia* trees to absorb and accumulate in their biomass the metals taken up from the soils of recreational park areas in Dnipro city. For this, it was developed the following tasks:

1. to determine the degree of soil and aboveground biomass contamination by Cr, Ni, Co in recreational plantings of park areas;
2. to establish the potential of *R. pseudoacacia's* biomass for absorption and accumulation of Cr, Ni, and Co from the soil by biological accumulation factor.

Materials and Methods

The study was conducted in park areas of Dnipro city during the growing season: from May to October 2022. The study was conducted in accordance with the Convention on Biological Diversity (1992). Characteristics of experimental sites are given in Table 1.

Table 1. Locations of experimental sites in recreational plantings of parks in Dnipro city

Name of the recreation object	Park area, ha	Geographical coordinates	Height above sea level	Landscape type	Terrain element	Share of *R. pseudoacacia* in the park's plantings, %
Taras Shevchenko Central Culture and Leisure Park	45	48°27'42'' N 35°04'18'' E	90	Valley-adjacent gully	Right-bank slope, upper part, slope angle 3-4°	20
Lazar Globa Central City Children's Park	26	48°28'14'' N 35°01'31'' E	56	Valley-terrace	Floodplain	9
Park Sahaydak	34	48°29'08'' N 35°03'37'' E	55	Valley-terrace	Floodplain	15
Druzhby Park	90	48°32'07'' N 35°05'25'' E	79	Valley-terrace	Third terrace	15

Table 1, Continued

Name of the recreation object	Park area, ha	Geographical coordinates	Height above sea level	Landscape type	Terrain element	Share of *R. pseudoacacia* in the park's plantings, %
Metallurgists Square	3.8	48°28'26.00" N 34°59'31.00" E	65	Watershed-gully	Upland	50
Urban Youth Park recreation and leisure "Novokodatskyi"	35	48°29'13.43" N, 34°56'32.59" E	82	Valley-terrace	Upland Floodplain	25
Green Grove Park	53.6	48°26'10'' N, 35°00'35'' E	145	Watershed-gully	Ravine (plateau within the north-eastern slope)	16
Prydniprovsky Park	7	48°24'01" N, 35°07'56" E	75	Valley-terrace	Sandy terrace	35
Botanical garden of DNU	46	48°26'10'' 35°02'32'' E	127	Watershed-gully	Upland	27

Source: developed by the authors

Table 2 shows the characteristics of the soils in the park areas, in *R. pseudoacacia* plantations where experimental samples were selected. Soil classification and assessment of granulometric composition were carried out in accordance with the IUSS Working Group (2022). Nine sample points were taken to determine the soil physical and chemical properties and the content of chromium, nickel and cobalt. The sampling depth was 0-20 cm; the weight of each sample was about 300–350 g. Values of pH, total mineralisation, salinity, and electrical conductivity of soil samples were determined using a combined moisture-proof TDs/pH/EC/Salinity/Temp meter EZ9909A (Kelilong Electron, China). Samples of aboveground biomass of black locust trees were taken from each soil experimental site; there are a total of 27 samples were selected, and samples of trunk wood, leaves, and fruit biomass were averaged. The sampling and preparation procedures followed the instructions given in Mac Naeidhe (1995).

Table 2. Characteristics of park soils

Object name	Soil type	pH value	Total mineralisation, ppm	Salinity %	Electrical conductivity, mcs/cm
Taras Shevchenko Central Culture and Leisure Park	Calcic Chernozem (Siltic)	9.04	30	23	47
Lazar Globa Central City Children's Park	Calcic Chernozem (Siltic)	8.48	124	93	188
Park Sahaydak	Fluvisol (Loamic)	8.85	62	46	96
Druzhby Park	Calcic Chernozem (Siltic)	6.37	42	32	64
Metallurgists Square	Calcic Chernozem (Siltic)	8.82	31	23	48

Table 2, Continued

Object name	Soil type	pH value	Total mineralisation, ppm	Salinity %	Electrical conductivity, mcs/cm
Green Grove Park	Calcic Chernozem (Siltic)	9.09	50	39	78
Urban Youth Park recreation and leisure “Novokodatskyi”	Calcic Chernozem (Siltic)	7.44	424	321	644
Prydniprovsky Park	Anthrosol (Loamic)	6.57	39	30	61
Botanical garden of DNU	Calcic Chernozem (Siltic)	8.23	110	86	174

