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Article

Metals Zn, Cu, Pb, and Cd in the "soil-plant" system of urban green zones

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Abstract. Many heavy metals (HMs) can be either essential or toxic. The aim of this study was to assess indicators reflecting the accumulation and behavior of Zn, Cu, Pb, and Cd in the soil-plant system of an urban ecosystem. Soil samples (0–10 cm) and leaves of silver birch *Betula pendula* were collected in Kirov (Russia), in the taiga zone with a temperate continental climate. Soil Zn exceeded the regional background (58 mg/kg) at most sites. The exceptions were residential areas remote from the city center. Copper content in the soil was above the standard (20 mg/kg) but within the regional background (28 mg/kg), except at a site with high traffic load (a 1.7-fold background exceedance). Zn had a higher proportion of mobile forms than the other HMs, peaking at the high-traffic site (58%). As a result, Zn's biological accumulation coefficient in *B. pendula* leaves exceeded 1 at 4 of 9 sites. Leaf asymmetry of *B. pendula* correlated most strongly with total soil Zn ($r = 0.67$), then mobile Zn ($r = 0.36$) and mobile Cu ($r = -0.38$). The relationship between fluctuating asymmetry (FA) and HMs content in leaves was weak ($r < 0.30$). Thus, increased FA in *B. pendula* leaves reflects soil metal content rather than metal accumulation in leaves.

Keywords: cadmium, lead, copper, zinc, accumulation, birch tree, *Betula pendula*, fluctuating leaf asymmetry, biological accumulation coefficient

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Научная статья

Металлы Zn, Cu, Pb, Cd в системе «почва-растение» зеленых зон города

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Аннотация. Многие тяжелые металлы (ТМ) могут иметь как эссенциальное значение, так и оказывать токсическое действие. Целью работы была оценка показателей, отражающих накопление и поведение Zn, Cu, Pb, Cd в системе «почва-растение» урбоэкосистемы. Пробы почвы (0–10 см) и листьев березы повислой *Betula pendula* были отобраны в г. Кирове (Россия), в зоне тайги с умеренно континентальным климатом. Накопление Zn в почве большинства участков было выше регионального фона (58 мг/кг), кроме отдаленных от центра жилых зон. Содержание Cu в почве было выше норматива (20 мг/кг), но в пределах регионального фона (28 мг/кг), кроме участка с высокой транспортной нагрузкой, где превышение фона составило 1.7 раза. Доля подвижных форм Zn была больше, чем у других ТМ, с максимальной лабильностью на участке с высокой транспортной нагрузкой (58%). Это привело к тому, что на 4 из 9 участков коэффициент биологического накопления Zn листьями *B. pendula* превышал 1. Асимметрия листьев *B. pendula* в большей степени коррелировала с валовым содержанием Zn в почве (r по Пирсону равен 0.67), концентрацией его подвижных форм (r = 0.36), и подвижными формами Cu (r =−0.38). Взаимосвязь флуктуирующей асимметрии (ФА) с содержанием ТМ в листьях оказалась слабой (r < 0.30). Таким образом, увеличение ФА листьев *B. pendula* – это в большей степени реакция на содержание металлов в почве, чем на их накопление в листьях.

Ключевые слова: кадмий, свинец, медь, цинк, аккумуляция, береза, *Betula pendula*, флуктуирующая асимметрия листьев, коэффициент биологического накопления

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Introduction

The well-being of urban ecosystems is ensured by the presence of a well-developed network of green zones. According to the Forest Code of the Russian Federation[1], green zones are lands allocated to protect the population from the impact of adverse phenomena of natural and man-made origin, as well as to preserve and restore the environment. The city's green zones form its ecological framework, which performs ecological, social and aesthetic functions.

The city's ecological framework includes park, forest park, and water protection zones, as well as areas of specially protected natural territories and a ring of forest ecosystems of both natural and artificial origin (Mirzekhanova, 2000). An important part of urban landscaping is plantings along motor transport roads. They perform a barrier function, protecting residential areas from dust saturated with potentially hazardous substances.

Among the listed components of urban green spaces, the "soil–plant" system occupies a central place. The soils of cities around the world are characterized by an increased content of heavy metals (Hao et al., 2024; Krutskikh et al., 2016; Vodianitsky, 2008), petroleum products (Jing et al., 2024; Lysak and Lapygina, 2018), benzopyrene (Makaeva and Korchin, 2017, Saltiene et al., 2002), rare earth elements (Maurizio et al., 2025; Zhornyak and Yazikov, 2008). In response to pollution, the ecological and biological properties of the soil change. For example, in the city of Orenburg, the level of phytotoxicity of soils in park areas suppressed the growth of test cultures. It was demonstrated that there is a significant correlation between the phytotoxicity index of soils (for the test organism *Avena sativa* L.) and the total content of mobile forms of heavy metals in them ($r = 0.95$), primarily zinc ($r = 0.87$) and lead ($r = 0.75$), as well as the total content of their total forms ($r = 0.74$) (Verkhoshentseva and Galaktionova, 2014). Pollutants are absorbed by plants, accumulating in their structural parts. For example, in the city of Solikamsk, an elevated content of total forms of Zn (127 mg/kg), Cu (9.85 mg/kg) and Pb (5.68 mg/kg) was found in the leaves of small-leaved linden (*Tilia cordata* Mill.) (Kaigorodov et al., 2009).

The examples given show that the state of urban soils and plants in urban ecosystems is often the subject of study due to their ecological and social importance. The aim of this study was to establish the relationships between soil pollution in urban green areas and the indicator characteristics of the soil and the plants growing on it.

Materials and methods

Territory and study sites

The study areas are located in the urban agglomeration of the city of Kirov (Russian Federation). Kirov is one of the large cities, it is the regional center of the Kirov region, and it is part of the territorial group of regions in the Volga region – the Volga Federal District. The city is located in the southern taiga subzone. It should be noted that the taiga zone covers about 60% of the Russian Federation.

The study sites (Fig. 1) were located in the city's green zones, which were situated in the following areas:

1) recreational areas:

– in the city centre: the park named after Kirov and Alexandrovsky Park;

– on the periphery of the city: a square in the Sadakovsky and the Poroshino forest park;

2) residential areas with low traffic load: the Komintern district, the "Solnechny Bereg" district, the Malaya Subbotikha district, Iskra Street;

3) the transport-heavy part of the city – the square on Lepse Street.

