Recreation Areas Optimisation and Nature Exploitation in Urban Ecosystems

Studia Regionalne i Lokalne
Nr 3(93)/2023

ISSN 1509-4995
E-ISSN 2719-8049
doi: 10.7366/1509499539304

Liudmyla Bezuhla
Dnipro University of Technology, Tourism and Enterprise Economics Department, Dmytro Yavornytskyi Av 19, Dnipro 49005, Ukraine; e-mail: bezuhla.l.s@nmu.one; ORCID: 0000-0002-6520-4325

Mariia Bieloborodova
Dnipro University of Technology, Tourism and Enterprise Economics Department, Dmytro Yavornytskyi Av 19, Dnipro 49005, Ukraine; e-mail: bieloborodova.m.v@nmu.one; ORCID: 0000-0001-8329-7679

Liudmyla Bondarenko
Dnipro University of Technology, Tourism and Enterprise Economics Department, Dmytro Yavornytskyi Av 19, Dnipro 49005, Ukraine; e-mail: bondarenko.l.a@nmu.one; ORCID: 0000-0003-4904-7435

Tetiana Herasymenko
Dnipro University of Technology, Tourism and Enterprise Economics Department, Dmytro Yavornytskyi Av 19, Dnipro 49005, Ukraine; e-mail: herasymenko.t.v@nmu.one; ORCID: 0000-0002-5437-437X

Abstract

It has been substantiated that the increase in the concentration of heavy metals in the environment has especially aggravated in the conditions of military operations on the territory of Ukraine. The use of woody plants for the purposes of phytoremediation is one of the most effective options for optimising the state of the environment in urban ecosystems, regardless of the nature and source of contamination by metallic elements, which is of significant relevance in the conditions of post-war environmental restoration of Ukraine. The purpose of the study is to explore the peculiarities of some heavy metals accumulation by the assimilation apparatuses of the black locust (*Robinia pseudoacacia* L.) plants growing in the recreational areas of the city of Dnipro in order to further optimise tree plantings with the aim of improving the environment. The content of heavy metal elements (Cu, Zn, Pb, and Cd) in the biomass of the *Robinia pseudoacacia* L. leaves and in the soils of Dnipro recreation areas has been determined. The intensity of the accumulation of heavy metals in the phytomass of the *Robinia pseudoacacia* L. represents the following sequence Zn > Cu > Pb > Cd, which demonstrates a more intense absorption and accumulation in the phytomass of the leafy fraction of Zn and Cu in the phytomass of the deciduous fraction, and less significant of Pb and Cd. With the help of geo-information systems, cartographic material has been developed. It demonstrates the concentration gradient of Pb, Cu, Cd, and Zn in the assimilation organs of the black locust plants in the city of Dnipro recreational areas. Based on the cartographic analysis, it has been proved that the general condition of the soils in the recreation areas of Dnipro is characterised by significant disproportions in the level of pollution. The maps show the existing potential of the accumulative capacity of *Robinia pseudoacacia* L. to deposit Pb, Cu, Cd, and Zn, which allows for additional city functional zoning by considering phytoremediation functions of the existing and planned green spaces.

Keywords

nature exploitation, recreational areas, parks, heavy metals, pollution, accumulation of heavy metals, phytomass of deciduous fraction

Introduction

Sustainable urban development that supports valuable ecosystems opens up vast opportunities to improve lives and livelihoods. Increasing forest cover in cities can help cool them in the summer, which means less need for air conditioning (Petit-Berghem et al., 2021). Among other things, greening of cities has a direct positive effect on the real estate market. The relevance of urban greening has become even more obvious during the COVID-19 pandemic (Arkhypova et al., 2022; Cook & Larsen, 2021; Noelwak et al., 2022). It is vital for a person to exist near living plants – they have an impact not only on physical, but also on mental health, as they help to cope with stress, etc.

The problem of greening in various fields of economic activities has been widely considered in the scientific literature. Thus, the monograph by Bulisheva et al. (2018) is devoted to the issue of sustainable economic relations in the system of recreational land use. It is also worth noting the study on greening the recreational sphere in urbanised territory, which is considered in the monograph by Clark et al. (2009). Also, in the work by Cortinovis et al. (2018), the relationship between recreation and green urban infrastructure is examined.

Among the Ukrainian authors who dedicated their research to the problems of greening the service sector and local communities, we should note Babov et al. (2021), Horoshkova et al. (2020), Koshkalda et al. (2022), and Dikanov (2019). However, despite the rather wide development of the mentioned issues, the problem of recreational zones optimisation in order to improve the state of the damaged environment in urban conditions remains insufficiently researched.

The problem of determining the concentration of heavy metals in the soil was considered in the study by Hun'ko (2021). The author determined the variation of Cd concentration in the soil using the ArcGIS software of the Spatial Analyst module, which allowed him to establish abnormal zones of the Cd content in the soils of the city of Kamianske, the Dnipro region.

The preservation of the environment, the reduction of damage from production, efficient energy consumption, and resistance to climate change are the main priorities in the issue of the recovery of Ukraine after the victory. The post-war reconstruction of Ukraine must be green. This requires serious efforts, large finances, and a well-thought-out institutional framework. In Ukraine, a national council was created, which included more than 20 expert groups of different directions, and environmental protection is among them. Approximately 2,500 experts work in these groups. During the discussion, they submitted programmes and projects that they plan to implement during the reconstruction. The main leitmotif of the green reconstruction is: "We don't just have to restore what was destroyed by the Russian occupiers; we have to do it better".