Source: developed by the authors

Heavy metal concentrations (Zn, Cu, Pb, Cd) in the soil was estimated using a modified aqua regia extraction method (Shahid *et al.*, 2017). According to this method, a 100-mg sample of fine soil dried at 105°C was mixed with 200 μL of water and four acids (900 μL of hydrochloric acid, 300 μL of nitric acid, 300 μL of hydrofluoric acid, and 150 μL of perchloric acid). The resulting mixture was treated with the microwave cleavage, then centrifuged (5000 rpm), and the supernatant was harvested to determine the concentration of the elements. Preliminary preparation of plant material samples for heavy metal detection included washing the biomass with distilled water, drying at room temperature for two weeks and at 105°C for 4 hours, followed by homogenisation. Dried leaf samples were ground to a fine powder using an ultra-centrifugal (Retsch Centrifugal Grinding Mill ZM 1000). 100 mg of each sample was mixed in centrifuge sample tubes with 200 μL of ultrapure water and 1.9 ml of 65% nitric acid. This mixture was incubated for 1 hour under a fume hood. Then the samples were mixed with 600 μL of aqueous solution of 4.8% hydrofluoric acid and put in a microwave oven for 1-2 hours. After processing in a microwave oven, the liquid phase of the supernatant was supplemented with ultrapure water. Prior to the direct measurement of element concentration in solutions, the samples were diluted 1:10. The concentration values of the samples were measured by mass spectrometry using an ICP-MS instrument (model X Series 2, Thermo Fisher Scientific, Dreieich, Germany). To assess the accumulation properties of the aboveground biomass of the studied tree species, bioaccumulation factors (BAF)s was calculated using the following formula:

$$BAF = [metal]_{biomass} / [metal]_{soil}, \qquad (1)$$

where: $[metal]_{biomass}$ is average metal content in part of the above-ground biomass, $mg \cdot g^{-1}$; $[metal]_{soil}$ is metal content in the substrate, $mg \cdot g^{-1}$ (Sekabira *et al.*, 2011).

Results and Discussion

According to the Hygienic regulations for the permissible concentrations of chemicals in soils (Order of the Ministry..., 2022), the maximum permissible concentrations (MPC, $mg \cdot g^{-1}$), of the mobile form are the following: 4.0 for nickel; 5.0 for cobalt; 6.0 for chrome (III) in comparison with Clark levels (background) (2.1.7.2511-09 “Approximate permissible concentrations of chemical substances in soils”). Figures 1-3 presented data on the actual concentrations of mobile forms of the studied metals in comparison with the standard data of the maximum permissible concentrations.

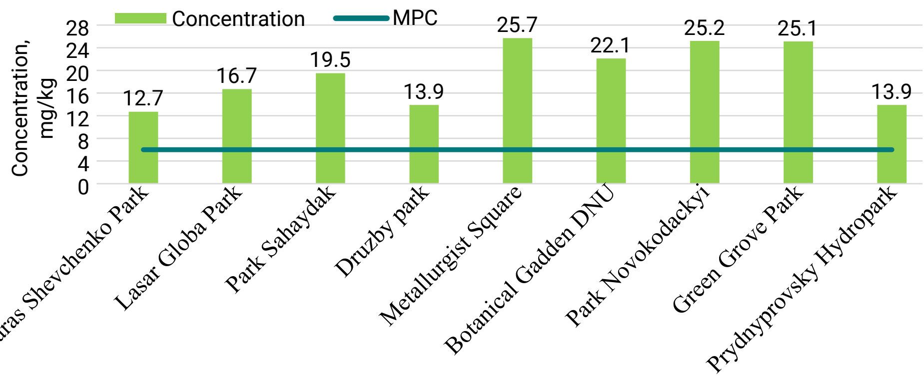

Figure 1. Chromium concentrations in the soils of recreational areas of Dnipro city
Source: developed by the authors

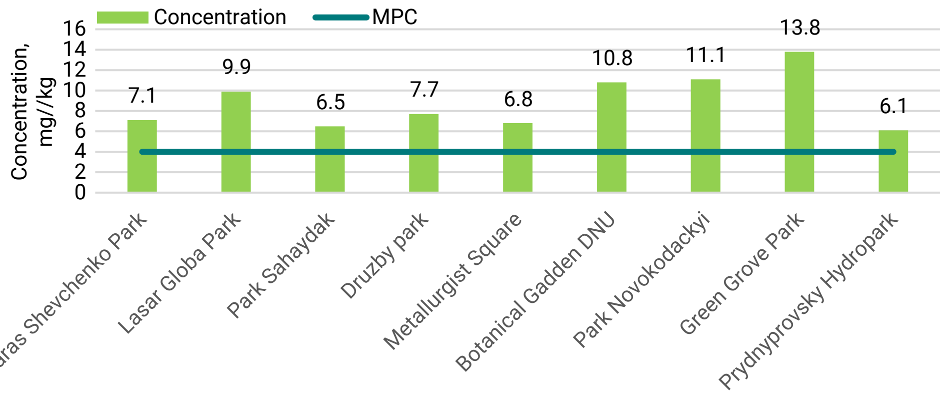

Figure 2. Nickel concentrations in the soils of recreational areas of Dnipro city
Source: developed by the authors

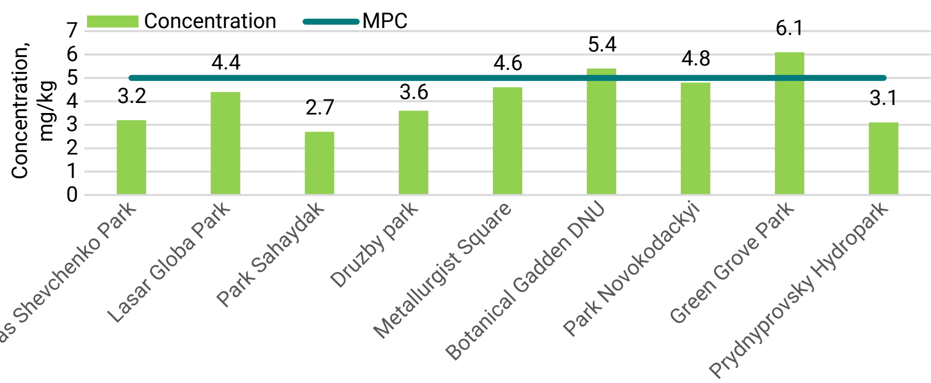

Figure 3. Cobalt concentrations in the soils of recreational areas of Dnipro city
Source: developed by the authors