Soil research

The type of soil was determined using the "wet" field method. Urban soils, in terms of their genesis and preserved structure, were close to sod-podzolic soils with a sandy and sandy-loam granulometric composition.

The soil in the plots was taken from the upper root layer with a depth of 0–10 cm using the envelope method, placing the sampling sites on the sides of a 10×10 m square. The dry samples were homogenized, and the averaged sample was sent for analysis.

[1] The Forest Code of the Russian Federation, 2007. Legal Literature, Moscow, Russia, 56 p.

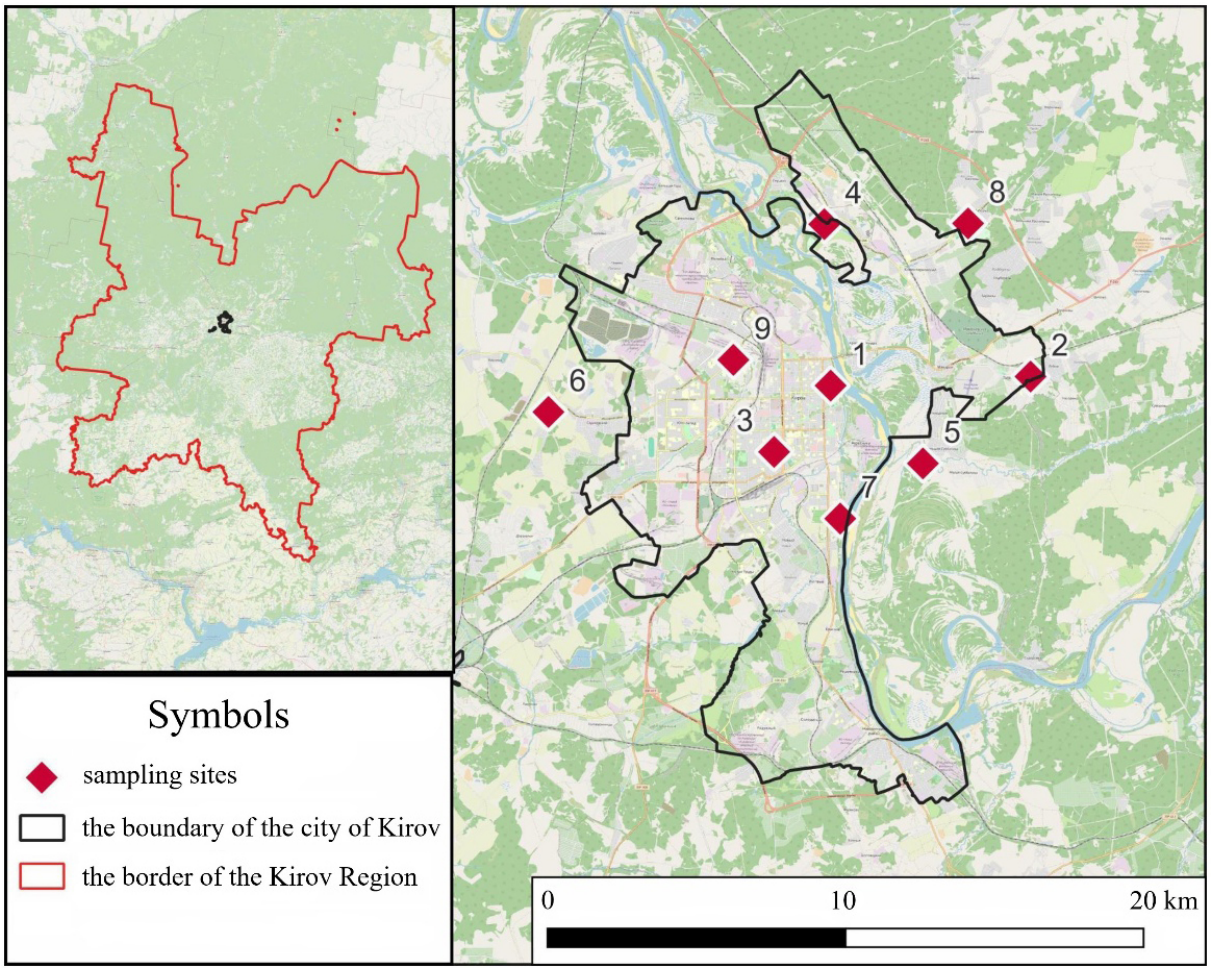

Fig. 1. Map-layout of sampling sites. 1 – Alexandrovsky Park, 2 – Poroshino Forest Park, 3 – Park named after Kirov, 4 – Komintern District, 5 – Malaya Subbokha District, 6 – Sadakovsky District, 7 – "Solnechny Bereg" district, 8 – Iskry Street., 9 – Lepse Street.

The following indicators were determined in the soil: the concentrations of total and mobile forms of heavy metals using the atomic absorption method[2]; the pH level in the aqueous and salt extracts (Kidin, 2008); the content of organic matter (GOST 26213-91[3]). Based on the data, the degree of metal mobility was calculated as the proportion of mobile forms of the metal relative to its total content in the soil.

To assess the level of soil pollution, the concentration coefficients of the elements were first calculated:

$$K_k = \frac{C_i}{C_\Phi},$$

where C_i is the content of the element in the soil of the study area, and C_Φ is the average content of the element in the background area. In our case, the concentrations of elements in the soil were compared with the regional background (Ekologo-geokhimicheskaya karta..., 1996) and with the established standards[4].

[2] Methodological guidelines for determining heavy metals in soils of agricultural land and crop production, 1992. Central Research Institute of Agrochemical Services for Agriculture, Moscow, Russia, 61 p.

[3] GOST 26213-91, 1991. Soils. Methods for determining organic matter.

[4] SanPiN 1.2.3685-21. Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans.

After determining the concentration coefficients, the total pollution index (TPI) was calculated using the following formula:

$$Z_c = \sum_{i=1}^{n} K_{ci} - (n-1),$$

where K_{ci} is the concentration coefficient of the i-th element in the sample; n is the number of elements taken into account.