Likewise, the best available technologies and practices should be applied in the recovery process. Now it is very important to focus on the preservation of ecosystems, national parks, nature reserves. In the cities of Ukraine, green spaces are located on an area of 4.6 thousand km² (38.4% of urban areas), and they are available for general use on an area of 1.6 thousand km² (13.4% of urban areas). In Ukraine, the actual figure on average green spaces per city resident is 16.3 m² (Ministry of Development of Communities and Territories of Ukraine, 2021). According to the international norms (UNDP, 2019), this indicator should be no less than 21 m². Only 6 large cities of Ukraine met this indicator in 2020, namely: Nikopol, Bila Tserkva, Rivne, Lviv, Ivano-Frankivsk, Ternopil.

Ukraine has a rich natural resource potential for the development of infrastructure for nature use and recreation. This is confirmed by the statistics of the green economy, which is expressed in the area of the green zone of Ukraine and is shown in Figure 1.

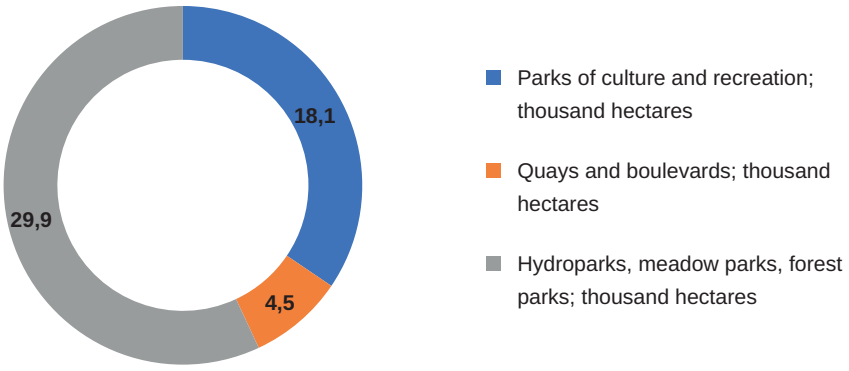

Figure 1. Green zone area in urban ecosystems of Ukraine in 2021

Source: Created by authors on the basis of Ministry of Development of Communities and Territories of Ukraine, 2021.

The directions of management, preservation, and transformation of the natural resource base of recreation in urban conditions can also be implemented through park management. The ecosystem

function of park plantings should be to level the effect of anthropogenic factors of the environment owing to the accumulation potential of plants. Park plantings are able to optimise the state of the environment due to the ability of the plants to absorb pollutants from both the soil and the air, and in order to remove heavy metals from the cycle of biogenic elements for a long time.

With the beginning of the war, the problems of the green infrastructure of Ukrainian cities became even more acute. "Ukraine is one of the most mine-contaminated countries in the world. Even before the ongoing military offensive, over 1.8 million people had already been living surrounded by mines for eight years," as UN OCHA (2022) tweeted. Almost 15% of the total area is mined. This will directly affect soil pollution. The de-mining of these territories or detonation of mines will also lead to soil and groundwater contamination with heavy metals. In addition to oxidation during the explosion, projectile fragments that enter the environment are dangerous. They have impurities of cast iron, carbon, sulpfur, lead, cadmium, and copper, which can lead to soil and underground water pollution.

Military equipment has the same negative impact as cluster bombs and projectile fragments. Impurities of heavy metals can pollute soil and underground water. It is also dangerous when equipment gets into rivers and lakes, because metal oxidation can lead to water pollution. One cannot also ignore the fact that due to the intensive development of industry, the content of heavy metal elements of the group of heavy metals in the surrounding natural environment has significantly increased, which causes a harmful effect on the functioning of ecosystems. Among the heavy metals, Cd and Pb are considered to be the main pollutants, as the human-made accumulation of these metals in the environment is at a high rate (Drozdova et al., 2015; Hryshko et al., 2012; Vabuolyte et al., 2021).

Among the anthropogenic sources of heavy metals entering the soil, agro-technical measures also play a huge role, e.g. the application of fertilisers, pesticides, and the use of wastewater for irrigation. For example, a significant source of diffuse environmental pollution with Cd can be fertilisers obtained from phosphorus-containing ores. The presence of Cd impurities in soils used for agriculture in Australia is largely due to the use of phosphate fertilisers. In the USA, the Environmental Protection Agency has set a maximum permissible concentration of Cd in zinc microfertilisers made from recycled waste, which is 1.4 mg/kg of Cd for each 1% of Zn concentration (Pizzol et al., 2014; Andersson & Siman, 1991). Even with a relatively small content of Cd in phosphorus fertilisers, its annual arrival on the soil surface is about 10 g/ha (Alriksson et al., 2001). Wastewater used in agriculture is also a source of soil pollution with heavy metals. Such chemical elements as Cd, Cr, Cu, Hg, Ni, Pb, Zn most often become the main toxicants that limit the possibility of using wastewater as a fertiliser (Menshov et al., 2021).

An increase in the concentration of metallic elements in the environment leads to a significant increase in their concentration in plants. At the same time, terrestrial plants are able to absorb metal ions from two sources – soil and air. The use of woody plants for the purposes of phytoremediation is one of the most effective options for optimising the state of the environment in urban ecosystems, regardless of the nature and source of contamination with metallic elements (Fernandez et al., 2017). This statement is particularly relevant under the conditions of post-war environmental restoration of Ukraine. According to many researchers, some woody plants in technogenic loaded urban ecosystems are characterised by resistance to metal elements of the group of heavy metals (Davis et al., 2017; Lazzaro et al., 2018; Li et al., 2014).