In the studied soils of all recreational plantings, an excess of MPC of chromium was recorded, which corresponded to the range of 2.1-4.3 times. All the studied soils did not meet the standard values of nickel content, and exceeded the MPC by 1.5-3.5 times. A more favorable situation was observed for cobalt concentrations in the soils of recreational plantings, since a slight excess of MPC was recorded only in two experimental sites: Botanical Garden of DNU and Green Grove Park (1.4-1.5 MPC).

Heavy metal concentrations in the aboveground biomass of R. pseudoacacia trees. Formation of the elemental composition of plant biomass and the deposition of individual elements is influenced by numerous abiotic and biotic factors, among which soil physical and chemical properties are decisive and crucial. Results on metal element concentrations in various components of the aboveground biomass of *R. pseudoacacia* trees (in the trunk wood, leaves and fruits) are given in Table 3.

Table 3. Heavy metal concentrations in aboveground biomass fractions of *Robinia pseudoacacia*

Park name	Heavy metal concentration, mg · kg^{-1}		
	Cr	Ni	Co
	Trunk wood		
Taras Shevchenko Central Culture and Leisure Park	0.14 ± 0.01	0.39 ± 0.01	0.10 ± 0.00
Lazar Globa Central City Children’s Park	0.30 ± 0.01	0.32 ± 0.01	0.10 ± 0.00
Park Sahaydak	0.35 ± 0.01	0.77 ± 0.01	0.10 ± 0.00
Druzhby Park	0.22 ± 0.01	1.04 ± 0.02	0.10 ± 0.00
Metallurgists Square	0.17 ± 0.01	0.80 ± 0.01	0.10 ± 0.00
Botanical garden of DNU	0.65 ± 0.02	0.64 ± 0.02	0.15 ± 0.00
Urban Youth Park recreation and leisure “Novokodatskyi”	0.20 ± 0.01	0.57 ± 0.01	0.10 ± 0.00
Green Grove Park	0.30 ± 0.02	0.16 ± 0.01	0.10 ± 0.00
Prydniprovsky Park	0.10 ± 0.01	3.55 ± 0.01	0.10 ± 0.00
	Leaves		
Taras Shevchenko Central Culture and Leisure Park	3.5± 0.05	1.79 ± 0.01	0.09 ± 0.00
Lazar Globa Central City Children’s Park	5.35 ± 0.05	2.98 ± 0.01	0.13 ± 0.00
Park Sahaydak	5.70 ± 0.05	3.22 ± 0.01	0.13 ± 0.00
Druzhby Park	4.89 ± 0.03	3.88 ± 0.01	0.17 ± 0.01
Metallurgists Square	4.94 ± 0.03	2.98 ± 0.01	0.13 ± 0.00
Botanical garden of DNU	5.63 ± 0.01	4.25 ± 0.02	0.21 ± 0.01
Urban Youth Park recreation and leisure “Novokodatskyi”	2.77 ± 0.02	2.34 ± 0.01	0.12 ± 0.00
Green Grove Park	11.67 ± 0.08	2.56 ± 0.01	0.11 ± 0.00
Prydniprovsky Park	3.51 ± 0.04	1.79 ± 0.01	0.09 ± 0.00
	Fruits		
Taras Shevchenko Central Culture and Leisure Park	0.46 ± 0.01	2.37 ± 0.01	0.10 ± 0.00

Table 3, Continued

Park name	Heavy metal concentration, mg · kg^{-1}		
	Cr	Ni	Co
	Trunk wood		
	Fruits		
Lazar Globa Central City Children's Park	0.43 ± 0.01	1.19 ± 0.01	0.10 ± 0.00
Park Sahaydak	1.27 ± 0.03	1.79 ± 0.00	0.10 ± 0.00
Druzhby Park	1.12 ± 0.02	5.91 ± 0.02	0.10 ± 0.00
Metallurgists Square	1.98 ± 0.01	2.38 ± 0.00	0.10 ± 0.00
Botanical garden of DNU	1.55 ± 0.01	4.00 ± 0.01	0.10 ± 0.00
Urban Youth Park recreation and leisure "Novokodatskyi"	0.67 ± 0.01	3.82 ± 0.02	0.10 ± 0.00
Green Grove Park	0.57 ± 0.01	1.65 ± 0.01	0.10 ± 0.00
Prydniprovsky Park	0.35 ± 0.01	8.46 ± 0.03	0.11 ± 0.00

Source: developed by the authors

Chromium concentrations in aboveground biomass corresponded to the range of 0.10-11.67 mg · kg^{-1}. The greatest concentration of this element occurred in the vegetation fraction. The physiological essentiality of nickel in plants is still a controversial issue, and the toxicity of its high concentrations is obvious. When MPC of nickel was exceeded in the studied soil, Ni was acquired minimal concentration in the trunk wood tissues of the studied trees equal to 0.32 mg · kg^{-1}. The greatest accumulation of nickel occurred in fruits, where its highest concentration was recorded to be 8.46 mg · kg^{-1}. It should be noted that the maximum concentration of this metal occurred in recreational plantings of the Prydniprovsky Park. Cobalt had the lowest concentration values among the studied metals, the range of its content was 0.09-0.21 mg · kg^{-1}, and it had almost the same concentration level in the biomass of trunk wood, leaves and fruits.