The obtained TPI values characterized the degree of soil pollution: more than 128 indicates extreme pollution, 32–128 indicates dangerous pollution, 16–32 indicates moderately dangerous pollution, and less than 16 indicates permissible pollution (Metodicheskie ukazaniya, 1987[5]; Saet et al., 1990).

Plant research

In the studied areas, woody vegetation is represented by *Betula pendula* Roth, *Populus tremula* L., *Tilia cordata* Mill., and *Acer negundo* L. in various combinations. The hanging birch *B. pendula* were chosen for the study, as it grew in all areas. For the study, 10 medium-aged trees without signs of phytophagous damage were used. At the end of the growing season (August) 2023, 10 leaves were collected from each tree; the selection was carried out from the lower branches at a height of 1.5–5 m, evenly from all sides. Subsequently, the coefficient of fluctuating asymmetry[6] and the accumulation of metals in the biomass during the growing season were determined for the leaves using atomic absorption spectrometry[7]. Before atomic absorption spectrometry, fresh biological samples were washed with distilled water to remove aerogenic contamination, dried to an air-dry state, homogenized, and subjected to acid decomposition[7]. To clarify the data, sampling from one of the sites was repeated in August 2024.

Bioaccumulation of heavy metals in birch leaves is estimated by the bioaccumulation factor (BAF) (Eid et al., 2021; Guo-hang et al., 2018). It is defined as the ratio of the content of an element in a plant (or its part) to the content of the same element in the soil (growing substrate). If the biological accumulation coefficient is less than 1, it is considered that the plant avoids accumulating the element; if it is greater than 1, the plant is classified as an accumulator (Baker, 1981).

Mathematical processing of results

The obtained data were checked for normality using the Shapiro-Wilk test in the freely available R program. Subsequently, the results were presented as the mean value and their standard deviation. The significance of differences between the indicators at different sites was determined using a one-way analysis of variance ($p = 0.05$). The relationship between the various indicators was determined using the Pearson correlation coefficient (r).

Results

Characteristics of the soil in the green areas of the city of Kirov

The most of the studied areas were characterized by slightly acidic and acidic soil reactions. In terms of the degree of organic matter accumulation, the soils were classified as medium-humus (Soil Science, 1988) (Fig. 2).

For most green areas in the city of Kirov, the situation regarding metal accumulation in the soil can be described as favorable. Cadmium (hazard class I) is found in the soil in minimal quantities, amounting to less than 8 % of the established standard[8].

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[5] Methodological guidelines for assessing the degree of hazard posed by soil contamination with chemicals No. 4266-87, 1987. Ministry of Health of the USSR, Moscow, USSR, 23 p.

[6] Methodological recommendations for assessing the quality of the environment based on the condition of living organisms (assessment of the stability of the development of living organisms based on the level of asymmetry of morphological structures), 2003. Order of the Ministry of Natural Resources No. 460-r dated 16.10.2003. Ministry of Natural Resources, Moscow, Russia, 24 p.

[7] Methodological guidelines for determining heavy metals in soils of agricultural land and crop production, 1992. Central Research Institute of Agrochemical Services for Agriculture, Moscow, Russia, 61 p.

[8] SanPiN 1.2.3685-21. Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans.

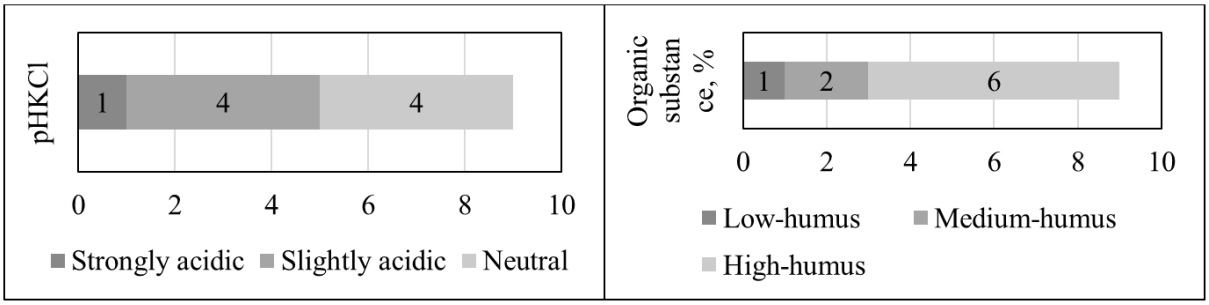

Fig. 2. Distribution of the number of soil samples by pH and organic matter content. Deviations from the mean in pH measurements were no more than 5% (n = 3), and in determining the concentration of organic matter, they were no more than 2% (n = 2).

The concentration of lead (hazard class I) in the soil is above the standard only in one area (Poroshino, by 2.7 times). Its accumulation in the transport zone and one of the areas of the recreational zone (the “Komintern” district) exceeds 0.5 MPC (Fig. 3**A**). The regional background levels for Pb are stricter than federal standards, so the critical line is exceeded in the specified areas (Fig. 3**B**).

The concentration of zinc (hazard class II) at all sites was ≥ 0.5 MPC; an excess of the standard was detected only in the transport zone and one recreational site (Alexandrovsky Park, 3.9 times higher). A comparison of the data with the average regional level indicates a process of Zn accumulation in urban soils: at most sites, the indicator is above 1, except for residential areas located away from the city centre (Iskry St. and Malaya Subbotikha district).

For copper (hazard class III), the situation is characterized by the fact that the average regional level of its content in the soil exceeds the federal standard by 1.4 times. The concentrations of total forms of Cu in the soil of the city of Kirov are quite high. In the transport zone, in all recreational areas, and in two out of four areas of the residential zone (the “Komintern” and “Solnechny Bereg” districts), the indicator has reached or exceeded the permissible limit (from 1.2 to 2.3 times). At the same time, due to the high regional background level, copper contamination was recorded only in two areas (Alexandrovsky Park and Lepse St.). The maximum excess of the background level is observed in the transport zone (1.7 times higher).