It is worth noting that the problems of using plants in urbanised ecosystems for the purpose of improving the environment have been considered by various authors. The dissertation work of Hotsii (2020) is dedicated to the study of the bio-ecological features of the *Parthenocissus Planch*. in the conditions of the urbogenic environment of the city of Lviv. The results of the study showed that the content of heavy metals in soil habitats of *Parthenocissus Planch*. is significantly lower than the maximum permissible standards, and the accumulation of some elements in the phytomass significantly exceeds the maximum permissible standards and their content in the soil. The elements of intensive accumulation include Cu, Ni, and Cd.

The phytoremediation ability of poplars and willows, which mineralise some harmful and carcinogenic substances from air, soil, and water, such as herbicides, pesticides, and heavy metals, has been studied widely (Ali et al., 2013; Hound et al., 2016). An important aspect in determining

the remedial properties of tree species that grow in polluted conditions is selective signs of heavy metal accumulation. For example, as established by several different studies, the representatives of the genus *Salix* significantly accumulate Cd, Cu, and *Betula pendula* – Fe, Mn. The ability to accumulate Pb, Al is the same for both species (Das et al., 1997). The remedial potential of *Robinia pseudoacacia* in relation to pollutants is highlighted in works by Aman et al. (2018) as well as Lazzaro et al. (2018).

During the application of the phytoremediation method, natural processes occurring in the plant are used, as this method does not require the use of additional equipment or labour resources, since the main work is performed by the plants themselves. Moreover, to clean the territory using this method, it is not necessary to excavate and remove the soil and pump out groundwater, which saves energy. Trees and small plants also prevent soil erosion, improve the appearance of areas contaminated with heavy metals, as well as reduce noise levels and improve air quality.

The study of the absorptive capacity and storage potential of phytomass on the example of one of the most common types of woody plants in the recreational zones of industrial cities of the steppe zone of Ukraine – and the city of Dnipro in particular – is an urgent issue today and in the near future. The vegetation of the Dnipro urban ecosystem consists of trees, shrubs, lawn grasses, and decorative and ruderal plants. Dust- and gas-resistant breeds with bactericidal properties especially predominate in the stands of industrial districts of the city. Considering the abiotic conditions and the historically-formed landscape culture of the city of Dnipro, the parks of the city have a small composition of dendroflora. Among woody plants, an introducer from North America – *Robinia pseudoacacia* L. – is of particular interest, as this species is widely used in the landscaping of the city of Dnipro and is represented in the plantings of public park zones and recreation areas of the city.

The purpose of this study is to explore the peculiarities of some heavy metals' accumulation by the assimilation apparatuses of the black locust (*Robinia pseudoacacia* L.) plants growing in the recreational areas of the city of Dnipro for the further optimisation of tree plantings with the aim of improving the environment. To achieve the objective of the study, the following tasks were defined: the determination of the concentration of metal elements in soils on the example of park areas of the city of Dnipro; the determination of the concentration of metal elements in the leaves of the black locust – the most common species in the park zones of Dnipro; the development of cartographic material of the gradient distribution of metallic elements in the assimilation phytomass of park plantations of the corresponding species; research on the possibilities of using phytoremediation (on the example of the black locust) to improve the ecological condition of the studied recreational areas.

Material and methods

In order to justify the need to optimise recreational areas in the conditions of planning modern urban ecosystems, the following general scientific and research methods have been used: method of abstraction, comparison, graphic method. The equipment used for the research includes: scales, drying cabinet, atomic absorption spectrophotometer. The research methodology aims to establish the remedial potential of *Robinia pseudoacacia* L., which is part of the park plantings of the recreational zones of the Dnipro urban ecosystem, with the aim of improving the state of the environment and reducing soil pollution by heavy metals in the mentioned territories.

The study of the accumulation potential of the black locust (*Robinia pseudoacacia* L.) was carried out in the recreational plantations in the parks of the city of Dnipro, namely: the Druzhby Narodiv Park, the Lazar Globa Park, the Sorokarichchya Vyzvolennya Mista Park, the Prydniprovs'kyy Park, and the Botanical Garden of the Oles Honchar Dnipro National University.

The preparation of soil samples, i.e. selection, packaging, storage, and transportation in order to determine the concentration of heavy metals was carried out according to the requirements of DSTU ISO 10381-4:2005 and VND 33-1.1-17-2001. Experimental soil samples in the amount of 15 were taken from the park plantations. The content of metal elements in soil samples was determined by the method of atomic absorption spectrometry according to the requirements of DSTU ISO 10381-4:2005 at wavelengths (nm): Cd – 228.8; Pb – 283.3; Cu – 324.7; Zn – 324.7.

When determining the concentration of metallic elements, the preparation of experimental samples of the deciduous fraction phytomass was carried out according to the method of Zverkovskiy et al. (2018). The concentration of chemical elements in the experimental samples of soil and leaf phytomass was processed by the methods of mathematical statistics using the IBM SPSS Statistics 23 software. Maps of metal elements distribution were developed by the method of weighted interpolation (Inverse Distance Weighted Interpolation) using the QGIS programme. The developed maps were based on the calculated values of the heavy metals' concentration, which were determined in experimental samples of the assimilative organs of the *Robinia pseudoacacia* L. plants in Dnipro recreation areas.