BAF represents the plant ability to regulate (to a certain extent) the absorption of inorganic contaminants from the environment and their further migration to vegetation and generative organs. Table 4 shows the calculated values of BAF of the studied metals in the "soil – trees" system.

Table 4. BAF values for heavy metals in aboveground biomass fractions of *Robinia pseudoacacia*

Park name	Heavy metal concentration		
	Cr	Ni	Co
	Trunk wood		
Taras Shevchenko Central Culture and Leisure Park	0.011	0.055	0.031
Lazar Globa Central City Children's Park	0.018	0.032	0.023
Park Sahaydak	0.018	0.118	0.037
Druzhby Park	0.016	0.136	0.028
Metallurgists Square	0.007	0.118	0.022
Botanical garden of DNU	0.029	0.059	0.028

Table 4, Continued

Park name	Heavy metal concentration		
	Cr	Ni	Co
	Trunk wood		
Urban Youth Park recreation and leisure "Novokodatskyi"	0.008	0.052	0.021
Green Grove Park	0.012	0.012	0.016
Prydniprovsky Park	0.007	0.581	0.032
Leaves			
Taras Shevchenko Central Culture and Leisure Park	0.036	0.333	0.031
Lazar Globa Central City Children's Park	0.026	0.120	0.023
Park Sahaydak	0.065	0.274	0.037
Druzhby Park	0.080	0.772	0.028
Metallurgists Square	0.077	0.350	0.022
Botanical garden of DNU	0.070	0.369	0.019
Urban Youth Park recreation and leisure "Novokodatskyi"	0.027	0.348	0.021
Green Grove Park	0.023	0.119	0.016
Prydniprovsky Park	0.025	1.385	0.036
Fruits			
Taras Shevchenko Central Culture and Leisure Park	0.277	0.252	0.028
Lazar Globa Central City Children's Park	0.320	0.302	0.029
Park Sahaydak	0.291	0.494	0.046
Druzhby Park	0.351	0.506	0.047
Metallurgists Square	0.192	0.438	0.028
Botanical garden of DNU	0.255	0.392	0.039
Urban Youth Park recreation and leisure "Novokodatskyi"	0.110	0.213	0.025
Green Grove Park	0.465	0.185	0.018
Prydniprovsky Park	0.213	0.156	0.019

Source: developed by the authors

The difference in BAF values allows detecting metal elements with a high and low level of translocation from the soil to the tissues of aboveground plant organs. According to the obtained values of BAF, we should note that the bioconcentration phenomenon was not observed for all the studied metals. The BAF values of the metals in all components of biomass of *R. pseudoacacia* did not exceed 1, which indicates a low ability to deposit the studied elements, even if their excess content in the soil (Shrivastava *et al.*, 2019).

Using GIS analysis methods, it was interpolated the calculated BAF, which was determined in the studied areas of recreational plantings of *R. pseudoacacia*. The application of the isoline method was the most appropriate to map the results of the study, since BAF is a continuous indicator. As a result, the maps were constructed that show the distribution of the calculated BAF of accumulation of chromium, nickel and cobalt in biomass of leaves and trunk wood over the territory of Dnipro city (Fig. 4-9).

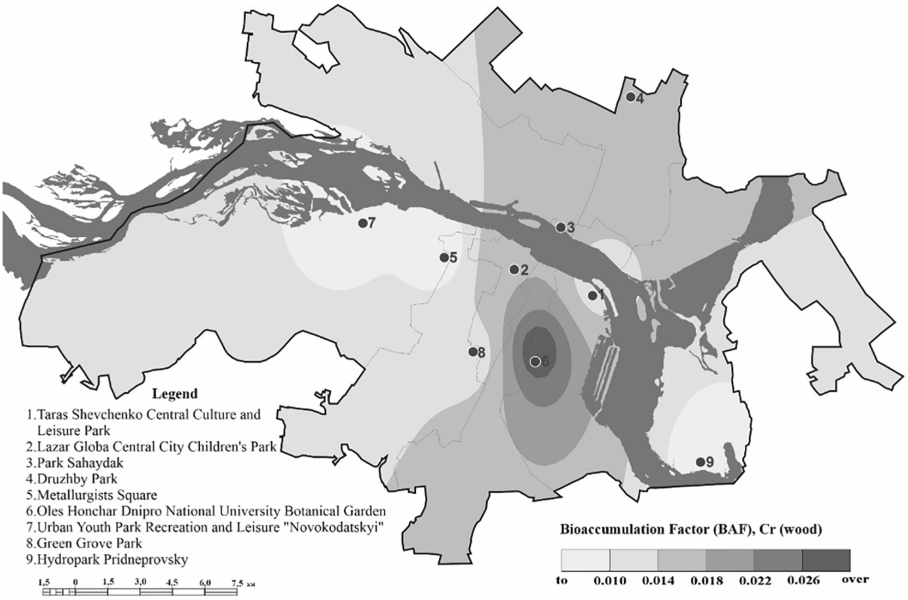

Figure 4. Chromium concentrations in the trunk of *Robinia pseudoacacia* plantings in Dnipro city
Source: developed by the authors

