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Smart and Sustainable Urban Ecosystems: Challenges and Solutions

Proceedings of Smart and Sustainable Cities 2022

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Preface

This manuscript contains a selection of edited, refereed and revised papers, which were presented at the International Conference "Smart and Sustainable Cities-2022 (SSC-2022)" entitled "Sustainable urban ecosystems: challenges and solutions". This cross- and multi-disciplinary conference was hosted by RUDN University, Moscow, Russia, on 20–22 July 2022. The SSC-2022 continued the series of international events focused on the environmental consequences of urbanization and possible solutions for sustainable development of urban ecosystems: Megacities 2050 conference (2016) and SUITMA 9 congress (2017), Smart and Sustainable Cities conferences (2018 and 2022). Compared to the previous events, the SSC-2022 aimed to strengthen connection between challenges and solutions for sustainable urban development. Recreational load, soil pollution, wildfires and other anthropogenic and environmental risks urban ecosystems are exposed to be discussed in the context of corresponding solutions, such as bioremediation, blue-green infrastructures, landscape planning and nature-based solutions. A particular attention was given to technological solutions, express and non-destructive soil survey methods, remote and proximal sensing, real-time monitoring and Internet of things.

SSC-2022 conference provided a panel for an interdisciplinary discussion between scientific and research community, municipal services, landscape architects and engineers, environmental protection agencies and practitioners in urban management and greenery. We would like to thank more than 150 participants and 80 speakers who contributed with plenary, oral and poster presentations, round tables and excursions. We wish to express our special gratitude to the authors who contributed to these proceedings. The volume contains 23 research papers, which were selected by the scientific committee with the additional help of external expert reviewers from over 50 submissions. The authors were asked to consider the reviewers' comments and have made all necessary edits to improve the quality of the papers. The papers addresses the following main topics: 1) environmental challenges in urban ecosystems: recreational load and over-compaction, wildfires, soil pollution by hydrocarbon and heavy metals in different bioclimatic conditions (from tundra to steppe zones); 2) technologies and solutions, including advances techniques in monitoring biodiversity, carbon and water balance, and other ecosystem services at different spatial and temporal scales, nature-based solutions and landscape planning projects.

The conference was organized under the umbrella of the International Union of Soil Sciences. The organizational and financial support to the SSC-2022 Conference was provided by "RUDN University Strategic Academic Leadership Program". We would like to express our gratitude to the many people who put essential efforts to ensure this successful conference: keynote speakers, members of organizing and scientific committees, conveners of sessions and round tables, reviewers and technical editors.

We believe these proceedings will be valuable and informative for researchers, practitioners and policy-makers, involved in sustainable urban development.

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Wageningen, The Netherlands — Viacheslav Vasenev
Moscow, Russia — Elvira Dovletyarova
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Contents

Chapter 1
Hydrocarbon Content and Enzymatic Activity of Urban Soils in Kola Subarctic

Vladimir Myazin

Abstract The soils of the urbanized territories of the Kola Subarctic have been studied. The content of hydrocarbons in soil samples in various functional zones of Murmansk ranged from 57 to 2287 mg/kg. The maximum content of hydrocarbons was noted near roads with intensive traffic. The average value of hydrocarbon content in the residential zone of Murmansk was 538 ± 95 mg/kg, and in the recreational zone—185 ± 50 mg/kg. The biological activity of the urban soils of Murmansk, determined by the activity of soil enzymes, is at medium and high level, but there is a decrease in the activity of hydrolytic enzymes and an increase in the activity of redox enzymes. As a criterion for assessing the level of pollution, it can use the percentage ratio of hydrocarbons to soil organic carbon. In accordance with the method, 60% of the studied samples from the urban soils of Murmansk can be classified as uncontaminated or lightly polluted, and 40%—polluted and highly polluted.

Keywords Urban soils · Pollution · Hydrocarbons · Enzymatic activity · Subarctic zone

1.1 Introduction

The natural components of the urban environment experience an extremely high degree of anthropogenic and technogenic pressure. One of the priority pollutants in urban environments are oil and products of its processing. Therefore, the urban soils require special attention in the constant influence of transport, industry, construction and combustion of fossil fuels. As a result, in the soils of urban areas, a certain complex of hydrocarbons of various classes is formed, which are in different states of aggregation.

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The constant load on the soil leads to a change in all its components, from agrochemical and physical properties to microbiological and biochemical parameters. Under the anthropogenic impact, microbial diversity, biochemical parameters and biological activity of soils change first.

Many studies have been carried out in various countries aimed at assessing the urban soils, including the determination of the content of hydrocarbons in the soils of urban landscapes (Adeniyi and Owoade 2010; Erofeeva and Anikina 2021; Garcia-Flores et al. 2009; Khalilzade et al. 2020; Nikolaeva et al. 2017; Quiñonez-Plaza et al. 2017) and the activity of soil enzymes (Baranova et al. 2010; Kazimov and Ali 2012; Trifonova and Zabelina 2017). At the same time, there are few similar works carried out in the northern regions (Alekseev et al. 2016; Korneykova et al. 2021; Vishnevaya et al. 2016).

The study of the urban environment of the Kola Subarctic requires special attention, since the northern ecosystems are considered the most vulnerable to technogenic stress and have a low rate of natural self-recovery after damage. The health of people, the well-being and safety of the urban population depends on the state of the biotic components of the soil and soil cover.

The aim of this study was to assess the content of hydrocarbons in the urban soils of the Kola Subarctic (Murmansk) and the enzymatic activity of urban soils.

1.2 Materials and Methods

Sites Description. Soil samples were taken in the residential area of the Murmansk city at 35 sites (in yards and near roads with different traffic intensity). The site № 26 on the western coast of the Kola Bay in the forest-tundra, located at a distance from pollution sources and experiencing minimal anthropogenic load, was the background site (Fig. 1.1).

Sampling. For the study, the top layer of soil was sampling to a depth of 5–7 cm. The organogenic horizons have the maximum sorption capacity and accumulate the largest amount of hydrocarbons. The samples were placed in bags and transported to the laboratory, dried to air-dry state and analyzed.

Analysis Methods. The total petroleum hydrocarbons (TPH) in the soil were determined by IR spectrometry (PND F 16.1:2.2.22-98 1998), based on the extraction of hydrocarbons with carbon tetrachloride, purification of the extract on an aluminum oxide column and subsequent determination of the concentration of hydrocarbons in the eluate using an AN-2 analyzer "Neftekhimavtomatika".

The content of organic carbon in the soil (SOC) was determined by the Nikitin's method with a colorimetric ending according to Orlov-Grindel (Mineev 2001).

The activity of soil dehydrogenase was determined by a colorimetric method based on the reduction of the colorless salt of 2,3,5-triphenyltetrazolium chloride to red triphenylformazan; phosphatase activity—colorimetrically by the Dubovenko

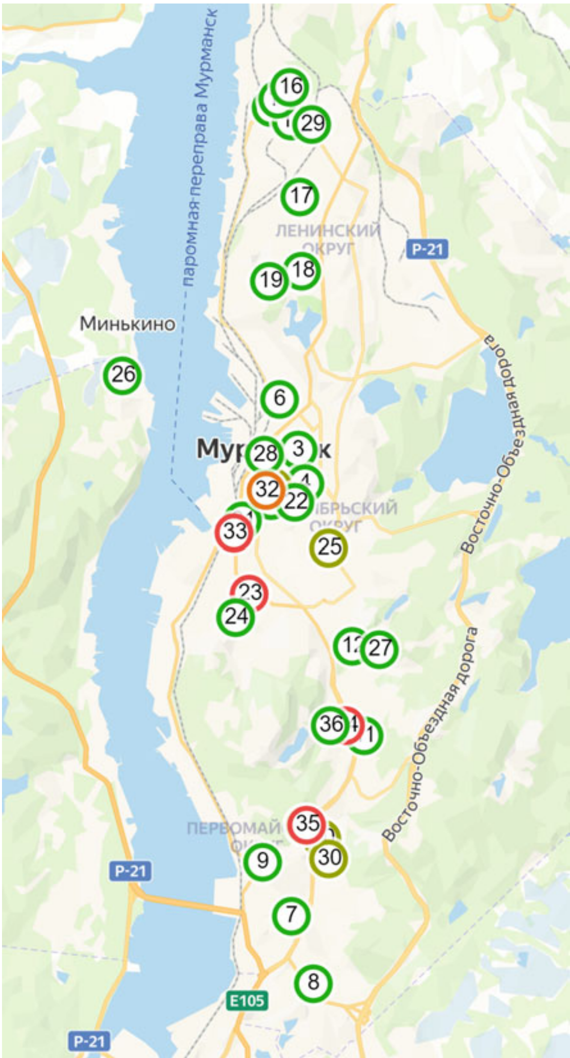

Fig. 1.1 Map of sampling sites in Murmansk

method, using sodium phenolphthalein phosphate as a substrate; urease activity—colorimetrically with Nessler's reagent according to the Shcherbakova method (Mineev 2001).

Statistical Processing. Statistical analysis of the data was carried out using the applied programs Statistica 6.0 and Microsoft Excel 2007. Student's t-test was used to determine the reliability of the coefficients. Pearson's method (significance level 0.05) was used to calculate the correlation coefficient (*r*).

1.3 Results and Discussion

Hydrocarbon Content. The content of TPH in soil samples at different sites ranged from 57 to 2287 mg/kg. The average value of TPH content in the residential area of Murmansk is 538 ± 95 mg/kg (median value is 302 mg/kg), in the recreation area—185 ± 50 mg/kg. The minimum content of TPH is typical for the residential area of the Leninsky district (256 ± 32 mg/kg), the maximum for the Oktyabrsky (661 ± 195 mg/kg) and Pervomaisky (605 ± 200 mg/kg) districts, which is due to more intensive traffic and the presence thermal power facilities. The maximum content of TPH was noted near the roads with heavy traffic. According to Murmanskstat in the Murmansk region in 2019, the amount of hydrocarbon emissions from stationary sources was 8.7 thous. tons, volatile organic compounds—3.2 thous. tons. At the same time, the proportion of unsatisfactory samples exceeding the MPC on roads in the residential area in 2020 was 0.93 (Report on the state and environmental protection of the Murmansk region in 2020 2021).

The results are consistent with the other studies of urban soils carried out in various regions. The average and background concentrations of TPH in Moscow in 2007 were 689 and 308 mg/kg, respectively, and near the road, it reached 7281 mg/kg (Nikolaeva et al. 2017). Other studies have shown that the average content of TPH in the soils of Moscow ranged from 40 to 588 mg/kg with increases up to 876–1144 mg/kg (Erofeeva and Anikina 2021; Yuzefovich and Kosheleva 2009). In the administrative building sector in Samara, the average content of TPH was 732.9 mg/kg, maximum—1605.7 mg/kg (Vorobieva and Prokhorova 2017). The average content of TPH in the soils of the coastal zones of small rivers in Khabarovsk ranged from 11.3 to 366.6 mg/kg, but in some areas, it reached 1925 mg/kg (Koshelkov and Matyushkina 2018). The soils of Krasnoyarsk content of TPH in the range of 100–500 mg/kg, which corresponds to the level of increased background. The average concentrations of TPH in the soils of the recreational and residential zones were 110 and 125 mg/kg, respectively, and in the soils of the industrial zone, they reached moderate (1180 mg/kg) and dangerous levels (2300 mg/kg) (Sharafutdinov et al. 2018). The content of TPH within the largest urban systems of the Saratov region ranged from 248 to 1127 mg/kg (Larionov and Larionov 2009).

For the northern regions, the content of TPH in the soil is within the same limits. In the soil samples of most settlements of the Yamalo-Nenets Autonomous Okrug, the content of TPH was up to 70 mg/kg. However, higher concentrations (up to 1100 mg/kg) were also noted (Alekseev et al. 2016). The average content of TPH in the soils of Arkhangelsk ranges from 466.20 to 1342.2 mg/kg, reaching 4788 mg/kg (Vishnevaya et al. 2016).

The higher TPH content in the roadside areas of Murmansk is also consistent with results obtained in other studies. The degree of contamination of the soil with TPH in the city of Sumgayit (Azerbaijan) depended on the functional zone: the content of TPH in the roadside soils is on average 2.8 times higher compared to the park soils (Khalilzade et al. 2020). The concentration of TPH in the roadside soil of the city of Tijuana (Mexico) was 608 mg/kg, in road dust, it was 7 times higher—4105 mg/

kg (from 1186 to 9982 mg/kg). The highest concentrations of TPH were found in residential and commercial areas with heavy bus, taxi and truck traffic. Nearly all asphalt roads showed higher TPH concentrations compared to concrete roads. At the same time, the ANOVA test showed that there is no significant difference between TPH concentrations and traffic intensity (Garcia-Flores et al. 2009). The content of TPH in the roadside soils of various functional areas of Ibadan City (Nigeria) ranges from 167 to 923 mg/kg (Onianwa 1995). The content of TPH in the roadside soil in Lagos, Nigeria, was 40 times higher than the average values in the background soil of this region, and in the area of the bus stop, the TPH content reached 16,110 mg/kg (Adeniyi and Owoade 2010).

Soil Enzyme Activity. The urban soils of Murmansk are characterized by a decrease in the activity of hydrolytic enzymes (urease, phosphatase) and an increase in the activity of redox enzymes (dehydrogenase). The activity of urease involved in nitrogen metabolism was 29.39 ± 12.06 mg NH_4/10 g in urban soils and 132.45 ± 72.26 mg NH_4/10 g in the background soil. The activity of phosphatase, which carries out the biological mobilization of organic phosphorus, was 6.16 ± 0.52 mg P_2O_5/10 g and 17.40 ± 4.01 mg P_2O_5/10 g in urban and background soils, respectively. The activity of dehydrogenase, which is an indicator of the intensity of microbiological decomposition of substances, was almost 2 times higher in urban soils (0.72 ± 0.28 mg TPP/10 g) than in the soil of the background plot (0.40 ± 0.29 mg TPP/10 g) however, this difference statistically not reliable.

A decrease in the activity of hydrolytic enzymes in urban soils was shown earlier in the study of soils in the city of Apatity in the Murmansk region (Korneykova et al. 2021), as well as in other regions (Baranova et al. 2010; Kazimov and Ali 2012). An increase in dehydrogenase activity can be caused by a rearrangement of the soil microbiota community, an increase in the number and proportion of bacteria in soil microorganisms (Korneykova et al. 2021). This can be considered as an adaptive response of the soil to anthropogenic influence, pollution neutralization and self-purification (Trifonova and Zabelina 2017).

Correlation analysis did not show any relationship between the activity of the studied enzymes and the content of TPH in the soil. At the same time, significant correlations were established between the content of organic carbon and the activity of urease ($r = 0.64$, $t = 5.03$; d$f = 34$, $p = 0.05$) and phosphatase ($r = 0.84$, $t = 9, 30$; d$f = 34$, $p = 0.05$).

Thus, in the urban soils of Murmansk, there was a tendency to increase the activity of redox enzymes and a significant decrease in the activity of hydrolytic enzymes, which is a soil response to anthropogenic impact in general. The activity of enzymes is largely determined by the content of organic carbon, pH value, the number and composition of microorganisms and not by the detected content of hydrocarbons. According to the scale for the comparative assessment of the biological activity of soils based on the activity of enzymes, the background soils are classified as very high biological activity soils (according to the activity of hydrolytic enzymes), and urban soils are classified as medium and high biological activity soils.

Assessing the Degree of Hydrocarbon Pollution. The assessment of the soil pollution level with oil products is very difficult due to the lack of approved standards. At present, the standards for the TPH content have been developed for individual regions, and the Murmansk region is not one of them. For example, the regional standards for the TPH content in soils of residential areas in the Samara region and Saint Petersburg are no more than 180 mg/kg of soil (Regional standard for soil protection in St. Petersburg 1994; Vorobieva and Prokhorova 2017). In accordance with the scale developed for the city of Arkhangelsk, soils with the TPH content of less than 5 mg/kg are uncontaminated, from 5 to 100 mg/kg are slightly polluted, from 101 to 500 mg/kg are moderately polluted and more than 500 mg/kg are heavily polluted (Vishnevaya and Popova 2016; Vishnevaya et al. 2016). These are rather low MPC standards in comparison with other regions and countries. For example, the MPCs for hydrocarbons in soils set by Mexican law are 3000 mg/kg for residential areas and 6000 mg/kg for industrial and commercial areas; with mixed land use MPC is 3000 mg/kg (Quiñonez-Plaza et al. 2017).

Using these regulatory documents, it is difficult to assess the level of hydrocarbon pollution, since any soil contains compounds defined as of hydrocarbon, which are its natural components. For example, the content of hydrocarbons at the background site near Murmansk is 540 mg/kg, which is higher than these standards. Therefore, the content of TPH in the soil must have a regional standard, which takes into account the characteristics of soil types and the presence of specific and non-specific organic compounds in it. Determination of TPH in uncontaminated soil, along with the studied one, should be mandatory (Okolelova et al. 2019).

To assess the effect of biogenic hydrocarbons on the content of TPH and to more objectively interpret the results, it is necessary to take into account the content of organic carbon in the soil. As a criterion for assessing the level of pollution, it can use the percentage ratio of the amount of TPH to the amount of soil organic carbon:

$$(\mathrm{TPH}/\mathrm{SOC}) \times 100, \tag{1.1}$$

where TPH is the content of hydrocarbons in the soil, mg/kg, SOC is the content of organic carbon in the soil, mg/kg.

An analysis of the TPH content and organic carbon in the soils of Murmansk showed that in the background soil in the forest-tundra area, this ratio is 0.12–0.27, and in urban soils, it reaches 6.62. Based on this criterion, it can evaluate the level of soil pollution in the city of Murmansk with hydrocarbons on the following scale: uncontaminated—0–0.3; lightly polluted—0.3–1; polluted—1–3; highly polluted—more than 3.

According to this method, 60% of the studied samples from the urban soils of Murmansk can be classified as uncontaminated or lightly polluted, and 40%—as polluted and highly polluted (Table 1.1).

Table 1.1 Content of TPH and the level of soil pollution in various functional zones of Murmansk

Functional zone	Content of organic carbon, %	Content of TPH, mg/kg	Ratio (TPH/SOC), %	Pollution level
Recreation zone	12.5–16.8	135–235	0.11–0.14	Uncontaminated
Residential zone	0.6–29.3	57–1037	0.18–2.95	Uncontaminated, lightly polluted, polluted
Roadside zone	2.6–8.1	723–2287	1.08–6.62	Polluted and highly polluted
Background in the forest-tundra	27.5	540	0.20	Uncontaminated

1.4 Conclusion

This study made it possible to determine the amount of hydrocarbons in urban soils in various areas of Murmansk and to assess their degree of pollution. A method for assessing the degree of contamination of urban soils with hydrocarbons is proposed, taking into account the content of organic carbon in the soil, which makes it possible to more objectively assess the degree of contamination. In accordance with the method, 60% of the studied samples from the urban soils of Murmansk can be classified as uncontaminated or lightly polluted, and 40%—polluted and highly polluted. The most polluted soils are located near roads and in areas with a high concentration of industrial enterprises, including thermal power facilities. At the same time, there are highly polluted areas in the yards of residential buildings also. A high degree of pollution is determined by hydrocarbon emissions as a result of fuel combustion, leakage of oil products in case of vehicle malfunctions, settling of solid particles of aerotechnogenic emissions from industrial enterprises, asphalt and rubber particles from the roadway.

The biological activity of the urban soils of Murmansk, determined by the activity of soil enzymes, is at a medium and high level, but there is a decrease in the activity of hydrolytic enzymes and an increase in the activity of redox enzymes. This indicates the processes of restructuring the community of soil microorganisms as a response to anthropogenic impact. In general, urban soils in the residential and recreational areas of Murmansk are characterized by a low level of hydrocarbon pollution and a relatively high biological activity.

An assessment of the degree of pollution of urban soils with hydrocarbons, taking into account the content of organic carbon and the biological activity, provides more objective results about the state of urban ecosystems. It will make possible to determine the direction and rate of transformation of disturbed ecosystems and the possibility of their restoration.

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Chapter 2
Acute and Chronic Phytotoxicity of Subarctic Urban Soils and Industrial Wastes

Irina Mosendz, Marina Slukovskaya, Anna Shirokaya, Svetlana Drogobuzhskaya, Liubov' Ivanova, and Irina Kremenetskaya

Abstract Soil degradation is a combination of natural and anthropogenic processes that lead to changes in soil functions, quantitative and/or qualitative deterioration of composition and properties, and a decrease in the natural and economic significance of lands. The state of the soil cover in Russia is far from satisfactory, and in some areas even critical. The Murmansk region is highly industrialized and urbanized region in the Arctic zone. We have tested the acute and chronic phytotoxicity of various industrial materials (expanded vermiculite, nepheline waste and quartz waste), urban and suburban soils of industrial, traffic and recreational zones, soil of urban farm, and conditionally background soil. The water-soluble, plant available, and acid-soluble metal fractions were analyzed. To assess the acute toxicity of industrial wastes, pre-grown hydroponic lawns from *Lolium* spp. were used, and the duration of the experiment was 7 days. The chronic toxicity was assessed using marigolds (*Tagetes* spp.), after 28 and 60 days. The highest level of metals was found in soils of the suburban zone near the plant of nonferrous metallurgy and in the traffic zones, but it was revealed that the presence of nutrient elements in high concentrations can partly neutralize the toxic effect of these soils. Phytotesting showed that the weak

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acceleration of roots to the substrate after 3–7 days of exposition is the express indicator of the presence of high concentrations of toxic metals in the substrates and an unfavorable pH level. Thus, we propose the following low-cost algorithm for the rapid field assessment of soil phytotoxicity in the Subarctic: testing of acute phytotoxicity using hydroponic lawns; testing of chronic phytotoxicity using marigolds in case when acute phytotoxicity is absent; the chemical analysis of mobile fractions of heavy metals and nutrients only for soils which revealed the toxic effect to develop the recommendations for improving soil quality or to make decision about their replacing.

Keywords Lawn · Marigold · Phytotoxicity · Urban soil · Industrial waste · Subarctic

2.1 Introduction

Various pollutants are released into the environment in large quantities. Industrial activity, poor agricultural practices and urbanization accelerate environmental pollution. Soil pollution is currently attracting considerable public attention as the problem is growing rapidly, especially in highly industrialized regions of the World. Heavy metals are among the most hazardous substances in the soil environment due to their high persistence and toxicity to biota. In soil, heavy metals tend to be strongly adsorbed to the soil matrix and, unlike organic pollutants, are not degraded by microorganisms or by chemical oxidation. The accumulation of heavy metals in the soil can reduce crop yields, cause disease, affect food security and impede sustainable development (Minisha et al. 2021).

Remediation of sites contaminated with heavy metals using chemical or physical methods is a complex task. Phytoremediation is a “low-tech, high-efficiency” purification method that can be used as an alternative to expensive methods. Numerous studies have been carried out aimed at developing an effective and economical way to restore soils contaminated with heavy metals (Alkorta et al. 2004; Erakhrumen 2007). However, in the conditions of polar latitudes, the accumulation of biomass during the year is slow and extremely uneven, which significantly affects the efficiency of such technologies. There are environmental-friendly technologies for the remediation of soil objects using mining waste, the products of which have an acid-neutralizing ability and sorption properties (Slukovskaya et al. 2018). This technology has been tested on the territory of the Subarctic in the impact zone of a copper–nickel plant, but mining wastes have various composition and should be tested before the use in remediation.

Environmental hazard assessment of soils and industrial substrates could be carried out by quantitative methods based on comparing the physicochemical composition with the permissible content of pollutants, and by qualitative assessment accounting the reaction of organisms in biotesting. Physicochemical approach cannot provide a comprehensive assessment of soil toxicity due to the antagonistic or synergistic action of different chemical elements and also has such limitations as costs and labor.

Biotesting methods are based on the organism response to the negative impact of pollutants, and they can provide reliable information about the quality of the substrate (Timofeeva 2011). One of the biotesting methods determines the acute and chronic toxicity of controlled objects for plant organisms. The toxicity criterion is a reliable quantitative change in parameters of testing organisms, based on which a conclusion about the soil toxicity is made.

Phytotesting in an express laboratory version (seed germination in contact with an aqueous soil extract or soil in a humid chamber), carried out in a short period (4–5 days), is known as acute phytotoxicity (Blok et al. 2008), when a longer vegetation experiment (3–6 weeks) in known as chronic phytotoxicity (GOST R ISO 2010).

One suitable plant organism for assessing the degree of toxicity may be the genus *Tagetes* L. (*Asteraceae*) or marigold which is an annual plant 20–30 cm high and widely distributed throughout the World (Politi et al. 2016). The reproduction rate of marigolds is high, the life cycle is short, growth is fast and the root system is well developed (Chatterjee et al. 2012; Goswami and Das 2017; Chintakovid et al. 2008; Sathya et al. 2020). *Tagetes* L. is very popular due to its ease of cultivation and wide adaptability, including poor soils (Coelho et al. 2017). Marigolds show rapid phytoextraction of heavy metals from the soil during their initial growth phase (Choudhury et al. 2016). *Lolium multiflorum* L. was used to assess acute phytotoxicity. The plant is one of the valuable grass species for fast creation of plant communities due to its rapid growth and high biomass, which is necessary for phytoremediation of contaminated areas in harsh climatic conditions (Slukovskaya et al. 2018). Biological reclamation of disturbed areas and industrial dumps, as well as greening of urban spaces in the Subarctic climatic conditions, often requires quick decision-making on the choice of an action strategy and, in particular, such parameters as the composition of soil constructions and plant assortment. In this regard, the purpose of the work was to substantiate the method of field phytotesting of acute and chronic toxicity of urban soils and mining wastes with varying degrees of pollution, applicable in the Subarctic zone.

2.2 Materials and Methods

2.2.1 Characteristics of Industrial Wastes and Urban Soils

Samples were collected from the depth 0–15 cm from different land-use zones in the Murmansk region, Russia (NE Europe).

2.2.1.1 Industrial Zone

Tested substrates were sampled from the depositions of different mining wastes.

Expanded vermiculite (**IV**) (LLC Kovdorlyuda, Kovdor) with a particle size of 1–2 mm was obtained from the vermiculite concentrate of the Kovdor deposit by firing at 500–550 °C in an electric modular trigger furnace designed by Nizhegorodov (Kremenetskaya et al. 2020). The initial sample was a typical vermiculite for the Kovdor deposit with a noticeable admixture of phlogopite. Vermiculite chemical composition (wt%): SiO_2 (30.9), MgO (27.0), Al_2O_3 (9.6), Fe_2O_3 (5.3), CaO (4.0), Na_2O (3.3), K_2O (0.9), C (0.5), H_2O (7.7). The acidity of the water extract was 8.97.

Quartz waste (**IQ**) (JSC Olkon, Olenegorsk) was formed during the processing of ferruginous quartzites, and the production of iron ore concentrate (Suvorova et al. 2012). After the enrichment of iron ores, fine-grained waste was formed, millions of tons of which were annually deposited into the tailings. The annual mass of waste disposal is 53936401 tons/year. Chemical composition (wt%): SiO_2 (66.8), Fe_2O_3 (19.7), CaO (4.8), Al_2O_3 (4.0), MgO (2.9), K_2O (0.9), Cl (0.25), MnO (0.24), TiO_2 (0.2), S (0.14), P_2O_5 (0.07). The acidity of the water extract was 8.07.

Nepheline waste (**IN**) (LLC Lovozersky Mining and Processing Plant, Revda) was formed after the extraction and processing of loparite ores, followed by the production of a concentrate of rare earth metals, as well as niobium and tantalum. The annual mass of waste disposal is 397413 tons/year. The content of elements in the sample (wt.%): Na (9.08), K (2.98), Ca (0.89), Mg (0.25), Mn (0.18), Al (10.57), Fe (4.4), Sr (0.19). The acidity of the water extract was 8.89.

2.2.1.2 Urban and Suburban Zone

Soils were collected from three industrial cities in Murmansk region, Russia: Monchegorsk, Apatity and Kirovsk.

Soil of industrially polluted zone (degraded podzol) (**PD**) was sampled from the suburban territory near JSC Kola MMC, Monchegorsk. This area is located on the industrial wasteland and is highly polluted. The proportion of element content in the mobile fraction for potentially toxic metals was (%): Cu (58.1), Ni (44.7), Pb (36.4), Fe (26.5), Al (20.2). The acidity of the water extract of the soil was 4.2–4.8, the content of organic carbon-1.3%, the carbon content of humic acids-0.35%, the content of total nitrogen-0.07%, of which 2.5–4.0 mg/kg of nitrate nitrogen and 0.8 mg/kg of ammonium nitrogen (Ivanova et al. 2021).

Soils of traffic zone were sampled from the territory near the administration building of Monchegorsk (**TM**) and a roadside site in Apatity (**TA**) (Saltan et al. 2021). The total composition (wt.%) of the soil in Monchegorsk: Na (4.02), Mg (1.3), Al (8.35), Si (71.3), P (0.4), K (2.13), Ca (2.4), Mn (0.16), Fe (9.7), Co (0.008), Ni (0.08), Cu (0.06), Zn (0.02), Pb (0.004). The acidity of the water extract was 6.78. The composition of the soil sample in Apatity (wt.%)—Na (4.2), Mg (1.5), Al (8.7), Si (68.9), P (0.1), K (3.7), Ca (3.06), Mn (0.13), Fe (8.97), Co (0.008), Ni (0.13), Cu (0.42), Zn (0.1), Pb (0.004). The acidity of the water extract is 6.23.

Soils of recreational zone: Soil sample was taken in the city park of Kirovsk (**RK**). The total composition of the sample (wt.%): Na (4.75), Mg (0.81), Al (13.33), Si (62.1), P (1.1), K (3 0.04), Ca (3.4), Mn (0.14), Fe (11.27), Co (0.003), Ni (0.02), Cu (0.03), Zn (0.02), Pb (0.008). The acidity of the water extract is 5.79.

Soils of urban farming zone: The soil sample was taken from the farm field of the Polar Experimental Station of the Vavilov All-Russian Institute of Plant Genetic Resources (**UF**). The total composition of the sample (wt.%): Na (5.06), Mg (1.14), Al (13.88), Si (60.44), P (0.5), K (2.33), Ca (3.89), Mn (0.15), Fe (12.51), Co (0.003), Ni (0.017), Cu (0.03), Zn (0.014), Pb (0.002). The acidity of the water extract was 6.15.

Soils of background zone: Soils were sampled at the experimental site of the Polar Alpine Botanical Garden-institute (**BG**). The total chemical composition of the sample (wt.%): Na (5.3), Mg (0.97), Al (14.4), Si (61.06), P (0.15), K (4.73), Ca (2.48), Mn (0.17), Fe (10.6), Co (0.003), Ni (0.013), Cu (0.028), Zn (0.02), Pb (0.001). The acidity of the water extract was 5.79.

2.2.2 Phytotoxicity Testing

To test the acute toxicity of samples of industrial wastes, seeds of annual ryegrass (*Lolium multiflorum* L.), manufacturer: Agroprogress, class Izorskii RS-1 were used. Hydroponic carpet lawns were previously grown during 7 days in the 1 cm layer of expanded vermiculite on the plastic tray. After this, turfs were layered on the moistened industrial wastes. Test parameters—assessment of root development and growth to the substrate were evaluated after 7 days of the experiment. The acute phytotoxicity of samples of soils and wastes from industrial zone was assessed using *Lolium multiflorum* L. since this plant was used in the technology of remediation of industrially disturbed areas using mining waste as the dominant species of grass cover and was proven to be resistant to harsh climatic conditions of Arctic and Subarctic (Slukovskaya et al. 2018).

To assess the chronic phytotoxicity of samples, we used erect marigolds (*Tagetes patula* L.), manufacturer: AELITA (GOST 12260-81). *Tagetes* L. is the most common plants used in urban landscaping and they are able to grow and blossom in soils of good quality in the Subarctic. Marigolds were preliminarily germinated on filter paper in Petri dishes for three days before planting in tested samples. The duration of the experiment for the samples of the industrial zone was 28 days of vegetation, for the samples of the urban zone—60 days. The test parameters are the length of aboveground plant organs, water balance and the content of chlorophylls a and b in plant leaves. The experiments were carried out in triplicate, and the results were processed statistically ($p < 0.95$). The content of chlorophyll a, b and water band index (WBI) was determined using a SpectraVue Leaf Spectrometer CI-710 s. WBI is the index used for the assessing of water stress and related to them indicators, i.e., productivity determination, etc.

Phytotesting was carried out in laboratory conditions at air temperature of 20–22 ºC. Plants were grown in a well-ventilated room using both daylight and artificial lighting.

2.2.3 Methods of Soil and Waste Analysis

To determine the pH, 5 g of soil and mineral samples was placed in 50 ml of distilled water, and the pH of the suspensions was measured after 1 h using an Expert-001 pH-meter-ionomer liquid analyzer with an ESL-63-07SR glass laboratory electrode and auxiliary laboratory silver chloride electrode EVL-1M3.1.

The total content of heavy metals (HM) and content of their acid-soluble and water-soluble fractions were analyzed. Total content of metals was determined after autoclave microwave decomposition in the SW4 system in the DAK 100 autoclaves (Berghof, Germany). A mixture of HF and HNO_3 concentrated acids was used to decompose the soil samples. Content of water-soluble fraction (WSF) was determined after treatment of fresh soil (10 g) with deionized water (50 ml), shaking (1 h) and filtering using membrane filter with pore size 0.45 μm. For samples of urban and suburban soils, the content of acid-soluble metal fraction (ASF) was determined after treatment of air-dried soil (1 g) with 0.2 N HCl (50 ml), mixing (1 min), shaking (15 min) and filtering through 'blue ribbon' filter paper with pore size 2–3 μm. For industrial zone samples, a stronger 1N HNO_3 acid was used to obtain acid-soluble metal fraction. Solutions were analyzed using a Perkin Elmer ELAN 9000 DRCe inductively coupled plasma mass spectrometer. Multielement calibration solutions Inorganic Ventures (USA) (IV-STOCK-29, IV-STOCK-21, IV-STOCK-28) were used for the instrumental calibration. For quality control, standard reference materials were used: CRM-SOIL-A (High purity standards, USA), GSO 7126-84 Bil-1, GSO 902-76 SP-2, GSO 903-76 SP-3, SDPS, SKR -1 (Russia).

2.3 Results

2.3.1 Characteristics of Industrial Wastes

The assessment of the chemical properties of mineral substrates was carried out based on the results of determining the water-soluble, available to plants and acid-soluble fractions of chemical elements (Table 2.1).

Table 2.1 Results of chemical fractionation of mineral substrates

Concentration, mg•kg^{-1}													
Sample	Na	Ca	Mg	Al	Fe	P	K	Mn	Cu	Ni	Zn	Si	S
Water-soluble fraction													
PD	18	*63*	*18*	7.75	7	1.375	9	0.65	**11**	**3.1**	0.12	20	**85**
IQ	18	*58*	*16*	3.3	7.25	1.15	11	0.32	0.22	0.07	0.1	13	18
IN	88	0.2	0.7	2.52	1.4	12.25	5	0.03	0.24	0.024	0.17	9	0
Plant available (1 M $CH_3COOH + NH_4OH$, *single extraction) fraction*													
PD	10	22	6	**427**	**110**	4.75	17.75	1.1	**175**	**6.75**	0	32	**300**
IQ	9	*1100*	11	4	37	0	16.5	12.75	0.142	0.217	4.75	2	32
IN	**1100**	202	8	**470**	22	*52.5*	*150*	*32.25*	0.825	0.177	*10*	*515*	0
Plant available (1 M $CH_3COOH + NH_4OH$, *second + third extractions) fraction*													
PD	12	35	6	**700**	**187**	13.25	15.5	5.75	**102.5**	**4.35**	0.15	77	**42**
IQ	11	*390*	11	2.4	28	0	15.25	6.25	0.375	0.065	1.65	5	0
IN	925	77	3	**625**	57	*28.5*	*77.5*	*14.75*	0	0.105	*4.25*	*430*	0
Acid-soluble (1N HNO_3) *fraction*													
PD	26	392	72	**4450**	**825**	117.5	20.5	14.75	**200**	**13.75**	11.5	1675	45
IQ	24	725	67	60	190	222.5	20.5	4.07	0	0.127	7	80	57
IN	**17,575**	*2450*	57	**32,450**	590	*1300*	*5050*	*102.5*	0	0	31	*44,850*	**1000**

Note Elevated levels of elements that may be significant for the substrate toxicity are highlighted in color, a negative effect is bold, a positive effect is italic

Extremely high concentrations of plant available fraction of such elements as Na, Al, P, K and Mn were obtained for IN substrate. High concentrations of the first two elements can have a negative effect on plant growth, and the last three are nutrients that can be beneficial for plants. The IQ substrate contains high concentrations of Ca and is depleted in both nutrients and toxic metals. Naturally, the highest level of metals is characteristic of PD, in which, there are no elements in elevated concentrations that can neutralize the negative impact, primarily of Cu, Ni and sulfates.

2.3.2 Study of Phytotoxicity of Industrial Wastes

2.3.2.1 Acute Phytotoxicity

The appearance of plants and roots after exposure for 14 days is presented in Table 2.2. As a result of the express test, it was revealed that the complete growth of the roots of *L. multiflorum* occurred in experiments with expanded vermiculite and agricultural soil, which were characterized by the most optimal pH values. Growth of mini lawns to other mineral substrates was not noted. The degree of development of the root system was assessed by visual inspection in points from 1 to 10, where 1 is the absence of roots growth, 3 is very weak growth, 8–9 is good growth and 10 is excellent growth (Table 2.2). In the variant with nepheline waste (IN), an active development of the root system occurred (10 points), for IV, this indicator was 9 points, for UF and IQ—8 points. The most toxic was the contaminated podzol soil (3 points). The results obtained correspond to the results of the chemical analysis of the substrates. The lack of growth of mini lawns reflects the presence of high concentrations of toxic metals (PD) in the substrates and unfavorable pH levels (IN and IQ), and the development of the root system correlates with the availability of nutrients (IN).

Thus, the mini lawns test makes it possible to compare the acute toxicity of different substrates and assess the possibility of their turfing and root development.