Results

The first stage of the study involved the determination of the content of heavy metals (Zn, Cd, Pb, Cu) in the experimental soil samples, which were selected in the test plots of the park areas of the city of Dnipro. Table 1 shows the values of the actual content of metal elements in the soils of the parks, the values of the permitted normative concentrations of the studied contaminants, and the concentrations of these elements in the soils of urban ecosystems. The given values of maximum permissible concentrations and approximately permissible concentrations of the gross content of chemical substances in soils of various uses make it possible to determine a significant difference between the normative values of the concentration of chemical substances in the soil (Department of Ecology and Natural Resources under Dnipropetrovsk Regional State Administration, 2020; Main Department of Statistics in Dnipropetrovsk Region, 2020).

Table 1. The content of metal elements in the soils of park zones, Dnipro city, mg·kg^{-1}

Metals	Name of the park					Maximum permissible concentration (Ministry of Health of Ukraine, 2020)	Approximately permissible concentrations (ODK 2.1.7.2511–09, 2009)	Clarks of elements in soils
	Druzhby Narodiv Park,	Botanical Garden of the Oles Honchar Dnipro National University	Sorokarichchya Vyzvolennya Mista Park	Lazar Globa Park	Prydni-provs'kyy Park			
Zn	32.8	23.8	24.1	29.2	20.5	23.0	110.0	158.0
Pb	73.2	73.8	81.5	68.0	61.3	32.0	65.0	54.5
Cu	15.0	22.1	22.1	22.3	11.4	3.0	66.0	39.0
Cd	0.74	0.46	0.77	0.67	0.79	not normalized	1.0	0.9

Source: Calculated by authors.

Analysing the condition of the soils of the parks of the city of Dnipro, the following can be noted. In the soils of the Druzhby Narodiv Park, the Lazar Globa Park, and the Sorokarichchya Vyzvolennya Mista Park, there is an excess of three studied elements, namely: Zn, Pb, and Cu. Exceeding the standards for Pb and Cu is typical of the soils of the Botanical Garden of the Oles Honchar Dnipro National University and the Prydniprovs'kyy Park. It should be noted that the soil in the Prydniprovs'kyy Park has the minimum excess of all the parks of Dnipro.

Thus, the soils from all the investigated trial areas of the city of Dnipro parks do not meet the standards of maximum permitted concentrations for metallic elements – Zn, Pb, and Cu. The content of Cd corresponds to approximately permissible concentrations, provided that there is no legitimate value of the maximum permissible concentration. The determination of the content of elements of the group of heavy metals was performed on the phytomass of the deciduous fraction of the black locust (*Robinia pseudoacacia* L.). The results of the analysis of the concentration of the studied metals are provided in the Table. 2.

Table 2. The content of elements of the heavy metals group in the deciduous fraction of the phytomass of black locust (*Robinia pseudoacacia* L.) in the park areas of Dnipro

Name of the park	Metals, mg kg^{-1} of dry substance			
	Zn	Cu	Pb	Cd
Druzhby Narodiv Park	30.28	8.23	8.78	0.35
Botanical Garden of the Oles Honchar Dnipro National University	17.61	7.06	8.85	0.18
Sorokarichchya Vyzvolennya Mista Park	21.17	16.43	10.59	0.42
Lazar Globa Park	24.54	17.20	9.52	0.41
Prydniprovs'kyy Park	15.80	4.77	8.58	0.39

Source: Own elaboration.

Provided that the maximum permitted concentration of Cu in the studied soils is slightly exceeded, a sufficiently low concentration of 4.8–16.4 mg·kg^{-1} has been recorded in the phytomass of the assimilating organs.

The study has found that the concentration range of the toxic metal Cd in the above-ground phytomass of assimilating organs of *Robinia pseudoacacia* L. trees is 0.18–0.42 mg kg^{-1}. This metal element is not essential for the growth and development of plants, but it is effectively absorbed by the root system. Therefore, the fact that Cd is present in any concentration in plant tissues may indicate a suboptimal state of the environment where the plant grows due to the presence of this metal element.

The analysis of the results of the study on the concentration of Pb in the leaves of *Robinia pseudoacacia* L. made it possible to establish that for the concentration of the given contaminant in the soils of park zones, which slightly exceeded the normative values of the maximum permissible concentration, the content of the given element in the assimilative organs of the studied plants was 8.5–10.6 mg kg^{-1}. There is no significant dispersion of Pb accumulation by locations of phytomass sampling. Based on the concentrations that are considered optimal for the growth and development of plants, it can be noted that the determined concentrations of Pb in the leaves of *Robinia pseudoacacia* L. park plantations in Dnipro significantly exceed the optimal, and can be defined as toxic for the functioning of the studied species.

The values of the concentration of metals obtained in the study allow us to state that greater levels of accumulation of metals that cause a toxic effect are shown by *Robinia pseudoacacia* L. trees, which are components of the phytocenoses of the Sorokarichchya Vyzvolennya Mista Park and the Lazar Globa Park. The phytomass of the assimilating vegetative organs of trees of the studied species in the Botanical Garden of the Oles Honchar Dnipro National University is characterised by much lower accumulation of both Cd and Pb.

The data presented in Table 2 allows us to establish that the concentration of Zn in the assimilative organs of the black locust (*Robinia pseudoacacia* L.) in Dnipro park zones is in the range of values of 15.8–30.2 mg·kg^{-1}, i.e. there is a twofold difference in the content of the given element. The maximum concentration of Zn is recorded in the deciduous fraction of black locust plantations of the Druzhby Narodiv Park, and the minimum concentration is in the black locust plantations of the Prydniprovs'kyy Park.