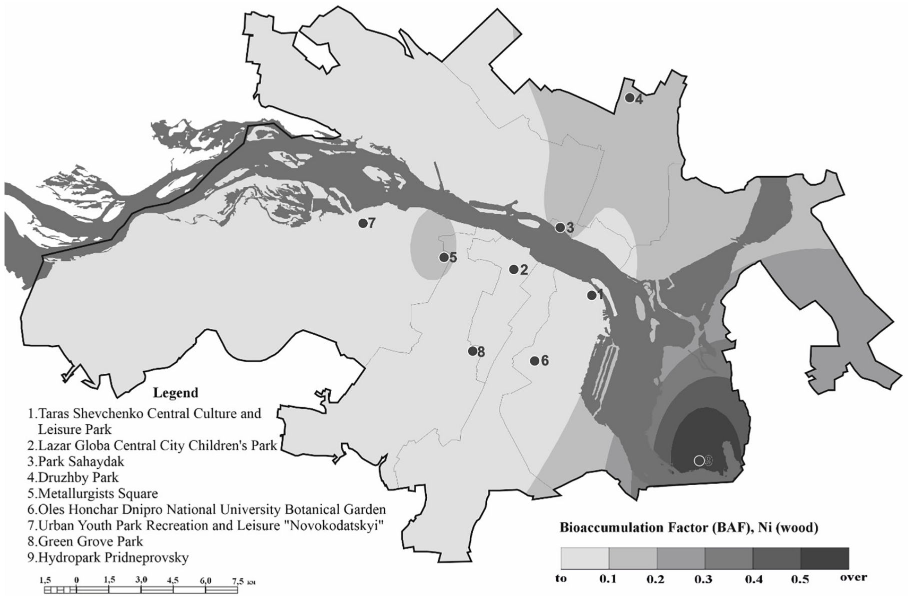

Figure 5. Nickel concentration in the trunk of *Robinia pseudoacacia* plantings in Dnipro city
Source: developed by the authors

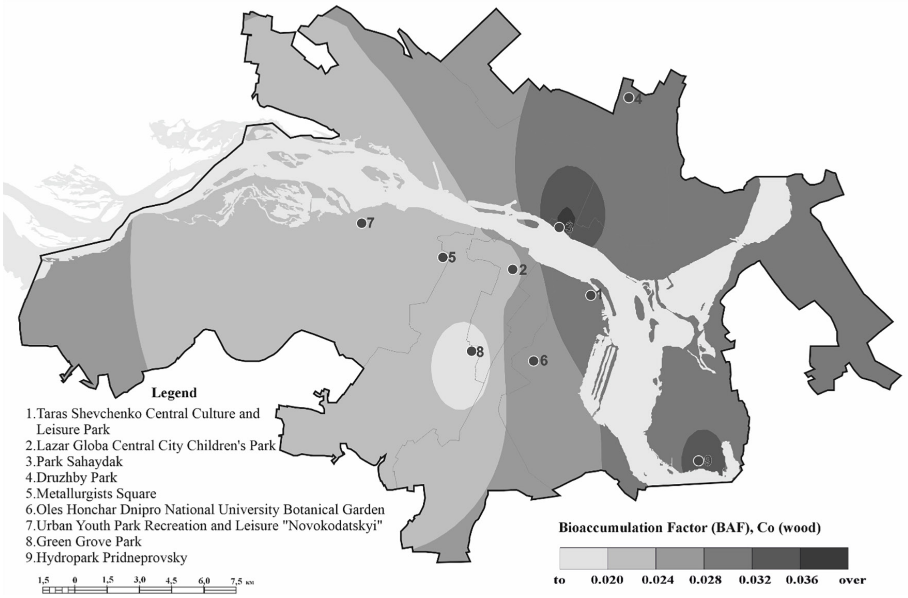

Figure 6. Cobalt concentrations in the trunk of *Robinia pseudoacacia* plantings in Dnipro city