Table 2.2 Root appearance and development of the root system of *Lolium multiflorum* L

Index	IQ	IN	PD	UF	IV
Appearance					
Growth to the substrate	No	No	No	Yes	Yes
Roots development	8 points	10 points	3 points	8 points	9 points

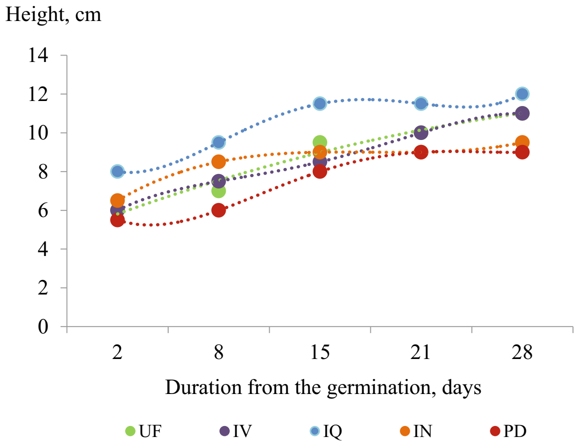

Fig. 2.1 Height of *Tagetes patula* L. in the experiment with industrial wastes

2.3.2.2 Chronic Phytotoxicity

Phytotesting with marigolds showed that the least favorable substrate for plant growth and development is degraded podzol, which is characterized by the highest content of Cu and Ni (Fig. 2.1). The maximum height of marigolds on the degraded podzol reached 9 ± 0.5 cm at the 21st day of vegetation. The greatest height of marigolds was present in the experiment with quartz tails (IQ)—12 ± 0.5 cm. In comparison with the control soil sample, experiments with mineral substrates were characterized by the best results due to the high content of macronutrients such as Mg and Ca.

The results of the study of water balance index (WBI) are presented in Fig. 2.2. This index is designed to assess the moisture content in vegetation. The water content is an important indicator; high humidity is characteristic of healthy vegetation. WBI is used for water stress analysis, productivity determination, fire hazard analysis, irrigated land management, etc. (Penuelas et al. 1995; Champagne et al. 2003).

The lowest WBI values were in the experiment with nepheline waste (IN), and the rest of substrates had almost the same optimal level.

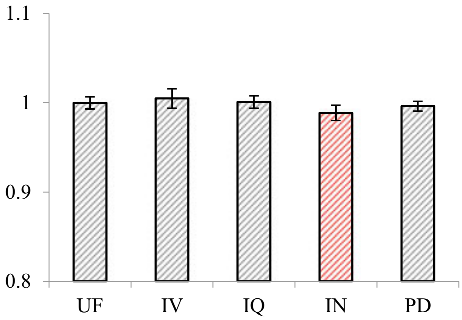

Fig. 2.2 Water band index of *Tagetes patula* L. in the experiment with industrial wastes

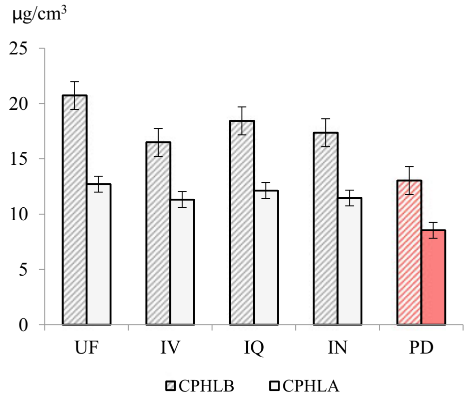

Fig. 2.3 Chlorophyll content in the leaf blade of *Tagetes patula* L. in the experiment with industrial wastes

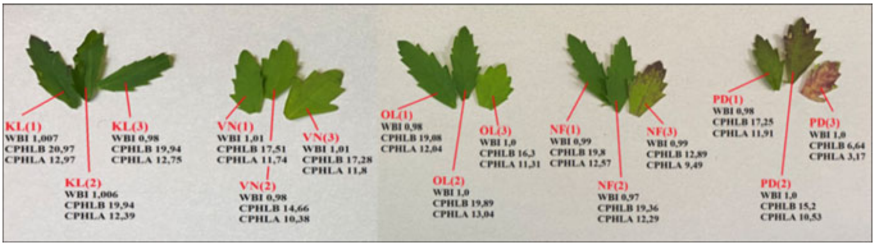

Fig. 2.4 Image of leaf blades of *Tagetes patula* L. analyzed on a leaf spectrometer

The maximum value of chlorophyll content in the leaf blade belonged to the marigolds grown on the control soil (Fig. 2.3). The minimum content of chlorophylls was noted in the experiment with degraded podzol, which was also reflected in the visual inspection of the leaves (Fig. 2.4).

2.3.3 Characteristics of Urban Soils

The hydrophysical characteristics, acidity and content of carbon and nitrogen compounds of urban soils are given in Table 2.3, the results of chemical analysis—in Table 2.4.

Soil samples differ in the content of organic carbon, availability of mobile nitrogen, actual and exchangeable acidity. According to the availability of phosphorus and potassium, all samples are classified as highly endowed. The TM and UF samples had the highest content of NO_3 which is likely related to the input of mineral fertilizers as a part of planting maintenance activities. The TM and TA samples from traffic zones are characterized by the high content of mobile Cu and Ni, which is related to the proximity to the nonferrous factory (TM) or logistic factor—transportation of

Table 2.3 Characteristics of urban soil samples

Land-use zone	Urban farm	Background	Recreational	Traffic, city center	Traffic, divine lane
Index	UF	BG	RK	TM	TA
Bulk density, kg/dm^3	0.88	1.05	0.41	1.01	0.63
Humidity of field samples, %	21.45	23.23	50.94	18.98	36.42
Humidity of air-dried samples, %	2.82	2.67	3.61	1.57	2.29
Loss of ignition, 900 °C	14.01	5.52	20.58	8.51	17.98
Field water capacity, %	67.49	39.83	135.29	51.14	96.71
NH_4^+, mg/kg	3.9	4.8	2.1	2.1	0.9
NO_3^-, mg/kg	145.9	34.7	18.1	253.6	21.9
C, %	6.2	3.4	9.3	3.5	8.3
N, %	0.3	0.1	0.5	0.2	0.3
H, %	1.1	0.9	1.4	0.7	1.2
pH (H_2O)	6.15	6.42	5.79	6.78	6.23
pH (KCl)	4.81	5.1	4.33	5.94	4.6
Eh	216	266	209	208	242

contaminated substrate from sand career to other towns of the region (TA). The BG sample is characterized by a high content of Al due to the natural soil properties of Podzols.

2.3.4 Phytotoxicity of Urban Soils

The results of the assessment of chronic toxicity of urban soils are presented in Fig. 2.5.

The most toxic was the soil with a high content of Cu and Ni (TA, traffic zone in Apatity), where the plants died on the first day of vegetation. High levels of Cu and Ni were also found in the TM soil, where however the presence of calcium and phosphorus partly neutralized the metal toxicity. The background (BG) soil was more toxic than the TM soil due to the high content of mobile Al, about 2 wt.%; plant height on the last growing day was 6.3 ± 0.5 cm.

Table 2.4 Chemical composition of urban soil samples

Sample	Na	Mg	Al	Si	P	K	Ca	Mn	Fe	Co	Ni	Cu	Zn
Total content, wt.%													
UF	2.26	0.51	6.21	27.03	0.22	1.04	1.74	0.07	5.60	15	80	134	66
BG	2.47	0.45	6.76	28.53	0.07	2.21	1.16	0.08	4.96	14	61	132	97
RK	1.81	0.31	5.08	23.66	0.42	1.16	1.28	0.05	4.29	12	78	132	83
TM	1.89	0.61	3.92	33.43	0.17	1.00	1.13	0.07	4.58	38	**378**	**305**	113
TA	1.57	0.58	3.33	26.34	0.04	1.45	1.17	0.05	3.43	29	**513**	**1609**	**390**
Acid-soluble fraction (0.2 N HCl), mg/kg													
UF	195	445	5850	1860	*2130*	*820*	*4800*	133	1105	1.7	6	19	25
BG	390	295	**19,500**	7100	*785*	*375*	*2650*	160	645	1.4	4	12	13
RK	355	340	8050	1105	*5250*	*540*	*13,650*	131	1145	1.2	11	18	56
TM	142	430	3350	2030	*1985*	*230*	*6450*	78	1080	4.7	**105**	**200**	41
TA	1200	585	4900	3850	*350*	*700*	*4050*	43	840	9.3	**265**	**1500**	32
Water-soluble fraction, mg/kg													
UF	10	1.4	0.6	4.3	2.9	41	5.9	0.04	0.24	0.001	0.008	0.030	0.005
BG	10	0.7	**9.3**	13.7	0.7	16	3.6	0.15	1.38	0.008	0.050	0.245	0.208
RK	7	0.4	1.1	9.4	0.7	14	2.3	0.02	0.57	0.000	0.009	0.034	0.010
TM	10	2.5	0.7	2.9	2.5	14	15.3	0.02	0.57	0.001	0.119	0.132	0.009
TA	15	0.5	1.7	30.0	0.3	7	1.3	0.02	0.87	0.003	0.070	0.796	0.075

Note Elevated levels of elements that may be significant for the substrate toxicity are highlighted in color, a negative effect is bold, a positive effect is italic

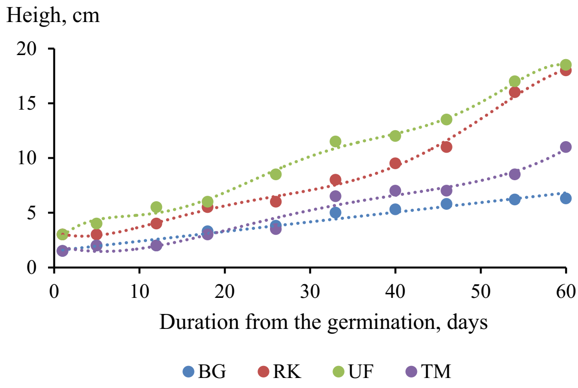

Fig. 2.5 Height of *Tagetes patula* L. in the experiment with urban soils

The chronic toxicity of RK and UF soils was the same; the height of the marigolds was 18.5 ± 0.5 cm at the end of the experiment. The RK soil sample contained mobile Ni and Al, but also contained mobile Ca, which is known to reduce the toxic effect of metals.

2.4 Conclusions

Existing enterprises and an increased regional background for the content of heavy metals in several regions of the Russian Arctic zone require the preservation of natural vegetation, regular planting of greenery and maintaining a high quality of vegetation cover. In the Murmansk region, there are mining enterprises that store thousands of tons of waste, which can be used in the technologies of restoration of industrially polluted and poor urban soils. These products contain layered materials that have high sorption activity with respect to metals, a high specific surface area and the ability to retain moisture and are available in quantities sufficient to the remediation of large areas.

Complex study of the chemical properties of urban soils and industrial wastes and phytotesting of their acute and chronic toxicity using test plants *Lolium multiflorum* L. and *Tagetes patula* L.) shown that the use of these species provide an adequate assessment of the complex phytotoxicity effect of the analyzed materials. At the same time, the data on the chemical composition mainly on the content of mobile forms of the components is needed for the development of recommendations for improving soil quality.

The assessment of acute and chronic phytotoxicity showed the high toxicity of podzol soil from the suburban area of the city Monchegorsk located near the nonferrous plant. This soil contains high concentrations of metals and is depleted in nutrients for essential plants, which are also able to neutralize the toxic effects of metals. The most active development of the root system was observed in variants with expanded vermiculite, nepheline waste and quartz waste. Therefore, these wastes can be easy remediated and also used as components of soil constructions on the areas with lost soil cover.

Phytotesting of urban soils from different land-use zones of three subarctic cities showed that the most toxic was soil with a high content of mobile copper and nickel from the traffic zone of Apatity town, where all plants died. Another tested soil from traffic zone of Monchegorsk town also contained a high concentration of copper and nickel, but this soil was highly provided with phosphorus and calcium, which levels the toxicity of metals.

Thus, we propose the following algorithm for the rapid field assessment of soil phytotoxicity in the Subarctic:

(1) The testing of the acute phytotoxicity (5–7 days) by the root attachment to soil of pre-grown hydroponic lawns from *Lolium* spp.
(2) The testing of chronic phytotoxicity (21 days) using marigolds (*Tagetes* spp.) in case when roots of grasses demonstrated the growth in tested substrate.
(3) The chemical analysis of mobile fractions of heavy metals and nutrients for soils which revealed the toxic effect to take measures to improve the quality of such soils or decide to replace them.

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Chapter 3
The Ecotoxicological State of Urban Soils of the Saint Petersburg City

Vyacheslav Polyakov, Azamat Suleymanov, Alexander Kozlov, Ivan Kushnov, Timur Nizamutdinov, Ekaterina Kozlova, and Evgeny Abakumov

Abstract The intensive urbanization of environments and technogenic activity has an effect on the accumulation of trace elements in the soil and increases the toxicological risk to the terrestrial ecosystems and human health. We studied the distribution of seven priority trace elements (As, Cd, Pb, Zn, Ni, Cu, Hg) in the soil of the northernmost city in the world with a population more than 1 million people. To identify the spatial distribution of the trace elements, the GIS technologies have been used. Based on the data obtained, interactive maps of soil pollution were made. It was found that the content of the studied trace elements exceeds the background values for the region and has a "hot spots" character. Four of the studied elements (Cu, Zn, Pb, As) on average exceed values of maximum permissible concentrations in soil. The highest levels of pollution are concentrated in the central part of the city, and this is associated with the location of major transport roads, as well as railway stations located in the city center. Accumulation of trace elements occurs in bottom sediments in the rivers of St. Petersburg, and this is associated with lateral runoff of dust from roads and adjacent areas. The level of contamination of bottom sediments varied with the degree of proximity to major transportation hubs. According to the analysis of the index, Zc was found that 57.35% of all the points studied have extremely high levels of pollution. The data obtained indicates that the accumulation of extremely high concentrations of trace elements can lead to a deterioration in the quality of life of the population.

Keywords Soil pollution · Zc index · Heavy metals · Risk elements

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3.1 Introduction

Nowadays, 76% of the people of developed countries (Canada, USA, Germany, France, Japan, South Korea and, etc.) live in cities due to the rapid rates of urbanization (Vasenev et al. 2012). The process of urbanization includes both the formation of new urban areas and the expansion of existing cities (Bullock 1991). Rapidly progressing urbanization and an increase in the area occupied by cities and settlements lead to the formation of urban ecosystems (Blum 2005). An urban ecosystem is a natural urban system consisting of fragments of natural ecosystems surrounded by houses, industrial zones and highways (Polyakov et al. 2020). Urban ecosystem is characterized by the creation of new types of artificially created systems as a result of degradation, destruction and (or) replacement of natural systems and is characterized by less recreational value, disruption of biocycling, reduction of biodiversity both in composition and in structural and functional characteristics (Shamilishvili et al. 2016). In the process of urbanization, natural landscapes undergo a key transformation—the soil and vegetation cover change, and the resulting urban ecosystems are radically different from natural ecosystems (Polyakov et al. 2021). The specificity of soil formation within the urban environment is mainly influenced by the anthropogenic factor, as well as the specific heterogeneity and heterochronicity of soil composition and properties (Ji et al. 2019). Natural landscapes are transformed into anthropogenic ones, and there are local changes in biochemical cycles, volumes of accumulation and removal of chemical elements (Polyakov et al. 2021). Among the main factors that affect the processes of soil formation in the urban environment, it is necessary to distinguish: formation of soils on bulk, reclaimed or mixed soils and cultural layer; presence of inclusions of construction and household garbage, both in the upper horizons and in the whole profile change in acid-alkaline balance with a trend toward alkalization; high pollution with heavy metals and petroleum products; change in physical and chemical properties of soils (reduced moisture capacity, increased compaction, stoniness and other features), profile growth due to intensive aerial spraying (Kapelkina 2010).

Urban soils, as a depositing component of the urban landscape, accumulate many trace elements, including heavy metals and metalloids, as well as organic compounds toxic to living organisms (Lado et al. 2008). Regressive-accumulative distribution of trace elements over the soil profile is characteristic of technogenic territories regardless of the soil type: metals accumulate in the upper humus horizon of the soil and their concentration in the lower horizons decreases sharply. The character of redistribution of heavy metals and metalloids in the profile is influenced by a complex of soil factors such as: the particle size distribution of soils, pH reaction, soil organic matter content, cation exchange capacity, the presence of geochemical barriers as well as drainage (Lu et al. 2014).

Atmosphere and hydrosphere—the most dynamic systems, and changes in their geochemical appearance occur over short periods of time, in contrast to the pedosphere (Maksimova and Abakumov 2015). The study of the geochemical parameters of the soil cover gives an idea of the centers of stable pollution by chemical elements, formed over a certain period of exposure to pollution sources (Ji et al. 2019). In this regard, the environmental assessment of the territory of cities is rational to use the geochemical method, which is based not on the study of the emission of pollutants from man-made sources (which are focused on departmental monitoring systems), but on the study of the accumulation of pollutants in the depositing natural environments, soils in particular (Korchagina et al. 2014). Despite the obvious importance of information on the ecological condition and functioning of urban soils, at the moment there are actually no objective maps of urban soils or a unified approach to their classification (Polyakov et al. 2021). The main reason is the unique spatial variability of urban soils and their properties (Vasenev et al. 2012). The leading environmental control organization in Europe is the European Environment Agency (EEA), and EIONET-CSI system is used to collect data, which is controlled by the European Soil Data Centre, where data on soil contamination in European countries is accumulated and processed (ESDAC: The European Soil Data Centre 2022). The datasets obtained from both governmental organizations and individual researchers are aimed at studying the pathways of human exposure which is a key issue in contaminated regions, and the integration of soil contamination datasets with epidemiological data is a key step for the development of effective environmental biomonitoring and soil cover studies of urban areas (Abrahams 2002; Panagos et al. 2013).

Changes in the quality of the human environment in the city lead to a decrease in the comfort of the population, which is witnessed by medical and demographic indicators, in particular, a high level of morbidity, an increase in genetic diseases and a decrease in life expectancy. Thus, the aim of this study is to investigate the distribution of trace elements in the city of St. Petersburg and to assess the total pollution index of the territory of the city. To achieve this goal, the following objectives were formulated: (1) to evaluate the degree of soil contamination in the city by trace elements; (2) to provide geochemical maps based on the concentration of the pollutants in the soils of Saint Petersburg; (3) to calculate the total soil pollution index (Zc).

3.2 Materials and Methods

Study Area. The studies were conducted in the city of St. Petersburg in Russia, within the Prinevskaya lowland. The city covers an area of 1 439 km^2 with a population of about 4.99 million people. The historical center of the city is located on Litorin marine sediments of various compositions (sands, loams, clays); the northern part of the city is located on limno-glacial deposits of the second Baltic glacial lake. The climate is temperate, transitional from temperate continental to temperate marine. The average annual temperature is +5.8 °C. The annual precipitation is 662 mm (Polyakov et al. 2021).

Sampling Methodology. Field studies were conducted in the 2021–2022 years. The study areas belong to different functional zones of the city in areas free from asphalt. The soils were selected from the upper horizons (0–20 cm). Samples were taken in plastic bags and transported to the Applied Ecology Laboratory at SPbSU. The air dry samples were sieved through a 2 mm sieve. 68 soil samples were taken from various functional areas of the city. They include both alluvial territories and soils associated with post-lithogenic soil formation. The sampling points are shown in Fig. 3.1.

Methods. To establish the pollution status of the soils and create interactive maps of the city pollution by the risky elements, the following indicators were studied: Zn, Cu, As, Pb, Ni, Hg, Cd. The chemical analysis of the soils was carried out in the Department of Applied Ecology, SPBU. The determination of the content of (Zn, Cu, Pb, Ni, Cd) and metalloids (As) in the soil was carried out in accordance with the inversion voltammetry method on TA analyzers (Soil Quality 1998). The assessment of the risky elements was carried out by comparing the obtained data with the existing hygienic standards and background contents. The geochemical background was used for St. Petersburg according to About the environmental situation in the Leningrad region in 2018 (Region AotL 2018).The total soil pollution index (Zc) is the sum of concentration ratios of toxicants (pollutants) of classes I, II and III of toxicological hazard in relation to background values (3.1).

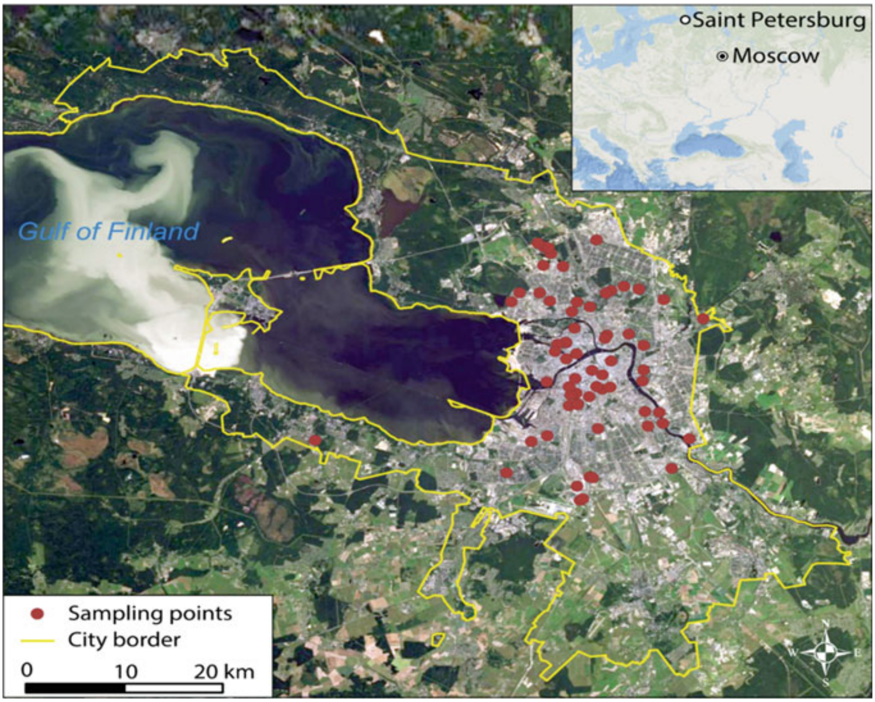

Fig. 3.1 Study area of St. Petersburg. *Source* Sentinel-2A

$$\mathrm{Zc} = \sum_{i=1}^{n} \mathrm{Kc} - (n-1) \tag{3.1}$$

where Kc—concentration coefficient of the *i*th chemical element, *n*—the number equal to the number of elements in the geochemical association.

The concentration coefficient (Kc) is calculated by the formula (3.2):

$$\mathrm{Kc} = \frac{\mathrm{Ci}}{\mathrm{Cbc}} \tag{3.2}$$

where Ci—the actual content of the element, Cbc—geochemical background.

Satellite Data. The inverse distance-weighting (IDW) method was used to determine the spatial variability and mapping the soil properties on the study plot. The IDW is one of the most widely used tools for interpolating various values, including soil properties (Bhunia et al. 2018). The formula for IDW (3.3) is defined as:

$$Z(x_0) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}} \tag{3.3}$$

where $Z(x_0)$ is the predicted value at the non-sampled location x_0; x_i is the *i*th data value; h_{ij} is the separation distance between the interpolated values; and β indicates the weighting power (Bhunia et al. 2018).

3.3 Results and Discussion

Soils in the Urban Ecosystem. To analyze the soil cover of St. Petersburg. The soils of four functional zones were studied: residential, recreational, industrial and traffic. Examples of selected soil profiles of St. Petersburg are shown in Fig. 3.2. Nowadays, in St. Petersburg, soils of fallow lands with a relatively high level of fertility are actively involved to building and city development, as well as, in the west of the city, there is an active alluvial soil formation. In the forest-park zone, the development of soils according to the zonal type of soil formation is noted. The main factors of soil formation in urban environment are humus accumulation, humus formation, overcompaction, overwatering, waterlogging, redeposition of mineral material and salinization (Polyakov et al. 2020). Humus accumulation and humus formation take place mainly in the residential and recreational zones, where soils are less exposed to contamination by priority toxicants. However, due to high anthropogenic load, signs of soil overcompaction can be noted, which negatively affects the hydrothermal regime of soils and may lead to local loss of vegetation (trails and roads). On young soils, formed as a result of alluvial and superficial processes, there are signs of overwatering and waterlogging of the territory (characteristic for park zone) (Maksimova and Abakumov 2015). Soils formed in the industrial and traffic zones, as a result of active anthropogenic impact, are exposed to the greatest transformation. Soils usually have no genetic horizons, or may have a polygenetic structure as a result of redeposition of soil in the course of construction works. These soils have a relatively low organic carbon content, and soil formation processes are poorly observed. The soils forming near linear road objects deserve special attention, and they are subjected to systematic inflow of pollutants together with dust, which, according to some authors (Vlasov et al. 2022; Wei and Yang 2010), is the priority factor of urban soil pollution. Such dust can contain dozens of times more pollutants than in the adjacent soil. Soils of the city of St. Petersburg have a neutral to weakly alkaline pH reaction, and this is due to the alkalinity of the area by introducing reagents, as well as construction dust, which contains lime (Polyakov et al. 2021; Abel et al. 2015). Thus, in the urban environment, we can find both zonal variants of soil formation formed in the recreational zone, weakly transformed soils in the residential zone, alluvial (superficial) soils, as well as completely transformed soils in the industrial and traffic zones.

Natural soils are represented by Histosols (O–TO_1–TO_2–TO_3 profile) with active processes of organic matter accumulation and Hypo-Stagnic Retisol Ruptic (AY–EL–BI–BC–Cg profile) with illuviation of mineral particles. Soils formed in traffic zone—Technosol Entic, Transportic (C_1–C_2–C_3–C_4) have poorly developed soil profile in which processes of soil formation and separation of soil horizons are not marked. The sealed soils of the traffic zone—Technosol Transportic Ecranic (C_1–C_2–BT–C_3–C_4–G) can retain the structure of the soil profile and serve as buried soils. Relatively young soils of St. Petersburg are alluvial soils formed on the alluvial territories of the city (C_1–C_2–C_3–C_4) with signs of the processes of initial soil

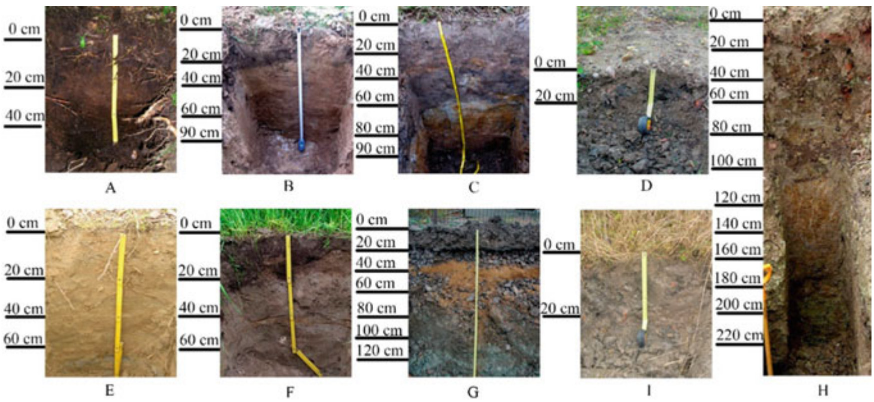

Fig. 3.2 Soil diversity of Saint Petersburg city. **a**—Histosol, recreation zone; **b**—Hypo-Stagnic Retisol Ruptic, recreation zone; **c**—Thapto-Umbric Retisol, recreation/residential zone; **d**—Technosol Entic, Transportic, traffic zone; **e**—Flivosol Antric, alluvial territories, recreation; **f—**Techosol Transportic, recreation/residental zone; **g—**Technosol Transportic Ecranic, traffic zone; **h—**Technosol Entic, industrial zone; **i—**Polygenetic soils: Technosol/Retisol/Gleysol, industrial zone

formation and humus accumulation (AY–C_1–C_2–Cg). Soils of an industrial zone—Technosol Entic (C_1–C_2 profile) and Polygenetic soils: Technosol/Retisol/Gleysol (AY–C_1–C_2–El–BT–C_3–C_4–G_1–G_2) as well as the industrial zone are characterized by both complete absence of soil formation processes, and polygenetic profile structure caused by redeposition of material. According to the analysis of the TOC content, it was noted that the highest carbon content is noted in the recreational and residential zones. Soils formed in the industrial and traffic zones are characterized by low content of organic carbon, and this is associated with weak processes of humus accumulation and a low degree of development of soil-forming processes under the influence of anthropogenic pressure. As for cation exchange capacity rate values, they well correspond to clay content and higher in topsoils, also due to increased organic matter percentages. This also good evidence of the soil role in mitigation of urban ecosystems contamination (Lu et al. 2003). In addition to the presented soils, a separate place in urban soils is occupied by park soils and their cultural layers, which reflect those or other processes related to the development of the city (Matinyan et al. 2017). With the gradual increase in the rate of urbanization, more and more lands will be subjected to anthropogenic pressure and transformation, so the study of urban soils is an important task of modern soil science (Blum 2005; Abrahams 2002).

The soil contamination by heavy metals and metalloid. We analyzed 68 soil samples at a depth of 0–20 cm (Fig. 3.3). According to the data obtained, we can note that soils have a high degree of contamination by trace elements, i.e., Cu, Zn, Pb, and their average content in the soil exceeds the level of maximum permissible concentrations (MPC) several times. The content of Cd, Ni, Hg, As on average does not exceed the MPC, which indicates a low involvement of these elements in the environment and soil cover. However, all the studied trace elements on average exceed the background concentrations (Table 3.1).

According to the maps of distribution of trace elements, it was found that the pollution of soils with trace elements has a "hot spots" characters, which seems to be associated with the activities of industrial facilities and transport interchanges. Only

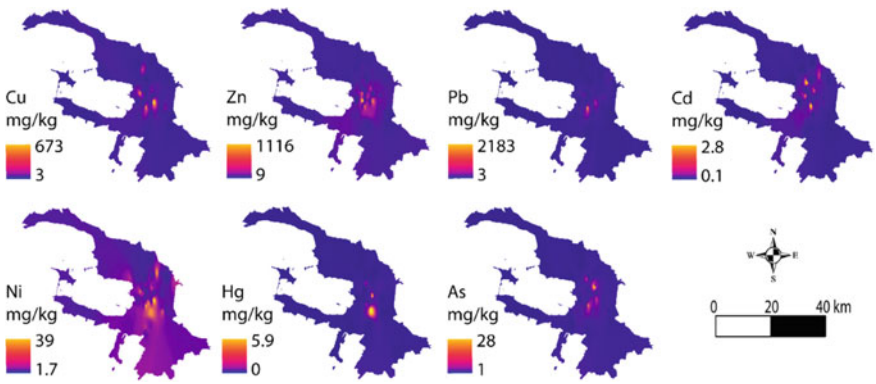

Fig. 3.3 Geochemical maps of the different heavy metals in St. Petersburg, Russia

Table 3.1 Descriptive statistics of the risky element concentrations in the soil samples

Element	n	Mean, mg/kg	Min., mg/kg	Max., mg/kg	SD[a]	CV[b], %	MPC	Background, Mg/kg
Cu	68	97.18	2.80	940.20	176.40	181.51	55	1.78
Zn	68	192.94	9.70	1116.50	219.48	113.75	100	5.54
Pb	68	124.43	2.90	2388	313.07	251.58	30	5.02
Cd	68	0.42	0.10	2.77	0.60	141.63	0.5	0.07
Ni	68	10.87	1.70	41	8.36	76.97	85	1.48
Hg	53	0.46	0.01	5.91	1.06	225.61	2.1	0.04
As	68	3.60	0.99	28.05	4.77	132.42	2	0.05
TOC[c], %	38	7.18	0.12	66	19.11	265.97	–	–
CEC[4], CMP+/kg	38	14.23	3	78	16.84	118.35	–	–
Clay, % to fine earth	34	32.14	5	59	2.69	48.92	–	–

[a]SD—standard deviation
[b]CV—coefficient of variation
[c]total organic carbon
[d]Cation exchange capacity

with regard to Ni, we can note a relatively uniform distribution. The main sources of soil pollution by heavy metals are emissions of pollutants into the atmosphere from transport, energy facilities and industrial enterprises. Metals accumulate relatively quickly in the soil and are very slow to be removed from the soil (Khan et al. 2008; Ufimtseva et al. 2011; Adama et al. 2016).

Analysis of the distribution of trace elements in different functional areas of the city is shown in Figs. 3.4 and 3.5.

From the obtained graphs, we can note that the accumulation of trace elements occurs mainly in the industrial and traffic zones. It is associated with industrial activities, as well as with automobile emissions. However, we can note single extreme values of trace elements in residential zone (e.g., cadmium and lead), it indicates local sources of trace elements in this functional zone. This could be associated with a local sources of pollutions such as construction rubble and other anthropogenic artifacts. The lowest content of trace elements is noted in the recreational zone.

To analyze the relationships between trace elements and pH, factor analysis is proposed (Fig. 3.6).

From the obtained graph, we can note that most of the studied trace elements are in the same block (Ni, Zn, As, Pb, Cu), which may indicate one source of these elements in the soil, while the relationships between Cd, Hg and pH level were not observed. This indicates a low relationship in the accumulation of trace elements and pH level.

Contamination of soil with trace elements occurs through their technogenic dispersion: with emissions of combustion products and dust into the atmosphere during

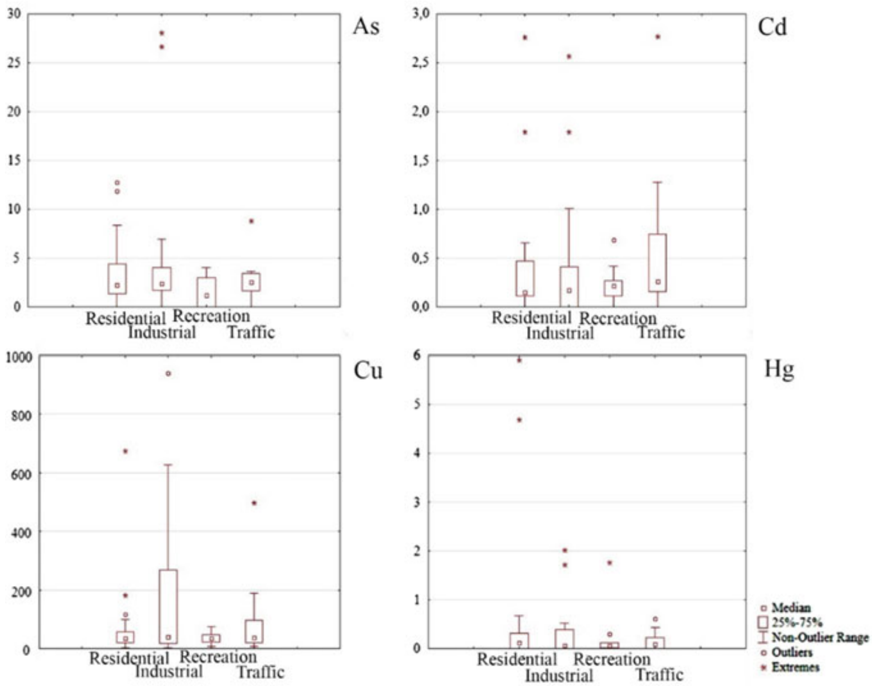

Fig. 3.4 Distribution of trace elements in different functional zones. The concentration is presented in mg*kg^{-1}

high-temperature technological processes (metallurgy, power industry). Heavy metals together with precipitation relatively quickly reach the surface of the soil cover. A significant part of them is included in the soil-forming process, a certain amount is absorbed by plants, as well as carried out with surface runoff of groundwater. As a result, anthropogenic geochemical hotspots of trace elements arise, which are further characterized by a rapid decrease in the concentration of metals from the source of pollution to the periphery (Wei and Yang 2010; Vodyanitskii and Yakovlev 2011; Chen et al. 2005).

The Total Soil Pollution Index (Zc). Calculation of Zc pollution index revealed that most of studied samples were extremely highly polluted with trace elements. According to our calculation, 39 samples (57.35% of the total number of samples) showed extremely high pollution level values; 22 samples (32.35%) showed high pollution level values; 4 samples (5.88%) showed moderate pollution level values and 3 samples (4.42%) had low values of pollution. In general, studied soils could be characterized as extremely highly or highly polluted (Table 3.2).

The highest value of Zc index (2741.84, extremely polluted) was observed, it is probably due to the impact of automobile highway, railway and industrial zone, located nearby. The following soil which was sampled close to the previous location,

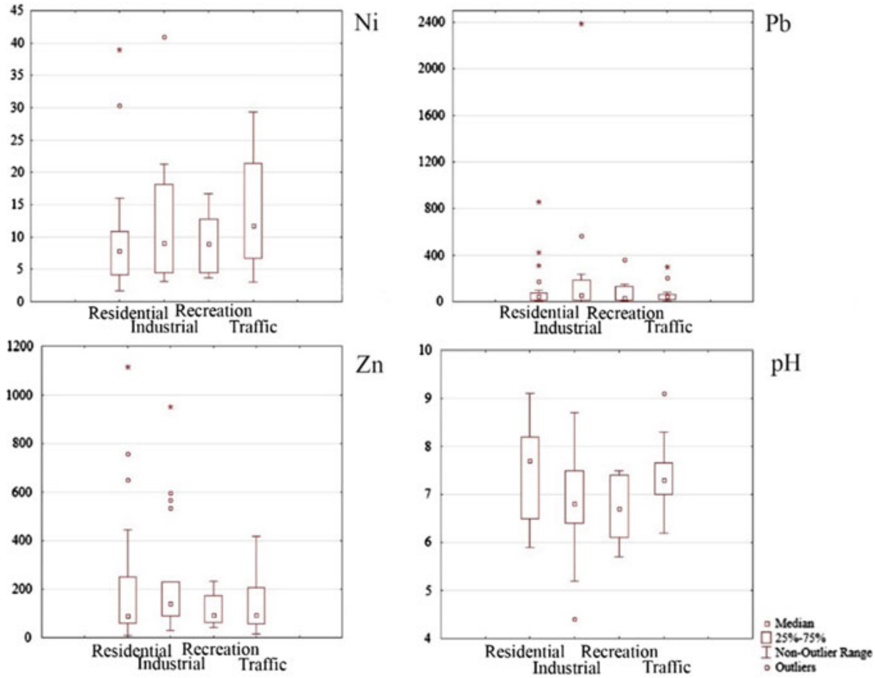

Fig. 3.5 Distribution of trace elements and pH in different functional zones. The concentration is presented in mg*kg^{-1}

also showed extremely high values of pollution load (913.6). The site which is located close to the road with high-density traffic showed high pollution load (125.84). On the other hand, the lowest value of Zc index (3.39) was observed in the sample which is located in the northern part of Saint Petersburg, far away from factories and major roads, on the coast of the lake which is used by locals for recreational purposes. Thus, we can say that industries and traffic considerably increase pollution load of studied soils in the city, mostly up to extremely polluted level, while in remote locations, soils showed low or moderate pollution levels.