The mechanisms of action of many heavy metals are similar: deactivation of enzyme proteins, in particular due to the blocking of sulfhydryl groups (SH), and replacement of macroelements in cell structures (Caito et al., 2014). This explains the assessment of the toxic load on the soil using the TPI index, also known as Zc (Fig. 4).

According to the Methodological Guidelines (1987)[9], all sites are characterized by permissible pollution, as the TPI was less than 16. Interestingly, the maximum total pollution indices were identified for two areas with recreational functions. Pb and Cu (Poroshino), Cu and Zn (Alexandrovsky Park) made a significant contribution to the high TPI.

An important characteristic of any soils is the degree of metal mobility. Figure 5 shows these indicators for Cd, Pb, Cu, and Zn. Copper, which is characterized by a high background content in the region’s soil, is characterized by a minimal proportion of mobile forms (from 0.04 to 1.1). For the majority of the samples, the metal mobility was recorded as no more than 20%. Only for Zn in Alexandrovsky Park, Malaya Subbotikha district, and Lepse Street, the value was 28%, 27%, and 58%, respectively.

[9] Methodological guidelines for assessing the degree of hazard posed by soil contamination with chemicals No. 4266-87, 1987. Ministry of Health of the USSR, Moscow, USSR, 23 p.

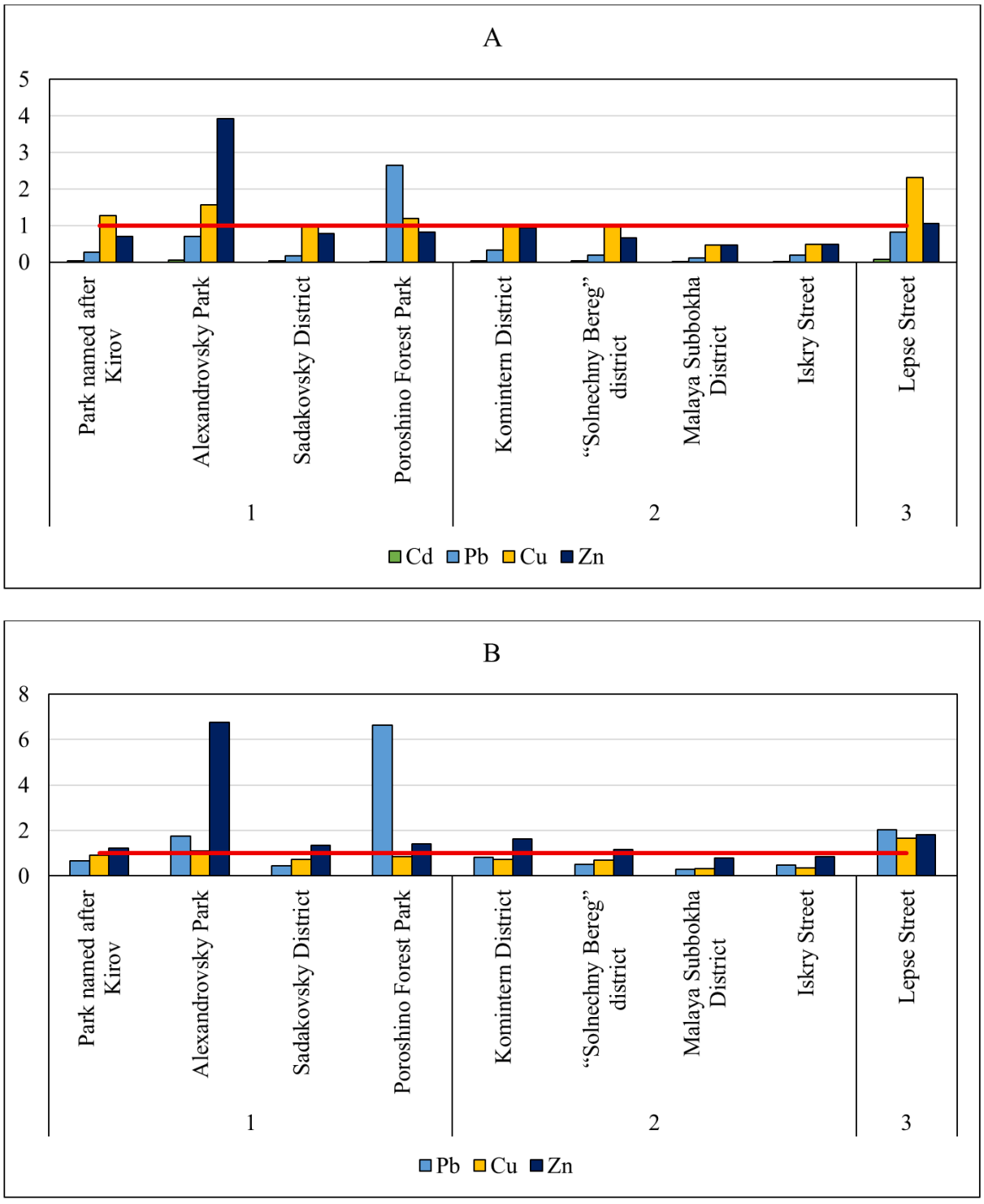

Fig. 3. The ratio of the content of total forms of heavy metals to the MPC level (**A**) and the regional background (**B**). The red line indicates the levels of exceeding the MPC. According to SanPin 1.2.3685-21, MPC for metals: Cd – 5 mg/kg, Pb – 30 mg/kg, Cu – 20 mg/kg, Zn – 100 mg/kg; regional background for Pb – 12 mg/kg, Cu – 28 mg/kg, Zn – 58 mg/kg, no regional background has been established for Cd. 1 – Recreation area, 2 – Residential area, 3 – Transport zone.