Source: developed by the authors

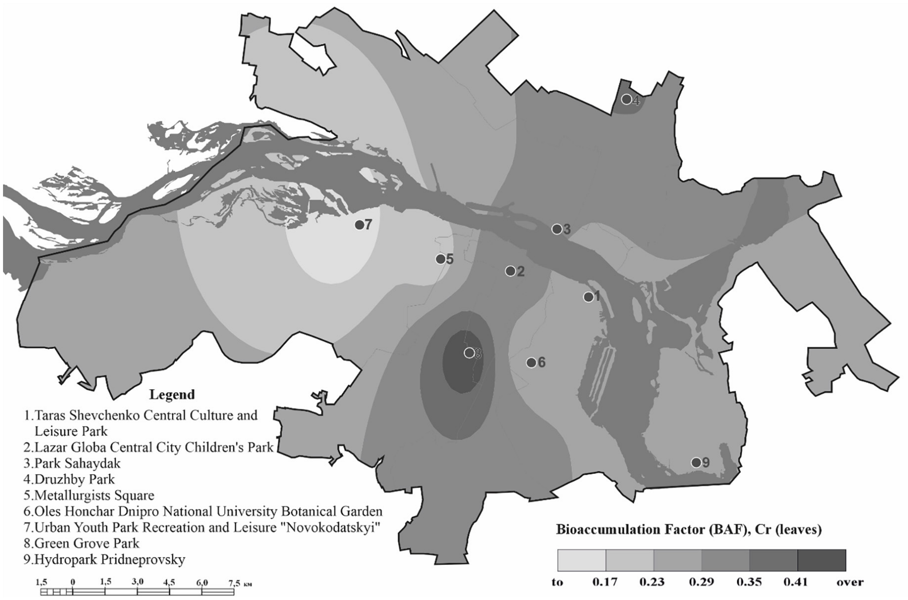

Figure 7. Chromium concentrations in the biomass fraction of leaves of *Robinia pseudoacacia* plantings in Dnipro city

Source: developed by the authors

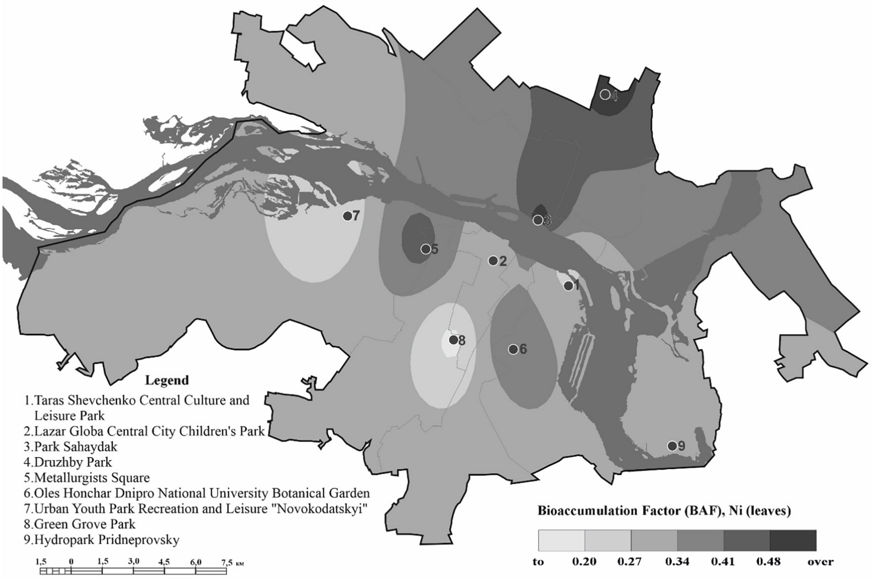

Figure 8. Nickel concentrations in the biomass fraction of leaves of *Robinia pseudoacacia* plantings in Dnipro city

Source: developed by the authors

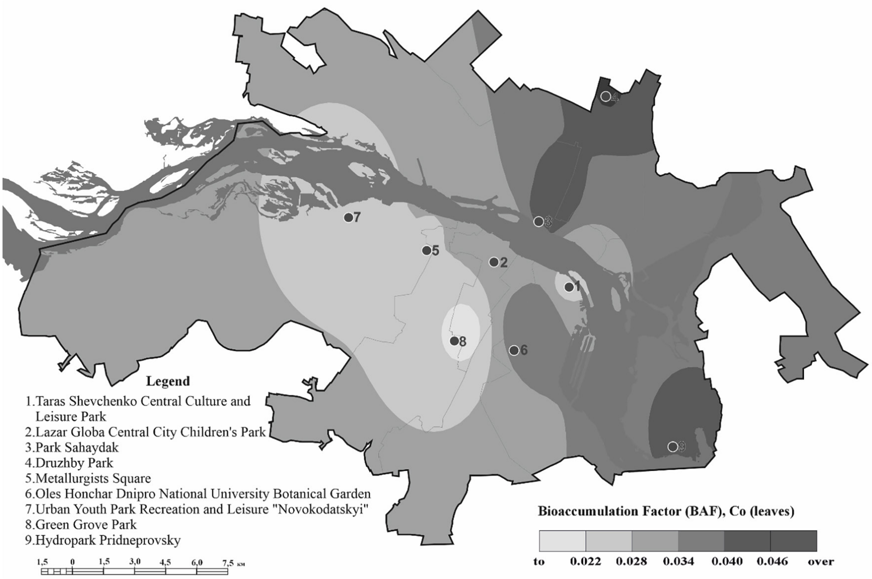

Figure 9. Cobalt concentrations in the biomass fraction of leaves of *Robinia pseudoacacia* plantings in Dnipro city