Saint Petersburg is a city with many rivers and canals, and it would be interesting to see, how these water objects affect pollution load of adjacent soils and sediments. For instance, sample which is a bottom sediment of the Chyornaya River, in the city center, showed extremely high degree of pollution (365.57). On the other hand, sample of bottom sediment sampled from the Neva River, in the south-eastern part of the city, showed high level of pollution according to Zc index (40.93). This high pollution load level is probably connected with presence of industrial zone nearby, however, this value is much lower than in the Chyornaya River which may be

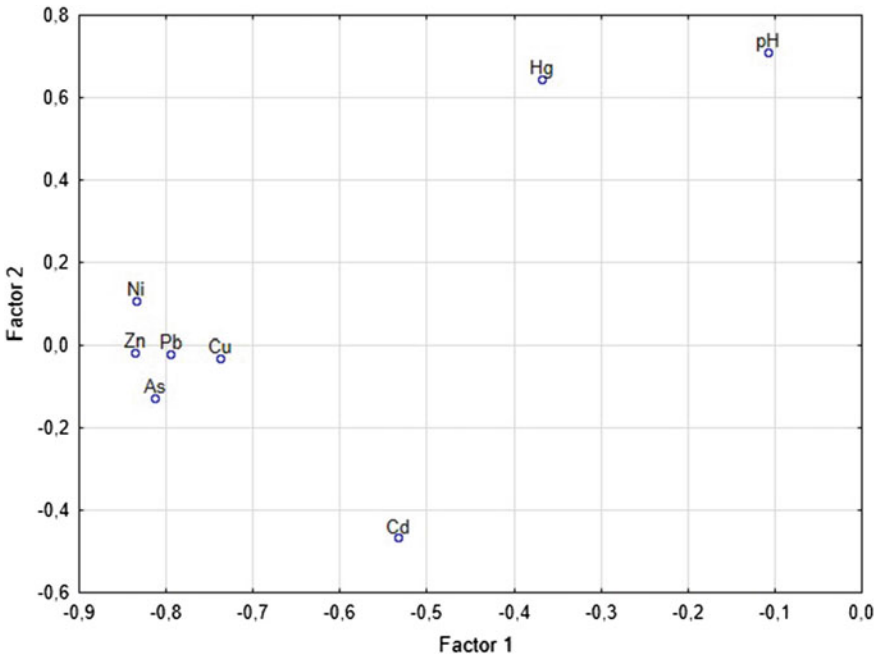

Fig. 3.6 Factor analysis among trace elements and pH level

Table 3.2 Levels of soil contamination by total soil pollution index (Revich et al. 1990)

Contamination level	Total soil pollution index (Zc)	Number of study sites	Impact on human health
Low	8–16	3	The lowest rates of morbidity in children, the frequency of functional abnormalities is minimal
Moderate	16–32	4	Increase in the general morbidity rate of the population
High	32–128	22	High level of general morbidity, increase in the number of frequently ill children, children with chronic diseases, disorders of the functional state of the cardiovascular system
Extremely high	> 128	39	High rate of child morbidity, violation of women's reproductive function (increased toxicity of pregnancy, premature birth, stillbirth, hypotrophy of newborns)

connected with the fact that Neva River flows from the south-east to north-west direction. Relatively clean water flows to the city and, further, become more polluted in direction to the city center which may cause additional pollution of bottom sediments and adjacent soils in case of flooding.

Soils formed in the urban environment have significant differences from natural soils, this is due to the high heterogeneity of urban development and a high degree of transformation of the landscape (Bullock 1991). Thus, soils in Moscow were characterized by significant diversity and heterogeneity of soil cover, and the coefficient of variation in carbon content varies within 90%, indicating the requirement to develop significantly new approaches for the study of soils in an urban environment (Vasenev et al. 2012). Considering soils formed near large road networks in the west part of Moscow, it can be noted that there are different dynamics of accumulation of heavy metals, in soils near roads accumulated mainly Zn (up to 1364 mg*kg^{-1} in PM 10 of road dust), while other heavy metals do not exceed MPC. Significant increase in concentration of heavy metals is noted in road dust and particulate matter (PM) 10 fraction, which is associated with large specific surface area of PM 10 (Vlasov et al. 2022). Aerial sediments (as a dust PM 10, 2.5) play an important role in the formation of urban soils, and they contain significant amounts of trace elements that contribute to the transformation of anthropogenic-transformed soils (Prokof'eva et al. 2015). In Nanjing, China, the same features of accumulation of heavy metals in soil as in large Russian cities were observed, the highest content corresponds to roadsides (Pb content here reaches up to 308.5 mg*kg^{-1} and the lowest in the park area; Lu et al. (2003) assume that road transport emissions are the main source of Pb in the city. In the eastern district of Moscow, the most polluted soils are in the industrial zone, mean content of Ni is 30.7 mg*kg^{-1}, Cu is 329 mg*kg^{-1}, Zn is 150 mg*kg^{-1}, As is 6.34 mg*kg^{-1}, Cd is 0.93 mg*kg^{-1} and Pb is 143 mg*kg^{-1}, and the level of pollution here is higher than in the residential, recreational and traffic zones, 3.5 times higher than in the sealed soils in the same functional areas of the city (Nikiforova et al. 2022) and associate with the level of pollution in the studied soils of St. Petersburg. Urban soils have local anthropogenic pollution by heavy metals, this is mainly due to the functioning of industrial centers, as well as the development of the road network (Gorbov et al. 2015; Paltseva et al. 2022). Urban soils are underestimated in terms of ecosystem services, but in an urban environment have an important regulating function, as well as providing and cultural functions (Romzaykina et al. 2021; Deeb et al. 2020). Distribution of trace elements and other pollutants in the urban environment occurs by other mechanisms than in natural soils (Shamilishvili et al. 2016; Vodyanitskii and Yakovlev 2011). This is due to the fact that the soil in the urban environment is anthropogenic-transformed and the natural soil is buried under it, and the cultural layer of such soil can reach several meters (Matinyan et al. 2017). In natural conditions, pollutants mainly accumulate in the upper layers of soils and weakly migrate along the profile, while in the urban environment, soils may have many peaks of heavy metals in the soil profile as a result of the introduction of fresh soil (Polyakov et al. 2020). In Europe, according to data from the European Soil Data Centre, the proportion of potentially polluted sites is

1170*1.000 in urban area, 127*1.000 sites polluted and only 58*1.000 sites remediated. However, according to the predicted calculations, the number of potentially polluted sites will increase up to 2553*1.000, and the number of polluted sites up to 342*1.000 (Panagos et al. 2013). Metallurgy takes the first place among other industries participating in the pollution of urbanized territories (13% of all pollution sources). An important source of urban soil pollution is the input of rubble as a result of construction work, construction rubble is a major source of Pb (219.5 mg*kg^{-1}), Cu (119 mg*kg^{-1}), Zn (282.2 mg*kg^{-1}), Hg (1.56 mg*kg^{-1}), which can later enter groundwater (Abel et al. 2015). The same conclusion was reached by scientist from Poland, who noted that anthropogenic artifacts play a significant role in the differentiation of the urban soil (Greinert 2015). Among the priority, pollutants are heavy metals (34.8%), polycyclic aromatic hydrocarbons (10.9%) and aromatic hydrocarbons (10.2%) (Panagos et al. 2013). In Europe, each country spends about 1483.2 million euros per year on remediation measures (80.6%), 15.1% on site investigation and only 4.3% on follow-up care and reclamation measures (Panagos et al. 2013). According to earlier studies conducted in Saint Petersburg, the Summer Garden soils show increased content of heavy metals in the upper soil horizon, high humus content and alkaline reaction, all this indicates an active anthropogenic influence and formation of specific urban soils in the garden park ensembles of the city (Matinyan et al. 2017). As a result of the urbanization, in St. Petersburg were formed artificial alluvial areas, which are a model of soil development in the urban environment, in conditions of active anthropogenic load was revealed that soils are characterized by an increased degree of hydromorphism and the formation of gley conditions, low content of biogenic elements, which negatively affects the vegetation cover area (Maksimova and Abakumov 2015). According to the data on pollution of the territory of the city with heavy metals and polycyclic aromatic hydrocarbon, it was noted that the studied soils of the city are characterized by a dangerous and extremely dangerous level of pollution (Shamilishvili et al. 2016).

3.4 Conclusions

Accumulation of trace elements in the soils of urbanized areas is a significant problem in St. Petersburg. It was noted that the content of trace elements in the city exceeds the background content. It was found that Cu, Zn, Pb, which have "hot spots" distribution, indicating local sources of trace elements, makes the largest contribution to pollution status of the city. Based on the data obtained of trace elements distribution, geochemical maps of the pollution of the city were made. It was revealed a high anthropogenic load, which indicates that the active pace of urbanization has a negative impact on the ecotoxicological state of the soil of the city. Pollution of soils is mainly noted in the central part of the city, where there are major transport interchanges. Out of seven trace elements studied, the average values of 4 elements (Cu, Zn, Pb, As) exceed the values of MPC. According to the calculations the total soil pollution index (Zc), it was found that 57.35% of the total number of samples showed extremely high pollution level, which may adversely affect the health of the city population and quality of life in general. In the territory of the city, in areas with high man-made load is necessary to carry out activities to remediate the soil, as high levels of pollution can lead to negative consequences for public health. The data obtained can be used for further development of sustainable soil management systems in the highly urbanized ecosystem of St. Petersburg, located near the Russian–Finnish transboundary zone.

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Chapter 4
Assessment of Soil Quality in Urban Green Areas of Two Russian Cities by Means of Chemical and Biological Methods

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Abstract The quality of urban soils in green zones is a result of combination of natural processes, anthropogenic pollution and management. The elevated presence of heavy metals in soils of the urban environment has been recognized as an important source of metal intake into the human body. The aim of this study was to evaluate the concentration of heavy metals in soil of 24 parks and public gardens obtained in Kazan (with 1 Mio citizens) and its satellite city Zelenodolsk. The soil samples and two different herbaceous perennial plant *Plantago major* and *Trifolium repens* were analyzed for 5 metals (Cd, Cu, Pb, Ni, Zn) using ICP-MS. We also determined the physiological profiles of microbial communities using the Biolog Ecoplate multi-substrate testing method and the diversity of plants in urban green zones. The results from the study showed that the heavy metal concentration in soil samples ranged between 0.06 to 0.70 mg/kg, 0.82 to 30.02 mg/kg, 0.06 to 66.42 mg/kg, 9.91 to 71.33 mg/kg and 4.41 to 24.51 mg/kg for Cd, Pb, Cu, Zn, Ni, respectively. In average, the concentrations of the metals in soils did not exceed the levels recommended by WHO. In plants, the concentration of Zn exceeded the recommended levels by 10–25 times. The Shannon–Wiener diversity index for plant communities varied from 2.32 to 2.96, and for microbial community (AWCD)—from 0.143 to 1.695. No significant differences between the diversity indices for large and satellite cities were found. No correlation between the level of metal contents and diversity indices was found.

Keywords Heavy metals · Urban Park · Plant diversity · Functional diversity of soil microbial community

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4.1 Introduction

The urban environmental quality is of importance because the majority of people now live in cities (Tresch et al. 2018). Urbanized areas are rapidly expanding at the expense of natural habitats and the corresponding human population shift. It has resulted in landscapes created by humans–urban green spaces, including parks and public gardens, have become a substitute for the lost environmental spaces (Francini et al. 2018; Yan et al. 2019).

Soil of urban green spaces and provides key ecosystem services for a comfortable living in city (Li et al. 2018). Its quality is one of the components of environmental quality, as with the quality of water and air (Andrews et al. 2002). The world's population is increasingly urbanized, with 55% living in city areas, and predictions of up to 66% by 2050 (Różański et al. 2018). Therefore, interest to urban soils due to the potential impact of this soils on population has recently increased (Morel and Heinrich 2008). This is due to the fact that soils in urban and suburban areas are greatly impacted by human activities. This can have significant consequences for the health of people, plants and soil organisms, as well as the ability of water to penetrate the soil (Page-dumroese 2020).

Urban green spaces (UGS) are defined as areas primarily covered by plants, including trees, grasses and shrubs, that have a direct or indirect positive impact on people's lives by purifying toxic substances and improving the microclimate (Haq 2011). This soils quite different from natural soils due to the high level of human activity, leading to increased pollution, physical disruptions and alterations to the surface. This soils quite different from natural soils due to the high level of human activity, leading to increased pollution, physical disruptions and alterations to the surface. Urban soils are frequently associated with degraded or contaminated soils low levels of soil organic carbon and biological activity (Ajmone-Marsan and Biasioli 2010; Scharenbroch et al. 2005) compared to non-urban soils. Compared to them, urban soils are also influenced by the local microenvironment as well as the process of its formation.

In many places around the world, the chemical environment of soils has been modified due to the rapid urbanization and industrial growth (Johnson and Demetriades 2011). The sources of pollution can be transport (motor exhaust, brake pads, tire wear), domestic activities (such as waste disposal and construction, wastewater), commercial and industrial emissions (including those from metallurgical industry, electronics, chemical plants, fuel combustion) and agricultural activities (such as the use of fertilizers, pesticides and wastewater irrigation) (Argyraki and Kelepertzis 2014; Wei 2018).

Along with polyaromatic hydrocarbons, chlororganic compounds and radionuclides, heavy metals are typical urban pollutants that can be transferred into humans and influence their health (Madrid et al. 2002). Toxic metals, such as Pb, Cd and Cr, are still increasingly accumulating in urban environments, causing concern because urban soils as they easily come in contact with humans, e.g., in the form of suspended dust (Ljung et al. 2006; Sörme et al. 2001). These are pollutants that do not undergo chemical or biological degradation and therefore can be accumulated in soils or living organisms. Human exposure to heavy metals can occur through ingestion, inhalation and skin contact and in different places, mainly in urban parks (Penteado et al. 2021). Urban soil in parks acts as a sink for pollution of potential toxic elements (PTE) because to the presence of large open exposed areas of soil (Gu et al. 2016; Zhao et al. 2014).

Human outdoor and activities have increased in parks on a daily basis, for benefits to people's health. Particularly during the COVID-19 pandemic period in 2020–2021, parks and public gardens provided an important place for residents (especially children) for outdoor relaxation and entertainment purposes (Brtnický et al. 2019). Children are at higher risk of exposure to pollution due to their frequent contact with soil and other surfaces (Brtnický et al. 2019; Gu et al. 2016; Zhang 2019),, which can lead to contamination through skin contact, inhalation and hand-to-mouth ingestion (Li et al. 2014b), even at low concentrations. Children are more vulnerable to pollution due to their smaller size, developing nervous systems and higher absorption rates. For instance, while the portion of ingested Pb which absorbed an adult's body less than 5%, children can absorb up to 50% due to their less developed gastrointestinal tracts (Maddaloni et al. 1998).

Urbanization also has a specific effect on the plant development and bacterial soil communities due to conversion of native habitats to various forms of land use and habitat loss (McIntyre 2000). Outstanding properties of urban soils are limited aeration and drainage, which can lead to anaerobic conditions, disrupt nutrient cycling and result in elevated temperatures (Bae and Ryu 2017). Excessive concentration of metals above the maximum permissible limit can negatively impact the quality of soil organisms, such as microfauna and macrofauna, as well as ground and drinking water. This can ultimately impact the quality of food (Nganje et al. 2020; Wang et al. 2020). The contamination of urban soils with heavy metals was discovered to have an impact on soil microorganisms, including microbial biomass and diversity, basal respiration rate, physiological profile and the activities of dehydrogenase, sulfatase, glucosidase and phosphatase (Yang et al. 2006).

Urbanization results in the expansion of cities' boundaries, causing greater patchiness in the landscape. This, combined with loss of habitats, is the primary factor contributing to the decline of biodiversity (Grimm et al. 2008). Being the primary green areas of urban landscapes, they represent important biodiversity hotspots in cities (Nielsen et al. 2014). Parks and public gardens are generally composed of grassy areas, with tree and shrub species commonly used that support limited biodiversity, particularly if non-native and less capacity for critical ecosystem services (Aronson et al. 2017).

Comparing small and big cities can be difficult at times because the studies' methodological approaches, including soil fraction, contaminants studied and chemical extractions. The size of the city does not directly determine the level of contamination, as small urban areas can be in close proximity to industrial areas (Gallego et al. 2002) and experience the same anthropogenic pressures as bigger cities. Although suburban areas don't contribute significantly to industrial pollution, they do contaminate the environment through the disposal of household and yard waste, storm drains, construction activities and materials and traffic (Callender and Rice 2000).

In the present work, quality of soil of urban green areas situated in a Russian big city (over 1 Mio citizens) as well as its satellite small city (about 0.1 Mio citizens)—Kazan and Zelenodolsk, respectively—was studied. Currently, poor information is available about urban soil quality in Russian cities while this country represents about 11.5% of the land on the planet. The study was conducted in summer 2021. The plant and bacterial biodiversity as well as the level of heavy metals pollution were analyzed in the urban green areas investigated.

4.2 Materials and Methods

4.2.1 Study Site

This research was carried out in two Russia cities: Kazan (55°47′19.46″ N 49°07′19.70″ E) and Zelenodolsk (55°50′37.54″ N 48°31′4.22″ E). These cities have significant natural, geographical and industrial aspects. Zelenodolsk is a classic satellite city of the monocentric Kazan agglomeration. The both cities are located on the left bank of the Volga River, and the population of Kazan city is 1,259,173 people (as of January 2022), of Zelenodolsk—99 235 people. The city of Zelenodolsk belongs to the category of medium cities. 145 urban green zones are situated in Kazan, covering about 0.84% of city area. Currently, the area of green common areas in Zelenodolsk is 13.1 m^2/person, which corresponds to the established requirements of at least 7 m^2/person for medium-sized cities (Zakirova and Khusnutdinova 2018).

4.2.2 Estimation of Plant Biodiversity

The species diversity of (sub)urban habitats, including parks and gardens, can be extremelyhigh (Gilbert 1989). The plants in the plot were identified and cover of individual plant and the whole community in the quadrat. From the estimated dominance–abundance of the herbaceous vegetation and for trees and shrubs taxa, the Shannon–Wiener the standard biodiversity index was computed (Hermy and Cornelis 2000). Major herbaceous species in the region include *Achillea millefolium, Dactylis glomerata, Medicago sativa*, *Plantago major, Trifolium repens* and *Urtica dioica.*

4.2.3 Soil and Plant Sampling

Sampling on July—August 2021 involved systematic sampling from 15 parks of Kazan and 9 green zones of Zelenodolsk which selected randomly and situated in different districts of these cities. The characteristics of parks and public gardens both cities are listed in Appendix Table 4.1.

Soils and dust (10—20 g) were taken in three replicates from the right corner, middle and left corner of the main/south entrance of each park from 0 to 5 cm depth. Replicates were stored at ca. 4 °C in zip-lock plastic bags prior to transport back to the laboratory. Soil samples were sieved through 1 mm plastic mesh before analysis. The sizes of the inventory area to determine plant diversity were 10 × 10 m^2. Three leaves clover samples and plantain from each of the three population were collected in separate zipper bags from each sites. The distance was approximately 4 m and at least 2-m.

4.2.4 Estimation of Heavy Metals Content in Plants and Soils

Before the estimation, plants and soils were air dried till the constant weight. The homogenized plant tissues (0.1 g) were placed in a glass beaker and dissolved with 10 ml of HNO_3, gradually heated with a rotation speed of 146 ± 1 rpm at 95–98 ˚C for 3 h. After the samples were slightly cooled, 1 ml of 33% H_2O_2 was added and heating of the samples for 1 h. The samples were cooled and 2.5 ml of bi-distilled water was added, filtered and brought to 15 ml (Ji 2012).

For the determination of heavy metals concentration in the urban soil, the homogenized samples (0.5 g) were accurately weighed into 50 ml «Falcon» poly(propylene) centrifuge tubes (pre-cleaned with 10% nitric acid followed by repeated rinsing with bi-distilled water) and 20 ml of 0.1 M HNO_3 solution added to the tubes. The tubes were shaken on a shaker at 200 °C with a rotation speed of 30 ± 1 rpm for 24 h. In each batch, a blank sample containing the same reagents was also subjected to the extraction procedure. The extracts were kept in a fridge at 4 °C prior to ICP-MS analyses (Hutton et al. 2004).

4.2.5 Quantification of Soil Heavy Metal Contamination/ Pollution Index (MPI)

The contamination/pollution index (MPI) was calculated as a ratio of a heavy metals concentration to the permissible standard of set out by EU and WHO top soils standards (Lacatusu 2000; World Health Organization (WHO) 1996).

4.2.6 Estimation of Bacterial Activity and Functional Diversity

To investigate of activity bacterial soil communities, the so-called community level physiological profiling has been demonstrated to be effective at observing spatial changes in microbial communities (Doan et al. 2013). Garland and Mills were the first who used the BIOLOG system to characterize microbial communities in soil (Garland and Mills 1991).

Community level physiological profiles (CLPPs) were assessed by the Biolog EcoPlate™ system (Oxoid, Hampshire, England). Biolog Inc., CA, USA). Each 96-well plate consists of three replicates, each one comprising 31 sole carbon sources and a water blank. Soil suspensions (soil 5 g, distilled water 45 ml) were shaken for 30 min at 250 rpm. Tenfold dilutions were performed and aliquots of 140 μl from a 10^{-4} dilution were inoculated into the microplates. The plates were incubated at 25 °C, and color development in each well was recorded as optical density (OD) at 595 nm with a plate reader at regular 24 h-intervals (Gomez et al. 2006).

With the help of the results received, the following parameters were calculated: average well color development (AWCD) (1) and alpha biodiversity Shannon index (2). The formulae used to calculate the indices are presented below:

$$\mathrm{AWCD} = \sum \frac{A_i - A_0}{31} \tag{4.1}$$

where A_i—the optical density within each well; A_0—is the absorbance value of the control well

$$-\sum p_i * \ln_{p_i} \tag{4.2}$$

where p_i—proportional color development of the well over total color development of all wells of a plate.

4.2.7 Statistical Analysis

All measurements were conducted in three replicates. The indexes of alpha diversity calculated for each community were the Shannon–Weaver Index (Takada 1954) and Simpson index (Simpson 1949). Error bars in the figures represent the standard error of means from the replicates. Statistical significance of differences was analyzed using nonparametric criteria such as Mann–Whitney U test ($p > 0.05$). Statistical analysis was performed in Statistica 10.0 software (StatSoft Inc., Tulsa, OK, USA). Graphs were prepared using Microsoft Excel 2019 MSO (Microsoft, Redmond, WA, USA).

4.3 Result and Discussion

4.3.1 Heavy Metals Concentrations in Soils

The soil has the property of absorbing heavy metals as a result of industrial and anthropogenic activities (Ediene and Umoetok 2017). The main environmental standard for metal soil pollution is so-called maximum permissible limits (MPL), i.e., such a content of a pollutant in the soil that does not affect to animals, plants, microorganisms and natural communities as a whole during constant contact or during interaction over a certain period of time (Ediene and Umoetok 2017; World Health Organization (WHO) 1996). According to WHO prescriptions (1996), the MPL for cadmium, lead, copper, nickel and zinc are 0.8 mg/kg, 85 mg/kg, 36 mg/kg, 68 mg/kg, 50 mg/kg of soil and 0.02 mg/kg, 2 mg/kg, 10 mg/kg, 10 mg/kg, 0.6 mg/kg of plant, respectively. The concentration of heavy metals in soils each parks and public gardens is shown on Fig. 4.1a–e.

Anthropogenic activities such as industrial waste disposals, fertilizer application and sewage sludge disposals on land have led to the accumulation of cadmium (Cd) in soil and its leaching under certain soil and environmental conditions (Alloway 2013). The WHO/FAO recommended maximum tolerable intake of Cd is 70 $\mu g\ day^{-1}$. With the estimated half-life of Cd in soil varying between 15 and 1100 years (Kabata-Pendias 2010), its accumulation in the environment and its entry into the food chain are of great concern. In the present study, the determined concentrations of Cd in soils in Kazan parks were in range of 0.17–0.70 mg/kg, while in Zelenodolsk sites, they varied between 0.06 and 0.39 mg/kg (Fig. 4.1a). The highest Cd concentration was recorded for the sample No. 5 in Kazan. The values for Cd across the sampling points do not exceed the 0.8 mg/kg soil range set by WHO and were below the MPL of 3.0, 1.4 and 400 mg/kg set out by EU, UK and USA Standards, respectively, for Cd in soil (Ediene and Umoetok 2017).

We compared our results with the results of other study which estimated the content of heavy metals in a big city and small cities. According to Li. et al., the average concentration of Cd in the urban soils of Copenhagen was 0.84 mg/kg, which is about 5 times higher than the concentration in the reference soil (Li et al. 2014a). The Cd concentrations in urban parks of the third-largest city in China, Guangzhou were ranged 0.028–2.408 mg/kg (Lu et al. 2007). The study paper Kwaterczak et al. presented results of research of Cd distribution in land on playgrounds situated near busy streets in Cracow (Poland). Samples of sand and soil were collected from the most top layer (0–10 cm). Concentration of examined metal was varied from 1.60 to 2.61 mg/kg. The highest concentrations were found in sampling points near the busiest roads (Aleksander-Kwaterczak and Rajca 2015).

Lead (Pb) is accumulating profoundly in the soil through anthropogenic activities (Mulligan et al. 2001). Being a toxic substance and having high transfer rates (from soil to plant), it is therefore studied broadly especially in context to food safety, quality, and biotesting purposes (Uzu et al. 2009). As follows from the Fig. 4.1b, the highest Pb value was revealed in sample No.15 obtained from Kazan—30 mg/kg,

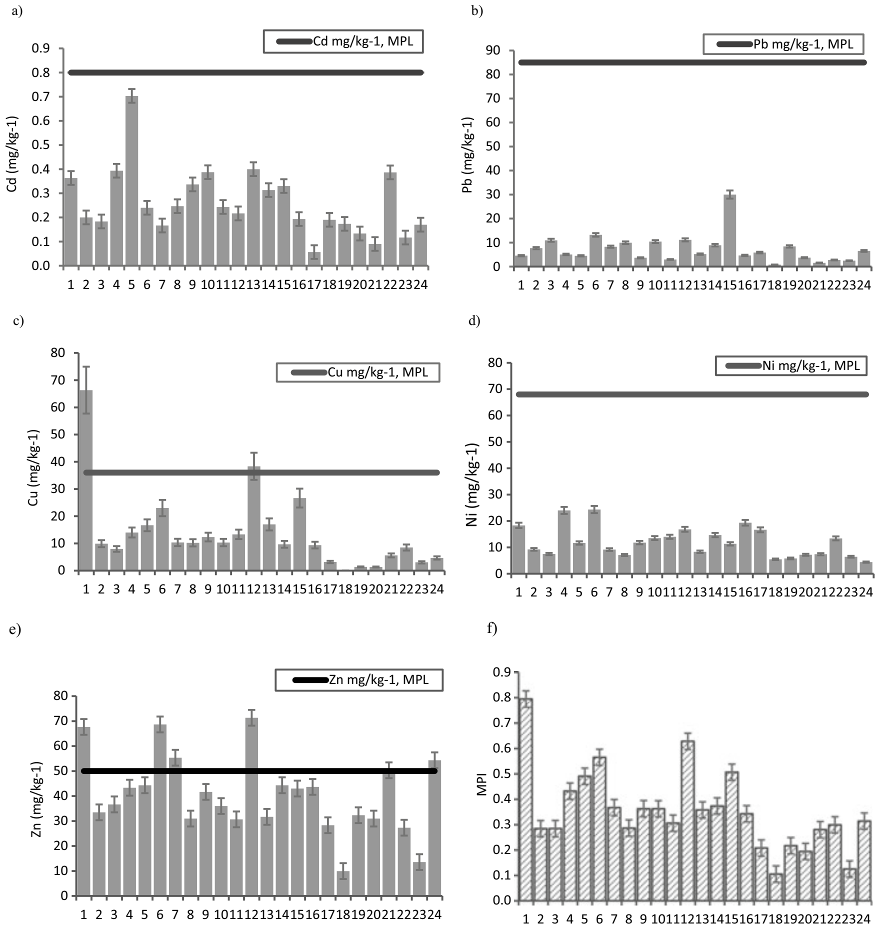

Fig. 4.1 Concentrations of Cd (**a**), Pb (**b**), Cu (**c**), Ni (**d**), Zn (**e**) and contamination/pollution Index (MPI) (**f**) found in urban soils sampled in Kazan (1–15) and Zelenodolsk (9–24) cities (Russia). The black lines indicate the maximum permissible limits according to the WHO standards

the lowest sample No.18 from Zelenodolsk—0.81 mg/kg. The highest value of Pb concentration recorded in the urban park was not higher than the WHO (85 mg/kg) and the 6.4 mg/kg UK standards (70 mg/kg) (Ediene and Umoetok 2017).

Galušková et al. (2014) conducted a study that compared Pb concentrations in Prague and Ostrava parks. The values open areas ranged between 22–213 mg/kg in and 27–125 mg/kg, respectively. The soil pollution may have been contributed by the former brown coal burning in local heating plants (Galušková et al. 2014). According to literature (American Society of Agronomy 1982), highest Pb concentrations were detected in areas with higher population density and more industrial activity. Additionally, Pb pollution may result from the past use of leaded gasoline and emissions from vehicles (Vig et al. 2003). The soil in Durham city's park (North

Carolina, USA) had a lead concentration of 42.1 ± 25.0 mg/kg, which is consistent with other U.S. cities such as Indianapolis and Greensboro, where soils near homes had the highest lead concentration due to exterior house paint. However, in cities like Detroit and New Orleans, soils near roadways pose the highest lead exposure risk due to the contamination of soil being resuspended. Despite this, the soils from city parks and suburban areas showed lower concentrations of metals(loids) that were comparable to the natural levels found in the environment (Wang et al. 2022).

Copper (Cu) is considered as a micronutrient for plants however, it may be toxic in excess quantities (Ediene and Umoetok 2017). Cu particulates are released into the atmosphere by windblown dust and anthropogenic sources, including transport and industrial emissions. Evaluation of Cu in soils of parks and public gardens in Kazan (Fig. 4.1c) showed that values were ranged from 7.97 to 66.33 mg/kg, while the Zelenodolsk soils recorded a mean of 4.12 mg/kg. In soil samples No.1 and No.12, concentrations of Cu were recorded above the maximum permissible limit set by WHO, but were below the MPL of 140, 1.4 and 3.0 mg/kg set out by EU, UK and USA, respectively.

According to Paltseva et al., the concentration of Cu in urban soils (0–20 cm) in cities with over 1 Mio citizens such as Vienna, Moscow, Mumbai (Bombay) was equaled to: 18 mg/kg, 30 mg/kg and 147 mg/kg, respectively. At the same time, in cities with less than 1 Mio people, this value was recorded to 24 mg/kg in Oslo (Tijhuis et al. 2002) and 16 mg/kg in New Orleans (Mielke et al. 2019). In general, in European cities, the concentration of Cu was lower than recommended by WHO, with the exception of the soils from Mumbai (Bombay) (Wang et al. 2022). High concentrations of Cu in the parks of Kazan may be due to the presence in the region of a developed oil production and oil refining industry.

Nickel (Ni) has been considered to be an essential trace element for human and animal health (Nazir et al. 2015). The concentration values obtained for Ni at the urban green areas (Fig. 4.1d) revealed a range of 7.09–24.33 mg/kg, while a mean of 9.56 mg/kg was recorded in Zelenodolsk parks. The overall results indicate that in all the collected soil samples, there was low concentration of Ni found.

According to the literature (Zhong and Jiang 2017), contamination of Ni in urban soils of small cities is higher than in big ones. The value of Ni in Berlin and Melbourne was recorded 8 mg/kg and 15 mg/kg, respectively. While in soils in Baltimore and Novi Sad and Izmit (Turkey), it was 2.8, 28.7 and 39 mg/kg. This suggests that although heavy metal contamination of soil and water has been limited by some government policies, historically produced heavy metals are retained in soil due to their perdurability and degradation durability. In some places, the concentration of nickel has surpassed even the Chinese soil criteria (grade II), and its concentrations also exceed the national quality soil standards (Chen et al. 2020).

Zinc (Zn) is one of the important trace elements that play a vital role in the physiological and metabolic process of many organisms. Nevertheless, higher concentrations of Zn can be toxic to the organism (Nazir et al. 2015).

Concentration of Zn in soils samples from Kazan ranged between 30.67 mg/kg to 71.33 mg/kg and 9.97 mg/kg to 54.33 mg/kg obtained from Zelenodolsk, respectively

(Fig. 4.1e). The highest value of 71.33 mg/kg was recorded at No.12, closely followed by values of 68.67 mg/kg of No. 6 and 67.67 mg/kg from the ground No.1.

The quantity of Zn observed at Kazan parks and public gardens greatly exceeded the value of 50 mg/kg recommended by WHO. The level of Zn in sample No. 24 from Zelenodolsk was as well as higher than WHO's recommended limit—54.33 mg/kg.

According to Lee with co-authors, in Hong Kong (about 7.4 Mio citizens), concentrations of Zn ranged from 23 to 930 mg/kg, while in Karachi (about 14 Mio people), it was 99.5 mg/kg (Karim and Qureshi 2014). In small cities such as Zagreb (Croatia), soil contamination with Zn averaged 70 mg/kg (Romic and Romic 2003). The probable sources of Zn contamination primarily include wastewater discharges, followed by automobile transportation and unauthorized dumping of household waste.

To determine the pollution loading of the soil at the various sampling points in parks and public gardens, the MPI was used. According to Lacatusu, the MPI index is the ratio of analyzed concentration of the heavy metal to the maximum allowable limit in the soil (Lacatusu 2000). Despite on the fact that the content of Zn and Cu was exceeded the level recommended by WHO in 5 and 2 parks of 24, respectively, the MPI index in all samples did not exceed 1.0. Therefore, that the level of metal pollution is acceptable. It should be noted though, that the average value of MPI for all metals was higher in Kazan than that in Zelenodolsk (Fig. 4.1f).

4.3.2 Heavy Metals Concentrations in Plants

According to the literature, there is a certain relationship between the chemical composition of plants and the elemental composition of the environment. Different plant parts contain different heavy metals quantities; the highest quantities are in roots and leaves, and the lowest are in fruits and seeds. Some plants species were found to have lower tolerance to toxic metals uptake in parks of soil as they were found to accumulate high concentrations of Cd, Cu, Ni, Pb and Zn (Guala et al. 2010).

In the present study, metals were determined in the two plant species present in all the parks—plantain (*Plantago major* L.) and white clover (*Trifolium repens* L.). The results are presented on Fig. 4.2 and compared with the corresponding WHO standards for plants (Bani et al. 2015). It was found that the concentration of Ni was below the limits in all the plant samples. The concentrations of Cd, Pb and Cu exceeded the limits in 5, 1 and 1 samples, respectively. And the concentrations of Pb were by 10–25 times above the limits in all the plant samples analyzed.

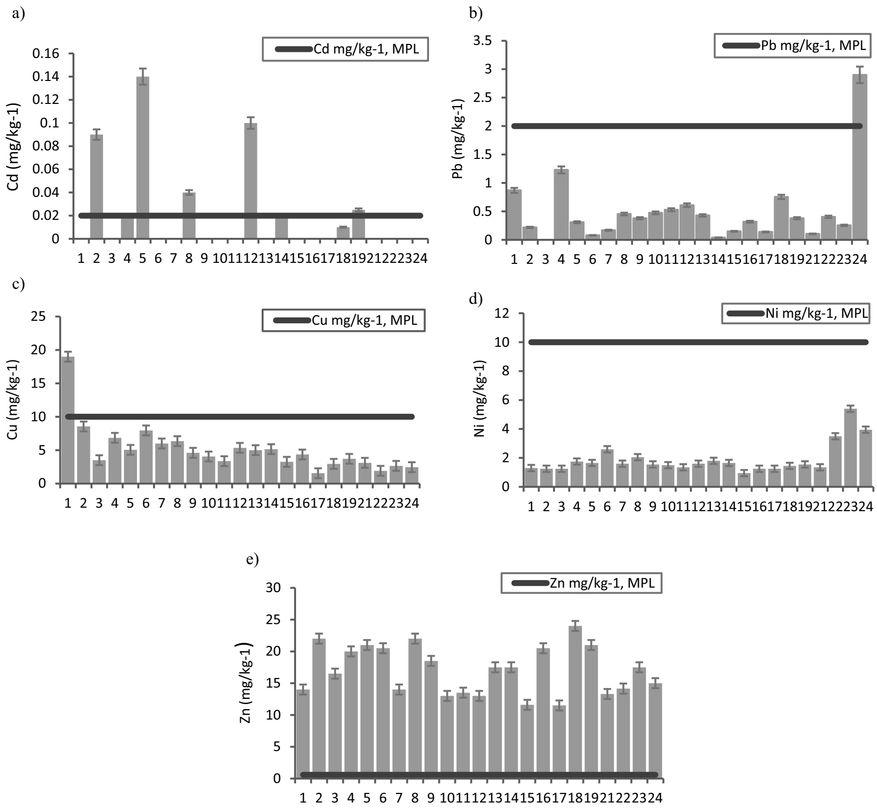

Fig. 4.2 Concentrations of Cu (**a**), Pb (**b**), Cu (**c**), Ni (**d**), Zn (**e**) and Transfer Factor (TF) (Appendix Fig. 4.5) found in plants samples in Kazan (1–15) and Zelenodolsk (9–24) cities (Russia). The black lines indicate the maximum permissible value according to the WHO standards

4.3.3 Plant Diversity and Cover at Various Study Sites

Species diversity is a crucial index mostly employed to evaluate the sustainability at various ecosystem scales and is a multifaceted factor used to estimate a variety of plant indicators (Eshaghi et al. 2009; Ricotta 2005).