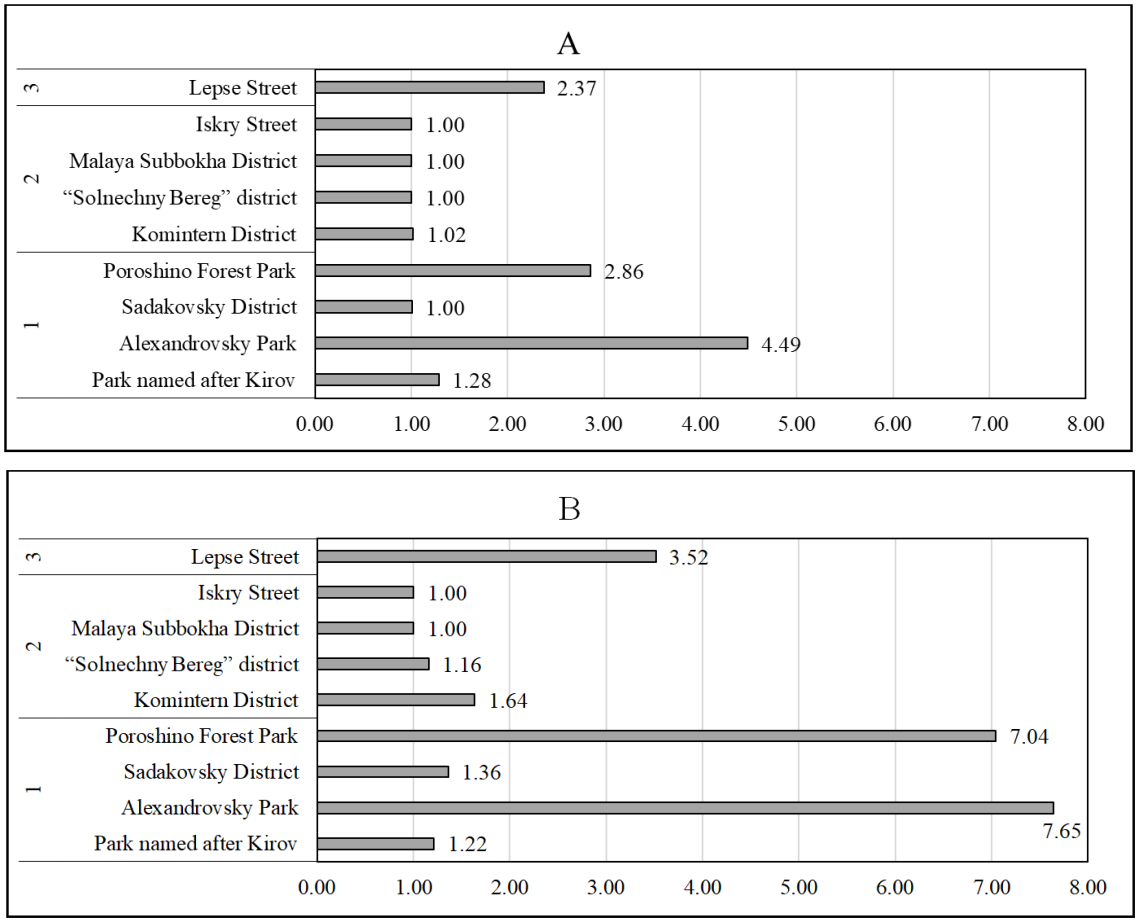

Fig. 4. Total indicator of heavy metals soil contamination compared to MPC (**A**) and regional background level (**B**). 1 – Recreation area, 2 – Residential area, 3 – Transport zone.

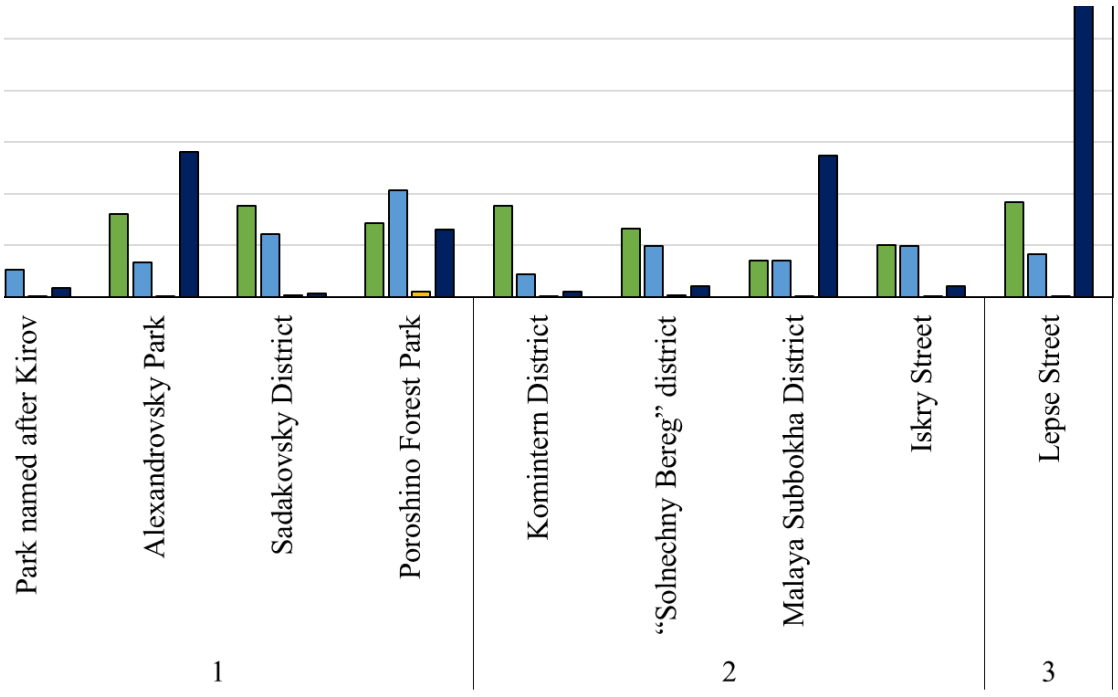

Fig. 5. Heavy metals mobility in the soil of the studied sites. 1 – Recreation area, 2 – Residential area, 3 – Transport zone.

Accumulation of metals by birch leaves

The bioaccumulation of elements reflects the intensity of the processes of their migration from the substrate into plant tissues (Pachura et al., 2015). The higher the metal content in the soil, the higher the concentration of the element observed in plant tissues. There are specific features of plants both in the accumulation of elements and in the avoidance of some of them (Berezin and Olkova, 2024).