Source: developed by the authors

The constructed cartographic materials can be used to determine the potential ability of aboveground biomass of *R. pseudoacacia* trees to accumulate chromium, nickel and cobalt for any location of Dnipro city area**.**

The creation of remediation plantings in heavily polluted cities, selecting of non-native plant species ecologically suitable for recreational areas of industrial cities is the subject of research by both Ukrainian and foreign scientists. W. Yan *et al.* (2017) examined how *Robinia pseudoacacia* and *Amorpha fruticosa* rapidly adjusted their carbon balance strategies under repeated drought conditions. The study demonstrated species-specific physiological responses aimed at maintaining carbon homeostasis during environmental stress. Research by J. Banaszek *et al.* (2014) applied GIS techniques to analyse the spatial structure and ecological value of urban parks located in industrial areas. Their work highlighted landscape fragmentation and suggested planning improvements for urban green spaces. Z. Shi *et al.* (2021) developed a soil quality index to evaluate how *Robinia pseudoacacia* influenced soil health under various planting arrangements. The findings revealed that spatial configuration significantly affected soil properties and overall ecosystem function.

The functioning of tree species corresponding to microclimatic and edaphic conditions of park phytocenoses contributes to the intensification of the pedogenesis process and the formation of soil organic matter, which can ensure the balance of urban ecosystems and the economic feasibility of recreational plantings (Aman *et al.*, 2018). *R. pseudoacacia* is polymorphic tree species widely used for remediation of areas covered with degraded soils in Ukraine (Zverkovskyy *et al.*, 2018), Poland (Kraszkiewicz, 2016). In China this tree species has a wide ecological adaptability and adaptive capacity (Liang *et al.*, 2018; Yuan *et al.*, 2018). Under conditions of introduction, in the absence of care for plantings, *R. pseudoacacia* is able to intensively reproduce vegetatively and form monodominant communities; this species is naturalised exclusively in anthropogenically transformed landscapes (Kidawa *et al.*, 2021). However, in case of effective planting management, *R. pseudoacacia* effectively implements certain benefit functions, as anti-erosive, remediation, and quickly produces aboveground biomass (Grünewald *et al.*, 2009).

Because of presence of symbionts, nitrogen-fixing bacteria, *R. pseudoacacia* trees are able to fix nitrogen, which is crucial for nutrient-depleted soils. In addition, the plant litter of *R. pseudoacacia* has a favorable effect on the development of soil cover, since the litter enriches the nutrient-depleted soils in degraded ecosystems with the necessary micro- and macronutrients. These components mainly come from the *R. pseudoacacia's* litter that is being decomposed (Palowski *et al.*, 2016).

According to A.I. Anderson *et al.* (1972) in soils, concentrations chromium varied from excessive to toxic levels: 10 to 100 $mg \cdot kg^{-1}$. The mobility of nickel in the soil depends on the acid-base balance and the concentration of organic substances, mainly of humic acids. Nickel migration has a complex nature: on the one part, nickel enters the plant through soil solution; on the other part, its amount in the soil is replenished due to the destruction of soil minerals, the vegetation and bacterial die-off, as well as due to its entry with atmospheric precipitation.

Some authors note in their review that the toxic effects of chromium are associated with the formation of reactive oxygen species (ROS), which cause oxidative stress in plants (Ao *et al.*, 2022). The toxicity of Cr depends on the mechanisms of its uptake, translocation and subcellular distribution, as well as its effect on other plant metabolic processes, such as chlorophyll biosynthesis, photosynthesis and plant defence systems. Researchers A. Ekta & N.R. Modi (2018) indicated the existence of a mechanism for binding chromium ions in *R. pseudoacacia* roots, which inhibied its entry into the aboveground fraction and could explain the results obtained.

Cobalt belongs to the essential elements of plants that are involved in the formation of metalloenzymes. This metal activates enzyme systems, thereby participating in oxidative phosphorylation and photosynthesis, and is able to inhibit ethylene biosynthesis and increase plant drought resistance. The toxicity of elevated concentrations of this element is primarily associated with the development of oxidative stress and inhibition of assimilation.

Scientists A. Sharma *et al.* (2018; 2020) noted that some elements belonging to the heavy metals perform biogenic functions, such as activators of enzymes and structural components of metalloproteins. Nickel and cobalt are among such elements. At the same time, essential elements could show toxic effects when their concentrations exceeded those found as safe, which may be due to their gradual accumulation of heavy metals in the plant tissues.

Studies by Y.M. Li *et al.* (2003) conducted for herbaceous species of the genus *Alyssum* showed that these species hyperaccumulated Ni, but not Co. In this case, Ni uptake decreased at lower soil pH values and increased at higher soil pH values. According to A. van der Ent *et al.* (2018), a hyperaccumulative tree species such as *Glochidion cf. sericeum* (*Phyllanthaceae*) can simultaneously accumulate both nickel and cobalt in its leaves (until 1500 μg g^{-1}). The authors suggested that the hyperaccumulation of Co coincides with the hyperaccumulation of Ni, which occurs via similar physiological pathways. However, unlike Ni, which accumulates mainly in the cells of the leaf epidermis, the Co accumulation reaction consists of an extracellular mechanism.