In our study, we assessed the biodiversity of plants in parks and squares in Kazan and Zelenodolsk. The amount of grass coverage on the site was determined by the relative occurrence of each species and the number of species in each park.

The Shannon–Wiener index across the parks ranged from 1.51 to 2.43 of Kazan, and from 0 to 2.53 of Zelenodolsk (see Fig. 4.3). According to the literature, urban parks included annual and perennial plants species such as *Zoysia species* (with no petals), *Trifolium repens* (with white petals) and with subcomponent species such as *Sonchus oleraceus, Oxalis corniculate, Cirsium japonicum, Trifolium pretense and Ajuga nipponensis* in Yokohama (Japan) (Tomitaka et al. 2021). In the study,

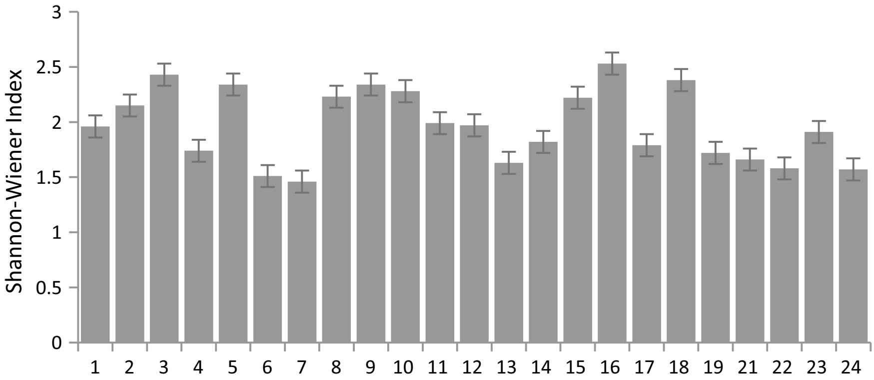

Fig. 4.3 Shannon–Wiener index indicating plant biodiversity in urban green zones in Kazan and Zelenodolsk

Muratet et al. noted that in the park «Parc des Buttes Chaumont» (France), that covers 25 ha. among the native species recorded in the park, the majority were spontaneous species generally considered to be weeds, including *Trifolium repens, Hordeum murinum* and *Veronica chamaedrys* (Scharenbroch et al. 2005). Dominant species in Kazan were *Achillea millefolium, Arctium lappa, Chenopodium album, Convolvulus arvensis, Plantago major and Poa trivialis.* Dominant species in satellite city were *Achillea millefolium, Trifolium repens, Artemisia vulgaris, Cichorium intybus, Dactylis glomerata and Plantago major.* Dominant species in Zelenodolsk were the same. No significant differences in the species list as well as in the level of Shannon–Wiener indexes between the two cities were found.

We made in attempt to compare the level of metals' pollution of soils with the plant diversity indexes in urban green zones. However, no correlation between the MPI and Shannon–Wiener index was found.

4.3.4 Bacterial Activity and Functional Diversity in the Soils from Urban Green Zones

Currently, many ways to estimate the state of the microbiomes in the soils are used. These might be wide range of methods, from estimations of soil microbial biomass and respiration to analysis of soil microbial diversity using next generation sequencing methods. All these methods have their own advantages and disadvantages and should be chosen according to the investigation's main goal. In our study, quick, reproducible method semi-independent on climate conditions were required, and the Biolog Ecoplate® profiling met the requirements (Use of Biolog for the community level physiological profiling (CLPP) of). Using this method, two characteristics of the soil microbial communities were determined—(i) the AWCD indicating the

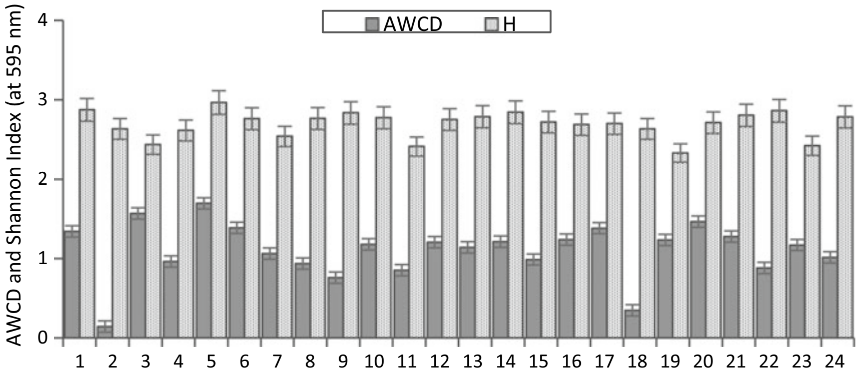

Fig. 4.4 AWCD and the biodiversity Shannon index of microbial communities in the soils of urban green zones as revealed by Biolog Ecoplate® method

intensity of microbial decomposition of different organic substrates means overall microbial activity in the soil samples; and (ii) the Shannon H-index indicating the functional diversity of the microbial community (Fig. 4.4). (Li et al. 2007; Monard et al. 2016).

The highest AWCD index was found in sample No. 5 (1.695 ± 0.340), the lowest one—in sample No. 2 (0.143 ± 0.250), while no correlation was revealed between the level of metal pollution or vegetation diversity and AWCD. The values received correspond with the data obtained by other authors which analyzed soil samples from native vegetation site (roadside verge) and topsoil (0–15 cm deep) (Liu et al. 2012; Xue et al. 2008). It can be suggested that the differences in AWCD are due to differences in organic matter content in the samples, indeed, according to high microbial counts and diversity are usually attributed to rich soils. Thus, in the investigations carried out by Dobrovolskaya et al. and Kovda et al., tight direct correlation between the biological activity of microorganisms and organic matter content in soil was shown. Shannon index showing the level of functional alpha diversity in the community ranged between 2.32 and 2.96. No correlation between the Shannon indices and the AWCD or the level of metal pollution of soil was found (Kumar et al. 2017; Li et al. 2013).

4.4 Conclusion

It can be concluded that in overall, soils from urban green zones in a large (Kazan) and satellite (Zelenodolsk) cities contain Pb, Zn, Cu, Cd and Ni in the concentrations below the WHO standards. Unique cases of exceeding were determined for Cd, Cu and Zn, but the pollution was not complex.

No differences between the green zones and in large and satellite city (biodiversity of plants and microorganisms) as well as no correlation between the metal content and diversity indices were found. It was found that the migration of Pb, Ni, Cu for plantain and white clover don't as intense as in the case of Zn and Cd. Perhaps these urban plants, which grow everywhere, are able to accumulate these metals and also get on the leaves with urban dust.

The absence of a direct stable relationship allows us to conclude that a comprehensive assessment of the state of green areas is applicable, where the content of heavy metals is lower and does not have a significant impact on biodiversity. Accordingly, these measures relate not only to human health, but also more indirect aspects of the quality of life: the structural integrity of the surrounding ecosystems. This work is part of a large research cycle and measurements will be made for other environmental components.

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Appendix

See Table 4.1 and Fig. 4.5.

Table 4.1 Characteristics of urban green space at Kazan and Zelenodolsk (Russia)

No	Park name	Location coordinates	Area, % Natural, manicured, unkempt	Park age	Size, m^2	Park description
1	M. Karima public garden	55.763388° 49.14939°	40 50 10	1	5500	Public garden near a car highway, people walk through every day
2	Public garden(Ippodromnaya street)	55.773302° 49.147741°	60 10 30	< 10	2680	Small public garden, people walk through every day, next to the kindergarten
3	Public garden of Labour Glory	55.755792° 49.122546°	50 10 40	25–50	6500	Local garden next to the Kazan Synthetic Rubber Plant (Founded in 1936), realized for the workers. The park is located in a remote area of the city
4	Park Molodozhenov	55.774184° 49.09985°	55 30 15	25–50	25,000	It rather a big park, but not popular. Next to the river port, there are no playgrounds in the park. This is a remote area of the city
5	Gorkiy Central Park of Culture and Recreation	55.799874° 49.147063°	60 40 0	85	244,794	Quite big, will require 2–3 h at least to get around. It seems like forest than urban park. Clean and cozy, there are many playgrounds for kids, many places to eat, great for picnic

(continued)

Table 4.1 (continued)

No	Park name	Location coordinates	Area, % Natural, manicured, unkempt	Park age	Size, m^2	Park description
6	Kirov Garden	55.785683° 49.112507°	30 40 30	61	10,286	Central public garden with the fountain, a lot of people walk through every day. Clean park, located next to an elite residential complex
7	Shkolnikov public garden	55.822214° 49.116643°	40 50 10	5	13,637	Near to the school, there are small lake too. Many types of ornamental shrubs are grown in the park. The lawn is mowed regularly
8	«Sosnovaya Roshcha» Park	55.824225° 49.089368°	70 30 0	~ 50	86,011	Clean and cozy, there are many playgrounds for kids, comfortable for walking and doing yoga
9	«Aktash» Park	55.794808° 49.230825°	40 15 45	4	9144	Small park next to multi-story apartments and the private sector. it‘s not popular park. There are dog‘s training ground too
10	«Muzykalnyi» public garden	55.790177° 49.222738°	15 70 15	~ 10	10,117	The public garden is located next to the sports center; many young people train here. Football, basketball playgrounds. Near garden the multi-story buildings

(continued)

Table 4.1 (continued)

No	Park name	Location coordinates	Area, % Natural, manicured, unkempt	Park age	Size, m^2	Park description
11	«Dubovyi kardon» public garden	55.750428° 49.236008°	30 10 60	~ 15	5333	Small public garden, only oak trees grow in this park, there are no playgrounds
12	Tat'yanin public garden	55.783665° 49.110683°	30 10 60	< 10	1475	Public garden near a car highway, there are no playgrounds, near to church
13	«Millenium» Park	55.78359° 49.123183°	15 65 20	16	52,172	Park is located at the center of Kazan. The big park with fountain. The park has lots of benches to relax on and admire the view. No playgrounds
14	Public garden (Peterburgskaya street)	55.782852° 49.130877°	30 40 30	10	1957	Small public garden next to five-story office building
15	Leninskiy Garden	55.794019° 49.123481°	30 50 20	131	25,608	Park is located at the center of Kazan. Leninsky park is situated next to university. There is a beautiful fountain in the middle of the park. No playgrounds
16	Memorial of Memory and Glory (Aisha village, Zelenodolsk region)	55.869668° 48.629383°	35 15 50	–	4172	Small public garden in the center of Aisha village

(continued)

Table 4.1 (continued)

No	Park name	Location coordinates	Area, % Natural, manicured, unkempt	Park age	Size, m^2	Park description
17	Public garden next to multistorey building (Komarova street)	55.85801° 48.564893°	30	–	3142	Public garden in the center of Zelenodolsk, there is a little fountain
			10			
			60			
18	N.Altynov public garden	55.854286° 48.553947°	40	6	6533	This small park famous for a tank weighing 40 tons, which stand there. Next to multi-story buildings
			20			
			40			
19	Green area opposite «Temple of the First Apostles Peter and Paul»	55.871510° 48.548155°	15	130	3137	Small green area next to the temple
			85			
			0			
20	Temple of the First Apostles Peter and Paul	55.871269° 48.547893°	10	130	4489	Area of the temple is small but well-organized
			90			
			0			
21	Public park (Kosmonavtov street)	55.848502° 48.505101°	15	> 10	~ 7000	Most-visited park in Zelenodolsk
			85			
			0			
22	Summer cafe (Karl Marks street)	55.849247° 48.510100°	40	> 10	300	It is a part of big park. This summer cafe has been closed for a long time. So no one walks here, as the grass is tall
			0			
			60			

(continued)

Table 4.1 (continued)

No	Park name	Location coordinates	Area, % Natural, manicured, unkempt	Park age	Size, m^2	Park description
23	Public park (near lake)	55.851756° 48.508549°	40	5–10	~ 2500	This green area can hardly be called a city park. This place is not completed, has a bench and gazebo, but it is difficult to get here. The park is very unkempt
			0			
			60			
24	Park «Rodina»	55.845695° 48.490492°	30	–	22,040	Clean and cozy, there are many playgrounds for kids, comfortable for walking. Next to school
			70			
			0			

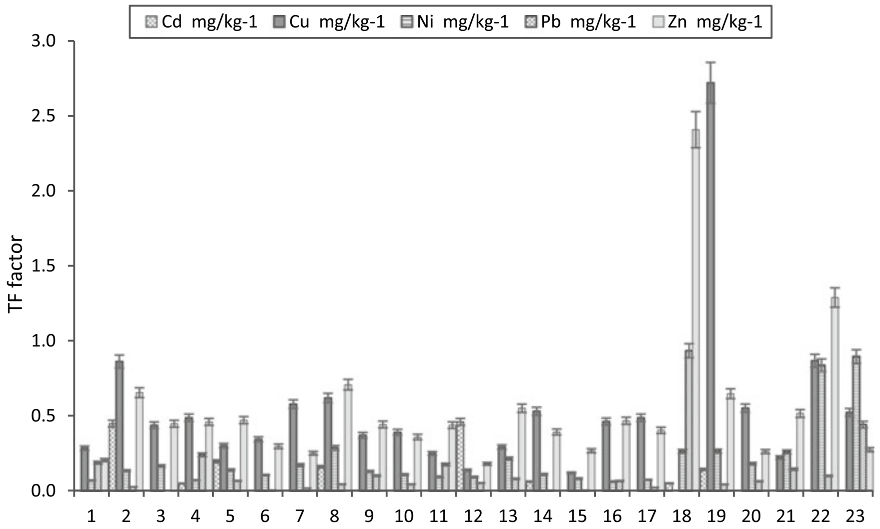

Fig. 4.5 Transfer factor (TF) found in plants samples in Kazan (1–15) and Zelenodolsk (9–24) cities (Russia)

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Chapter 5
Assessment of Urban Soil Pollution by Heavy Metals (Russian Federation, Republic of Bashkortostan)

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Abstract Introduction. This chapter presents the results of a study of the quality of soil cover in cities located on the territory of the mining districts of the Trans-Urals of the Republic of Bashkortostan. The object of the study was the soils of the lands of various purposes of the cities of Uchaly, Sibay and Baymak. During the study of the soils of industrial zones, samples were selected adjacent to the dumps and tailings dumps of mining production, at a distance of up to 500 m. The recreational zone included the territories of parks, all residential neighborhoods where the city's population lives were included in the residential zone. The territories of collective gardens located near pollution sources were also studied. Material and methods. The total content of heavy metals was determined by atomic absorption method. To assess the degree of soil pollution, the values of the maximum permissible concentrations and the regional geochemical background generally accepted in ecology were used. To assess the degree of soil contamination, the total Zc index was calculated according to the formula of Yu. E. Saet. Results. As a result of studies, in all studied soil samples, an excess of maximum permissible concentration (MPC) in total forms was revealed in terms of Cu, Zn, in some cases Mn, Cd, Co. The soils of industrial territories are the most polluted. According to the general indicator Zc, calculated by the total content of heavy metals, urban soils of all types of land have an acceptable category of pollution. Conclusion. The level of polyelement pollution of the soil cover of urbanized areas in the conditions of the mining region depends on the intended purpose of urban lands. Soils of industrial zones, which are located close to industrial enterprises, are subject to the greatest pollution. In all the studied cities, the lack of sanitary protection zones of enterprises led to the development of residential buildings. In these residential microdistricts, there are household plots where the population grows vegetables and fruit and berry crops.

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Keywords Heavy metals · Mining industry · Trans-Urals of the Republic of Bashkortostan

5.1 Introduction

The Republic of Bashkortostan is a subject of the Russian Federation, which is part of the Volga Federal District. The Republic is located in the southern part of the Ural Mountains, on the border of Europe and Asia. It occupies most of the Southern Urals and the adjacent plains of the Bashkir Cis-Urals and the high-plain strip of the Bashkir Trans-Urals.

The southeastern territory of the republic or the Trans-Ural zone is the center of the mining and manufacturing industries. On its territory, there are a number of administrative districts and cities: Baymaksky (with the cities of Sibay and Baymak), Uchalinsky (with the city of Uchaly), Khaibullinsky, Abzelilovsky, Burzyansky, Zilairsky, Zianchurinsky (Suyundukov et al. 2014).

In terms of relief and geology, the region represents the fourth belt of the Southern Urals, enriched with ore-bearing igneous rocks. The climate of the territory is sharply continental. Winters are cold and snowless, summers are warm and dry.

Industrial activity is a source of negative impact on the environment, including the soil cover (Kovalsky 1991; Ilyin 1990). The ore is mined by open and underground methods. As a result of the functioning of these enterprises, technogenic provinces were formed, with a high content of toxic elements in the soils. An anomalous content of chemical elements was found in the soils of the environs of more than 40 depleted deposits (Belan 1998). As a result of mining and enrichment of ore material, huge masses of rocks are extracted and processed. Some of them are used, and the remaining processed raw materials are stored in dumps and tailings. Huge dumps are sources of mineral dust and effluents, which are characterized by high concentrations of toxic elements. Every year, about 1000 tons of dust is blown off the dumps, which includes about 20 different toxic elements (Opekunova et al. 2002; Fatkullin 2002). Roshydromet data, presented in the State Report “On the state and protection of the environment of the Russian Federation in 2016”, emphasize that Sibay and Baymak are included in the list of points in the Russian Federation that fall into the moderately hazardous category of soil pollution. The total indicator of pollution (Zc) of the soil cover in a kilometer zone from the source of pollution is assessed as hazardous. Priority pollutants include copper, cadmium, zinc and lead (State Report "On the State and environmental protection of the Russian Federation in 2016 2017). In the studies of (Opekunova et al. 2002), it is emphasized that in the area of the tailing dump of the Bashkir copper-sulfur plant, which is located in the city of Sibay, an excess of approximately permissible concentrations for copper by 1.2–2.4 times, zinc—1.6–2.6 times, arsenic—1.1–1.8 times. The high values of copper, zinc, iron and sometimes cadmium in soils adjacent to mining enterprises are confirmed by the studies of (Shagieva and Suyundukov 2001; Suyundukov et al. 2013; Baimova et al. 2007).

The soils around the dumps of the Sibai quarry have a high content of total forms of copper, zinc, iron, manganese, cadmium and mobile forms of cadmium, copper and zinc. Evaluation of soils by total damage index Zc by detection total forms are rated as "moderately dangerous", for mobile—"dangerous" (Abakumov, et al. 2016). Polyelement pollution of the urban environment in man-made areas, the association of lead, cadmium, arsenic, zinc, copper and other toxic elements. There is a high risk of metal poisoning in the human and animal body, entering the body with food and water, often deposited in organs and tissues, which will be a potential hazard to public health (Rafikova et al. 2017; Teregulova et al. 2009).

The concentration levels of heavy metals in the dry matter of plants growing in the soils of the Trans-Ural zone of the Republic of Bashkortostan in some cases exceeded the permissible limits, in particular lead (more than 10 times), cadmium (more than 6 times) and zinc (2 times) (Semenova et al. 2016).

The soil cover of household and collective gardens in the town of Sibay is characterized by a high content of acid-soluble and mobile forms of copper, zinc, lead and cadmium, within a radius of 5 km from the industrial zone. Suyundukov et al. (2013) noted that for the majority of cultivated plants, an excess content of zinc, a deficiency of iron and manganese was revealed. Belan (1998) states that for the town of Uchaly, out of the total amount of toxic elements entering the human body, local vegetables receive 9% of copper and zinc, cadmium—40%, lead—up to 73%. This is many times higher than the recommended standards.

To date, quite a few works have been published showing the features environmentally dependent diseases of the population of the mining region (Zakharenkov et al. 2015; Savilov et al. 2016; Vekovshinina et al. 2018). So, in the work of Starovoy et al. (1998), there is a high level of overall morbidity of the population, the spread of diseases of the circulatory and nervous systems, respiratory and digestive organs, skin inflammation, an increase is observed by 1.3–2.5 times. In children, there is an increase of 1.5–3.0 times in diseases of the respiratory system, digestion, endocrine system and metabolism, nervous system and sensory organs. In the works of L.N. Belan in the Uchaly district, there is a high level, compared with the average republican indicators, of primary morbidity in the adult population, diseases of the endocrine system, blood and hematopoietic organs, circulatory system, diseases of the nervous system and oncological diseases (Belan 1998). In the study of Shaykhlislamova et al. (2017), the features of diseases of workers of the Uchalinsky mining and processing plant showed violations of the musculoskeletal system of workers. In the blood of residents of the town Uchaly, there is an excess of the norm for cadmium and nickel and a deficit for copper, zinc and manganese. High levels of chromium, zinc, lead, copper, arsenic, nickel, and manganese were found in hair (Suleymanov et al. 2008). An excess of iron, manganese and zinc is also noted in the hair of children in the Baimaksky district.

Excess Fe, Mn and Zn were found in hair samples of the children's population of the Baymak district: in 100, 72.5 and 54.5% of cases, respectively, as well as excess Ni, Cd and Pb in a small number of children (in 18.2, 13.6 and 9.1% of the studied population, respectively). Deficiency of Cu and Co, essential trace elements for human health, was found in 27.3% of the surveyed population (Semenova et al. 2018).

The specificity of soil pollution with the development of the mining industry requires research on hygienic control and the development of preventive measures.

The aim of the study is to study the ecological and geochemical state of urbanized soils in the mining region of the Bashkir Trans-Urals.

5.2 Materials and Methods

The research was carried out on the territory of towns Sibay, Baymak and Uchaly. In the period from 2016 to 2022, soil sampling was carried out on the territory of industrial, recreational and residential areas of the city, as well as in collective gardens located in suburban areas. The soil cover of industrial zones is mainly bulk (technogenic surface formations), although chemically transformed natural soils of varying degrees violations persisted in the peripheral parts of the industrial zone.

Soil samples were taken according to the methods generally accepted in geochemistry and soil science. At each polygon, soil and soil samples were taken from the upper layer of the soil cover (from 0 to 20 cm) at three equidistant points. These samples were thoroughly mixed and formed the average sample. Soil samples were ground in a mortar and passed through a sieve with a hole diameter of 1 mm. The total content of heavy metals was determined by atomic absorption method. To assess the degree of soil contamination with heavy metals for copper, zinc, nickel, manganese, lead, the values of MPC or ODC generally accepted in ecology for soils close to neutral, neutral (loamy and clay), pH KCl > 5.5 (MPC and ODC 2006), cobalt and cadmium content regional background values were used (Usmanov et al. 2014; Taipova and Semenova 2012). To assess the level of soil contamination with heavy metals, the total Z_c index was calculated for formula proposed by Saet et al. (1990):

$$Z_c = \sum \left(K_i/K_f\right) - (n - 1);$$

where Z_c is the total indicator of heavy metal pollution; K_i–specific element concentration in soil (mg/kg); K_f—is the background concentration of a particular element (mg/kg); n—is the number of summed elements.

The following critical values are distinguished, which characterize the level of soil contamination with toxic metals: permissible contamination ($Z_c < 16$); moderately dangerous ($16 < Z_c < 32$); especially dangerous ($32 < Z_c < 128$); extremely dangerous at ($Z_c > 128$).

5.3 Results

In the conditions of the city, the conditions of soil formation regimes, which determine urban pedogenesis, change. The soil cover of cities is represented by urbanozems. In the towns of Sibay and Uchaly, they make up to 60–70% of the area, in Baimak up to 40%. The recreational zone accounts for about 15% of the territory, they are characterized by minimal anthropogenic impact.

Figure 5.1 (A, B) shows the content of total forms of heavy metals in the soil cover of towns

Surveys of the soil cover of the functional zones of towns showed the excess of the maximum permissible concentrations for copper, zinc, in some cases for manganese

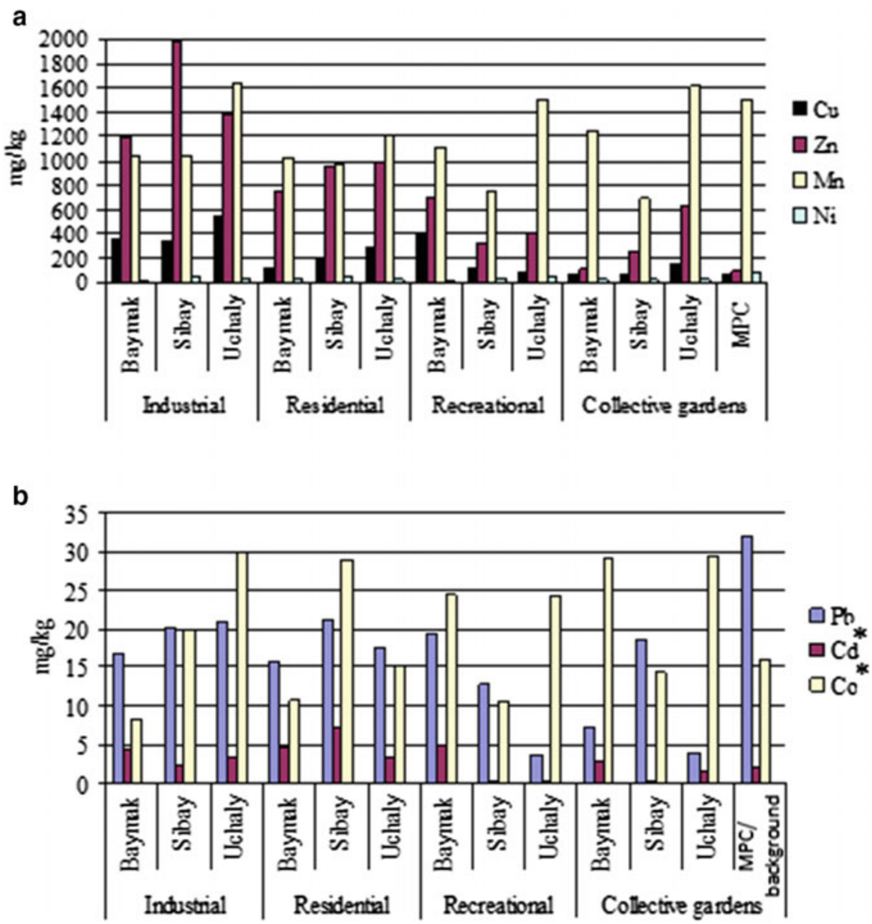

Fig. 5.1 Concentrations of total forms of heavy metals in the soil cover of towns in the Trans-Urals. Note. For Cu, Zn, Mn, Ni, Pb—MPC, for Co, Cd—background values

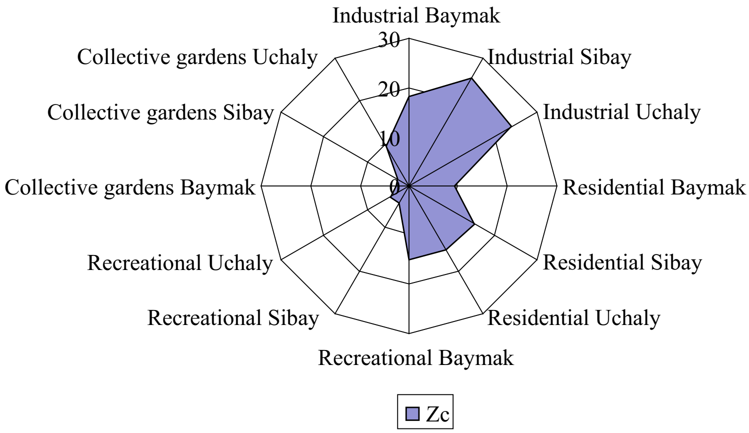

Fig. 5.2 The total indicator of contamination with heavy metals Z_c of urban soils in the mining area in terms of total forms

and cadmium. Exceeding the permissible concentrations by 9.7 times, manganese by 1.9, cobalt by 1.1 was found in the soils of the industrial zone of the town of Uchaly. In the town of Sibay, an excess of permissible norms for zinc by 19.8 times and for cadmium by 3.6 times was revealed in a residential area located in close proximity to the dumps of the quarry. Calculations of the pollution index according to Saet (Z_c) showed that the soils of all studied functional zones in terms of total content belong to the permissible category of pollution. The level of contamination of the surface layer of the soil with heavy metals in all the studied towns is higher in industrial areas, then in residential areas (Fig. 5.2).

In the residential areas of Uchaly and Sibay, a high content of toxic metals was found in suburban areas (Uchaly-2, Buransy in Uchaly, Zoloto and Gorny in Sibay), which are located along quarry dumps. In the town of Baymak, high concentrations of toxic metals have been found in a recreational area. There is a large city park located along the city, on its territory there is a Baimak foundry and mechanical plant with a huge warehouse (more than 1 million tons) of metallurgical slag, the sources of which were former copper smelters. They are sources of polyelement pollution of soils.

5.4 Discussion

According to the results of this study and the data presented in the reports of the Territorial Committee of the Ministry of Ecology of the Republic of Bashkortostan, the main sources of pollution of the urban environment in the Trans-Urals are motor vehicles and mining enterprises that determine the flow of heavy metals into various environmental objects. The priority polluting metals in the soils of Sibay, Baymak and Uchaly are Zn, Cu and Cd, in some cases Mn, the level of accumulation and contrast of the areal distribution of which is determined by the functional use of the territory. A comparative analysis of soil pollution inside urban areas showed that the most polluted soils are located in the center and other old areas of the city located directly near industrial enterprises. Relatively clean are the soils of recreational areas of Uchay.

The study of the specificity of polyelement pollution with heavy metals of urban soils in the mining region of the Trans-Urals of Bashkortostan confirms the opinion of other researchers about the presence of high mosaicity (Usmanov et al. 2014; Taipova and Semenova 2012). Several reasons contribute to this. The presence of different geochemical provinces, which differ in the elemental composition of rocks. Dispersion of heavy metals by aerogenic means during the extraction, transportation of raw materials, storage of waste in the course of mining enterprises. Movement of substrates with a high content of toxic metals over landscape elements as a result of water and wind erosion. For cities, additional sources of toxic metals are the presence of vehicles, highways, thermal power plants and other facilities.

5.5 Conclusion

The level of polyelement pollution of the soil cover of urbanized areas in the conditions of the mining region depends on the intended purpose of urban lands. Soils of industrial zones, which are located close to industrial enterprises, are subject to the greatest pollution. In all the studied cities, the lack of sanitary protection zones of enterprises led to the development of residential buildings. In these residential microdistricts, there are household plots where the population grows vegetables and fruit and berry crops.

When solving the problems associated with polyelement pollution of urban soils with heavy metals and improving the ecological situation of the urban environment, it is necessary to conduct periodic studies to control the quality of soils in functional zones for various purposes. The obtained data should be taken into account when planning land use, placing children's educational, sports and medical institutions, as well as when developing strategies for carrying out work on the reclamation of disturbed and polluted lands.

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Chapter 6
Distribution of Microelements in the Mineral Part of Chernozems Under Different Types of Plant Communities in the Rostov Agglomeration

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Abstract The features of the main trace elements distribution in the natural soils profile of the Rostov agglomeration under various types of woody plantings have been studied. Artificial forest communities in the steppe zone create conditions for the accumulation of zinc and lead in the upper humus-accumulative horizons and copper at the level of the carbonate barrier in the illuvial-carbonate horizons of chernozem.

Keywords Microelements · Calcic Chernozems · Park and recreational areas of the city

6.1 Introduction

Urban soils are same unique natural buffer and at the same time represent an area for the accumulation of major pollutants (Gorbov et al. 2015). Currently, the process of urbanization and related environmental problems cause the need for indication and assessment of the urban environment state (Korel'skaya and Popova 2012). Human influence on the soil cover of urban areas leads to the emergence of technogenic geochemical anomalies, which necessitates the inventory and systematics of such soils, as well as the study of the features of their ecological functions (Sereda et al. 2018).

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The influence of artificial woods, so-called "forest belts" on the characteristic of chernozem was studied in the "Stone Steppe" by Dokuchaev and noted in subsequent scientific work by others scientists (Gromovik et al. 2013; Trofimov et al. 2013; Ukenov and Verkhoshentseva 2017). However, the widely discussed problem of assessing changes in the basic properties of chernozems under the influence of atypical woody vegetation for them remains unresolved (Cheverdin et al. 2014).

The Rostov region is located in the steppe zone, which is the most transformed type of zonal landscapes of Northern Eurasia, but even with a significant anthropogenic load on natural complexes, it is distinguished by the preservation of a relatively high level of biodiversity (Fedyaeva et al. 2021). To create a microclimate in the steppe zone around cities, tree arrays are planted, which can also be considered as an anthropogenic impact on the soils of the urban environment. The planting of trees atypical for the steppe is accompanied by a series of changes. As tree crops grow and develop, forest litter begins to form in the surface horizons of these soils, which is a medium for the accumulation of atmospheric dust and heavy metals contained in it (Salnik et al. 2021).

With the growth and development of tree crops, the ecological conditions of functioning of steppe soils change, biological diversity increases, the water balance of the territory undergoes a significant change and, ultimately, the direction of the flow of natural soil-forming processes (Cheverdin et al. 2014). As a consequence, descending moisture currents begin to dominate in such soils, the distribution of humus in the soil profile and the depth of calcium carbonate occurrence change (Gorbov 2018).

The purpose of our research is to assess changes in the microelements composition of individual horizons of Calcic Chernozem under the influence of woody plant associations.

The aim of the study was to study the accumulation and profile distribution of microelements in soils under the influence of tree associations in the agglomeration conditions of the steppe zone.

6.2 Objects and Methods

The objects of the study were the natural soils of the park and recreational zones of the Rostov agglomeration, applying to one subtype—Calcic Chernozems, experiencing minimal influence of the anthropogenic factor (the soil cover has been preserved since the period of agrogenic use, the absence of modern human economic activity)—Temernitsky grove (soil profile cut 2103p), Shchepkin forest (soil profile cut 2101p), the Botanical Garden of the Southern Federal University—nursery of spruce planting (soil profile cut 2005p) and fallow (soil profile cut 2002p). Geobotanical descriptions were carried out for each forest park to assess species biodiversity. The projective coverage of a single geobotanical description site was determined visually (Fig. 6.1).

The total content of microelements in soils, namely Ni, Cu, Zn, and Pb was determined using an X-ray spectrometer "Spectroscan MAKS-GVM" (Spectron,

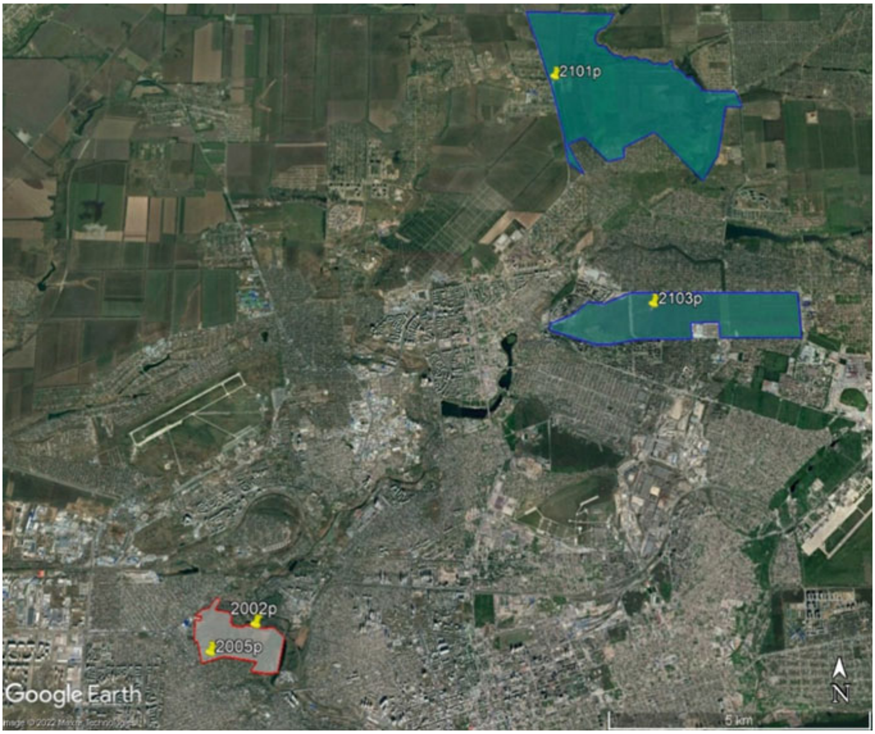

Fig. 6.1 Map of the location of the studied soil profiles: under steppe vegetation (fallow) (2002p) and under forest massive (2103p—Temernitskaya grove; 2101p—Shchepkinsky forest; 2005p—Spruce tree nursery)

Russia) in accordance with the certified methodology. The dried soil samples are crushed in an agate mortar to particle size of $\leq 250\ \mu m$. Boric acid is poured into a mold and a cup of at least 3 mm depth is formed using a shaped punch. The shaped punch is removed, the sample material is poured and pressed with the smooth punch. The tablet is placed into the sample holder and then into the spectrometer. The samples are analyzed automatically according to the preset program (16.1.42-04 2010). Statistical data processing was performed using the software Statistica for Windows 10.0, MS Exel.

The maximum species diversity of vegetation under geobotanical description was found on the territory of the Temernitskaya grove. It is dominated by representatives of families *Fabaceae* and *Aceraceae* (*Robinia pseudoacacia* L., *Gleditsia triacanthos* L., *Acer negundo* L., *A. tataricum* L., *Amorpha fruticosa* L.). In addition, representatives of weed-shrub, weed-meadow and forest-meadow vegetation with a predominance of 3–5 species take an important part in the herbaceous cover of the Temernitsky grove (*Glechoma hederacea* L., *Galium aparine* L., *Elytrigia repens* L., *Artemisia vulgaris* L., *Sonchus arvensis* L.).

On the territory of the protected area “Shchepkinsky forest”, the main area is occupied by plantings *Quercus robur* L., *Acer platanoides* L., *Fraxinus excelsior* L. Other species are also mixed, mainly from families *Aceraceae* и *Rosaceae* (*A. tataricum* L., *A. negundo* L., *Prunus mahaleb* L., *Rosa canina* L., *Pyrus communis* L.). In the nursery of the Botanical Garden of the Southern Federal University planted exclusively *Picea abies* (L.) H. *Karst)* (Nalivaychenko et al. 2021).