The BAF for the five metals of the study area is shown in Fig. 6. The accumulation of zinc was the most significant: the maximum BAF reached 4.63 (transport zone, Lepse St.) and 10.21 (recreational zone, the park named after Kirov). The detected concentrations of Zn made us doubt the results of the analysis. Therefore, in the next field season (2024), a repeat sampling of leaves was carried out in the park on Lepse Street. The samples were sent to the Analytical Certification Testing Center of the Federal State Budgetary Institution of Science Institute for Microelectronics Technology and Ultra-Pure Materials of the Russian Academy of Sciences (Russia, Chernogolovka), where they were analyzed using the atomic emission method. The Zn content in birch leaves was found to be 220 mg/kg (in 2023, it was 489 mg/kg). Consequently, the order of Zn concentrations determined by atomic absorption and atomic emission methods coincided.

Such excessive accumulation of Zn was not widespread. In other areas, values above the critical level of one were found, but they did not exceed 1.4 (Poroshino forest park).

The birch leaves accumulated other metals weakly, with some exceptions related not to the metal itself but to the specific area. For example, in the “Komintern” district area, the cadmium BAF reached 1.1.

Fluctuating asymmetry of the leaves of the silver birch

The asymmetry of the leaves of *B. pendula*, which grows in the urban area, varied in different areas from 0.040 to 0.060, which corresponded to almost all groups of plant development disorders (Fig. 7).

Two sections of the recreational area of the city (Poroshino and the park named after Kirov) were characterized by a significant deviation from the norm. Another one of them (Alexandrovsky Park) was in critical condition according to the bioindication indicator. No leaf asymmetry above the critical level (0.054) was found among the residential areas. However, two of the four sites (Komintern district and St. Sparks) had significant deviations from the standard.

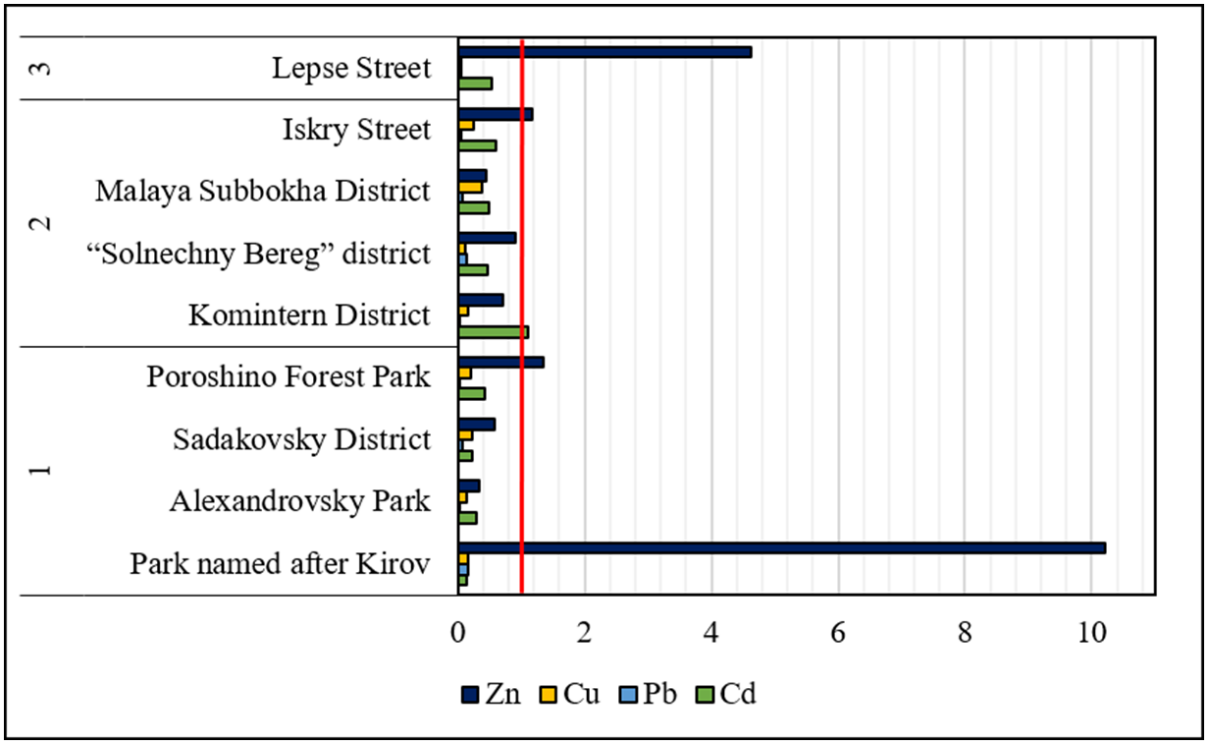

Fig. 6. Bioaccumulation factor (BAF) of heavy metals in B. pendula leaves at the study sites. The red line indicates the level equal to 1. 1 – Recreation area, 2 – Residential area, 3 – Transport zone.