A. Kabata-Pendias (2011) cited such concentrations of the studied elements that can cause toxic effects in plants (mg · kg^{-1}): Cr – 0.02-0.20; Ni – 0.1-2.7; Co ⩾ 11.6. Comparing the obtained results on the concentrations of the studied elements, it should be noted that nickel concentrations in biomass exceeded the given concentrations which are considered to be phytotoxic, but no morphological damage was recorded in trees of recreational plantings. According to D. Środek & O. Rahmonov (2022), species-specific physiological and biochemical traits of the metabolism of the studied trees cause differences in the ability and degree of metal element accumulation in certain tissues of vegetative structural, assimilating and generative organs, regulating to a certain extent their intake from the soil. Comparing the results presented in the abovementioned paper, it can be seen that the BAF of Ni in the leaves similar to the range of the different location but the distribution the BAF values of Cr is lower.

Under the conditions of man-made pollution increase, the soils of urban areas need remediation and bringing of its indicators to the normative and sanitary standards. Therefore, the search for woody plants with hyperaccumulative properties that can absorb and keep heavy metals bound in plant tissues for a long time requires research into the phytoremediation properties of trees in regards to toxic heavy metals. The creation and restoration of green infrastructure should be based on the results of such studies.

Conclusions

An excess of the maximum permissible concentration of chromium (2.1-4.3 MPC) and nickel (1.5-3.5 MPC) was recorded in the studied soils of recreational plantings in all experimental sites. Cobalt concentrations exceeded MPC only in two experimental sites: Botanical garden of DNU and Green Grove Park (1.4-1.5 MPC).

Chromium concentrations in aboveground biomass corresponded to the range of 0.10-11.67 mg · kg^{-1}; the greatest concentration of this element was recorded in the assimilation fraction. The greatest accumulation of nickel occurred in fruits, where its highest concentration was recorded to be 8.46 mg · kg^{-1}. The minimum concentration of nickel was found in the woody part of the studied species 0.32 mg · kg^{-1}. Maximum concentration of nickel occurred in recreational plantings of the Prydniprovsky Park. Cobalt had the lowest concentration values among the studied metals; its range was 0.09-0.21 mg · kg^{-1}. The maximum value (0.21 mg · kg^{-1}) of this metal was found in the leaves which grows within Botanical garden of DNU. In general, almost the same concentration level in the biomass of trunk wood, leaves and fruits was found.

BAF values for metal elements in all components of the biomass of *R. pseudoacacia* did not exceed 1, which indicates a low ability to deposit the studied elements, even if their excess content in the soil. The highest BAF values were found in the case of accumulation of nickel in leaves and fruits of *R. pseudoacacia*.

A promising direction for further research is the application of the obtained cartographic materials to assess the potential capacity of *Robinia pseudoacacia* aboveground biomass for chromium, nickel and cobalt accumulation in urban recreational environments.

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Conflict of Interest

None.

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Вплив насаджень робінії псевдоакації на ґрунт у паркових зонах м. Дніпро, забруднених важкими металами

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Анотація. Метою роботи було дослідження стану ґрунтів рекреаційних паркових зон м. Дніпро на вміст хрому, нікелю та кобальту, а також здатності різних компонентів надземної біомаси робінії псевдоакації до акумуляції цих забруднювачів. Перевищення гранично допустимої концентрації (ГДК) хрому (2,1-4,3) та нікелю (1,5-3,5) зафіксовано в досліджуваних ґрунтах рекреаційних насаджень на всіх дослідних ділянках. Концентрації кобальту перевищували ГДК лише на двох дослідних ділянках: в Ботанічному саду Дніпровського національного університету імені Олеся Гончара та парку «Зелений гай» (1,4-1,5). Проведено порівняння концентрації металів у вегетативних (листя, стовбур) та генеративних (плоди) органах *R. pseudoacacia*, а також у ґрунті під наметом дерев у цих насадженнях. Концентрації хрому в надземній біомасі відповідали діапазону

0,10-11,67 мг·кг$^{-1}$, найбільша концентрація цього металу спостерігалася в асиміляційній фракції. Найбільше накопичення нікелю зафіксовано в плодах, де його найвища концентрація дорівнювала 8,46 мг·кг$^{-1}$. Кобальт мав найнижчі значення концентрації серед досліджуваних металів, діапазон його вмісту становив 0,09-0,21 мг·кг$^{-1}$, причому він мав майже однаковий рівень концентрації в біомасі деревини, листках і плодах. Для визначення депонувального потенціалу *R. pseudoacacia* було розраховано коефіцієнт біологічного накопичення (КБН). Згідно з отриманими значеннями коефіцієнта, слід зазначити, що біоконцентрація відбувалася не для всіх досліджуваних металів. *R. pseudoacacia* здатна оптимально функціонувати в міських ґрунтах паркових зон з досить широким діапазоном концентрацій хрому, нікелю та кобальту. Зважаючи на низькі значення КБН, цей вид дерев не схильний до накопичення металів у таких концентраціях, які можуть становити ризик для використання цього виду в рекреаційних насадженнях індустріальних міських парків

Ключові слова: забруднення ґрунтів; хром; нікель; кобальт; коефіцієнт біологічної акумуляції