6.3 Results and Discussions

The quantitative content of microelements in soils is determined by significant factors, which include the direction and intensity of soil formation processes, as well as their content in the parent rock. Recently, the amount of mineral elements in soils has been increasingly influenced by anthropogenic pressure. In this regard, the work on the study of the trace element composition of soils, carried out before the stages of large-scale industrial growth and development of industrial enterprises in a single geochemical province, becomes especially important. Therefore, when studying the soils of the Rostov agglomeration, we take the data given in the work as background values (Akimtsev et al. 1962).

The results of the studies are shown in the Table 6.1. They indicate that the gross content of microelements in fallow Calcic Chernozem (soil profile cut 2002p) can be arranged in the following row: Cr>Zn>V>Ni>Pb>Cu>Co.

The highest content of microelements was observed on virgin soil in the humus-accumulative horizon, and the lowest—in the soil-forming rock. The increased values of individual microelements are associated with the concentration function of both individual plant species of the steppe zone and the entire plant association as a whole, since at least 17–19 chemical elements are known to concentrate in living matter, primarily in plant organisms (Vernadskiy 1983). However, in an urban environment, the high content of microelements in natural soils can also be explained by the cumulative effect of heavy metals caused by the processes of industrialization (the presence of a large paint and varnish enterprise CJSC Empils in Rostov-on-Don) and the likely migration of heavy metals along the soil profile. (Dubinina et al. 2016). It is also impossible to exclude the fact of pedo-geochemical specificity of loess-like loams themselves as a soil-forming rock for most of the region. (Akimtsev et al. 1962).

Thus, for the whole range of elements considered, nickel, copper, lead, and zinc are the most significant. This is caused both by the nature of the elements themselves and by the presence or absence of technogenic emissions characteristic of the Rostov agglomeration.

The profile distribution of nickel in the horizons of fallow chernozem and woodlands shows a gradual decrease in the content of this element with a depth in a narrow range of values, which indicates the stability of the compounds of these elements and their weak migration down the profile.

The distribution of copper along the profile of the natural soils of the city differs from the distribution of nickel. If there is a tendency for nickel to consolidate and accumulate in the humus-accumulative horizon, then copper compounds in the soil profile are more mobile. This is reflected, on the one hand, in a certain depletion of the surface horizons, on the other—in the occurrence of peaks in the concentration of this element in the middle part of the profile (Fig. 6.2). Thus, the amount of copper in the chernozem of the Shchepkin forest in the upper horizons lies in the range of 23–29 ± 3.18 mg/kg of soil, in the middle part of the profile—32–37 ± 3.33. A similar distribution is observed in the chernozem of the Temernitsky grove (upper horizons—24–27 ± 3.18 mg/kg, the middle part of the profile—37–40 ± 3.31). Analysis of the profile distribution of copper in agglomeration soils showed that the copper content in the middle part of the profile is the highest. Perhaps this indicates the accumulation of copper on the carbonate barrier during eluviation and confirms the possibility of movement of compounds of this element with descending moisture currents. However, it is necessary to take into account the fact that the parent rocks, represented by loess-like clays and loams, are initially rich in copper.

In the conditions of the Rostov agglomeration, the main source of zinc intake into the surface horizons of urban soils were large paint and varnish enterprises operating from the mid-twentieth to the beginning of the XXI century. Zinc shows a pronounced tendency to increase concentrations in the sod and humus-accumulative horizons, while in the underlying thickness there is an equalization of its content (Fig. 6.3). Humus substances of chernozems bind microelements with the formation of complex heteropolar salts (Bodeeva 2012), and zinc refers specifically to the

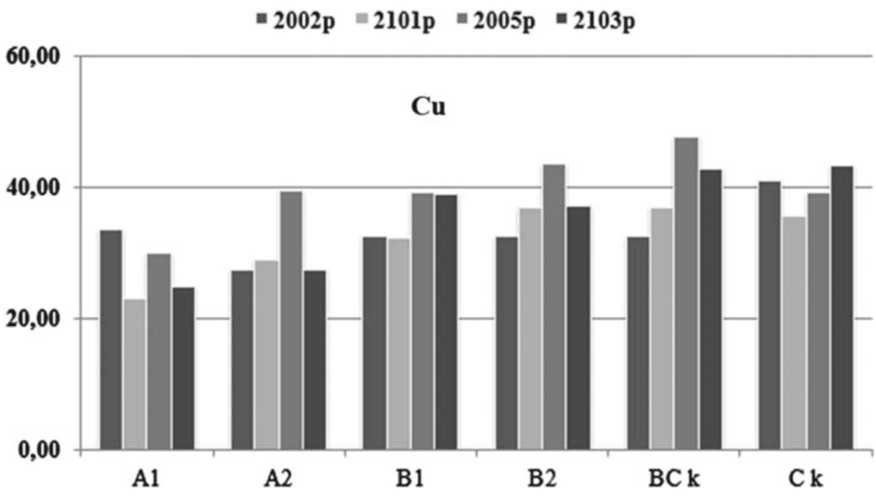

Fig. 6.2 Profile distribution of copper in Calcic Chernozem of Rostov agglomeration: under steppe vegetation (fallow) (2002p) and under forest massive (2103p—Temernitskaya grove; 2101p—Shchepkinsky forest; 2005p—Spruce tree nursery)

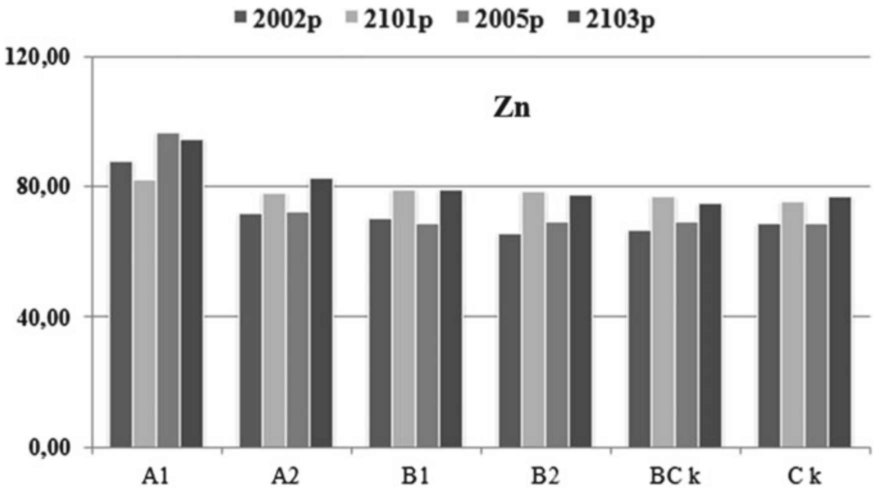

Fig. 6.3 Profile distribution of zinc in Calcic Chernozem of Rostov agglomeration: steppe vegetation (fallow) (2002p) and under forest massive (2103p—Temernitskaya grove; 2101p—Shchepkinsky forest; 2005p—Spruce tree nursery)

elements of biogenic accumulation, and there is a relationship between the content of organic matter and its concentration in soils (Yakhiyaev et al. 2011).

So, if on average for urban soils of the Rostov agglomeration, the gross zinc content is 65 mg/kg, then in the surface layer of forest soils, zinc concentrations significantly exceed the values given (Table 6.1). With an average zinc content of 85.72 mg/kg, the oscillation range is in the range of 73.95–96.73 mg/kg. The maximum amount of zinc is observed in the humus-accumulative horizon of Calcic Chernozem under the plantings of common spruce (Picea abies (L.) H. Karst)). This is due to the fact that among the coniferous plants introduced in the region, Picea abies (L.) H. Karst) is the most sensitive to air pollution, characterized by a high gas absorption capacity. Even at a distance from the sources of pollution, zinc accumulates in its litterfall (Borodina 2012).

The content and distribution of lead differ significantly in concentrations (Fig. 6.4). If the accumulation of lead in the surface horizons is explained by its proximity to major transport hubs and highways, then the wave-like migration of this element in the soil profile is due to its high affinity with humus substances. If the accumulation of lead in the surface horizons is explained by its proximity to major transport hubs and highways, then the wave-like migration of this element in the soil profile is due to its high affinity with humus substances. For example, in the Temernitsky grove, the average lead content in the upper horizon (0–15) is 25.64 ± 3.34 mg/kg, in the Shchepkin forest—18.56 ± 3.35, in the spruce nursery—36.22 ± 3.25 mg/kg. In the middle part of the profile, a low lead content is observed in the soil under forest vegetation, which may be due to the peculiarities of the granulometric composition and the specifics of the fractional group composition of humus in these horizons.

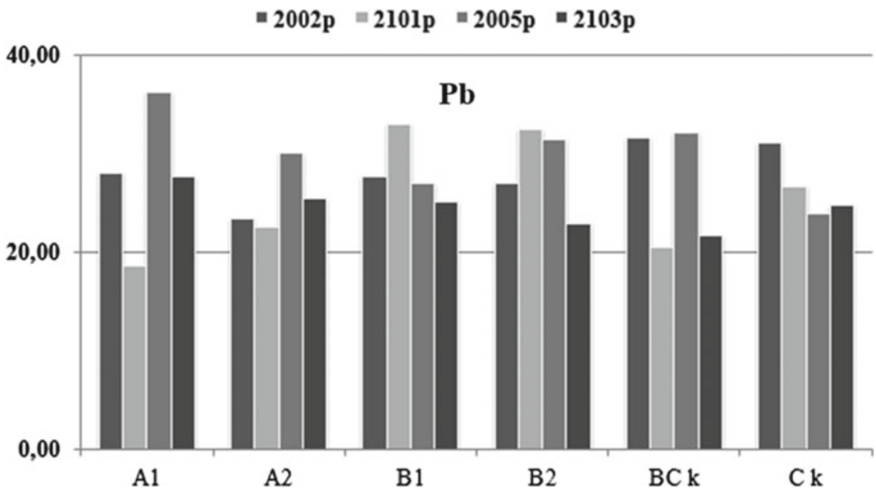

Fig. 6.4 Profile distribution of lead in Calcic Chernozem of Rostov agglomeration: steppe vegetation (fallow) (2002p) and under forest massive (2103p—Temernitskaya grove; 2101p—Shchepkinsky forest; 2005p—Spruce tree nursery)

6.4 Conclusion

The distribution of microelements in the profile of natural soils (chernozems of fallow areas and forest parks) shows stable patterns. In the Calcic Chernozem—in the fallow area of the Botanical Garden of Southern Federal University—the highest content of microelements is observed in the humus-accumulative horizon with a gradual decrease to the soil-forming rock.

Despite the fact that the soils of the recreation zones experience the impact of woody vegetation, which is unusual for them in genesis, the distribution of microelements remains within the limits characteristic of virgin chernozems forming under grass-grain associations. Regardless of the plant community type, copper compounds in the soil profile are characterized by greater mobility. It leads to peaks in the concentration of this element in the middle part of the profile at the level of the carbonate barrier. Nickel is characterized by a gradual decrease down the soil profile in a narrow range of values. The zinc content tends to increase concentrations in the humus-accumulative horizons, lead is characterized by a dispersion of concentrations in the soil profile with minimal values in its central part.

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Appendix

See Table 6.1.

Table 6.1 Microelements composition of Calcic Chernozem under steppe vegetation (fallow) and forests of Rostov agglomeration, mg/kg (ppm)

Horizon	Sampling depth	Microelement composition, mg/kg (ppm) (average values)			
		Ni	Cu	Zn	Pb
Background		45	30	65	20
Maximum allowable concentration		80	132	220	130
Calcic Chernozem, steppe vegetation (fallow), Botanical Garden. Soil profile cut 2002p					
A1	0–10	48.45 ± 2.65	33.49 ± 3.31	87.70 ± 2.71	28.03 ± 3.34
A2	10–35	47.04 ± 2.63	27.51 ± 3.28	71.92 ± 2.69	23.38 ± 3.39
B1	35–60	45.94 ± 2.63	32.59 ± 3.26	70.10 ± 2.60	27.70 ± 3.41
B2	60–75	41.35 ± 2.62	32.44 ± 3.31	65.54 ± 2.57	27.05 ± 3.41
BC k	75–95	42.26 ± 2.61	32.64 ± 3.34	66.67 ± 2.57	31.60 ± 3.40
C k	95–135	43.98 ± 2.65	40.91 ± 3.44	68.70 ± 2.59	31.10 ± 3.41
Calcic Chernozem, forest park, Temernitskaya grove. Soil profile cut 2103p					
A1	0–10	52.51 ± 2.70	24.77 ± 3.14	94.29 ± 2.70	25.64 ± 3.34
A2’	10–30	55.15 ± 2.62	27.48 ± 3.19	82.60 ± 2.62	27.39 ± 3.40
A2”	30–50	55.68 ± 2.61	29.66 ± 3.21	81.76 ± 2.61	32.45 ± 3.39
B1	50–70	60.62 ± 2.67	38.81 ± 3.38	79.08 ± 2.67	25.02 ± 3.46
B2	70–90	57.31 ± 2.78	37.08 ± 3.38	77.50 ± 2.66	22.93 ± 3.43
BC k’	90–110	54.75 ± 2.81	40.73 ± 3.45	76.15 ± 2.67	28.73 ± 3.47
BC k”	110–130	51.01 ± 2.76	42.75 ± 3.47	74.59 ± 2.66	21.61 ± 3.42
C k	130–150	53.83 ± 2.76	43.76 ± 3.46	76.98 ± 2.68	24.68 ± 3.42
Calcic Chernozem, forest park, Shchepkinsky forest. Soil profile cut 2101p					
A1	0–15	51.43 ± 2.54	23.12 ± 3.11	81.84 ± 2.56	18.56 ± 3.35
A2’	15–70 (15–35)	55.88 ± 2.61	28.59 ± 3.19	78.31 ± 2.56	10.51 ± 3.42
A2”	15–70 (35–70)	60.84 ± 2.76	29.43 ± 3.24	77.94 ± 2.62	34.64 ± 3.46
B1	70–95	62.73 ± 2.76	32.18 ± 3.27	79.20 ± 2.64	32.90 ± 3.44
B2	95–120	58.24 ± 2.76	36.87 ± 3.36	78.33 ± 2.66	32.44 ± 3.48
BC k	120–145	53.10 ± 2.72	36.81 ± 3.36	77.02 ± 2.64	20.41 ± 3.44

(continued)

Table 6.1 (continued)

Horizon	Sampling depth	Microelement composition, mg/kg (ppm) (average values)			
		Ni	Cu	Zn	Pb
Background		45	30	65	20
Maximum allowable concentration		80	132	220	130
C k	145–160	43.61 ± 2.57	35.54 ± 3.34	75.47 ± 2.59	26.60 ± 3.38
Calcic Chernozem, Spruce tree nursery. Soil profile cut 2005p					
A1	0–10	48.31 ± 2.60	29.84 ± 3.24	96.73 ± 2.75	36.22 ± 3.25
A2’	10–50 (10–30)	53.86 ± 2.72	38.63 ± 3.38	75.64 ± 2.64	44.19 ± 3.41
A2”	10–50 (30–50)	54.70 ± 2.74	39.08 ± 3.40	68.35 ± 2.61	34.86 ± 3.41
B1	50–70	56.03 ± 2.75	39.21 ± 3.40	68.41 ± 2.61	26.98 ± 3.39
B2	70–95	51.12 ± 2.73	43.51 ± 3.48	69.21 ± 2.63	31.49 ± 3.39
BC k	95–110	47.90 ± 2.72	47.68 ± 3.53	69.08 ± 2.62	32.17 ± 3.38
C k	110–140	47.01 ± 2.60	39.12 ± 3.38	68.50 ± 4.10	23.91 ± 3.33

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Chapter 7
Seasonal Dynamics of Mobile Phosphorus and Potassium in Podzol Soils Within Slope Catena of Different Anthropogenic Load at the RSAU-MTAA Forest Experimental Station

Solomon Melaku Melese, Ivan Ivanovich Vasenev, and Dmitry Vladimirovich Morev

Abstract Monitoring studies on the spatiotemporal variability of mobile phosphorus and potassium Podzol soils were carried out at the Forest experimental Station, RSAU-MTAA, which was established 160 years ago. The spatial and temporal variability of mobile phosphorus and potassium studied soils have considered the following: (a) their position (top of hillslope → middle slope → lower part (sole); (b) severity of the path network (c) soil horizons; (d) stock of mobile phosphorus and potassium. Three levels of anthropogenic load are considered. Soil samples were taken during three seasons of 2021: in spring, summer and autumn from a depth of 0–5, 5–10 and 10–15 cm. Mobile phosphorus and potassium were determined using a photo-electro-colorimeter and a flame photometer, respectively. Maximum mobile P_2O_5 (241 mg/kg) and K_2O (170 mg/kg) were found at the lower part of the slope and top of the hill slope, respectively, in the minimum anthropogenic load (0–5 cm). In contrast to phosphorus, the distribution of potassium along the slope is reversed. Mobile phosphorus and potassium are higher in spring than in summer and early autumn. During the growing season, there is a noticeable trend of a decline in the content of mobile phosphorus (on average 20%). As the anthropogenic load increases, the amount of mobile potassium fractions drops by about 30%. In all plots, mobile phosphorus and potassium stocks in the upper soil depth significantly decrease with an increase in anthropogenic load.

Keywords Mobile phosphorus · Mobile potassium · Soil stock · Podzol soils · Season · Anthropogenic load

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Abbreviations

GLM	General Linear Model
ANOVA	Analysis of Variance
SPSS	Statistical Package for Social Sciences
THS	Top Hillslope
MSNE	Middle part of slope with a northeastern exposure
LPNES	Lower part of slope base with northeastern exposure
RSAU-MTAA	Russian State Agrarian University—Moscow Agricultural Academy named after K.A. Timiryazev

7.1 Introduction

Forest ecosystems accumulate huge amounts of soil nutrients in various basins. Soil is the main component of the urban ecosystem, which interacts with the air, water, and bioinert components of the environment (Nizamutdinov and Abakumov 2021; Burdukovskii et al. 2020). The soil cover is the basic element of any landscape, which most fully reflects the current state of all ecosystems and plays an important role in ensuring biological diversity and resistance to the anthropogenic load of forest and urban biogeocenoses (Gracheva 1992; Yimer et al. 2015; Kizilkaya and Dengiz 2010). The main tasks of modern ecology become the maintenance of favorable environmental conditions and the stability of soil functioning under conditions of increased anthropogenic load in urban areas by taking into attention the regional and local regularities of nutrient and seasonal dynamics (Wang 1999; Yesilonis et al. 2016; Li et al. 2013).

The rate of accumulation of mobile fractions of phosphorus (P) and potassium (K) in different soils varied significantly (Emiru and Gebrekidan 2013). These differences were noticeable even within the same soil type and were influenced by many factors (Lemanowicz et al. 2014). Mobile phosphorus and potassium of the upper soil horizons are key variables in regulating the exchange of nutrients between soil, plants, and atmosphere. It is largely determined by the seasonal dynamics of soil respiration, microbiological activity, nutrient reserves in the soil, and microclimate of forest ecosystems in urban conditions (Wright 2009; Demin and Barabanshchikova 2021; Borzenko et al. 2007; Xu et al. 2012; Afanas'ev and Merzlaya 2013).

Despite the fact that there is a soil problem for forest ecosystems in urban areas, forest soils provide a variety of urban ecosystem services and ecological functions. The main environmental problem of large cities is a sharp increase in anthropogenic pressure on their natural environment, including soil cover of the natural forest ecosystem (Sorokina 2010). As a result, serious changes occur in the ecological functions and ecosystem services of urban soils. Thus, a systematic monitoring observation is required that takes into account both the initial spatiotemporal variability of soils and their changes in seasons (Krzyzaniak-Sitarz 2008; Song et al. 2006; Polupan and Velichko 2014; Land Monitoring Forum 2009).

The city's forest ecosystem is used as functions of regulating the composition of nutrients, immobilizing pollutants and regulating the water regime. Moscow is the largest metropolis in Europe, characterized by a high diversity of soil cover and anthropogenic load cities (Voronina et al. 2019). Among them is Forest Experimental Station, which is well-stocked podzolic soils (Baliuk et al. 2015; Sorokina 2010; Naumov et al. 2020). The purpose of this work is to analyze the seasonal dynamics of mobile phosphorus and potassium and its stock in the upper horizons of Podzol soils in different level of anthropogenic load with a representative slope of the Forest experimental Station of RSAU-MTAA.

7.2 Objects and Methods

The research was conducted at the Forest Experimental Station of RSAU-MTAA, named for K.A. Timiryazev. In the study area, there is a spatial heterogeneity, with a greater prevalence of windfall and windbreak. The average value of early spring snow cover thickness has increased on the lower part of slope (Eremina and Kayugina 2022). Investigation has been done monthly since April to September 2021. Topsoil samples from the depths 0–5, 5–10, 10–15 cm of Podzol soils were collected at the representative plots within the slope catena (Top hillslope (THS) → Middle part of northeastern slope (MNES) → Lower part of northeastern slope (LPNES)), with three levels of anthropogenic loads: minimum (Background), medium, and high (Table 7.1). The soil analysis was carried out in the soil testing laboratory of RSAU-MTAA, Department of Ecology. Quantitative mobile compounds of phosphorus and potassium were determined using a photo-electro-colorimeter and a flame photometer, respectively. Data were statistically processed using ANOVA according to the GLM procedure (IBM SPSS) version 25 and Microsoft Excel 2010.

7.3 Results and Discussions

In the studied area, mobile phosphorus distribution was affected by growing season, profile, anthropogenic load, and relief (Fig. 7.1). Mobile phosphorus is more abundant in the upper horizons of the profile, reaching up to 241 mg/kg in the 0–5 cm. Mobile phosphorus content was found lower in the podzolic soil at the depth of 5–10 cm and 10–15 cm than at the depth of 0–5 cm. These are due to the fact that the higher content of mobile phosphorus in the illuvial layer is apparently connected with the result of mineralogical composition and decomposition of tree leaves and others (herb and mosses etc.) (Zarishnyak et al. 2012; Kovaleva et al. 2021; Melese and Vasenev 2020).

Table 7.1 Brief description of the key areas of the studied area (Vasenev et al. 2020)

Slope	Relief	Dominant tree species	Soil: profile	Snow cover*
1 (TMH)	Top hillslope	The dominant tree species on the slope are *Tilia cordata and pine.* Crown density—60%	Podzol soils: O + 2 – AY8 – AEL16 – EL1(f)42 – EL2(g)53 – BEL(g)64 – BTg80 – BC120↓	29 cm
2 (MSNE)	Middle part of slope with a northeastern exposure	The dominant tree species on the slope are *Betula pendula*, *Tilia cordata*, *Acer Platanoides* and *Rough elm*. Crown density is 50–70%	Podzol soils: O + 1 – AY11 – AEL22 – EL30 BEL(g)65 – BTg80 – BC120↓	32 cm
3 (LSNE)	Lower part of slope base with northeastern exposure	The dominant tree species on the slope are *Quercus robur*, *Acer Platanoides* and *Pinus sylvestris* Crown density is 40–45%	Podzol soils gleyic: O + 2 – AY6 – AEL20 – EL(g)25 – BEL(g)55 – BTg80 – BCg120↓	40 cm

[a]Average value of early spring snow cover from 2009 to 2015 years, cm (Vasenev et al. 2020)

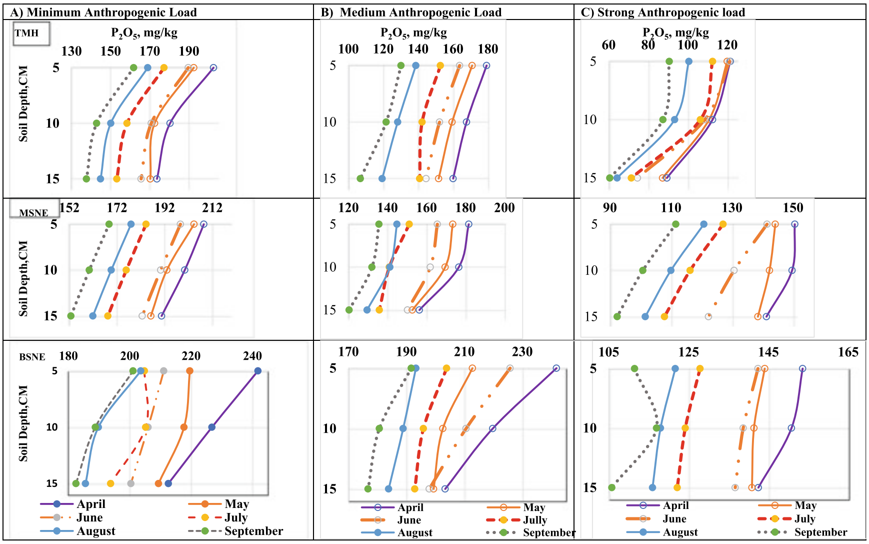

Fig. 7.1 Seasonal dynamics of P_2O_5 stock (mg/kg day^{-1}) in the slope catena of Podzol soils at the Forest Experimental Station RSAU-MTAA in a condition of different anthropogenic load

Seasonal dynamics of mobile phosphorus in soils for the months of April to September under different anthropogenic load conditions revealed significant variation. Thus, there is a pronounced trend of a decrease in the content of available fractions of this element during the growing season (about 20% on average) in all studied areas. There are obvious seasonal dynamics of the mobile P_2O_5 with maximum values in April and gradual decrease in September (Fig. 7.1). It is clearly expressed that the average mobile phosphorus in the summer months is approximately 1–1.5 times lower than in the spring (Fig. 7.1). High phosphorus concentrations are brought about in the spring by weathering, mineralization, desorption (immobilization), precipitation, runoff from lawns and urban areas, leaking septic systems, and sewage treatment of plant discharges (Ye et al. 2014; Condron et al. 2005; Melese and Vasenev 2022).

According to the data obtained, the areas with a high anthropogenic load are characterized by relatively low concentrations of mobile phosphorus and higher rates of its loss during the growing season (up to 35%). Background areas with a minimum anthropogenic load have the maximum content of mobile phosphorus (241 mg/kg, 0–5 cm depth) in April compared to the area with a strong anthropogenic load (150 mg/kg, 10–15 cm depth) in the lower part of northeastern slope (Fig. 7.1). There is a high content mobile phosphorus in a place with low anthropogenic loads due to low development of organophosphorus compounds and high phosphorus linkages with mineral particles (Vasenev and Raskatova 2009; Shen et al. 2011).

The lower part of slope had a higher content of mobile phosphorus (241 mg/kg) than middle slope (210 mg/kg) and the top hill slope (200 mg/kg). That is, in the case of relief, the availability of phosphorus rises down the slope (Vasenev et al. 2019). The soil is characterized by a higher content of mobile phosphorus in the upper horizon (0–5 cm) on the lower part slope and a low content of mobile phosphorus on the top of slope (10–15 cm). The higher content of mobile phosphorus in the lower slope is apparently connected with its leaching effect on the upper slope (Rupp et al. 2018). On average, mobile phosphorus of the humus-accumulative horizon (0–5 cm) in the soil with a minimum level of anthropogenic load was consistently 1–1.6 times higher than in the same soils of 5–10 and 10–15 cm depth. This may be due to the surface transfer of mobile fractions of nutrients and their accumulation is slow in profile (Lemanowicz 2018).

Findings have revealed that there are significant differences in the rate of accumulation of mobile fractions of potassium on different slopes, growing season, anthropogenic loads, and soil depth (Fig. 7.2). The spatial differentiation of the mobile potassium composition of the studied soils was lowest in the summer season compared to spring (Fig. 7.2). As seen in Fig. 7.2, during the summer period (June–August) and early autumn (September), there is a regular decrease in the value of mobile potassium in the soil. According to the growing season, there is a decrease in mobile potassium under all plots and was recorded in September. This may be due to the increase in soil moisture causing higher mobile potassium levels (April), which in turn improves availability and boosts potassium transport to plant roots (Borzenko et al. 2007; Afanas'ev and Merzlaya 2013; Vasenev et al. 2020). The

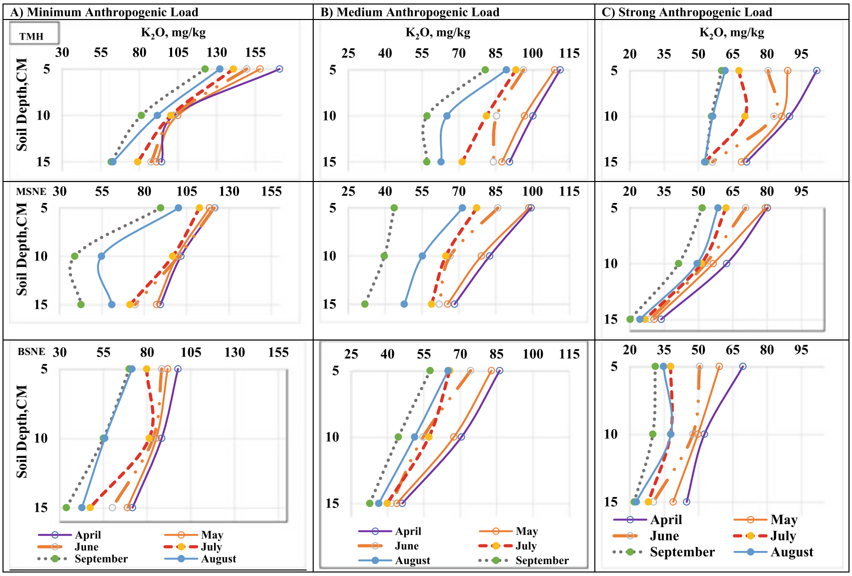

Fig. 7.2 Seasonal dynamics of K_2O stock (g m^{-2} day^{-1}) in the slope catena of Podzol soils at the Forest Experimental Station of RSAU-MTAA in a condition of different anthropogenic load

properties of the forest floor are also in close genetic relationship with the composition of plant residues from which forest litter is formed, and the conditions under which humification occurs (Vasenev et al. 2020).

The content of mobile potassium decreases as the anthropogenic load increases; approximately 30% is lost during the observation period. Particularly high rates of loss (up to 55%) have been observed in areas with the highest degree of anthropogenic load. An area with minimal anthropogenic load has the maximum content of available potassium (165 mg/kg, horizon A1) in April compared to the plot with medium load (117 mg/kg, horizon A1) and strong load (95 mg/kg, horizon A1) on the top of the moraine hill slope (Fig. 7.2). In contrast to phosphorus, the distribution of potassium along the slope has an inverse character: a higher content is noted in the areas at the top of the moraine hill slope. It is connected with the variations in physiological functions of potassium in plants. The increased concentration of K_2O in the background (areas with the lowest anthropogenic load) may be related to young trees and their root systems, which act as a nutrient pump, collecting nutrients from deep soil layers and transporting them to the surface layer via leaf fall (Vasenev et al. 2012). Generally, in all minimum anthropogenic loads, higher values of mobile potassium were recorded in the top hillslopes relative to middle slope and lower part slope. Composition and structure of the litter varies depending on the composition of the forest stand, development of undergrowth, age, density and sanitary condition of the forest (Afanas'ev and Merzlaya 2013; Vasenev et al. 2007, 2012; Eremina and

Kayugina 2022). According to Fig. 7.2, the K_2O content of the soil at the "RSAU-MTAA Forest Experimental Station" ranged from 28.2 to 121.6 mg/kg. Topsoil (illuvial) potassium concentration (0–5 cm) is higher than that at the lower level (5–10, 10–15 cm). It is suggested that the soil profile is greatly affected by the nature of the forest litter in the upper layers (Vasenev et al. 2007).

The soils on the lower part of the slope have higher mobile phosphorus stock in the spring (Table 7.2). According to Condron et al. (2005), mobile phosphorus stocks decline across slopes during the least wet and most hot seasons. On average, the lower part slope in the mobile phosphorus stock is 1–1.8 times higher than the top hillslope (Table 7.2). The lower part slope base with northeastern exposure (April) of minimum anthropogenic load (44.93 g m^{-2}) had a higher mobile phosphorus stock than the medium (42.2 g m^{-2}) and strong anthropogenic loads (32.39 g m^{-2}). Due to the poor solubility of phosphate compounds and the high P-binding capacity of soil components, the stock of mobile phosphorus is reduced at higher anthropogenic loads (Ye et al. 2014; Condron et al. 2005). The mobility of phosphorus stocks is higher with a lower anthropogenic load. It could be due to the availability of plants with sufficient phosphates, the ratio of the mobile fractions of phosphorus, the activity of microbiological processes in the soil, etc. (Ye et al. 2014). Minimum anthropogenic load, on the other hand, may have longer-lasting residual effects due to composition and preceding phosphorus application (Zavišić et al. 2018). It has been noted that as soil depth increases, soil phosphorus stock decreases as a result of hydrolysis in the soil profile. This finding is consistent with (Condron et al. 2005; Melese and Vasenev 2022; Zavišić et al. 2018).

The analysis of seasonal changes in the upper horizons of the studied Podzol gleyic soils showed highly significant differences in mobile potassium stocks (Table 7.3). The increase in anthropogenic load is associated mainly with a decrease in the mobile form of potassium stocks in the 0–15 cm layer of the studied soils. Changes in potassium stock with different levels of anthropogenic load are most pronounced in Podzol gleyic soils (Naumov et al. 2020; Melese and Vasenev 2020). The lowest potassium stock was found on the lower part of the slope (10–15 cm, 7.18 g m^{-2}) in September, while the maximum mobile potassium was found at the top of the hill slope (0–5 cm, 20.77 g m^{-2}) in April. The low available K_2O concentration in the lower part slope could be due to the inherently low soil K and/or the presence of K in unavailable form (Afanas'ev and Merzlaya 2013; Eremina and Kayugina 2022; Kour et al. 2020).

7.4 Conclusions

The seasonal dynamics of mobile phosphorus and potassium in Podzol soils of the representative slope catena with different levels of anthropogenic load were observed during the monitoring campaigns in the spring, summer, and autumn in the conditions of Forest Experimental Station, Northern District of Moscow. It was found that Timiryzev Forest Experimental Station is characterized by high variability in the

Table 7.2 Seasonal dynamics of mobile form of phosphorus stocks (g m^{-2}) in the upper part (0–15 cm) of Podzol soils slope catena at the Forest Experimental Station of RSAU-MTAA in conditions of different anthropogenic load

Key plot	Level loads	Depth (cm)	April		May		June		July		August		September	
			Stocks of P_2O_5 (g m^{-2}) in horizons in the 0–15 cm layer											
Top hillslope	Minimum	0–5	9.98	31.95	9.63	30.94	9.63	30.68	9.17	29.23	8.86	28.25	8.43	26.71
		5–10	10.60		10.17		10.13		9.73		9.46		8.98	
		10–15	11.38		11.13		10.91		10.33		9.93		9.29	
	Medium	0–5	9.92	30.51	9.47	30.23	9.29	29.29	8.82	28.45	8.02	25.40	7.48	23.28
		5–10	9.87		9.55		9.24		8.85		8.18		7.62	
		10–15	10.73		11.21		10.76		10.78		9.19		8.18	
	Strong	0–5	6.87	20.49	6.88	21.31	7.02	20.37	6.59	19.63	5.94	17.81	5.22	16.38
		5–10	6.91		7.46		7.39		7.29		6.54		6.17	
		10–15	6.71		6.97		5.97		5.76		5.34		5.00	
Middle part of slope with a northeastern exposure	Minimum	0–5	11.05	35.06	10.94	34.44	10.74	34.06	10.24	32.27	10.09	31.67	10.80	34.24
		5–10	11.62		11.29		11.25		10.66		10.46		11.15	
		10–15	12.40		12.21		12.07		11.37		11.12		12.29	
	Medium	0–5	10.08	31.34	10.58	33.07	10.19	32.17	9.53	29.46	9.30	29.05	8.48	26.78
		5–10	10.77		11.02		10.62		9.45		9.63		8.78	
		10–15	10.48		11.46		11.36		10.47		10.13		9.51	
	Strong	0–5	9.11	29.09	10.00	31.71	9.89	29.57	9.07	26.85	8.76	25.77	7.25	22.01
		5–10	9.81		10.58		9.79		8.89		8.53		7.46	
		10–15	10.17		11.13		9.89		8.89		8.48		7.30	
Lower part slope base with northeastern exposure	Minimum	0–5	14.97	44.93	14.10	44.86	13.41	43.39	13.15	42.85	12.58	41.45	11.56	36.99
		5–10	14.40		15.03		14.57		14.38		14.07		12.34	

(continued)

Table 7.2 (continued)

Key plot	Level loads	Depth (cm)	April		May		June		July		August		September	
			Stocks of P_2O_5 (g m^{-2}) in horizons in the 0–15 cm layer											
		10–15	15.57		15.73		15.42		15.32		14.80		13.08	
	Medium	0–5	12.74	42.2	12.14	40.48	11.79	39.01	11.7	39.02	11.84	37.65	10.70	34.01
		5–10	14.14		13.6		13		13.28		12.39		11.38	
		10–15	15.32		14.74		14.22		14.04		13.42		11.93	
	Strong	0–5	10.06	32.39	8.64	27.22	9.15	28.86	10.40	32.84	10.69	34.00	6.52	21.80
		5–10	10.86		8.90		9.43		10.74		11.11		7.72	
		10–15	11.47		9.69		10.27		11.69		12.21		7.56	

Table 7.3 Seasonal dynamics of mobile form of potassium stocks (g m^{-2}) in the upper part (0–15 cm) of Podzol soil slope catena of the Forest Experimental Station RSAU-MTAA in conditions of different anthropogenic load

Key plot	Level loads	Depth (cm)	April		May		June		July		August		September	
			Stocks of K_2O (g m^{-2}) in horizons of the 0–15 cm layer											
Top hillslope	Minimum	0–5	8.93	20.77	8.36	20.15	7.98	19.54	7.74	18.87	7.40	17.10	6.80	15.76
		5–10	5.66		5.85		5.79		5.81		5.40		4.80	
		10–15	6.18		5.94		5.77		5.32		4.30		4.16	
	Medium	0–5	6.15	18.12	6.09	18.31	5.44	16.90	5.40	15.90	5.27	14.19	4.73	12.60
		5–10	5.89		5.75		5.21		5.04		4.08		3.51	
		10–15	6.08		6.47		6.26		5.46		4.84		4.36	
	Strong	0–5	5.78	16.60	5.11	16.43	4.66	14.81	3.97	13.06	3.64	11.96	3.46	11.78
		5–10	5.48		5.82		5.65		4.82		3.94		3.93	
		10–15	5.33		5.50		4.50		4.27		4.38		4.39	
Middle part of slope with a northeastern exposure	Minimum	0–5	5.52	15.14	6.02	16.07	5.29	14.33	4.87	13.76	4.59	12.08	4.46	11.00
		5–10	5.04		5.15		4.36		4.34		3.76		3.82	
		10–15	4.58		4.91		4.69		4.54		3.74		2.72	
	Medium	0–5	5.17	14.95	4.91	14.41	4.78	13.68	4.43	12.56	4.04	10.42	2.73	7.88
		5–10	5.12		4.99		4.93		4.92		3.44		2.64	
		10–15	4.65		4.51		3.98		3.21		2.93		2.51	
	Strong	0–5	4.20	10.89	4.11	10.94	3.54	9.56	2.71	7.93	2.52	7.38	2.03	5.99
		5–10	3.45		3.70		3.57		2.90		2.95		2.23	
		10–15	3.23		3.13		2.46		2.32		1.91		1.74	
Lower part slope base with northeastern exposure	Minimum	0–5	6.66	19.20	6.55	18.91	6.77	18.37	6.47	17.89	5.87	13.93	5.15	10.68
		5–10	6.29		6.21		6.31		6.24		3.59		2.53	

(continued)

Table 7.3 (continued)

Key plot	Level loads	Depth (cm)	April		May		June		July		August		September	
			Stocks of K_2O (g m^{-2}) in horizons of the 0–15 cm layer											
		10–15	6.25		6.15		5.29		5.18		4.47		3.00	
	Medium	0–5	5.34	13.42	5.18	13.38	4.68	11.86	4.24	11.60	4.26	11.01	3.23	8.24
		5–10	4.62		4.81		3.93		4.19		3.81		2.80	
		10–15	3.46		3.40		3.25		3.17		2.93		2.21	
	Strong	0–5	5.25	12.47	5.63	12.46	5.06	11.52	4.54	10.80	4.35	10.36	3.02	7.18
		5–10	4.49		4.26		4.03		3.98		3.89		2.71	
		10–15	2.72		2.56		2.43		2.29		2.12		1.44	

content of mobile phosphorus and mobile potassium. As a result, mobile phosphorus and potassium were higher in the illuvial (0–5 cm) layer and lower in the eluvial layer (5–10, 10–15 cm). In the spring months (April–May), the mobile phosphorus and potassium and their stock were higher in comparison with summer and the beginning of Autumn. Season has a direct impact on the mobile phosphorus, potassium and their stock in the soil. In all cases of anthropogenic load, the maximum mobile phosphorus was recorded in the lower part of the slope, in contrast to mobile potassium. At the same time, mobile phosphorus stock was higher in the lower part of the slope with the minimum anthropogenic load on it, whereas mobile potassium stock was higher on top of the hill slope. We concluded that the established seasonal dynamics of phosphorus, potassium, and their stocks depended on the soil horizons in different parts of the urban slope landscape, even with a slight slope (up to 3–4°) and the presence of vegetation. It was observed that management practices and certain types of vegetation exert a profound influence on soil nutrients. Due to the changeability of mobile soil nutrients under the slope catena of diverse anthropogenic loads and the cyclical nature of the seasons in urban environments, it is crucial to promptly prepare and reviewing soil monitoring data as well as environmental impact assessments in a timely manner.