On the basis of the concentration values of metal elements in the phytomass of the black locust (*Robinia pseudoacacia* L.) estimated in the study, the cartographic material of the accumulation of contaminants in phytocenoses of the city of Dnipro has been developed using the method of GIS technologies. These maps show the deposition of elements such as Cu, Cd, Zn, and Pb in the phytomass of the black locust (*Robinia pseudoacacia* L.) The GIS study is shown in Figures 2–5.

The maps obtained through the study make it possible to state that the deposition of Cd in the above-ground phytomass of the black locust (*Robinia pseudoacacia* L.) trees is 0.21–0.39 mg·kg^{-1}. The maximum areas on which the systems of urban green spaces are concentrated are characterised by the maximum concentration (≥ 0.39 mg·kg^{-1}) of this element.

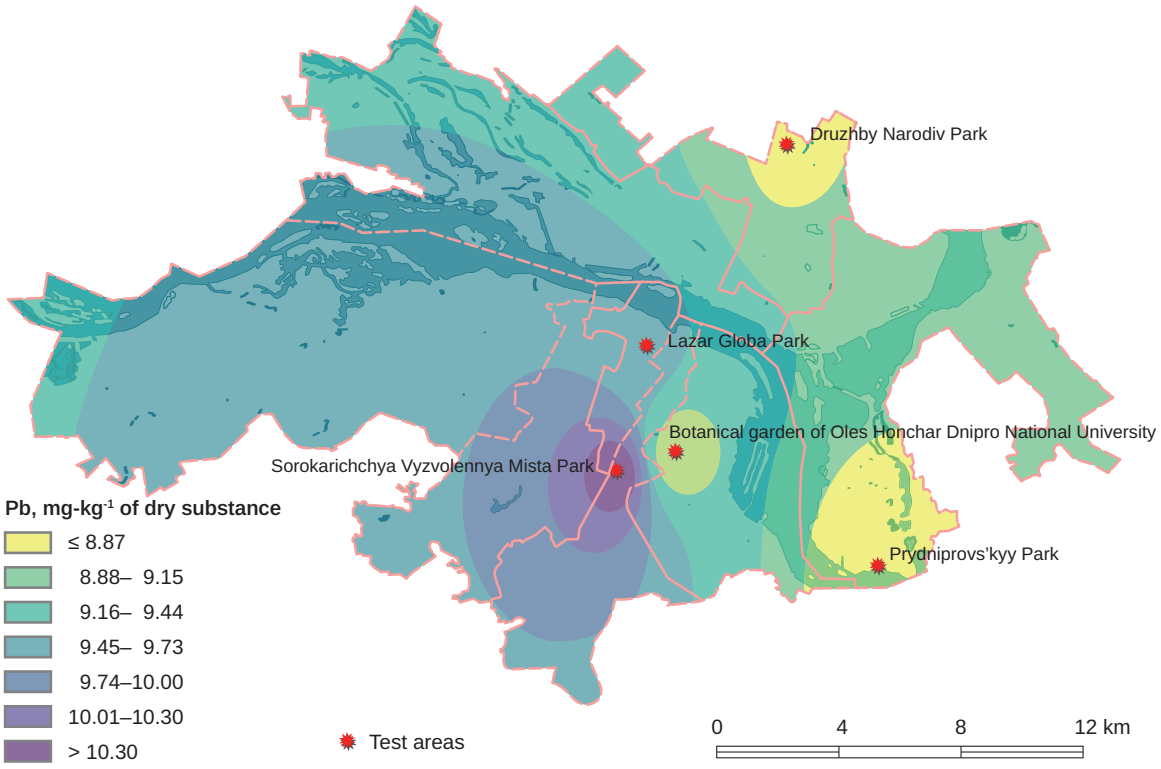

Figure 2. Accumulation of Cd in the phytomass of the assimilating organs of *Robinia pseudoacacia* L. plantations in the city of Dnipro

Source: Own elaboration.