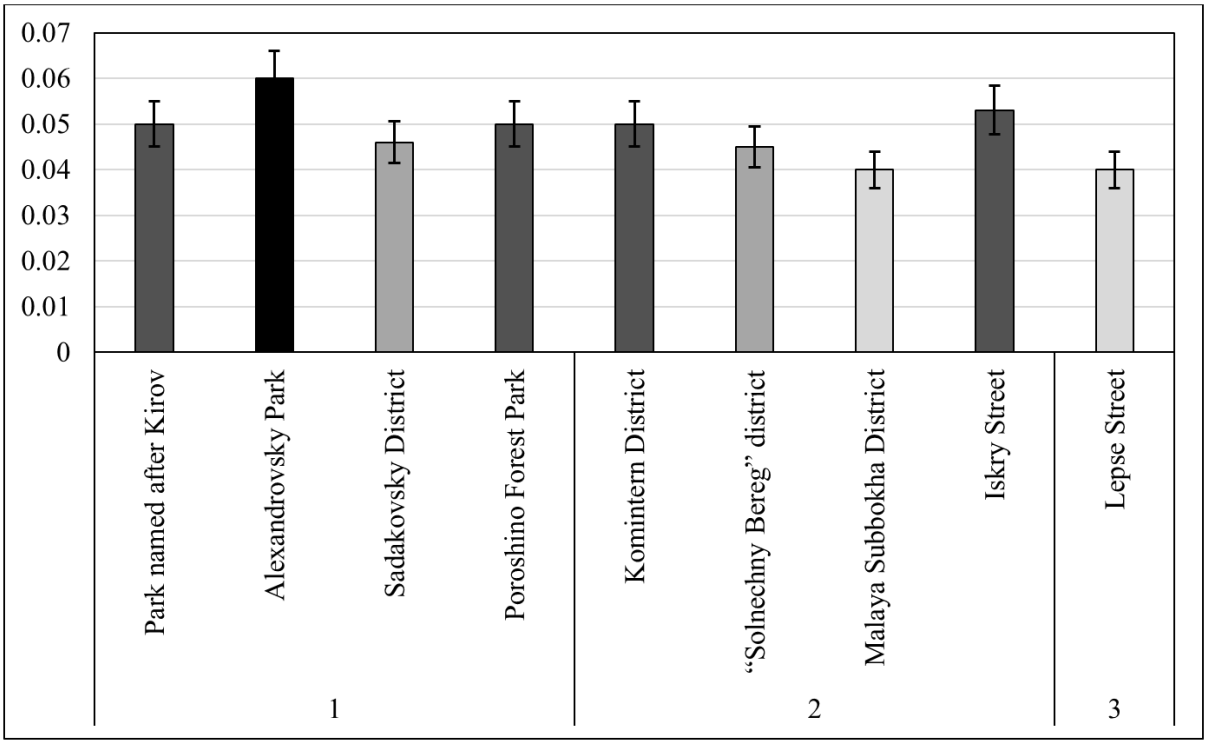

Fig. 7. Coefficients of fluctuating asymmetry of *B. pendula*. The deviations from the norm of development according to V.M. Zakharov (2000) are indicated by shades of gray: light gray – initial deviations from the norm (0.040–0.044), gray – average level of deviations from the norm (0.045–0.049), dark gray – significant deviations from the norm (0.050–0.054), black – critical condition (FA > 0.054). 1 – Recreation area, 2 – Residential area, 3 – Transport zone.

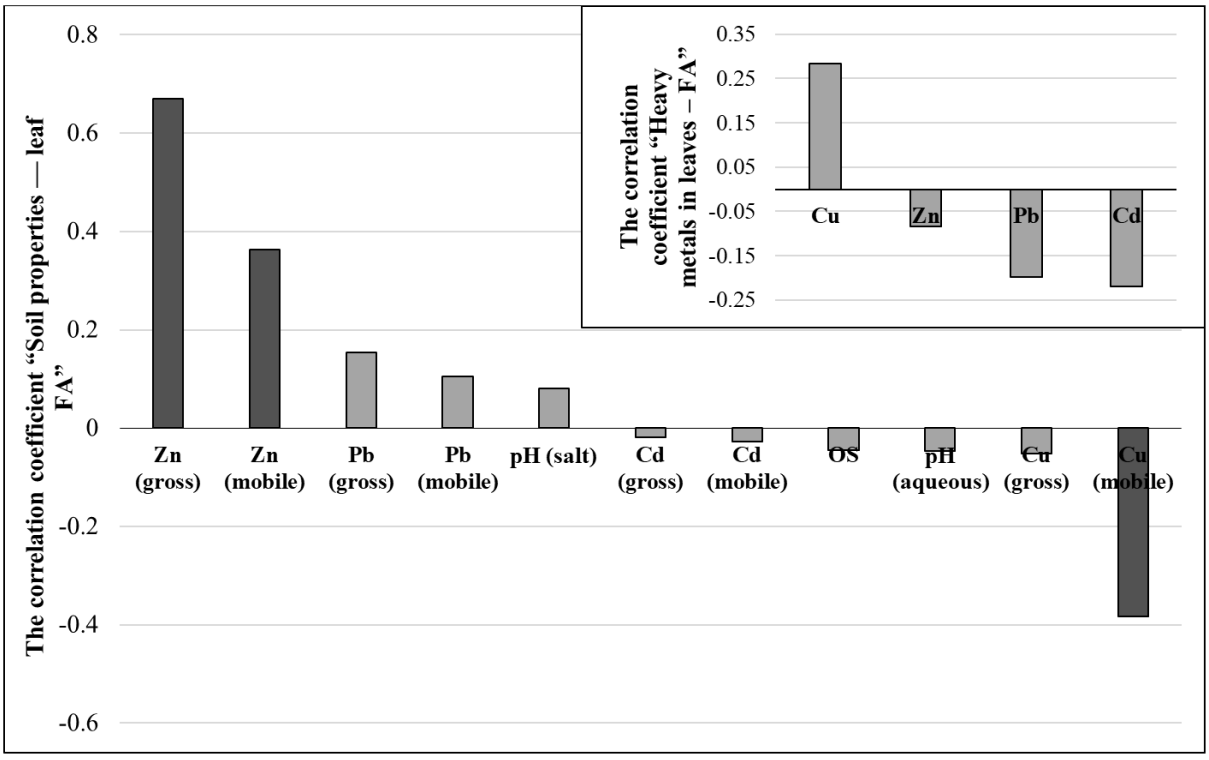

Fig. 8. The relationship between soil characteristics and the bioindication response of *B. pendula*. Shades of gray indicate the levels of correlation: dark gray – moderate level of correlation (0.3 < r < 0.7), light gray – weak level of association (< 0.3). Kk – correlation coefficient.

Correlation between soil characteristics and metal content in leaves, and leaf asymmetry

The results of determining the relationship between fluctuating asymmetry (FA) of birch leaves and various soil parameters and metal accumulation in the leaves are shown in Fig. 8. The content of Zn and Pb forms, as well as the pH level of the salt extract, have a direct correlation with the FA of birch leaves; the Cu forms, the pH of the water extract, and the content of organic matter have an inverse correlation. The total and mobile forms of Cd did not have a significant correlation with the FA of birch leaves. The bioindication indicator was most strongly correlated with the Zn content in the soil, and the level of correlation with the concentration of gross zinc forms was higher than with the mobile form. This is explained by the fact that in the rhizosphere, the proportion of bioavailable forms of elements can increase due to root exudates and the activity of specific microbial communities (Legrand et al., 2005).