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Chapter 8
Grazing Effect on Carbon Stocks and Fluxes in Soils of the Mountainous Pastures

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Abstract Grazing is known to have a negative impact on soil C stocks; however, the effects depend on the grazing intensity and management practices. This research aimed to study the effect of grazing on carbon stocks and CO_2 emissions in the mountainous pastures in the Northwest Caucasus, Chechenia Republic of Russia. WAYCARBON polygon established in Chechenia Republic aims to support investigation searching for the grazing practices which will not disturb soil C stocks. Soil survey and measurements of soil CO_2 emission were organized in summer 2022 at the three research sites representing different intensity of grazing: intensive (grazed zone, GZ), light (transit zone, TZ) and reference site, where sheep are not grazed. Topsoil C stocks at the reference site were 10.4 kg m^{-2} which was 10 and 40% higher than at the grazing and transit zones correspondingly. Almost 30% of the total topsoil C stocks at the reference site were distinguished by inorganic C. Soil CO_2 emissions were 2.8 ± 0.9, 1.7 ± 0.3 and 2.4 ± 0.9 g C m^{-2} day^{-1} at the grazed, transit and reference site correspondingly. The sustainability of soil C stocks expressed by T0.5 and T0.95 were similar for the grazed and reference sites, whereas soil C stocks at the transit area were almost three times more vulnerable to biodegradation. The absence of the negative effects of grazing on soil C stocks is a positive message for the land-use planners, which tested and verified by the further investigations.

Keywords Natural grasslands · Grazing intensity · Microbial respiration · Carbon balance · Carbon neutrality · Chechenia Republic

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8.1 Introduction

Together with deforestation and urbanization, the grazing effect on carbon stocks can be considered a classical topic in soil carbon assessments (Elmore and Asner 2006). This topic attracts additional attention for mountainous pastures, where the adjustment of the traditional farm households to a more intensive production has led to changes in grazing practices, and the environmental consequences of these changes remain poorly known (Garcia-Pausas et al. 2017; MacDonald et al. 2000). Soil carbon stocks can be considered a function of the balance between inputs from primary production and outflows from heterotrophic respiration—decomposition of organic matter by soil microbes (Chapin et al. 2006). As a result of overgrazing, the quantity of inputs to the soil may be reduced due to the aboveground biomass removal and belowground biomass disturbance by animals. This reduction in biomass causes decrease in primary productivity in comparison to nongrazed grasslands (Ferraro and Oesterheld 2002). At the same time, light or moderate grazing intensity can stimulate aboveground plant productivity by so-called compensatory growth, when plants respond to defoliation by allocating carbon between above- and belowground biomass (Chen et al. 2006; Zhao et al. 2008). The magnitude of this effect depends on the intensity of defoliation, nutrient availability and water availability (Klumpp et al. 2009; Zhao et al. 2008). In addition, an excess of trampling and continuous overgrazing increases the area of bare soil and correspondingly the risk of erosion. For example, the degradation of grasslands due to overgrazing in the Tibetan plateau caused relevant losses of soil organic carbon stocks during the last 30 years (Xie et al. 2007). In the Alps, degradation of the vegetation cover by overgrazing resulted in annual erosion rates up to 20 Mg ha^{-1} (Meusburger and Alewell 2014).

Although the negative effect of over-grazing on soil carbon stocks is widely accepted, soil organic carbon and especially soil respiration at the grazed pastures can be very heterogeneous. Overgrazing causes an alteration in soil physical, chemical and biological properties at short distances resulting in "patchy" spatial structure, where carbon stocks and fluxes at the neighboring sites are considerably different. Animals tend to graze on areas with the most nutritious plants, whereas they select particular landscape features for resting and ruminating. As a consequence, different types of vegetation develop, which in turn influences the subsequent behavior of animals. Soil nutrients' contents and availability increase from grazed to resting areas (Badia et al. 2008). For example, the availability of phosphorus increases as a consequence of cattle grazing and defecation (Güsewell et al. 2005). An increase of fresh organic matter and nutrients' availability may increase microbial decomposition of the native soil carbon stocks by so-called priming effect and therefore intensify CO_2 emissions. In mountainous areas, variability in soil C stocks and especially CO_2 emissions is further complicated by vertical gradient in abiotic conditions. For example, Komarova et al. (2022) showed that decomposition of organic matter in grazed and nongrazed meadows in the Northwest Caucasus was affected by soil temperature; however, the temperature sensitivity did not depend on vegetation type (Komarova et al. 2022).

Climate mitigation and carbon neutrality goals motivate decision-makers to explore opportunities to decrease carbon emissions and increase carbon sequestration in all principal spheres of the regional economy. In Chechenia Republic, sheep breeding is a traditional sphere of agriculture and regional economy, therefore studying grazing effect on carbon stocks and fluxes in mountainous pastures is highly relevant. Recent research claimed that sustainable practices can have a strong positive effect on carbon balance of the grazed pastures (Gavrichkova et al. 2022). This research aimed to study the effect of grazing on carbon stocks and CO_2 emissions in the mountainous pastures in the Northwest Caucasus, Chechenia Republic of Russia.

8.2 Materials and Methods

8.2.1 Research Area

The research area (42N, 46E) is located at the mountainous part of Chechenia republic and belongs to the experimental station "WAYCARBON" established in 2022 to monitor the effects of different agricultural practices on carbon stocks and fluxes in mountainous conditions. The research sites are located at the steep and moderate slopes Northwest Caucasus mountains, the elevation ranges between 1800 and 2000 m. The area is dominated by Mollic Leptosols. The vegetation of the area is dominated by subalpine meadow which were historically used as natural pastures. The research sites represent different intensity of grazing: intensive (grazed zone, GZ), light (transit zone, TZ) and reference site, where sheep are not grazed (Fig. 8.1).

8.2.2 Measuring Soil C Stocks and Fluxes

Soil survey in the area was carried out in July 2022. Sampling points were randomly selected in each of the sites, considering the vegetation patterns and elevation. Topsoil (0–10 cm) mixed samples (corners and center) were collected at 30 locations (10 location from each research sites). Additional samples from top 50 cm and top 100 cm were collected at 3 and 1 locations from each site correspondingly to describe the soil profile distribution and to collect. Subsoil samples from the soil horizons. Bulk density was measured in topsoils and further used to estimated soil C stocks. After transporting to the soil-ecological laboratory of RUDN University, soil samples were processed (roots and rock fragments were removed).

In the fresh samples, microbial biomass carbon (MBC) was measured by substrate-induced respiration (SIR) method, based on the registration of the highest initial microbial CO_2 production after glucose addition (Anderson and Domsch 1978;

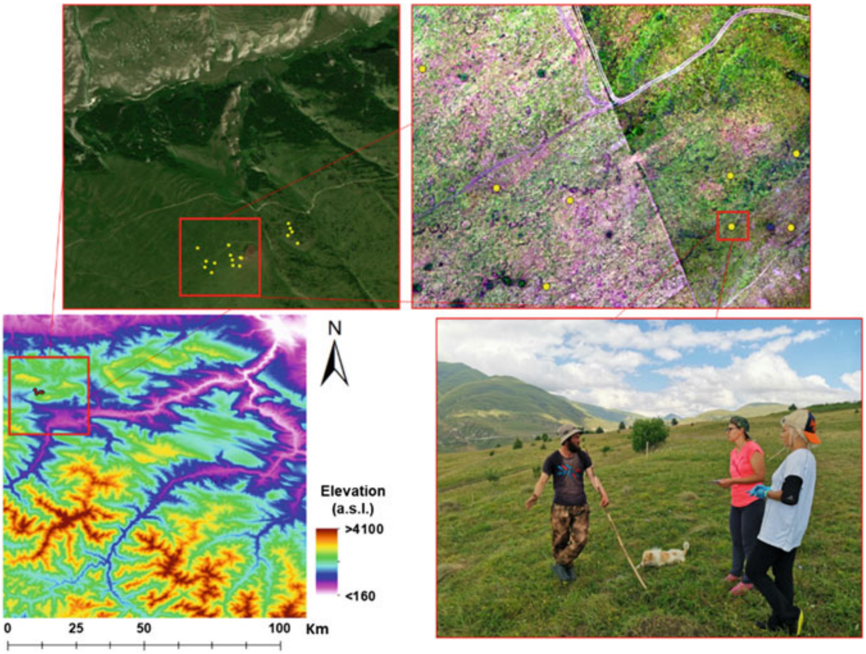

Fig. 8.1 Research area and soil survey locations (yellow points)

Ananyeva et al. 2008). The subsamples (2.0 g each) were placed in a vial (15 mL volume) and a glucose solution was added dropwise (10 mg glucose g^{-1}, volume was 0.1 mL). The vial was tightly closed and incubated at 22 °C during 3.5 h. The measured SIR was converted to MBC units (µg C g^{-1}) by the following equation: SIR (µl CO_2 g^{-1} h^{-1}) × 40.04 + 0.37 (Anderson and Domsch 1978). Basal respiration (BR) was measured in soil samples collected at zero moment, 2 and 14 months after Technosols' construction. In laboratory conditions, soil samples were moistened up to 55–65% water holding capacity (WHC) by distilled water and preincubated during 72 h at 25 °C. After preincubation 2 g subsamples were taken and placed in a vial (15 ml). The vials were tightly closed (time recorded) and incubated at the 22 °C during 24 h (ISO 16072:2002). After incubation of the subsamples, air samples from the vials were taken by syringe and injected into a gas chromatograph (KrystaL 2000 M, 'Meta-Chrom' manufacturer, Yoshkar-Ola, Russia) equipped with a thermal conductivity detector for measuring CO_2 concentration. The BR reflected the CO_2 produced by microbes in each subsample during the exposition period and was expressed in µg C g^{-1} dry soil h^{-1}. After the analysis, soil samples were dried in oven at 105 °C for 8 h to calculate soil moisture. Microbial metabolic quotient (specific respiration, qCO_2) was estimated as the ratio of BR to MBC (Anderson and Domsch 1993). In the dried and sieved samples pH_{H2O}, total, organic (SOC) and inorganic carbon (SIC) contents were analyzed. Relationships between C content and BR were analyzed to assess the resistance of soil organic matter to biodegradation, based on the biodegradation coefficient k and half-life time $T_{0.5}$. The half-life time is the time period (in years) needed for microbial decomposition of the half of soil organic matter (Smagin et al. 2018).

Soil CO_2 emissions were measured in situ at 10 locations by infrared gas analyzer Li-7810SC in the July and August once in each month with the parallel observation of soil temperature and soil moisture. Relationship between soil respiration and temperature were analyzed to study the abiotic drivers of soil CO_2 emissions, whereas correlation between C content and microbial parameters (MBC and BR) were analyzed to study the biotic factors of soil CO_2 emissions.

8.3 Results and Discussions

8.3.1 Soil C Stocks: Total, Organic and Inorganic Components

The descriptions of 100 cm deep soil profiles (RZ, TZ and GZ) reflect the main natural and anthropogenic factors of soil formation and functioning in the area. Soil of the area were formed on carbonated parent materials and inclusions of carbonates are abundant along all the three profiles. In soil profile of the grazed area, the carbonated C_{Ca} horizon is identifies, that can indicate a more intensive erosion compared to the other sites (Fig. 8.2). The highest bulk density was obtained for the transit zone, where it was 10–15% higher than at the other sites. The observed values 1.1–1.2 g cm^{-3} do not indicate over-compaction, that is likely explained by the short exposure time—active grazing started less than one month before the soil survey. All soil had basic pH, which did not differ significantly between the sites or along the profile. The highest content of total carbon was observed at the reference site, whereas the lowest values were obtained for the transit zone. The grazed zone was the most heterogeneous in C content with CV above 60% which was three times higher than at the other sites. This outcome confirms the previously reported effects of grazing on the short-distance spatial variability of soil properties at the natural pastures, when different activities of cattle (e.g., grazing, for resting or ruminating) results in different C inputs and outputs (Badia et al. 2008; Güsewell et al. 2005). Similarly, mean values and variance of N content at the grazed zone was the highest. C/N ratio ranged from 12 to 16 with the highest values observed at the reference site. Topsoil C stocks at the reference site were 10.4 kg m^{-2} which was 10 and 40% higher than at the grazing and transit zones correspondingly. Almost 30% of the total topsoil C stocks at the reference site were distinguished by inorganic C, which was almost two time higher than at the grazed zone (Fig. 8.3).

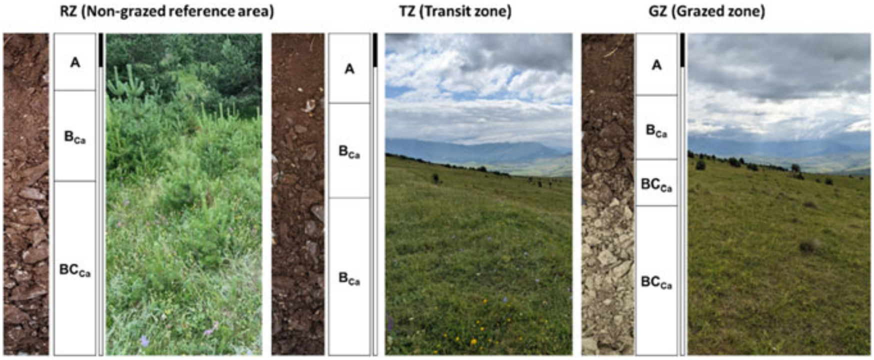

Fig. 8.2 Soil profiles exposed to different grazing intensity

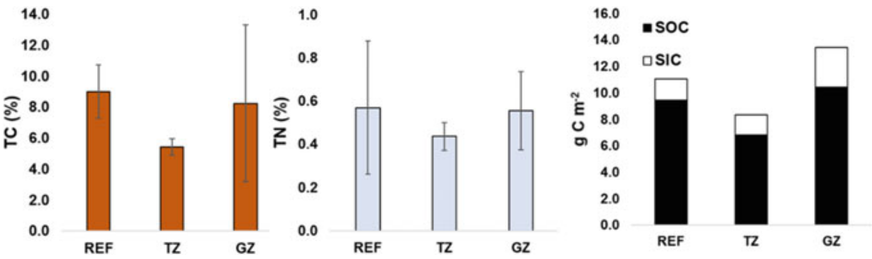

Fig. 8.3 Soil carbon and nitrogen contents and topsoil carbon stocks (organic and inorganic components)

8.3.2 Soil Microbial Properties and CO_2 Emissions

Microbial activity expressed basal respiration in reference areas was 20% lower compared to the sites affected by grazing. Likely, input of fresh organic matter with dropping could activate development of soil microbial community. A similar pattern was reported for the microbial biomass carbon, whereas qCO_2 were similar for all the sites. The magnitude of qCO_2 close to 1 indicate favorable conditions for microbial community development. This is quite unexpected for the grazed area, since physical disturbance is known to increase qCO_2 (Kooch et al. 2020; Qi et al. 2011; Vasenev et al. 2013). Possible reason could be the short period for which the areas was continuously grazed before soil sampling, or the positive effect of the implemented grazing scheme based on the rotation of the grazing sites. Previously the different impacts of high and low grazing intensity on soil microbial properties were reported for Altai mountains (Goenster-Jordan et al. 2021) or Mediterranean pastures (Gavrichkova et al. 2008). The sustainability of soil C stocks expressed by T0.5 and T0.95 were similar for the grazed and reference sites, whereas soil C stocks

Table 8.1 Soil mirobial properties at the research sites

Site	MBC µg C g^{-1}	BR µg C g^{-1} dry soil h^{-1}	qCO_2	k $years^{-1}$	T0.5 years	T0.95 years
REF	2327	2.3	0.96	0.11	7	29
TZ	2897	3.1	1.06	0.09	2	10
GZ	2838	3.0	1.03	0.14	7	30

at the transit area were almost three times more vulnerable to biodegradation (Table 8.1). Soil CO_2 emissions were 2.8 ± 0.9, 1.7 ± 0.3 and 2.4 ± 0.9 g C m^{-2} day^{-1} at the grazed, transit and reference site correspondingly. Soil temperature effect was not significant, likely due to the short observation period.

8.4 Conclusion

Sheep grazing at the natural mountainous pastures is historically a highly important agricultural practice in Chechnya which makes a considerable contribution to the republican economy. Monitoring soil carbons stocks and fluxes and the WAYCARBON polygon started in 2022 aim to assess the grazing effect on carbon balance and improve understanding sheep breeding as a sustainable agricultural practice. The first outcomes obtained in summer 2022 do not show negative effects of grazing on soil C stocks. Microbial biomass and activity at the grazed areas was also similar to the undisturbed reference site. The most likely reason is a short exposure period the area was continuously grazed for less than two months before the soil survey was organized; however, the effect of the light grazing intensity is also a possible option. The latter outcome would be an optimistic message for land-use planners in the region. This message shall be further tested and verified based on the results obtained in the research which can be considered a baseline for further investigation.

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Chapter 9
Ecosystem Services and Ecological State of Postpyrogenic Soils in Urban Forest Environments

Ekaterina Chebykina, Evgeny Abakumov, and Anna Shchepeleva

Abstract Forest fires are among the most significant types of disturbances on a global scale, affecting biodiversity and biogeochemical cycles with an essential contribution to global atmospheric chemistry. Direct damage from forest fires is estimated in billions of rubles annually; however, it can be even higher if indirect losses of environmental and natural values of forests and soils are considered. A novel approach is proposed to assess the ecosystem services of postpyrogenic soils in urban forests of Tolyatti city. A complex indicator to assess the ecological soils state (P_e) was used as a quantitative evaluation parameter. It can both serve as an indicator of the degradation of a separate soil property and be used in the economic assessment of individual environmental services of urban forests. Devaluation of ecosystem services by forest ecosystems and soils in result of wildfires shall be transformed into a cost valuation in future. The cost of ecosystem services restoration provided by the soil is very high and determines the need for maximum conservation of the soil cover in the implementation of economic activities.

Keywords Wildfires · Ecosystem services · Ecological soil state · Forest ecosystem · Urban landscape

9.1 Introduction

The Russian Federation has vast forest resources that provide numerous ecosystem services that are vital to society and the national economy. They contribute to climate mitigation by carbon sequestration, supply a high-quality timber and other forest products, prevent and mitigate damage from catastrophic weather events (storms, droughts, floods) (Schulze et al. 2022; Reitz et al. 2021). Forest tree stands regulate

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the hydrological regime at various scales, purify water, contribute to the creation and maintenance of water reserves in rivers, lakes and groundwater reservoirs (Asgharinia et al. 2022; Efrosinin et al. 2021). Forests also play an important role in the processes of pollination and biological plants protection from diseases, serve as a habitat for more than half of the known plant and animal species, form the soil and protect it from destruction (Bolund and Hunhammar 1999; Gamfeldt et al. 2013). The capacity of the forests to supply vital ecosystem services is affected by natural disturbances, among which wildfires are the most dangerous (Dobrovolsky 2002).

Fire risk is controlled by the interplay of climate, fuel (vegetation) and ignitions, with high risk periods occurring during summer droughts when fuels are abundant and ignitions are typically human-caused (Ganteaume et al. 2013). Under the climate change these risks can increase dramatically (Shvidenko and Schepaschenko 2013). The fire season has become virtually year-round. There are more and more forest fires over the years, and they are more widespread and larger and more catastrophic than before. Plants ignite more easily due to rising temperatures, heatwaves and dry weather.

The negative environmental impacts of forest fires are substantial. As sources of additional greenhouse gases emissions, forest fires have a clear negative impact on global climate (Shvidenko and Schepaschenko 2013). The total amount of annual carbon dioxide emissions from wildfires is about a quarter of those from burning oil, coal and gas. Another major contributor to global warming is black carbon produced and emitted by forest fires. On the other hand, forests accumulate and store the carbon, which has a beneficial effect on the climate. A forest damaged by fire weakens, regenerates more slowly, absorbs less carbon dioxide and releases less oxygen, and therefore does not help to slow climate change (Ilina 2011; Boisramé et al. 2017).

The area of natural wildfires in Russia over the past 20 years has averaged 8.9 million hectares per year, according to Information system for remote monitoring of the Federal Forestry Agency (Rosleskhoz). The area of forest fires in Russia in 2021 amounted to 18.81 million ha. This is maximum value since the beginning of the twenty-first century (Fig. 9.1).

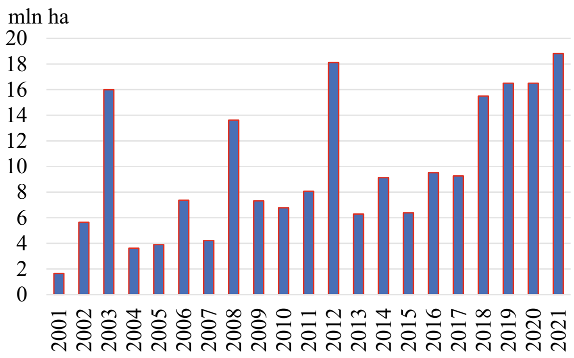

Fig. 9.1 The area of forest fires in Russia during 2001–2021 according to Information system for remote monitoring of the Federal Forestry Agency (Rosleskhoz) (Instructions for determining the damage caused by forest fires 1998)

The average temperature in the European part of Russia in June 2021 was the highest for more than 130 years of meteorological observations. There has been a drought since May in the Urals, the middle Volga and in many regions of Siberia. Yakutia region suffered the most from forest fires. In the conditions of the extreme heats, urban forests become very vulnerable to fire events and the potential health risks and damages from urban forest fires is especially high. A forest fire is fraught with great danger, since in addition to destroying large material values and killing animals and plants, the fire can spread to settlements, industrial enterprises and disable power lines. For example, the forest fires caused by extreme summer heat 2010 caused considerable human victims (Grigorieva and Revich 2021) and total damage of 85.5 billion rubles according to the Federal Forestry Agency. These data are likely considerably underestimated due to the fact that they take into account only the direct loss of wood resources, but do not take into account the loss of environmental and natural values by forests, and even more so do not take into account the indirect damage caused by fire and smoke to human life and health. In particular, a study showed an increase in the number of deaths among the population in the Volga basin (in the Samara region) and the proportion of deaths from diseases of the circulatory system was conducted (Lifirenko and Lifirenko 2010).

The Instructions for determining damage caused by forest fires (Instructions for determining the damage caused by forest fires 1998) states that it is necessary to take into account the damage from pollution of the environment by combustion products, but it does not take into account the fact of an increase in mortality due to fires, which was presented by the study described above (Lifirenko and Lifirenko 2010). Moreover, the Instructions does not take into account the damage from changes in ecological functions and properties of soils as a result of the burnt plant residues and other products income into the soil. It must be remembered that the forest is not only trees, but a whole ecosystem where everything is interconnected: apart from vegetation, fire destroys soils, animal communities, pollutes the atmosphere and much more. All these limitations contribute to the considerable underestimation of the forest fire damages by existing approaches, especially in urban forests, where connection between nature and society is very strong.

The identification of ecosystem services performed by green spaces, the development of approaches to their assessment and payment mechanisms are being conducted for urban landscapes (Baranova et al. 2020; Potapova 2016). Usually, only services for air purification from pollution and recreation are evaluated (Bukvareva and Sviridova 2020). Despite the accumulated significant information on soils, the assessment of ecosystem services of the soil component is not given sufficient attention. Soil transformations affect their functioning and fulfillment of their ecological functions, which should be manifested in ecological services by entire landscapes. Therefore, approaches to assessing the ecosystem services of soils, which are a valuable and hard-to-renew resource, deserve special attention. A natural soil profile formation is measured over centuries in contrast to revegetation.

The soil, as an integral part of the forest community, is affected by wildfires in many ways. Pyrogenic soil changes are the result of the direct fire impact, as well as indirect postfire changes in the biogeocenosis, which are being much more widespread. Frequent forest fires damage beneficial microorganisms in the soil and destroy nutrients. The forest does not fully recover, and if fires occur constantly, then it stops growing altogether. Therefore, soil erosion occurs and desertification begins. Such processes threaten not only biodiversity, but also the climate: these lands do not absorb carbon dioxide, it becomes more in the atmosphere, which means that global warming continues. The pyrogenesis processes are a widespread phenomenon that has a huge impact on the soil formation processes, which makes scientists pay special attention to them in case of natural ecosystems study. Therefore, at present, despite fundamentally different technologies in economic activity, the pyrogenic factor remains an acute problem for forest countries, which requires solutions both in connection with global climate change and a number of economic issues—the loss of ecosystem services provided by forests and soils, the loss of forests as an important component in the terms of decarbonization of the economy.

The research aimed to develop a novel approach to assess the ecosystem services of postpyrogenic soils in urban forests of Tolyatti city.

9.2 Materials and Methods

Research area. The Tolyatti city is a large settlement (more than 700 thousand inhabitants) of a diffuse type. Its areas are separated by forest islands—massifs, which are mostly old pine forests and open spaces (fields, meadows, wastelands). Tolyatti city is a city not only of the Russian automobile industry, but also of a large Russian chemistry (KuibyshevAzot, TolyattiAzot, Sintezkauchuk, Tolyattisintez). Therefore, urban forests are considered a "pine filter" for urban atmosphere. The abnormally dry year of 2010 provoked forest fires on the territory of Tolyatti city as elsewhere in the European part of Russia. This became a local disaster, as it completely changed the functioning of forest ecosystems. Ten destroyed large forest areas. The urban forests of Tolyatti city lost more than 2000 ha of old pine forests as a result of crown fires.

The tree layer survived in forests affected by the surface fire, but the fire of various intensity degree damaged trees trunks, which weakened their vitality and will lead to gradual loss in the future. However, it is woody plants that form communities and will determine the course of restore successions in the future. The grass and shrub layers were damaged to a greater extent. Tree and shrub plantations burned out completely in forest communities affected by the crown fire, as well as the grass and shrub layers, and spontaneous postpyrogenic successions began here. The processes of natural reforestation began already in the following year after the fire. Almost all burnt areas were gradually overgrown with trees and shrubs (Rakov et al. 2011).

The forest grows for a long time. Therefore, the problem of providing city residents with green spaces continues to be very acute, and it should be addressed immediately. According to the "Regional standards for urban design of the Samara region", the total area of green areas for common use (parks, squares, boulevards, etc.) should be at least 9.0 m^2 per person. In fact, one inhabitant of Tolyatti accounts for 2.9 m^2/person in residential areas, and 5.0 m^2/person in forests areas (before the fires in 2010); the average is 7.9 m^2/person. Moreover, within the framework of the activities of the Program, "Forestry Development for 2014–2018 and for the period up to 2022", work to clear illiquid forest areas affected by the consequences of forest fires have being carried out on the territory of the Tolyatti forestry. However, unfortunately, the situation is aggravated by the fact that forest fires in the urban forests of Tolyatti city are repeated, as it was in the summer of 2021.

The forests and green spaces of Tolyatti city perform extremely important aesthetic, landscape-forming, environmental, sanitary and architectural and planning roles. They create conditions for the life support of the city and its population, satisfy the needs for fresh air, places for recreation and communication with nature, are a source of forest resources of various nature and a green filter that reduces the degree of environmental pollution. The great achievement of foresters and population of Tolyatti city is the presence (where industrial structures and transport networks developed in the city) and the preservation (even after the large-scale construction in the end of the twentieth century) of large forest massifs (more than 8 thousand hectares) with their inherent forest environment and uniqueness of nature. Urban forests are characteristic of the cities in Siberia and the Urals to a greater extent. There are not such large forests in the Volga basin except for the urban forests of Moscow (for example, the Losiny Ostrov massif), comparable to the urban forests of Krasnoyarsk. Therefore, the assessment of the loss of an ecosystem service—the soil formation service—after forest fires in urban forests, using the example of Tolyatti city, is an urgent task, which is associated with the uniqueness and difficulty of soil replenishment.

Methods. The quality of ecosystem services in urban landscapes is undoubtedly affected by the ecological soils state. Methods of assessing the ecological state of the city soils have been developed and tested (Stoma and Romanova 2019; Kurbatov and Bashkin 2004). A complex indicator for assessing the ecological soils state (P_e) was used as a quantitative evaluation parameter. The ecological soils state was assessed according to the method of Stroganova et al. (2003). The ecological soils state is a complex of soil properties that determines the degree of their correspondence with the natural and climatic conditions of soil formation and suitability for the sustainable functioning of natural and anthropogenic ecosystems. Eleven parameters were selected for the assessment: thickness of the humus stratum, humus stochs, pH_{H2O}, particle size distribution, bulk density, trace metals content (total pollution index), soil respiration (biological activity), number and biomass of soil biota in the upper layer. Depending on the level of change in the soil property relative to its optimal values or natural analogues, an assessment was made on a 5-point scale (B_i is the assessment of individual *i*-diagnostic indicators of soil properties in points (5 is the optimal situation, 1 is an almost irreversible violation of soil property)) and multiplied by the weight significance coefficient of soil properties diagnostic indicators ($K_i =$ 0.5–1.5). Taking into account the weight significance of each property, a complex indicator for assessing the ecological soils state (P_e) was calculated, which can serve

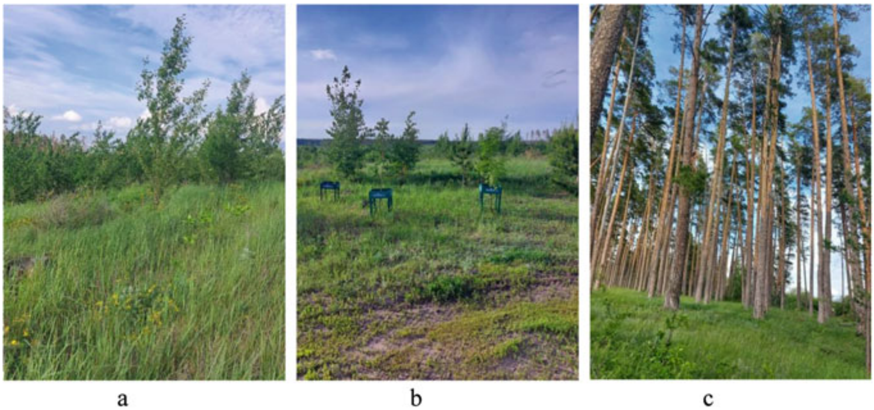

Fig. 9.2 **a** Surface forest fire revegetation plot; **b** crown forest fire revegetation plot; **c** control

both as an indicator of the degradation of a separate soil property and be used in the economic assessment of individual environmental services of urban forests.

Gray-humus sandy loamy soils with features of spodic processes but without the formation of an independent podzolic horizon formed on ancient alluvial Volga sands—Psamment Entisols were studied for assessment the ecological soils state after forest fires. Soil diagnostics were carried out according to the "Classification and diagnostics of soils of Russia" (Shishov et al. 2004) and the World Reference Base for Soil Resources, FAO 2015 (IUSS Working Group WRB 2015). The impact of two types of wildfires—surface and crown—was studied in comparison with the control variant. Figure 9.2 shows the landscape dynamics, the case immediately after wildfire is presented at (Maksimova and Abakumov 2015a).

9.3 Results and Discussion

Data on the main chemical parameters of soils were published in previous works (Maksimova et al. 2019, 2014; Maksimova and Abakumov 2015b; Abakumov et al. 2017). Studies have shown that forest fires alter the morphological and physicochemical properties of soils (Maksimova et al. 2019, 2014; Maksimova and Abakumov 2015b), and lead to complete or partial degradation of organic horizons and the formation of so called pyrogenic horizons (Abakumov et al. 2017).

Diagnosed postpyrogenic soils had the following soil horizons: in the case of postfire areas Qpyr-AY-AC-C; in the case of control area, O-AY-AC-C. The ash was a loose crumbling crust of a dirty gray color of small thickness (1–2 cm), with a significant admixture of small pieces of charcoal and soil particles (the ash seemed to be washed into the mineral horizons). The water-soluble components of the plant litter pyrolysis products together with precipitations will penetrate into the soil stratum and serve as the main agents affecting the organo-mineral part of the soil.

Fires lead to serious changes within the soil profile. The processes of humus loss are especially active when the litter and the upper humus horizon burn out. Changes in soil morphology are most noticeable in the upper horizons (widespread of coals, preservation of ocher tones in the horizons color).

The burning of the litter changes the occurrence and subsequence of soil horizons. As the vegetation develops, a new litter begins to form, but the former pyrogenic horizons persist for a long time. The soils acidity changes as a result of fires, usually toward alkalization. The loss of the most mobile nutrients (potassium, sodium, magnesium and manganese) is noted in the ash formed after fires.

The soil performs many ecological functions in ecosystems, and individual soil properties or their complex are involved in the implementation of certain ecosystem services provided. Transformation of soil indicators under the influence of various factors can lead to a change in the quality of ecosystem services. An assessment of the ecological soil properties state taking into account the degree of their transformation (or difference) relative to the natural potential or optimal values is presented in Table 9.1. Eleven soil properties that can ensure the performance of certain ecosystem services by the urban forest were selected.

The providing ecosystem services are determined by the number and biomass of soil biota from the selected soil indicators: bacteria, fungi, and actinomycetes. Regulatory ecosystem service "filtration and accumulation of chemical elements in ecosystem" correlates with a wide range of soil properties (bulk density, pH, particle size distribution, humus stocks, trace metal pollution), "weathering and soil formation processes" with only two soil properties—a decrease in the thickness of humus stratum and basal respiration as a parameter of biological activity.

The ecological state of postfire soils deteriorates compared to the control: the average P_e value significantly decreases from 5.8 to 4.1 (Table 9.1), and there are no differences between the soils of crown and surface forest fires. It varies significantly for individual soil properties from 2.0 to 7.5 and is below the control by 20–60%. A decrease in the ecological state of individual soil properties relative to the optimum is manifested in postpyrogenic soils in almost 80% of cases. The most negative contribution to the decrease in P_e is made by a decrease in the thickness of the humus horizon and the number and biomass of soil biota. Due to changed habitat conditions and direct burning of soil biota, its condition is significantly deteriorating. Individual indicators of the degradation level of its number and biomass are reduced from 5 to 2–3 points. Moreover, there is a significant deterioration in the ecological state of such diagnostic soil parameters as humus stocks and the thickness of the humus layer (from 7.5 to 3.0 points). Other soil properties do not change significantly as a result of fires.