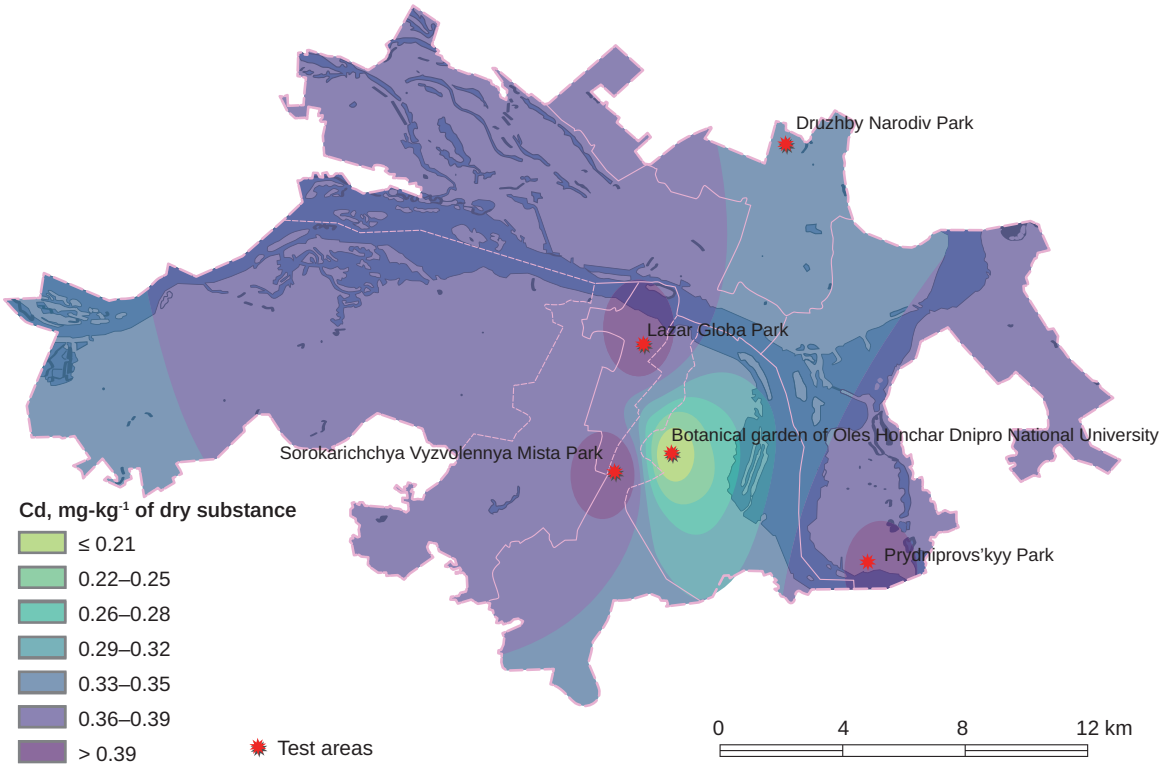

Figure 3. Accumulation of Pb in the phytomass of the assimilating organs of *Robinia pseudoacacia* L. plantations in the city of Dnipro

Source: Own elaboration.

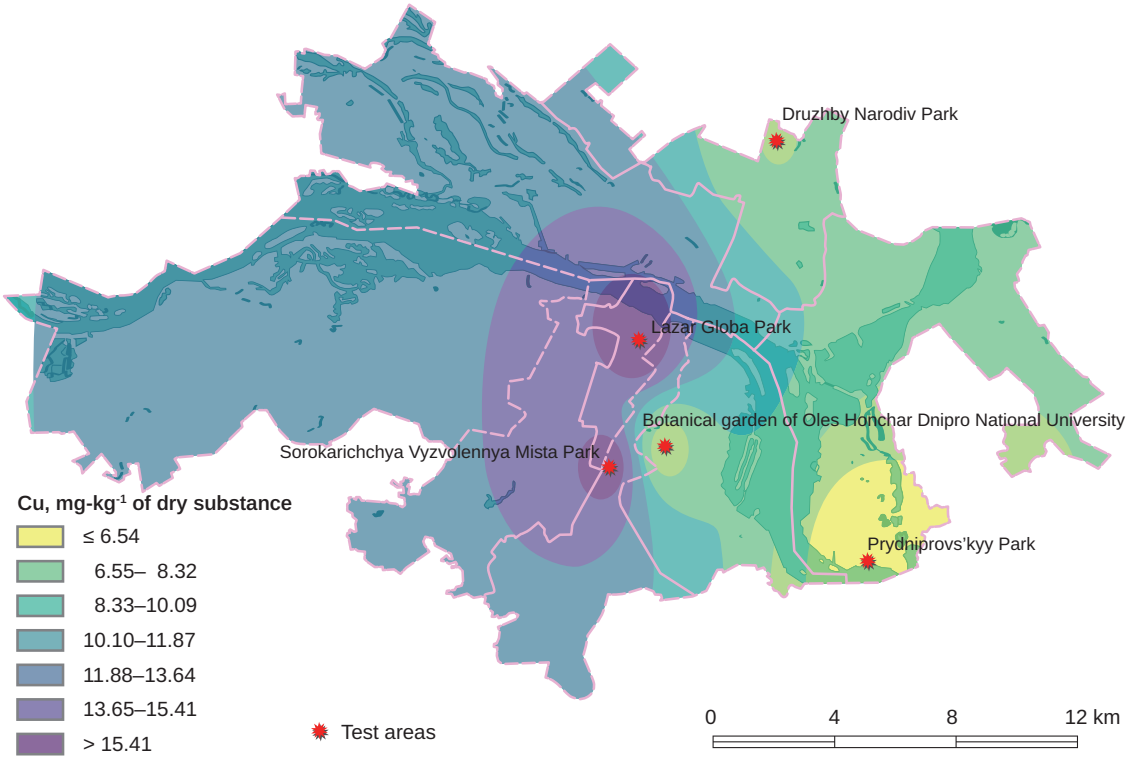

Figure 4. Accumulation of Cu in the phytomass of the assimilating organs of *Robinia pseudoacacia* L. plantations in the city of Dnipro

Source: Own elaboration.