The data obtained show that a decrease in FA (i.e., stabilization of leaf development) was observed in response to an increase in the content of mobile Cu. This is due to the essential effects of this metal. Unlike zinc, the copper content in most areas did not exceed the regional background level.

The accumulation of metals in the leaves had little effect on the formation of their asymmetry. A weak positive relationship has been shown for copper. This is explained by the fact that copper is an essential element for which the plant has mechanisms for its active accumulation. When the element is supplied in excess, toxic properties begin to manifest. A weak negative correlation has been shown for lead, cadmium, and zinc. This is explained by the fact that the critical level of accumulation of this bioindicator substance in the leaves has not yet been reached.

The content of Cd, Pb, Cu, and Zn metals in the soil, even within the established standards, affects leaf development to a greater extent than their accumulation in leaf biomass during the growing season.

Discussion

When assessing the concentrations of cadmium, lead, copper, and zinc in the soils of the green areas of the city of Kirov, it was shown that the maximum accumulation of metals is characteristic of a public garden located in the transport zone. In this area, the concentrations of total forms of Pb, Cu, and Zn exceeded federal standards, while Pb and Zn exceeded the regional background level. The city's recreational areas were characterized by isolated exceedances of the standards for one or two metals. This is likely due to the location of some of the areas in the city center. One of the oldest green spaces in the city, the Alexander Garden, has a high overall pollution level when compared to federal standards (4.5) and to the regional background (7.7). These values are not critical and fall within the permissible level of pollution[10]. The compared to the 2016 study (Olkova et al., 2016), the total pollution index has decreased by almost half. The green spaces in residential areas and peripheral recreational zones are not contaminated with heavy metals.

The described patterns are characteristic of the spatial distribution of metals in cities. In China, the mass accumulation of eight trace elements (Cu, Ni, Zn, As, Cd, Cr, Hg, and Pb) in soil increased significantly as proximity to large cities increased (Guo et al., 2023). In European cities, exceeding national safety threshold values is most often observed for metals such as Pb, Zn, Cu, Cr, and Ni (Binner et al., 2023).

In terms of mobility, the metals were arranged in the following order: Cu < Pb < Cd < Zn. It is known that an increased degree of metal mobility may indicate its anthropogenic origin (Daukaev et al., 2018). Copper is characterized by an elevated regional background level (Ekologo-geokhimicheskaya karta..., 1996). At the same time, exceeding the standards for zinc and its increased mobility, compared to three other elements, are associated with anthropogenic sources. The metals under analysis are often the leading causes of inorganic soil pollution in cities. In Chile, a study of four cities showed that Cu levels most often exceeded the established norms, followed by Pb and Zn (Vega et al., 2022).

Zinc, which proved to be the most mobile in some areas, accumulated in the leaves to a greater extent than other metals. For Zn, the BAF values are shown to range from 0.45 (on the periphery of the city) to 10.2 (in the center). Such a significant spread indicates local sources of pollution. The city has a non-ferrous metals processing plant and a machine-building plant. Zn concentrations in the soil exceeded the regional background level in most areas. This indicates atmospheric transport of pollution. The absorption of Zn by leaves, especially near industrial facilities, may exceed the amount entering the

[10] Methodological guidelines for assessing the degree of hazard posed by soil contamination with chemicals No. 4266-87, 1987. Ministry of Health of the USSR, Moscow, USSR, 23 p.

plant from the soil (Plekhanova and Obukhov, 1992). Metal ions penetrate the leaf mainly through the stomata or the cuticle (Cakmak et al., 2000; Harris and Taylor, 2001). Correlation analysis did not reveal a relationship between zinc and fluctuating asymmetry of leaves.

Based on the obtained BAF values, the silver birch avoided accumulating Cu, Pb, and Cd. The influence of the content of these elements in the leaves on their development has also not been detected. This is due to the relatively favorable environmental situation in the city of Kirov.

Conclusion

The accumulation and behavior of Zn, Cu, Pb, and Cd in the "soil–plant" system of an urban ecosystem located in the taiga natural zone were studied. The following indicators were analyzed: the ratio of the content of gross forms of heavy metals to the level of permissible daily intake and the regional background, the total indicator of soil pollution, the mobility of elements, the accumulation of Zn, Cu, Pb, and Cd in the leaves of *Betula pendula* birch trees in comparison with phytotoxic levels, and the plant's response to these indicators — fluctuating asymmetry. Using correlation analysis, we identified relationships between the level of leaf asymmetry and the content of total and mobile forms of heavy metals in the soil, the concentration of organic matter, and soil pH, as well as between leaf asymmetry and the content of Zn, Cu, Pb, and Cd in their biomass.

Zn and Pb metals contributed the most to soil pollution compared to Cu and Cd. The mobility of Zn was higher than that of Cd, Pb, and Cu. This was naturally reflected in the maximum positive correlation with the asymmetry of *B. pendula* leaves. At the same time, the degree of association between FA and the concentration of metals in the soil was moderate (with Zn) and weak (with Pb). This is explained by the fact that the content of these metals was within the regulatory limits in most areas. As a result, new patterns in the soil–plant system were demonstrated, using *B. pendula* as an example in the city's green spaces.

The relationship between FA and the total content of metals that dominate in terms of accumulation was found to be more significant than the relationship with the content of their mobile forms. This was observed for Zn and Pb using the example of the city of Kirov. The explanation may be, firstly, that soil samples were taken from the upper genetic horizon, whereas in the underlying horizons the proportion of mobile forms of metals may be different. Secondly, the by-products of rhizosphere microorganisms increase the bioavailability of many trace elements.

The relationship between leaf FA and metals contained within the regulatory limits may be inverse, as demonstrated for the city of Kirov using mobile forms of Cu as an example. Stabilization of leaf development in response to an increase in metal content occurs due to the essential properties of the latter as necessary trace elements.

The influence of Zn, Cu, Pb, and Cd contained in the soil on leaf FA was more pronounced than their content in the leaves themselves. This indicates that the edaphic pathway of metal entry into the plant is more significant than the combined effect of air and soil.

Thus, the asymmetry of the leaves of *B. pendula* is a bioindicator trait that consistently responds to the content of Zn, Cu, Pb, and Cd metals in the soil.

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