Devaluation of ecosystem services by forest ecosystems and soils as a result of wildfires shall be transformed into a cost valuation in the future. This is especially true for urban forests in the context of forest fire damage calculations. Similar cost estimates were previously successfully carried out for urban soils (Stoma and Romanova 2019; Semenyuk et al. 2019, 2021). Undoubtedly, the valuation of ecosystem services

Table 9.1 Ecosystem services and indicators of the ecological soil properties state of urban forests in Tolyatti city

Ecosystem services (Vasenev et al. 2018; Morel et al. 2015)	Soil properties	Value			B_i, points			K_i	P_e		
		1	2	3	1	2	3		1	2	3
The genetic material of the biota	$\frac{\text{Number (bln cells/g)}}{\text{biomass (mkg/g)}}$ of bacteria	$\frac{0.64}{12.8}$	$\frac{0.46}{9.2}$	$\frac{2.04}{20.4}$	3	2	5	1.0	3	2	5
	$\frac{\text{Mycelium length (m/g)}}{\text{biomass (mkg/g)}}$ of fungi and actinomycetes	$\frac{144.8}{204.9}$	$\frac{39.9}{63.38}$	$\frac{602.9}{832.81}$	3	2	5	1.0	3	2	5
Filtration and accumulation of chemical elements in ecosystem	Total pollution index Zc	32	7	12	4	5	5	1.5	6	7.5	7.5
	Physical clay content, %	14.9	14.1	15.8	4	4	4	1.0	4	4	4
	Bulk density, g/sm^3	0.78	0.85	1.03	5	5	5	1.0	5	5	5
	pH_{H2O}	8.0	7.9	6.5	3	3	4	1.5	4.5	4.5	6
	Humus stocks, t/ha	36	54	81	3	4	5	1.5	4.5	6	7.5
Weathering and soil formation processes	humus horizon thickness, sm	14	10	23	3	2	5	1.5	4.5	3	7.5
	Basal respiration (biological activity), mg CO_2 per 100 g per day	75	77	258	3	3	5	1.0	3	3	5
P_e average									4.2	4.1	5.8
P_e total									37.5	37	52.5

Note 1—surface forest fire, 2—crown forest fire, 3—control of urban forests affected by forest fires is of great practical importance in the framework of fire safety, forest fire risk assessment and urban planning and should be used as a tool for organizing the urban environment that regulates economic activity in urban forests and the ecological state of urbanized forests territories.

9.4 Conclusions

Forest fires remain one of the powerful natural factors that determine the large-scale environmental changes. The damage from forest fires is estimated in billions of rubles annually, however they take into account only the direct loss of wood resources, but do not take into account the loss of environmental and natural values by forests, and even more so do not take into account the damage caused by fire and smoke to people's lives and health. The ability of the forest and soils to support and supply ecosystem services is lost as a result of forest fires. The cost of ecosystem services restoration provided by the soil is very high and determines the need for maximum conservation of the soil cover in the implementation of economic activities. In order to assess the cost of damage from forest fires, it is necessary, first of all, to take into account the cost of ecosystem services delivered by soil, since their price is comparable to or an order of magnitude higher than the price of ecosystem services of green spaces, and some soil ecosystem services are invaluable due to the complexity of the renewal of this natural resource and the inability to fully compensate for their ecological functions.

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Chapter 10
The Dynamics Peculiarities of the Xylem Sap of Coniferous Woody Plants on the Example of Picea Abies in Rostov-on-Don

R. N. Ospischev, S. N. Gorbov, and A. M. Yaroslavtsev

Abstract The intensive process of urbanization increases the demand for urban green building. In order for the development of green infrastructure to correspond to the rate of urban growth and reduce its negative impact on human health, it is necessary to use methods of modern and continuous monitoring. Through innovative methods, it is possible to optimize the greening of the city, which will increase the efficiency of the functioning of green spaces. Monitoring was carried out with the help of TreeTalker+device in this work. The main parameter for the study chosen rate of xylem sap of woody plants. Representatives of common spruce Picea Abies were used as an object of study. When analyzing the data obtained during monitoring, it was possible to establish a rank correlation between xylem sap velocity and temperature, as well as to establish a relationship with phenological phases.

Keywords Urban landscaping · Express monitoring · TreeTalker+ · *Picea abies*

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10.1 Introduction

Currently, most of the world's population lives in cities, and the proportion of urban dwellers is steadily increasing, outpacing the population of rural areas in terms of growth rate. According to the forecasts of several specialists, the gap in this ratio of inhabitants will only increase (Dye 2008). As a consequence, the man-made load on the green framework of urban ecosystems, which, in turn, provides a neutralization of the negative factors of the urban environment, increases (Matasov 2020).

Urban green infrastructure, as the main compensating component of the city, affects both the formation of a comfortable microclimate for living and reduces the concentration of pollutants in the soil and the surrounding environment. At the same time, modern cities are characterized by spatial expansion due to the occupation of adjacent areas, and green infrastructure should keep up with this growth. However, there are several problems that prevent the formation of a balanced combination of park and recreational and industrial-settlement areas associated with the specific nature and climatic conditions, anthropogenic pressures, and limited space (Lisikov 2015).

In the context of Rostov-on-Don, these problems are exacerbated by the steppe type of biocenosis. Special climatic conditions with a large amplitude of temperature differences between summer and winter make it difficult to grow woody plants in this area. In addition, woody plants play an important role in the formation of the microclimate in the city of Rostov-on-Don. A decrease in the number of trees leads to dust storms and droughts. The solution to this problem is the introduction of the most appropriate species for the area, which requires a lot of time resources. At the same time, the introduced plants require special timely care and control of their condition, and consequently, the use of modern monitoring methods is necessary to optimize this process as much as possible. These methods make it possible to quickly give a quantitative assessment of the state of plants, namely trees growing in certain soil and climatic conditions. Such an approach will probably make it possible to leave the extensive development of urban greening to the intensive one, increasing its quality and efficiency (Gudzenko and Gudzenko 2012; Kozlovskiy et al. 2013).

The main problem of growing woody plants in the city of Rostov-on-Don is regular watering against the background of extremely high summer temperatures and dry winds, especially in the early years of rooting. In this case, the question of watering doses and maximum seasonal peaks in moisture consumption can be indirectly determined with TreeTalker+, as the device allows you to track the rate of xylem sap and establish in what period of the year the plant needs abundant watering for comfortable growth.

Thus, the quality of green infrastructure will be higher, and therefore, woody plants will perform their functions better. Thus, it is possible to move from extensive development of urban landscaping to intensive.

In this study, it is expected to establish a correlation between the rate of xylem sap and the temperature of the near-trunk part of the tree. It is also assumed that the phenological phases directly depend on the flow rate.

10.2 Objects and Methods

The territory of Rostov-on-Don is characterized by an arid climate. The amount of precipitation in the spring–summer–autumn period is 270–300 mm. In summer, the average temperature is + 22– + 23 °C. Also 180–190 days with a temperature above 0° C. Winter is moderately mild: the average temperature in January is −5 °C, the average absolute minimum of air temperature during the winter is −20–25 °C (Kozlovskiy).

Monitoring of Picea Abies was carried out in the nursery of the botanical garden of Southern Federal University. This decision was due to the growth of single-aged specimens of Picea Abies, formed in similar soil and microclimatic conditions, at the monitoring point. Picea Abies is actively used in the landscaping of the city of Rostov-on-Don, as it is resistant to the specific climatic conditions of the steppe zone. Covering an area of 165 ha and located in the central part of the city, the botanical garden is a unique reference monitoring site where it is possible to approximate the results obtained with TreeTalker+ to trees growing in watershed areas throughout the city. This relates to the fact that one of the advantageous features of the SFU botanical garden is the presence of all the main components of mesorelief characteristic of Rostov-on-Don city, including the flat upland part of the right bank of the Don River (Kozlovskiy et al. 2011).

The main factor in choosing a tree crop for monitoring was the frequency of its use in urban landscaping and its range. R. abies is widespread in the north-east of Europe, there it forms solid forested areas, in Russia the northern border of the range often coincides with the border of forests, and the southern reaches the chernozem zone (Novikov et al. 2008). P. Abies has a high drought and frost tolerance, which is one of the main qualities in its integration into the green frame of Rostov-on-Don. High shade tolerance of this tree allows its use in city parks in conjunction with broad-leaved trees.

We used three specimens of P. Abies. All selected trees were of the same age, identical habitus, and formed near each other (Fig. 10.1).

The TreeTalker+ device contains external and internal sensors. With the help of external sensors, the device is able to measure the intensity of sap flow (temperature and humidity of the xylem of the trunk) and an IR distance sensor (for measuring point radial growth). Internal sensors measure the temperature and humidity of the air, the intensity of solar radiation, and the light reflected in the crown in various wavelength ranges (12 ranges, from blue to near infrared), and the angular deviation of the trunk from the normal along three coordinate axes, using a gyroscopic sensor.

The monitoring was carried out from March 15 to September 15, 2021. The TreeTalker+ device was used to record parameter sap velocity (according to the Granier method) and air temperature in the rootstock part of the tree. In this method, two sensors are embedded in a tree trunk to a depth of 3 cm, one of which measures the temperature of a linear heat source (which it is itself) implanted in the sapwood part of the tree, in relation to the temperature of unheated wood, measured by the

Fig. 10.1 Map of TreeTalker devices in the nursery of the SFU Botanical Garden where: 1–3 Picea Abies

second sensor. When the flow rate is zero or minimum, the temperature difference between the two sensors will be maximum. As the flow accelerates, this temperature difference decreases.

During the growing season, the visual method (according to V.A. Alekseev) recorded the phenophases of Picea Abies. The presence of a meteorological station in the immediate vicinity of the nursery allowed recording microclimatic conditions for the entire monitoring period.

The rank correlation between xylem sap rate (variable) and tree rootstock air temperature (factor) was established using the STATISTICA program. In most cases, the rank correlation was found according to Pearson; the non-normal distribution method (according to Spearman) was used when searching for the dependence during the whole month. Scale diagrams were used to establish the reliability of the differences in juice flow (variable) from the time of day (grouping).

10.3 Results and Discussions

The analysis of daily TreeTalker+ data taken from Picea Abies rank correlation of xylem sap rate with temperature was traced daily in most cases in all investigated individuals, and the distribution was normal and the dependence was direct. The degree of reliability ranged from strong to weak. The correlation was strong ($p = 0.79–0.87$) in the spring months, moderate ($r = 0.36–0.71$) in the summer months, and weak ($r = 0.11–0.21$) in September (Fig. 10.2).

There was only rarely recorded an inverse dependence of xylem sap rate on temperature in individual specimens ($p = -0.41–0.62$), these anomalies occurred in the spring, and less frequently in the summer period. A similar inverse correlation appeared sporodically for each tested tree and was unaffected by weather conditions (Fig. 10.3).

A correlation was detected sporadically and not for all specimens during analysis of data of monthly fluctuations of sap flow, and the distribution was non-normal. The correlation was most frequent in the spring months, and it was weak ($r = 0.11–0.21$).

Mann–Whitney U-criterion analysis showed practically no reliability of differences in the rate of sap flow from the time of day. It was noted only on some summer days, with the highest rate of xylem sap occurring at night. However, the low occurrence of such cases casts doubt on the objectivity and representativeness of the results obtained.

A certain dependence can be traced when comparing phenological phases of Picea Abies and dynamics of xylem sap. Swelling of vegetative buds (PB1) in spruce begins

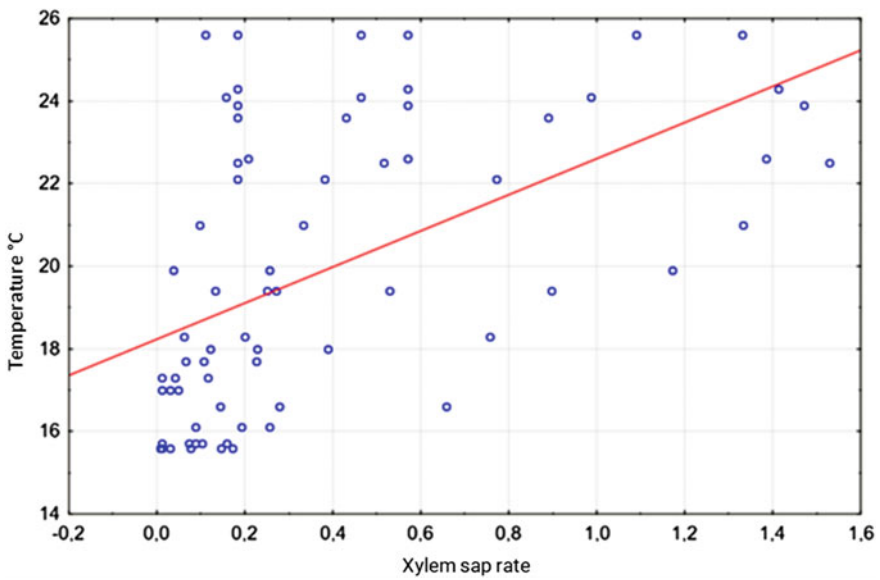

Fig. 10.2 Scatter diagram of xylem sap velocity and temperature of Picea Abies (16.05.2021)

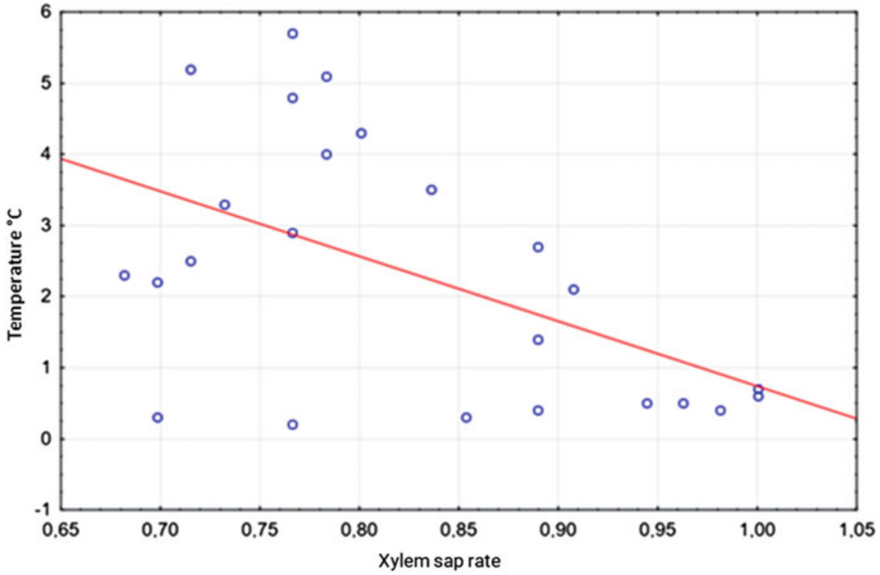

Fig. 10.3 Scatter diagram of xylem sap velocity and temperature of a single specimen of Picea Abies (26.03.2021)

in the middle of April, and from that moment a sharp increase of sap flow rate until the beginning of May is noted. In the described time interval, cutting of vegetative buds (PB2) and the beginning of linear growth of shoots (PB3) also take place. All these processes require a large amount of moisture, which is shown in Fig. 10.4. Further, from the middle of May, needles detachment (L1), flowering (C1), and growth shoots capsizing (PB4) start. These processes are also reflected in the form of response on the graph.

Nevertheless, the correlation observed cannot indicate that the rate of xylem sap depends only on the ambient temperature and phenological phase. The xylem construction and the structure of the root system of this or that plant species play an important role in the studied process (Chernishenko 1998). A significant role is played by spring and summer precipitation, the influence of which has been partially recorded. Thus, the analysis of weather archives data allowed us to trace the increase of sap flow rate on the days when precipitation of more than 15 mm and the day following it. However, it should be noted that such peaks of sap flow associated with atmospheric precipitation were not always tracked and were characteristic of heavy rainfall in summer (Gismeteo Weather forecast 2022).

A characteristic feature of holosemous plants is two phases of fluid saturation: summer and winter. In winter, there is much more moisture in the tree than in summer, which can also be partially traced by the TreeTalker+ results (Fig. 10.5). During summer periods, there is a decrease in the rate of xylem sap movement, with the maximum decrease occurring in August, when dry winds dominate the region. It

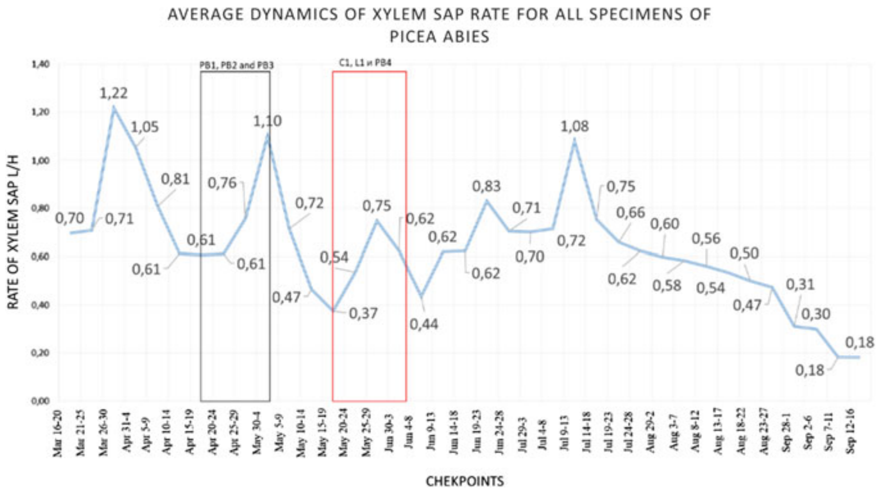

Fig. 10.4 Seasonal dynamics of the sap flow rate of Picea Abies from March 15 to September 15

should be noted that Picea Abies is characterized by a difference in dynamics and correlation between sap flow rate and temperature relative to other conifers of the region, such as Pínus sylvéstris. Thus P. Abies has a clear correlation throughout the season, and it is characterized by a clear dependence of individual phenological phases on the nature of xylem sap dynamics (Kramer and Kozlovskiy 1983; Ospischev et al. 2022).

10.4 Conclusions

1. As a result of IoT monitoring using TreeTalker+, a daily and monthly correlation between sap flow rate and temperature for Picea Abies was established. The dependence is observed throughout the monitoring period. However, the Mann–Whitney U-criterion analysis showed no significant difference between the sap flow rate and time of day.
2. The analysis of xylem sap dynamics during the whole vegetation season recorded the correlation of the studied index with the phenological phases of Picea Abies. It is most clearly traced at the beginning of the tree's vegetation. The first peak of sap flow occurs during the period of vegetative bud swelling and cutting, as well as during linear growth of shoots. The second peak of sap flow is associated with detachment of needles, flowering and capsizing of growth shoots.

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Chapter 11
Daily and Seasonal Dynamics of Mixed Forest Biodiversity in the Moscow Region According to Acoustic Monitoring Data

M. Goretskaya, I. Beme, J. Betancourt, M. Perov, and V. Matasov

Abstract The Moscow agglomeration is one of the largest in the world and the largest in Russia. Natural landscapes here influenced by the strongest anthropogenic impact, manifested in the increase of landscape fragmentation and reduction of natural habitats. Monitoring of biodiversity and study of species behavior patterns under anthropogenic pressure is one of the important goals of ecoacoustics—a scientific discipline at the interface of geography and ecology, which is only beginning to develop in Russia. In this work, the main subject of research is the diurnal and seasonal dynamics of avifauna of the temperate forests of European Russia. The key study sites were the mixed forests of the western Moscow Region ecopark "Nachiniye," the park "Korsar" and the preserve "Zvenigorod Biological Station". Audio data were collected by passive acoustic monitoring using Song Meter SM4 devices between January 2020 and October 2021. Five major acoustic indices were calculated using the R "seewave" package. Statistical analysis showed the relationship of bird vocalizations with the time of day, the season of the year, and the place of recording. The hourly changes in acoustic indices by seasons of the year for the temperate forests of the Moscow region were identified. Our results slightly differ from the previously identified regularities.

Keywords Ecoacoustics · Biodiversity · Song Meter · Temperate forest · Temporal dynamics

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11.1 Introduction

Numerous global initiatives aim to conserve biodiversity, but it would be successful only if biodiversity can be measured and its rate of change quantified (Buckland et al. 2005). Rapid changes in landscape use and the impact of climate change have a lot of consequences (Foley 2005; Stocker 2013), such as growing fragmentation of natural landscapes globally and further habitat loss with biodiversity drop, changes in behavioral patterns and temporal activity of different species, and transformation in ecosystems functioning in general (Crooks et al. 2017). Thus, the development of cost-effective methods for biodiversity monitoring at scale is an urgent global imperative (Newbold et al. 2015; Campos et al. 2021).

The sounds produced in the environment by geophysical (geophonies), biological (biophonies), and anthropogenic (technophonies) processes have been found to be an important indicator of the quality of a system (Schafer 1977). Recent developments in soundscape analysis have demonstrated the existence of a strict connection between ecology and sounds (Farina et al. 2014a). Acoustic diversity has been considered to be a good proxy for overall vocal animal richness (Depraetere et al. 2012). Different from bioacoustics which mainly investigates sound as a signal that transfers information between individuals, sound is regarded as an indicator of ecological processes for ecoacoustics (Xie et al. 2020; Doser et al. 2020). In particular, ecoacoustics aims to investigate natural and anthropogenic sounds and their relationship with the environment including populations and communities (Sueur et al. 2014; Gasc et al. 2015). Acoustic patterns may be used for assessing the complexity of ecosystems (Matsinos et al. 2008; Servick 2014).

In the literature, there is a long-standing idea of a biphasic, with peaks in the morning and evening hours, distribution of the daily activity of birds, including singing activity (Kasatkina, 1963; Ptushenko and Inozemtsev, 1968; Sheldon, 1994). As a rule, singing activity was measured in several (2–3) individuals of one species, and then, the results were extended to other representatives of the species studied (Podarueva, 1977). The use of automatic monitoring methods makes it possible to fill this gap, and such work is currently being carried out in different regions and on different continents (Sugai et al. 2019a). In the temperate forests of European Russia, such work is carried out for the first time, and it will allow us to describe in detail the nature of bird vocalization in different periods of the year. Therefore, the aim of the work is to analyze the seasonal and daily variability of biodiversity acoustic activity in the temperate forests of European Russia. So, our tasks were to collect acoustic data at key sites, calculate acoustic indices, and identify temporal variability.

11.2 Materials and Methods

11.2.1 Study Area

The research was conducted at three key sites: eco-park “Nachinanie,” park “Corsair,” Zvenigorod Biological Station. All three key sites are located in the Moscow region. The eco-park “Nachinanie” and park “Corsair” are located on the opposite banks of the Istrinsky reservoir, 38 km northwest of Moscow. Both key sites are located within the moraine-outwash plains of the Istrinsky landscape, which is characterized by a slightly undulating relief (Annenskaya et al. 1997). Zonal spruce and spruce-broadleaved forests due to early development of the territory have not been preserved—today within the ecopark, there are not only spruce and oak, but also larch and small-leaved forests due to reforestation after bark beetle damage.

Zvenigorod Biological Station is located 41 km west of Moscow on the right bank of the Moscow River. This key site is located within the Zvenigorod landscape, which is characterized by undulating outwash plains on interfluves and flat sandy terraces in the Moscow valley (Annenskaya et al. 1997). Spruce and pine-broadleaved forests are predominantly distributed within the study area.

11.2.2 Data Collection

The data collection method used in this work is passive acoustic monitoring. This method makes it possible to collect large acoustic data arrays without active human participation using special sound recording devices (Sugai et al. 2019b). The sound recording device used at all key sites is the Song Meter SM4. Sound recordings were made during the first half of each hour during the observation period. Thus, we recorded 12 h of sound per day. The sampling rate used was 48 kHz, with 16 bits quantization. Recording points were chosen to minimize anthropogenic influence on the collected audio data. For this purpose, the points were installed away from roads, paths, or other potential sources of anthropogenic noise. At each point of each key site, audio was recorded for at least one full day, after which the recorder was usually moved to another point or to another key site.

At the Zvenigorod Biological Station, sound recording was conducted at two points in May, June, August, and October 2020 and in April, May, June, and October 2021. In the Ecopark “Nachinanie,” sound was recorded at four locations in January, March, April, May, June, and September 2020 and in April, May, June, August, and October 2021. Corsair Park was recorded at four locations in January, February, March, June, and September 2020 and in April, May, June, August, and October 2021. In result, more than 500 gigabytes of audio data (1440 records in 2020 and 1603 records in 2021) were collected.

11.2.3 Data Processing

First, to clean the data, each recording was checked (listening and examining frequency plots) for extreme values and interference using the Avisoft-pro software, since weather conditions, mainly rain or very strong wind, external or artificial noise, or explosive vocal behavior of animals (frogs, insects, etc.) create erroneous recordings. When these inconsistencies in extreme conditions were checked, the corresponding wav files were deleted. In addition, only files with a recording duration of 30 min were selected to calculate the acoustic indices. All calculations of the acoustic indices were performed in the R environment using the "*seewave*" package (R Core Team 2014). For this work, five acoustic indices were selected to describe the daily and seasonal dynamics of the sound environments of selected key sites: ACI, BI, ADI, AEI, and NDSI.

The Acoustic Complexity Index (ACI) is based on the hypothesis derived from the observation that natural biotic sounds (e.g., birdsong or wolf howls) are characterized by intrinsic variability in intensity. Anthropogenic noises (e.g., the sound of passing cars or airplanes taking off), on the contrary, are often monotonous, even if not always. Thus, ACI should theoretically "extract" its natural component from an audio recording and quantify changes in behavior or biophonic composition from recording to recording (Pieretti et al. 2011). In this work, to reduce the influence of anthropogenic noise on the results obtained, only the frequency range of 500–12,000 Hz was used in the calculation of the ACI.

The Bioacoustic Index (BIO) is based on the hypothesis that most of the biophonic activity of the sound environment falls within a specific frequency range, which can be adjusted depending on the research objectives (Farina and Pieretti 2014). In this work, to reduce the influence of anthropogenic noise on the results obtained, only the frequency range of 500–12,000 Hz was used in the calculation of BI.

Acoustic Diversity Index (ADI) and Acoustic Evenness Index (AEI) are a pair of indices, which evaluate the variability of signals within an audio recording. Similarly to ACI, these indices use hypothesis about high internal variability of biophony. ADI is a Shannon index for signals louder than a certain threshold in various frequency bands. AEI similarly represents the Gini index. Thus, the presence of a single signal in multiple frequency bands marks the natural origin of the signal (Kasten et al. 2012). In this paper, to reduce the influence of anthropogenic noise on the results obtained, only the frequency range from 0 to 12,000 Hz with a threshold of 50 decibels was used in calculating the ADI and AEI.

Normalized Difference Soundscape Index (NDSI) is an index, the purpose of which is to determine the level of influence of anthropogenic impact on the soundscape by identifying the ratio of biophony to anthropony in the collected sound recordings (Farina and Pieretti 2014; Gasc et al. 2015). Thus, index values from -1 to 0 indicate the predominance of anthrophony in a particular sound recording, and from 0 to 1—biophony. In this work, the frequency range from 0 to 1600 Hz was chosen for anthrophony, and from 1600 to 12,000 kHz for biophony.

Statistical processing was also performed in the R environment using the "nlme" package. In this work, we used Linear Mixed Effects (LME) models, which are effectively used to estimate fixed and random variables as predictors of the model. The fixed variables were the time of day (hour of sound recording), the period of sound recording, and the key plot. Thus, these three characteristics of the sound recording were chosen as the primary determinants of the values of the acoustic indices. The recording device and the number of the point within the key section were chosen as random variables. The obtained values of acoustic indices showed a significant relationship with the fixed variables with 95% reliability. Thus, it was concluded that the statistical significance of bird vocalizations from the time of day, season, and place of sound recording.

To plot the daily and seasonal dynamics, the values of acoustic indices in a particular hour were averaged over the values of indices in the same hour at other points and other key sites. Thus, the average value of the acoustic index for a particular hour within all key sites was obtained. This method allows minimizing the influence of weather, human, and other interference in specific recordings. As a disadvantage of the chosen method, we should mention ignoring the spatial differentiation of the sound environment both at the level of one key site and at the regional landscape level.

The periods of the year covered with acoustic data were divided into seasons as follows: Period 1—January and February—Winter; Period 2—March—Spring; Period 3—April and early May—Spring; Period 4—End of May and beginning of June—Early Summer; Period 5—End of June and early July—Summer; Period 6—August—Late Summer; Period 7—September and October—Autumn.

11.3 Results

11.3.1 ACI Daily and Seasonal Dynamics

During the seven selected periods, changes of daily dynamics were observed, which are manifested primarily in the number and time of recorded peaks of ACI (Fig. 11.1).

In January–February, the latest hour of the morning dawn peak is at 9 a.m. This peak smoothly passes into a plateau of similar index values, which by 19 h compares with the night values. The March period of sounding is characterized by a similar daily dynamic: a morning peak by 8 a.m. and a rapid return to the night values of the index around 4 p.m. It should be noted here that the highest ACI values are recorded at 1 p.m. In the records from April and early May, the morning peak is shifted a few more hours back to 4–5 h in the morning. After a slight decline of the index during the day, a small evening peak at 8 p.m. is observed. On the ACI chart for period 4 during the dawn peak at 4 a.m., the maximum values for the day are reached; the evening peak is more pronounced than in May and early June, following a dip in the chart during the hot afternoon hours. In late June and early July, the maximum

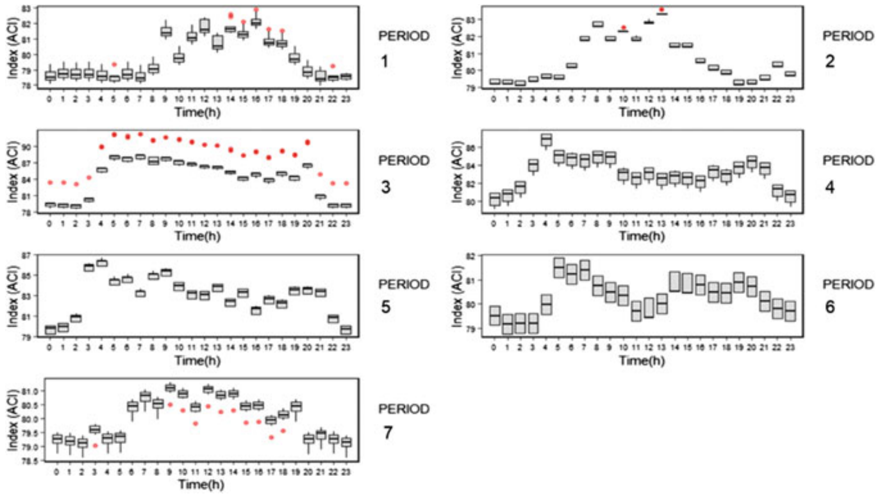

Fig. 11.1 Daily dynamics by seasons of the year of ACI index

ACI values are also recorded during the morning; similar ACI values are recorded throughout the day until darkness at 22 h, without a pronounced evening ACI. In August, the morning peak again begins to shift in the later hours, after which, as in other summer months, the index values fall in the hottest hours. The evening peak is not pronounced, comparing with the afternoon index values. In September and October, it is difficult to distinguish even the morning peak—we can simply distinguish a daytime period of increased ACI and a quieter nighttime period, which lasts almost the same amount of time.

Thus, the daily dynamics by seasons of the year has significant differences. In addition, seasonal differences are also manifested in the absolute values of ACI. From May to July, the peak values of the index are 86–87, which is 4–5 higher than at any other time. The night values of the index vary little throughout the year, ranging from 78 to 80.

11.3.2 BIO Daily and Seasonal Dynamics

The bioacoustic index shows similar ACI dynamics, with peak occurring in periods 3–5, i.e., from May to July (Fig. 11.2). Similarly, in January and October, peaks are not pronounced, but rather long periods of relatively high BIO during the day and silence at night. Similarly, the morning and evening peaks are most pronounced in May–July, with generally high daytime index values. A rare noticeable difference is the August period of sounding, during which the peaks, like in October, are not expressed, and the graph is divided into day and night periods.

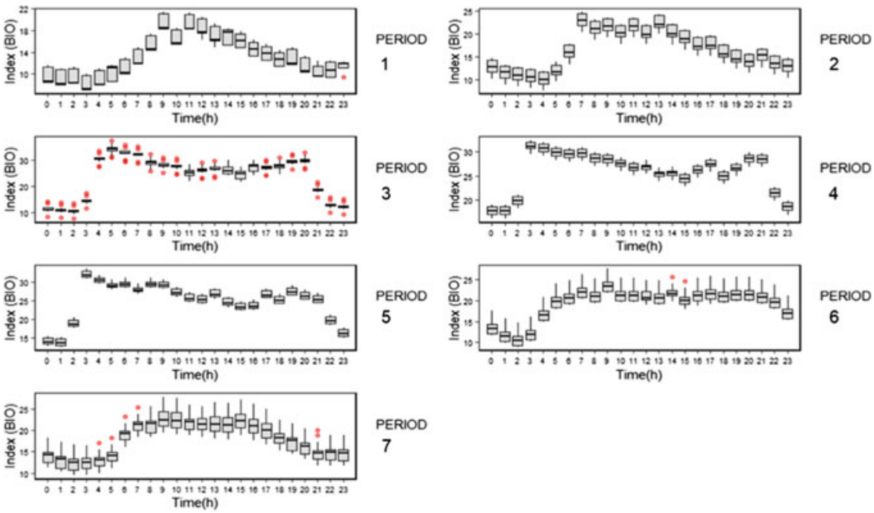

Fig. 11.2 Daily dynamics by seasons of the year of BIO index

11.3.3 ADI and AEI Daily and Seasonal Dynamics

The ADI and AEI indices, as evaluating the same phenomenon from opposite sides, will be considered in pairs (Fig. 11.3). The ADI index by higher values highlights periods of variable acoustic environment, and the AEI highlights the same periods by lower values. In general, the graphs of these indices repeat the previously described graphs of ACI and BIO with some peculiarities. Thus, ADI highlights the morning peaks brighter than the evening ones, unlike ACI and BIO, whose peaks in the morning and in the evening had approximately the same values. The exception is the August recording period, during which the maximum values are recorded during the sunset peak and smoothly pass into the nighttime. In addition, it is possible to distinguish morning and evening peaks ADI (and, hence, AEI) plots even in October soundings-the above-described ACI and BIO indices represented daytime soundings of this period as a plateau with approximately equal values.

11.3.4 NDSI Daily and Seasonal Dynamics

During the winter period of audio recording, the NDSI extreme values are recorded at 3, 9, 12, and 15 o'clock. At the same time, the difference in absolute values varies within 0.04. In general, the NDSI values in January and February have practically minimal values approximately all the time. In the March recording period, the night values of the morning peak at 6–8 a.m. clearly stand out against the background of the daytime values of the index, which do not differ much from the nighttime

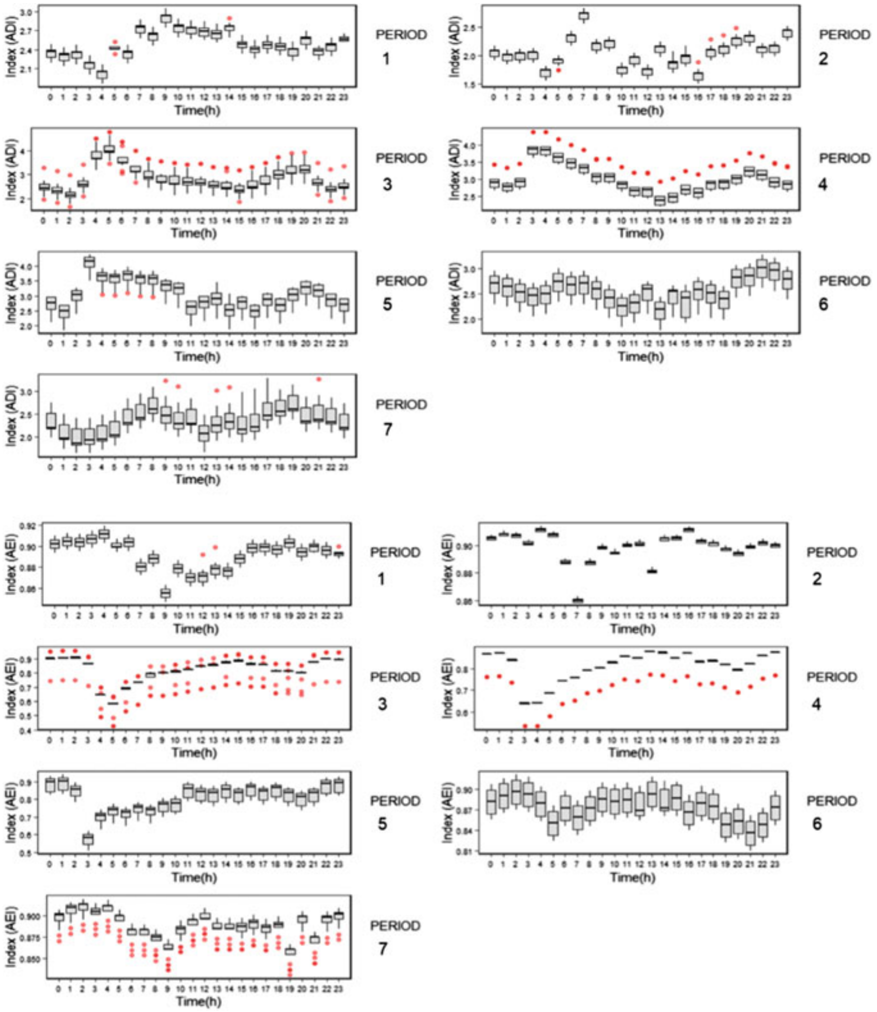

Fig. 11.3 Daily dynamics by seasons of the year of ADI (top) and AEI (bottom) indices

values—not more than 0.05. Nevertheless, even the sound recordings with the highest NDSI values show a clear predominance of low frequencies in the sound recordings (Fig. 11.4).