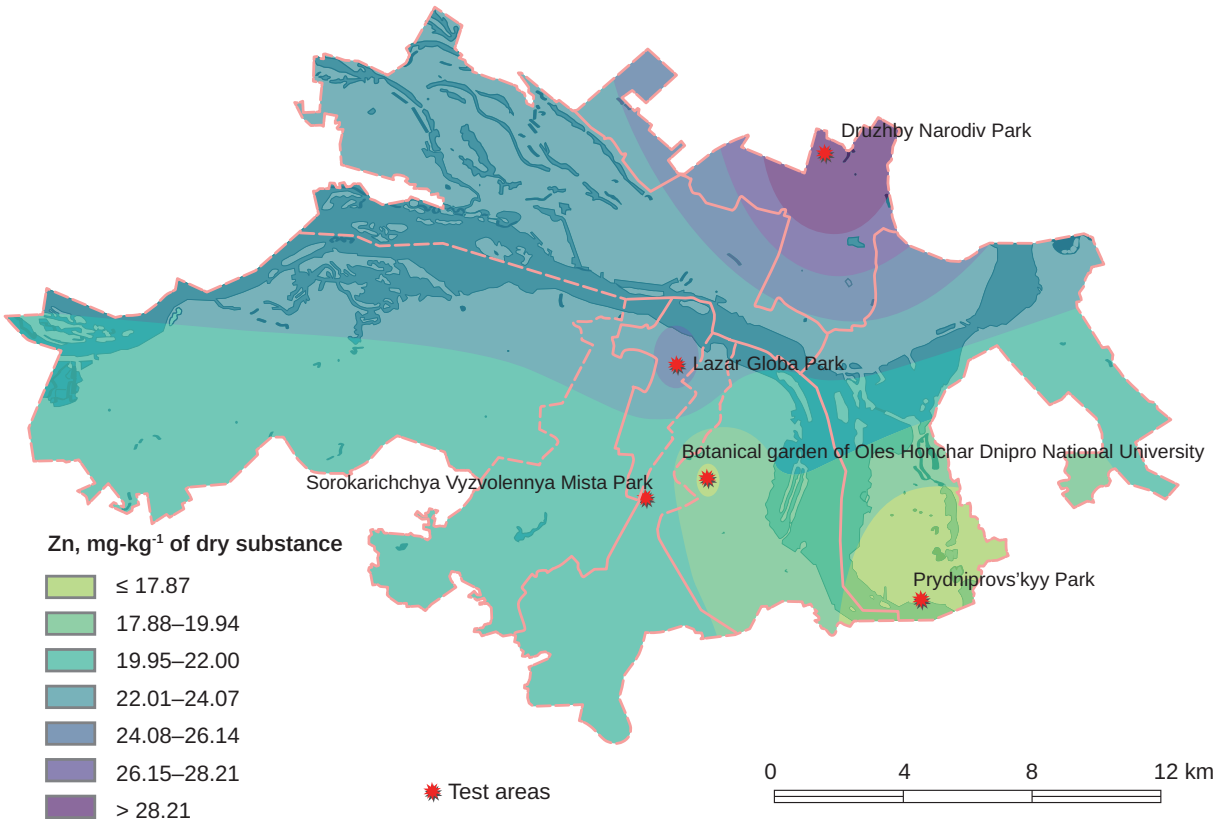

Figure 5. Accumulation of Zn in the phytomass of the assimilating organs of *Robinia pseudoacacia* L. plantations in the city of Dnipro

Source: Own elaboration.

The concentration of Pb in the assimilation organs of *Robinia pseudoacacia* L. is quite significant and constitutes to the range of values of 8.87–10.30 mg·kg^{-1}. The majority of the plantations of the studied species in Dnipro are represented by plantations that deposit 9.45–9.43 mg·kg^{-1} of this metal element in the deciduous phytomass and are concentrated in the western part of the city. According to the distribution of Cu concentration in the fraction of assimilating vegetative organs of *Robinia pseudoacacia* L. trees, it is possible to observe the dominance of the area in the western part of the city, where there are trees that accumulate Cu at a level of 11.88–13.64 mg·kg^{-1}. What attracts attention is the location with the maximum accumulation, more than 28.20 mg·kg^{-1} of this metal element, near the Lazar Globa Park.

Discussion

Pollution of the environment with harmful and toxic metallic elements has now acquired hectic pace and scale of distribution. The atmosphere of industrial cities is polluted by industrial emissions that contain elements of the group of heavy metals. Emissions of anthropogenic origin determine the presence of metallic elements in various compartments of the environment – air, surface and drinking water, in soils where the root systems of plants accumulate and enter the circulation of substances in natural ecosystems (Woch, 2018). That is why toxic metal elements are localised in food products, cosmetics, interior items, etc.

Metallic elements of the group of heavy metals and their compounds in certain concentrations have a toxic effect on the human body, causing various diseases. Some metals can accumulate for a long time in tissues, e.g. muscle, nervous, connective (blood, lymph, fibrous), etc. (Novikova, 2020).

Excessive intake of Cd in the body can lead to anaemia, liver damage, impaired lung function, osteoporosis, deformation of the skeleton, and the development of hypertension. This metallic element accumulates in the kidneys and can be the cause of urolithiasis.

Pb belongs to the class of highly dangerous substances. This element accumulates in bones, causing their gradual destruction, as well as in the liver and kidneys. It can also cause a decrease in working capacity, memory impairment, and even chronic brain diseases. The number of pollutant emissions into the environment is increasing; metal elements accumulate in the phytomass of woody plants, which affects their life. The World Health Organization of the United Nations believes that today 25–50% of the totality of all influencing factors is the influence of pollutants (World Health Organization, and Regional Office for Europe, 2018). Therefore, residents of megacities are more likely to be negatively affected by the environment. Considering the scope of recreational activities development, the functions of recreational nature use, and, in particular, nature protection, the main directions of nature protection activities in the process of recreational use of resources at the current stage are:

– to prevent degradation of natural recreational complexes and their components under the influence of anthropogenic activity, including recreational activity;

– to develop norms of recreational loads, basic standards of fees for the provision of general and special recreational services;

– to preserve normal functioning and maximum diversity of ecosystems of natural complexes. At the same time, it is important to pay attention to the protection of not only the recreational areas themselves, but also the surrounding areas, since recreation and an ecologically-harmful environment are incompatible;

– to increase capital investments in nature protection and to improve monitoring of the quality of the natural environment and the use of resources.

We believe that the issue of improving the state of the disturbed environment can be solved by the appropriate method of creating a system of green plantings and the selection of the best types of trees and their combinations. Optimising recreational areas from the point of view of nature management is an important component of successful restoration of human-made ecosystems by way of creating a system of green spaces for public use.

The benefits of successful urban parkland development can lead to the development of human-impacted areas, which will increase the range of ecosystem services that these areas can provide.

The creation of mapping materials of contamination in the phytomass of park phytocenoses with the appropriate concentration of heavy metals can be used by the relevant authorised bodies when creating programmes and strategies for the development of cities. In particular, the maps created as part of the research have been transferred to the Department of Parks and Recreation as well as the Department of Ecology and Natural Resources of the Dnipro City Council for further processing.

A number of researchers emphasise the importance of a strategic approach to urban space planning, including recreational space. We believe that new opportunities for increasing the efficiency of the urban territory use are opened up by the multi-functionalisation of the urban space in the form of the creation of compact planning entities with multi-purpose use of territories. Thus, Pleshkanovska (2005) notes that the efficiency of urban territory is based on the optimisation of the following indicators: the minimisation of the average communication radius of the city, the minimisation of travel time costs, the optimisation of the linear density of settlement, the minimisation of energy consumption, functional-spatial compatibility, the polyfunctionalisation of the use of urban plan territories.

The majority of scientists include mainly only infrastructural, historical, cultural, and social aspects in the areas of the optimisation of urban and suburban recreation areas. Thus, in the study of Wu and Ding (2022), it is noted that “the construction of garden parks and community parks should be promoted in the future planning of park green spaces to improve the overall supply quality. To support recreational activities, daily recreation parks should be arranged more rationally, and the construction of daily recreation parks should be increased to meet resident demands” (p. 10).

However, the discrepancy between the theory of spatial organisation alongside with the development of urban planning systems and the needs arising under new socio-economic conditions requires a new methodological platform for the spatial organisation of both urban planning and recreational systems. Theoretical positions that were formed on the basis of the division of the economy do not stand the test of the current reality. Under the conditions of post-war reconstruction, when the urban buildings of Ukraine, especially the agglomerations in the eastern part of it, suffer from the deterioration of the environment and the increase in the concentration of heavy metals in the soil, the use of green spaces as a tool for improving the condition of the soil in urban recreation areas becomes especially relevant. This opinion is confirmed by Shushulkov (2020), who emphasised that it is impossible to achieve ecological balance in urbanised areas, which is why the improvement of the state and quality of the urban environment is achieved by various measures: technological, technical, structural, architectural, and planning. The paper states that functional zoning is a recognised effective method of modelling territory, the result of which is not only its division into separate areas with recommended types and modes of use, but also the correlation of territory management methods with its priority tasks, planning of management measures, and conflicts resolution.

Conclusions

Today, under the conditions of military operations on the territory of Ukraine, there is an increase in the volume of environmental pollution with heavy metals. In addition, soils in cities that contain excessive concentrations of heavy metals lose their structure and are characterised by an increase in overall density and a decrease in the content of organic and nutrient substances. It is possible to optimise the state of the disturbed environment through the creation of a system of green plantings and the selection of the most appropriate types of trees and their combinations in recreational zones of urban ecosystems, in particular in gardens, parks, forest parks. The ability of plants to accumulate chemical elements of the group of heavy metals in high concentrations in the overground biomass can be widely used for the restoration of disturbed environments. Trial areas have been laid out in the recreational zones of the city of Dnipro – the Druzhby Narodiv Park, the Botanical Garden of the Oles Honchar Dnipro National University, the Sorokarichchya Vyzvolennya Mista Park, the Lazar Globa Park, and the Prydniprovs'kyy Park, where soil samples and phytomasses of assimilating organs of *Robinia pseudoacacia* L. trees were selected. It has been established that the soils of the studied parks of the city of Dnipro do not meet the standards of maximum permissible concentrations for metallic elements – Zn, Pb, and Cu (Ministry of Health of Ukraine, 2020).

The content of cadmium corresponds to approximately permissible concentrations, provided that there is no legitimate value of the maximum permissible concentration.

The intensity of the accumulation of elements of the heavy metals group in the phytomass of the assimilative organs of *Robinia pseudoacacia* L., which is part of the park plantations of the city of Dnipro, represents the series Zn > Cu > Pb > Cd, which demonstrates a more intense absorption and accumulation of Zn and Cu in the phytomass of the deciduous fraction, and less significant one of Pb and Cd. Based on the results of the research, mapping materials of contamination in the phytomass of park phytocenoses with the appropriate concentration of inorganic contaminants of Cu, Cd, Zn, and Pb in the deciduous fraction have been created, which can be used in further planning of the development of recreational zones in the conditions of urban ecosystems.

On the basis of the cartographic analysis, it has been proved that the general condition of the soils in the recreational zones of the city of Dnipro is characterised by significant disproportions in the level of pollution. The maps show the existing potential of the accumulative capacity of the biomass of the black locust assimilation organs to deposit Pb, Cu, Cd, and Zn; this allows for additional functional zoning, which is a recognised effective method of modelling the urban area. Effective implementation of such measures is possible only when taking into account the ecological framework of the urban area, which serves as the basis for the development of land management schemes, land use restrictions, proposals for the preservation and protection of natural landscapes, the determination of the share of built-up and unbuilt areas, and the justification of the total load on individual land plots.

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