The graphs of NDSI in periods 3, 4, and 5 are very similar to each other. At night, almost the minimum possible values of the index are fixed, after which the index values rise sharply above zero at 3–5 a.m. in the morning. The daytime values of the index still indicate the predominance of nominal anthropony, ranging from −0.5 to −0.8. However, these values are significantly (by 0.2–0.5) lower than during similar hours in early spring, autumn, and winter. In August, there is a sharp drop in the absolute values of NDSI—the maximum values do not exceed −0.9 even in the

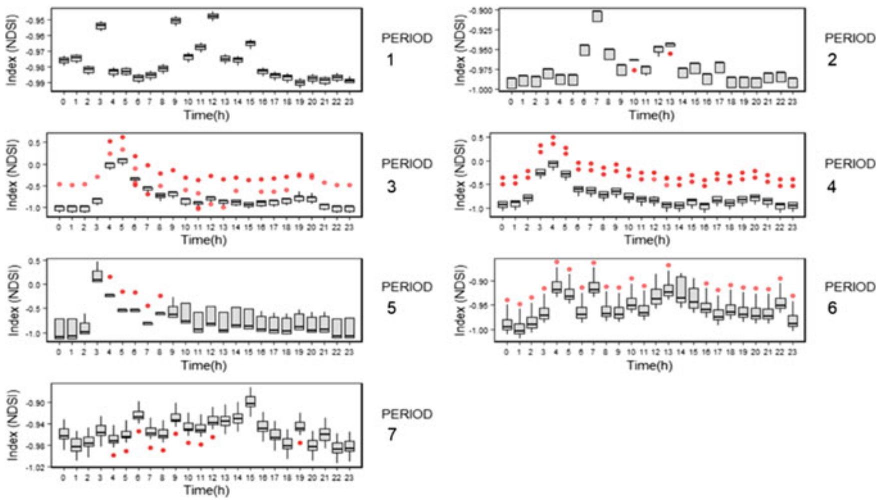

Fig. 11.4 Daily dynamics by seasons of the year of NDSI index

morning, and the "summer" appearance of the graph with a clear peak is lost. In the fall, the NDSI takes on the appearance of a set of extremely low values, which are only slightly higher than in January and February.

11.4 Discussion

Our data showed that, in general, in the temperate forests the acoustic indices reflecting the complexity of the acoustic environment and biodiversity have a pronounced seasonal variability. In the cold season, vocalization begins shortly before dawn and remains at a high level until 2 p.m., then it decreases slightly and disappears completely with sunset. In March, the period of vocalization is longer, but also limited by daylight hours. In spring and summer period, vocalization begins long before dawn (at 4 o'clock in April–early May and at 3 o'clock in June) and continues after sunset; the biotic component is absent only in the period from 23 to 2 o'clock. Interestingly, the maximum of vocal activity during the breeding season falls in the pre-dawn hours, the pre-dawn chorus characteristic of birds (Catchpole and Slater 2008), and then the level of vocalization declines somewhat, but remains high until 10–11 h. A slight decrease in vocalization activity occurs during the daytime only from 12 to 15 o'clock and then increases. Thus, the automatic monitoring revealed a much higher level of vocalization during the day than previously assumed (Depraetere et al. 2012; Eldridge et al. 2018).

We were limited by the number of sensors, so different points were recorded at different times within a season. Perhaps a preliminary comparison with AudioMoth (Farina et al. 2014b; Hill et al. 2019) and their use could help reduce costs and thus get more points recorded in parallel. The influence of the weather was also eliminated by averaging, but this factor should be considered separately in a further detailed analysis (Sueur et al. 2014; Borker et al. 2020). Verification with traditional biodiversity assessment methods is also needed.

With the development of acoustic monitoring systems, it is possible to incorporate them into decision-making systems. Since for the system of nature reserves and national parks one of the tasks is the monitoring of biodiversity, the introduction of such algorithms can significantly improve our understanding of the natural processes. In addition, analysis of vocalization is also important for the urban environment biodiversity assessment, including recreational infrastructure development in urban forests, as it allows to assess the impact of anthropogenic influence (Cohen et al. 2014; Klingberg et al. 2017). In addition, the combination of noninvasive monitoring with crowdsourced observations by city residents (Mydlarz et al. 2019) seems particularly promising for biodiversity and noise pollution assessment in urban conditions (Fang and Ling 2003; Dowling et al. 2012).

11.5 Conclusions

- For the first time, long-term acoustic monitoring studies in the Moscow region have been carried out.
- Representative series of daily and seasonal dynamics of acoustic indices in background mixed forests of temperate climate are obtained.
- According to the results of the analysis, the duration of the morning activity hours during the day (from predawn to noon) was longer than in the previous assumptions.
- The period of minimum activity of biota in summer months was only three hours (from 23 to 2 o'clock)

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Conflict of Interest The authors declare no conflict of interest.

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Chapter 12
A Tremendous Green Roof or Biodiversity Museum? First Outcomes from Soil Survey in Zaryadye Park

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Abstract Soils play a crucial role in functionality, sustainability and biodiversity of urban green infrastructures. Constructed Technosols not only contribute to biodiversity by creating conditions for vegetation growth, but also are niches for microbial communities. This effect is especially important in botanical gardens and urban parks, where Technosols aim to reconstruct the soil conditions typical for the plants from different biomes. In this research, Technosols properties were studied in Zaryadye Park—a unique green area in the centre of Moscow city, where the diversity of bioclimatic zones ranging from tundra to subtropics was reproduced. Soil survey was carried out in summer 2022. In total, 36 locations from 9 aggregated biomes were visited: tundra (*T*), coniferous forest (CF), mixed forest (MF), deciduous forest (DF), steppe (*S*), floodplain (*F*), meadow (*M*), subtropical forest (SF) and urban greening (UG). At each location, both disturbed and non-disturbed sires were examined. Soil organic matter (SOM) in Technosols was significantly different between the biomes, whereas soil pH, *P* and *K* contents were similar. Physical disturbance

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from recreational load resulted in topsoil over-compaction with the highest bulk density above 1.5 g cm^{-3}. Anthropogenic factors (e.g. urban heat island, aerial dust deposition and implementation of mineral fertilizers) resulted in mineralization of organic matters, shift in soil pH and phosphorous inputs decreased initial variability of soil properties, decreased their functionality and microbial diversity. Site-specific precise soil management followed by regular soil monitoring is needed to preserve biodiversity of the Zaryadye Park.

Keywords Technosols · Urban green infrastructures · Soil organic matter · Microbial diversity · MicroResp

12.1 Introduction

Although urban areas cover around only 2% of the global land area, in some countries, their extent reaches 20% and continues growing fast (Sharma et al. 2016). Urbanization has a strong and diverse impact on ecosystems, resulting in considerable and as a rule irreversible changes in vegetation and soils. Deforestation, pollution and soil sealing are the main negative consequence of urbanization which deplete urban ecosystem services (Dvornikov et al. 2021; Romzaykina et al. 2021; Vasenev et al. 2019). Development of green infrastructures, in contrast, enhance urban ecosystem services (Elmqvist et al. 2015; Gómez-Baggethun and Barton 2013). Urban green infrastructures provide cooling effect and contribute to climate mitigation and adaptation (Yan et al. 2018), support carbon accumulation and storage (Deeb et al. 2020; Vasenev et al. 2017), preserve and enhance biodiversity (Filazzola et al. 2019; Hostetler et al. 2011; Savvas 2016). In fact, urban green infrastructures are new ecological niches with unique environmental conditions for living organisms (Korneykova et al. 2021; McPhearson et al. 2016). Traditionally, urban sustainable development strategies and nature-based solutions focused on biodiversity preservation and control focus on the plant diversity and abundance as the main indicator (Basnou et al. 2020; Hoyle et al. 2017; Pierce et al. 2020). However, the role of urban soils remains overlooked or completely ignored.

Urban soils play a crucial role in functionality and sustainable development of urban ecosystems by delivering and supporting important ecosystem services, e.g. carbon accumulation, nutrients supply and water balance (Morel et al. 2014; Vasenev et al. 2018). Urban soils are exposed to direct and indirect anthropogenic influences, and they are very heterogeneous and dynamic. This variability is just partly considered by international soil classifications (e.g. Technosols in World Reference Base for Soil Resources, (Rossiter 2007; Schad 2018)), whereas much more detailed classification schemes were developed at the country and city levels (Charzyński et al. 2018; Kabała et al. 2020; Prokofyeva et al. 2011). Technosols are man-made soil constructions which "properties and functions are dominated by technical human activity" (Rossiter 2007). Technosols' properties and functions are usually studied from the perspective of a particular service they deliver, including reclamation of degraded lands (Moreno-Barriga et al. 2017; Slukovskaya et al. 2019), capturing surface run-off (Mueller and Thompson 2009; Sun et al. 2009) or supporting green infrastructures for sports and recreation (Ignatieva et al. 2017; Monteiro 2017). In contrast to long-term formation and evolution of natural soils, Technosols are constructed at a single moment in time and can be considered as a model for understanding the early dynamics of urban soil formation. At the zero moment, Technosols' properties are mainly distinguished by materials used for their construction (Smagin et al. 2012; Neina et al. 2016). Physicochemical and biological properties of peat materials, organic wastes, composts, biosolids, dredge sediments and other materials establish a baseline for Technosols' functions and ecosystem services (Ivashchenko et al. 2021). Their further evolution is driven by soil-forming factors, including climate, parent material and living organisms (Deeb et al. 2020; Séré et al. 2010).

Technosols have direct and indirect impact on urban biodiversity. Directly, Technosols under green infrastructures are niches for microbial communities, which functional and taxonomic diversity can be much higher compared to more disturbed urban areas or even to natural ecosystems (Burrow 2018; Hedde et al. 2019; Korneykova et al. 2021). Indirectly, Technosols contribute to biodiversity by creating conditions for vegetation growth. This indirect effect is especially important in botanical gardens and urban parks where diversity of plants from different biomes and bioclimatic zones is exhibited. In this case, Technosols aim to reconstruct the soil conditions typical for the plants from different biomes. At the same time, they are exposed to the effect of plants via, e.g. carbon input or metabolic exudate. These mutual relationships between Technosols and vegetation drive sustainability of urban green infrastructures.

The research aimed to investigate diversity of Technosols properties in Zaryadye Park—a unique green area in the centre of Moscow city, where the diversity of bioclimatic zones ranging from tundra to subtropics was reproduced. The concept of Zaryadye Park was to create analogue landscapes that reflect the natural zones of Russia: tundra, coniferous and broad-leaved forest, and steppe. A zonal vegetation is also represented in birch forests as an element of secondary vegetation of forest zones and meadows. Artificial phytocenoses have also been created in the park. Plants are placed on artificial relief and soil, mostly on the roof. These factors necessitate the study of the regularities of the dynamics of multispecies communities and the development of the regulations for their maintenance.

We hypothesized that Technosols properties will differ between the plant biomes. We also assume that dynamics in plant distribution and soil properties in comparison with the initial state will be observed.

12.2 Materials and Methods

12.2.1 Research Area

Zaryadye Park locates in the historical centre of Moscow megapolis (55.75 N; 37.63 E). Created in 2014 in the area of the demolished "Rossia" hotel, Zaryadye is one of the most famous places in Moscow, attracting more than 10,000 visitors every day (Kasyanov 2017). The principal aim of the park was exhibiting natural and cultural diversity of Russia. In result, biomes from tundra, taiga, deciduous and mixed forests, steppe, meadows, floodplain and even subtropical forest co-exist on the 10.5 ha area (Fig. 12.1). The collection of plants of Zaryadye includes 38 varieties, forms, varieties of 226 species, with 34 species listed in the Red Data Book of Moscow and/or the Moscow region and 7 species in the Red Book of the Russian Federation. The collection includes 29 varieties of trees and shrubs of 74 species belonging to 39 genera and 21 families (22 tree species and 52 shrub species); 9 varieties of herbaceous perennials, varieties forms of 137 species belonging to 101 genera 34 families; 9 species of aquatic and coastal aquatic plants belonging to 9 genera and 7 families; 6 species of ferns belonging to 5 genera and 6 families. Family Rosaceae Juss. is the most widely represented among tree and shrub species. Among the herbaceous perennials, the most common are the Asteraceae Bercht. and J. Presl, Poaceae Barnhart and Rosaceae Juss.

To support such a diverse vegetation, Technosols were constructed with consideration of the natural soil properties for the corresponding biomes, e.g. high-moor peat was recommended for tundra zones to create acid conditions, whereas valley peat was used to construct Technosols of the floodplain biomes (Rappoport et al. 2019). Soil functionality in the park is constrained by a very limited soil depth, which is less than 50 cm for the major part of the area. Technosols are underlain by

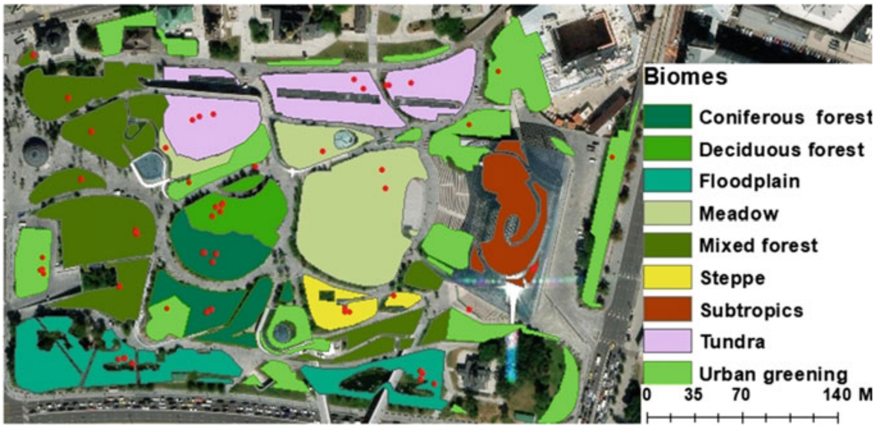

Fig. 12.1 Soil sampling locations (red points) at different biomes of Zaryadye Park

concrete constructions and engineering facilities and pipelines. In fact, Zaryadye Park can be considered a tremendous green roof, and therefore soil formation and functioning processes occur in a relatively shallow layer and are very intensive. Besides, these processes occur under permanent anthropogenic pressure. Thousands of visitors affect soils by over-compaction and physical disturbance. Located in the centre of Moscow and surrounded by roads with intensive traffic, Zaryadye ecosystem is also exposed to aerial deposition of dusts and heavy metals (Romzaykina et al. 2021) as well as to a strong urban heat island effect (Vasenev et al. 2021).

12.2.2 Soil Survey and Laboratory Analysis

To study variability of soil properties in Zaryadye Park, soil survey was carried out in summer 2022. In total, 36 locations from 9 aggregated biomes were visited: tundra (*T*), coniferous forest (CF), mixed forest (MF), deciduous forest (DF), steppe (*S*), floodplain (*F*), meadow (*M*), subtropical forest (SF) and urban greening (UG). At each location, both disturbed and non-disturbed sires were examined. Composite soil samples were collected from 0 to 10 cm by Edelman auger and transported to laboratory for physical, chemical, and microbial analysis. Bulk density samples were collected by Edelman and estimated after drying in the oven at 105 °C for 8 h. The contents of organic carbon (C_{org}, dichromate oxidation), available phosphorus and potassium (extract 0.5 M CH_3COOH, colorimetry and flame photometry, respectively) were determined in the soil samples. The pH_{KCl} was determined by potentiometry (soil:solution = 1:2.5).

The plate count method was used to determine the number of viable microbial cells. The next day after sampling, a series of soil dilution were prepared and plated on nutrient agar mediums: meat-peptone agar (MPA) to determine the total number of microorganisms and Czapek medium, acidified with lactic acid (4 ml/l), for micromycetes. After the incubation time, the grown colonies were counted in the form of colony forming units (CFU), calculation per gram of dry soil. The species composition of micromycetes was determined based on cultural and morphological characteristics using the following identification keys (Domsch et al. 2007; Raper and Thom 1968) and subsequent refinement using Index Fungorum database (http://www.indexfungorum.org).

Community level physiological profile (*CLPP*) was assessed by microbial respiration response on addition of different low molecular weight organic substrates, measured by MicroResp™ technique (Marinari et al. 2013; Moscatelli et al. 2018; Campbell et al. 2003). The substrates represent C sources of different quality: amino acids (glycine, L-arginine, L-leucine, α-aminobutyric and L-aspartic acids), carbohydrates (D-fructose, D-galactose and D-glucose), carboxylic acids (L-ascorbic, citric and oxalic acids) and phenolic acids (vanillic and syringic). The response of microbial community was detected by CO_2 production using colorimetric method after 6 h of incubation with detection gel at 25 °C. The absorbance by the detection gel was analysed at 595 nm wave length (microplate spectrophotometer FilterMax F5, US) before and after incubation. The absorption units were converted to μg C g^{-1} h^{-1} according to Moscatelli et al. (2018). Microbial functional diversity was assessed using the Shannon–Wiener index: $H = -\Sigma Pi \times \ln Pi$, where Pi is the ratio of respiration response to i substrate addition to total respiration response for all studied substrates.

12.2.3 Data Processing and Analysis

The primary outcomes were analysed by basic descriptive statistical tools and presented as mean and standard error for each biome. The significance of difference between the biomes was checked by analysis of variance (one-way ANOVA). The effect of disturbance was checked by *T*-test. Cluster analysis was implemented to distinguish microbial respiration response to different substrates for the CLPP analysis. To analyse temporal dynamics in soil properties, the research outcomes were compared to the initial values recommended for each biome when Technosols were constructed.

12.3 Results and Discussions

12.3.1 Variability of Soil Physical and Chemical Properties

All Technosols had neutral pH ranging from 6.0 to 7.2. The lowest values were obtained for tundra biomes, whereas soils under steppe vegetation had the highest pH. Neutral or slightly alkaline pH is typical for urban soils even in the areas where natural soils have acid reaction. It is usually explained by the aerial deposition of dust containing concrete particles and other substances (Brianskaia et al. 2020; Prokof'eva TV, Kiryushin AV, Shishkov VA, Ivannikov FA 2017). The investigated biomes varied in SOM content considerably. Technosols under tundra biome contained more than 14% of organic matter which was significantly higher than in any other biome. The lowest SOM contents were observed in steppe and meadow biomes. An average SOM content was 5.9% which is comparable to the values previously reported for urban soils in Moscow (Ivashchenko et al. 2014; Vasenev et al. 2013); however, the variance coefficient above 70% indicated high spatial variability of SOM content in Zaryadye Park. Available phosphorous ranged between 200 and 800 mg kg^{-1} and available potassium between 100 and 500 mg kg^{-1}. The highest nutrient contents were observed in soils under forest and steppe biomes, whereas tundra soils contained the lowest amount of available *P* and *K* (Fig. 12.2).

The average *P* and *K* contents were considerably higher than in natural references of the corresponding biomes. The maximal *P* concentrations above 800 mg kg^{-1} can be even considered toxic and likely indicate anthropogenic *P* income. High

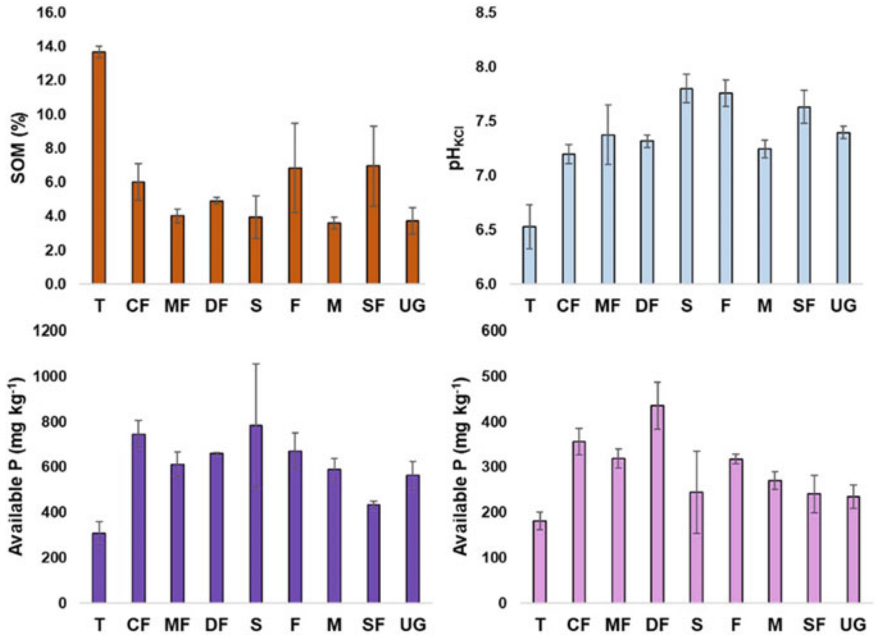

Fig. 12.2 Variability of soil chemical properties between and within biomes (mean and SD, see Sect. 2.1 for abbreviations)

P concentrations in urban soils were previously reported for Beijing (Han et al. 2011; Zhao and Xia 2012), Nanjing (Yang et al. 2021) or Apatity (Korneykova et al. 2022), which is sometimes referred as phosphorous pollution, which coincided with considerable environmental risks. The biome factor explained from 50 to 70% of total variance in soil properties with the highest effect reported for SOM ($R^2 = 0.73$, $p < 0.05$) and the lowest for pH and *P* content.

The effect of disturbance on soil agrochemical propertied was not significant (*T*-test, $p < 0.05$). This is not surprising considering that recreational load coincides with over-compaction and soil cover disturbance that has a stronger impact on soil physical properties. Soil bulk density in the park was normally distributed with the median value close to 1.0 g cm^{-3}. The lowest bulk density was observed at the non-disturbed plots of the coniferous forest biome. The highest bulk density observed at the disturbed meadow area was above 1.5 g cm^{-3} that indicates over-compaction with possible negative consequences for plant roots and soil microbiota (Fig. 12.3).

12.3.2 Variability of Soil Microbial Properties

The main integral indicator of the biological activity of the soil is the total microbial number, ranged from a minimum of 12 × 10^3 CFU/g soil in disturbed areas

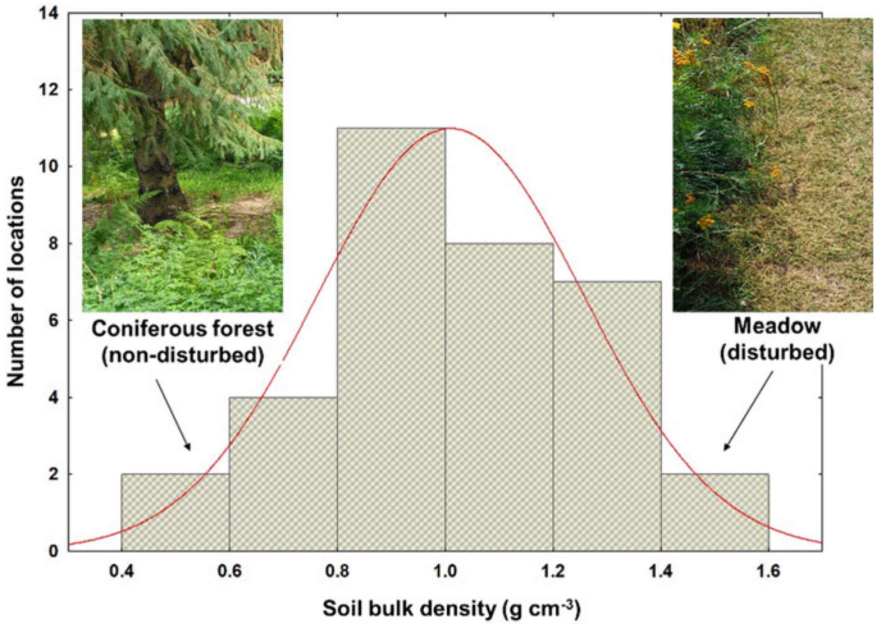

Fig. 12.3 Distribution of soil bulk density in Zaryadye Park

of the floodplain to a maximum of 1788 × 10^3 CFU/g in non-disturbed areas of the subtropic forest. The number of cultivated microscopic fungi in different landscape zones varied from 20 CFU/g soil to 2.6 × 10^3 CFU/g soil. The potential for decomposition of organic matter in soils is low. The number of micromycetes was higher in the soil samples of the "northern" landscapes, alpine and humid tundra, which corresponds to zonal patterns and can be explained by a more acidic reaction of the environment. In the species composition of the cultivated mycobiota, 20 species of micromycetes were identified, excluding the group of fungi with white sterile mycelium. These are mainly cosmopolitan species found on various organic, mainly plant, substrates. Representatives of the phylum *Ascomycota* prevailed (95% of the total species composition) the phylum *Mucoromycota* represented by the only species of *Rhizopus stolonifer*. Species diversity is low compared to zonal analogue, which corresponds to the concept of "dominance concentration" (Terekhova and Ashikhmina 2013) and is a characteristic consequence of the anthropogenic impact on the soil microbiota (Zvyagintsev et al. 2002). In terms of species diversity and occurrence, the genus *Penicillium* prevailed (Fig. 12.4) with the species *Penicillium miczynskii* dominated in various landscapes zones. The highest species diversity observed in the non-disturbed area of tundra landscape. In the landscapes of deciduous forest, monospecific communities have been identified.

The soil physiological profile showed the high level of carbohydrates and carboxylic acids mineralization. In the soils of tundra, high values of mineralization of amino acids (arginine, aspartic acid) were also noted. Physiological profile of

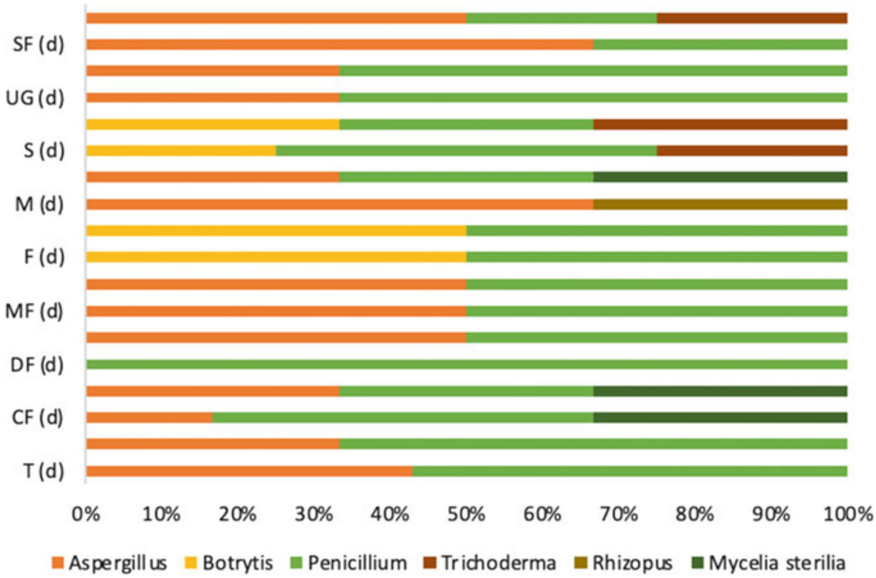

Fig. 12.4 Genus's taxonomy of micromycetes in soils of disturbed (*d*) and non-disturbed areas of different biomes of Zaryadye Park

microbial communities of non-disturbed zones of urban greening, steppe and subtropical forest turned out to be the most similar, demonstrating the greatest response to the introduction of various substrates (Fig. 12.5).

As a measure of microbial functional diversity of prokaryotic soil communities, the Shannon–Wiener index was used, the values of which varied from a minimum of 1.4 for disturbed mixed forest to a maximum of 2.6 for the disturbed urban greening (Fig. 12.6).

12.3.3 Dynamics in Soil Properties

Soil survey was conducted five years after the park was constructed that allowed analysing dynamics in soil properties by comparison with the initially recommended values. Even though initial data was not available for some of the biomes, the general patterns were clearly identified (Table 12.1). Depletion of SOM was shown for all biomes with the highest losses reported for tundra, steppe, meadows and floodplains where SOM contents decreased more than two times. Likely, depletion of SOM was caused by biodegradation of easily mineralizable compounds of soil mixtures (e.g. peat and compost) used for Technosols' constructions. High emissions from constructed Technosols in Moscow caused by biodegradation of organic compounds and intensified by urban heat island effect was previously reported for Moscow

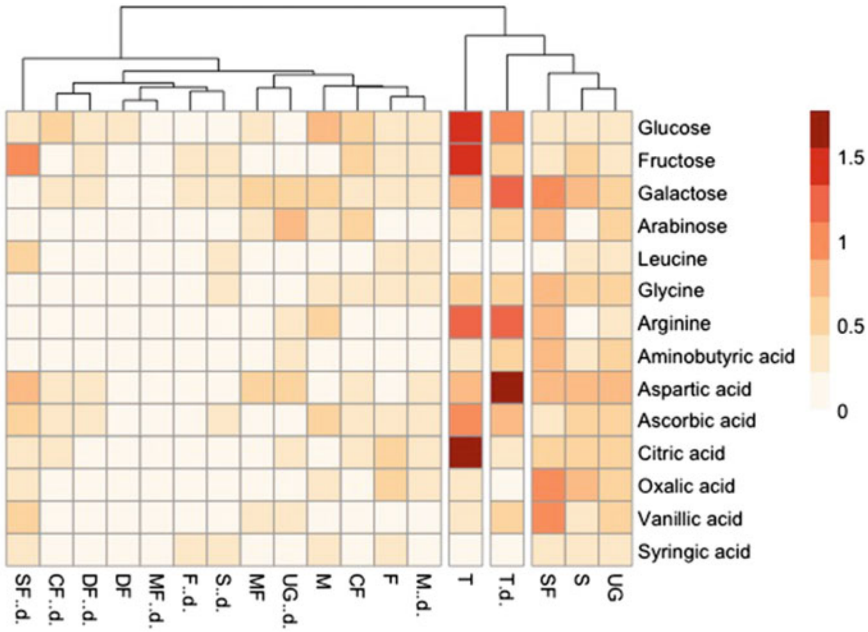

Fig. 12.5 Physiological profile of the microbial community of soils in disturbed (*d*) and non-disturbed areas of different biomes of Zaryadye Park

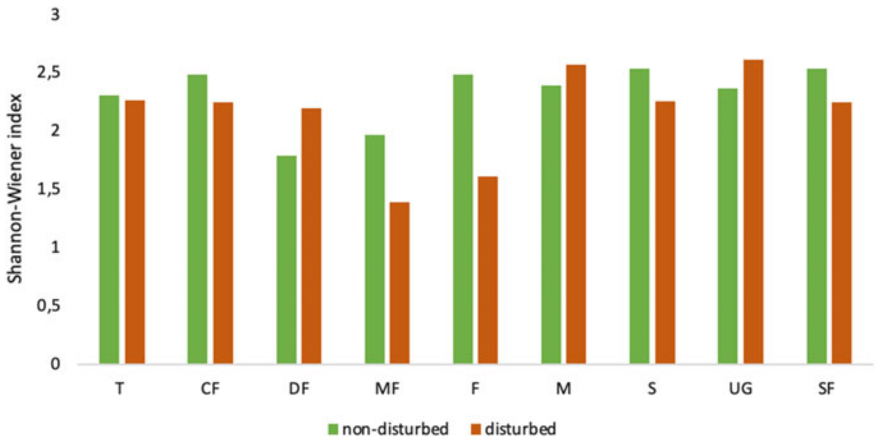

Fig. 12.6 Functional diversity of soil microbial communities in disturbed and non-disturbed areas of different biomes of Zaryadye Park, calculated using the Shannon–Wiener index

Table 12.1 Changes in soil properties in comparison with the initially recommended values averaged for biomes

Biome	SOM (%)			pH_{KCl}			*P* (mg kg^{-1})			*K* (mg kg^{-1})		
	2014	2022	Δ (%)	2014	2022	Δ (%)	2014	2022	Δ (%)	2014	2022	Δ (%)
T	27.5	13.7	– 101	4.0	6.5	39	89	308	71	138	181	24
CF	8.0	6.0	– 33	5.5	7.2	24	152	746	80	225	356	37
DF	8.0	4.9	– 63	6.0	7.3	18	152	659	77	225	436	48
S	8.0	4.0	– 103	6.9	7.8	12	300	783	62	300	245	– 23
F	15.0	6.8	– 120	6.0	7.8	23	250	671	63	250	317	21
M	8.0	3.6	– 122	6.3	7.2	14	225	588	62	225	270	17

(Shchepeleva et al. 2019; Vasenev et al. 2021). An increase of phosphorous was another pattern reported for all biomes. In 2022, soils of all biomes contained 60–70% more *P* than they used to in 2014. Similar pattern in *P* increase reported for all biomes indicates the anthropogenic source of *P* inputs, e.g. with mineral fertilizers. Potassium content also increased 20–40% in all biomes excluding steppe, where *K* content in 2022 was 23% less compared to the initially recommended values. Most remarkable changes were found for soil pH, which shifted 1.5 units in average and 2.5 units in tundra zone. Moreover, in comparison with the initial variability in soil pH, a homogenization patterns was clearly reported—CV in 2022 decreased almost three times compared to 2017.

12.3.4 Dynamics in Plants' Distribution and Variability

Based on the analysis of the abundance of species of herbaceous perennials over a five-year period, 4 resistant species were identified for the tundra biome, 4 species for the steppe biome, 9 species for the dry meadow, 8 species for the broad-leaved forest and 2 species for the coniferous forest. It has been established that about 50% of the species have reduced their abundance and 16% of the species have disappeared from the communities. Based on population studies of herbaceous perennials, it was revealed that some forest species (e.g., *Primula elatior* (L.) Hill, *Corydalis solida* (L.) Clairv., *Scilla siberica* Andrews) and steppe species (e.g., *Eryngium planum* L., *Tulipa biebersteiniana* Schult. & Schult. f.) self-renewed by self-seeding in multi-species communities of the park. The formation of sustainable artificial populations of forest herbaceous species is associated with both microclimatic conditions of growth and the possibility of seed or vegetative reproduction. Seed regeneration for many forest species in the broad-leaved forest of Zaryadye is associated with insects, mainly myrmecochores species. The diversification of the *Anemonoides ranunculoides* L. species occurs in two stages: the spread of seeds from the parent clump and the subsequent development of the daughter clump in a vegetative way. As a result, a sporadic spatial structure of the population is created. The species *C. solida* is characterized by vivipary, which ensures rapid seed germination already in the current growing season before the onset of the dry season. The possibility of formation of populations of forest species in the broad-leaved forest community of the park is also explained by the high coefficients of fruit flowering, seedification and real seed productivity. Thus, such species as *Anemone ranunculoides*, *P. elatior* and *S. siberica* are characterized by a high percentage of fruit flowering (87, 82 and 80%, respectively) and a high seeding coefficient (48% for *S. siberica* and 35% for *A. ranunculoides*) in the natural and climatic conditions of Moscow.

A constant migration of species between different communities revealed in the park, mainly characteristic of meadow species: 12 atypical species were recorded in tundra; 14 species in dry meadow; 19 species in steppe; 39 species in broad-leaved forest with 25 species belonging to the meadow plant community; 14 species in pine forest with 10 meadow species; 21 species in spruce forest with 9 meadow species. Migrate mainly such meadow species as *Linaria vulgaris* Mill., *Vicia cracca* L., *Poa pratensis* L., *Tanacetum vulgare* L., *Alopecurus pratensis* L., *Phleum pratense* L., *Melilotus albus* Medik., *Melilotus officinalis* (L.) Lam., *Medicago lupulina* L., *Trifolium pratense* L., *Trifolium repens* L., *Medicago falcata* L., *Dactylis glomerata* L., *Calamagrostis x acutiflora* (Schrad.) Rchb. etc.

12.4 Conclusion

Zaryadye Park is a unique ecosystem where plants from different bioclimatic zones co-exist under high recreational load and anthropogenic pressure of Moscow megapolis centre. In this circumstance, Technosols play a crucial role in supporting plants diversity and ecosystem sustainability. In their turn, Technosols are affected by plant communities and are also exposed to anthropogenic impact. In result, SOM in Technosols was significantly different between the biomes, whereas soil pH, *P* and *K* contents did not differ significantly. Physical disturbance from recreational load resulted in topsoil over-compaction with the highest bulk density above 1.5 g cm^{-3}. Anthropogenic factors such as urban heat island effect, deposition of alkaline dust and implementation of mineral fertilizers during the seven years of park exploitation resulted in considerable changes in soil properties. Mineralization of organic matters, shift in soil pH and phosphorous inputs decreased initial variability of soil properties, decreased their functionality and microbial diversity. Site-specific precise soil management followed by regular soil monitoring is needed to keep Zaryadye a biodiversity museum and prevent its evolution to a regular urban park. Based on phytocenotic, ecological-geographical and physiognomic principles, an assortment of new species was selected for the communities of the park for their restoration, reconstruction and renewal. Plans have been developed for planting natural species in communities, considering their phytocenotic ratio. These landings are planned for the fall of 2023 after all recommendations, based on the results of soil and environmental monitoring of Zaryadye Park in 2022, which will be implemented.

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Chapter 13
Carbon Stocks and Fluxes in Soils of the Urban Park in Grozny City

K. Ivashchenko, R. Bekmurzaeva, Z. Iriskhanova, V. Vasenev, D. Sarzhanov, M. Korneykova, and M. Nakhaev

Abstract Development of urban green infrastructures (UGI) is considered among the main nature-based solutions for climate mitigation and adaptation in cities; however, the role of urban soils in carbon balance of UGI remains overlooked and likely underestimated. In this research, we observed soil stocks of organic and inorganic carbon and soil carbon dioxide (CO_2) emission for the city park "Mothers' Glory" in Grozny, Chechen Republic, Russia. Soil survey in the park was performed in July 2022. Sampling points were randomly selected within the landscape part of the park. Topsoil (0–10 cm) samples were collected at sites of irrigated lawns, non-irrigated lawns and non-irrigated lawns with trees. Additional samples from top 50 cm and top 100 cm were collected. Soil respiration was measured in situ at the sites by infrared gas analyzer Li-7810SC during the period April–October 2022 with an average time step 2–3 weeks. In parallel, soil temperature and moisture were observed. Total soil CO_2 emission for the observation period was above 0.5 kg Cm^{-2}. Based on the estimated 5.5 years half-life time, C stocks at the managed green areas of Grozny are not resistant to biodegradation, and their vulnerability will likely further increase under ongoing climate change.

Keywords Technosols · Urban green infrastructures · Carbon balance · Carbon neutrality · Chechen Republic

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13.1 Introduction

Globally, cities consume almost three-fourth of energy resources and produce more than half of greenhouse gas' (GHG) emissions. Climate-mitigation strategies claim reduction in urban GHG emissions among the key priorities. The recent IPCC assessment report highlights cities as global warming hotspots, where climate change is exacerbated by urban heat island (UHI) and urban dryness (UD) effects (i.e., higher temperature and lower humidity compared to the surrounding rural areas). Actions on climate adaptation and carbon (C) neutrality are claimed a priority by more than a hundred cities all over the world (e.g., C40 or Cities Alliance). Development of urban green infrastructures (UGI) is considered among the main nature-based solutions (NBS) for climate mitigation and adaptation in cities (Sturiale and Scuderi 2019). City governments and investors have very high expectations from C sequestration by UGI and promote such initiatives as Million Trees in New York (https://www.milliontreesnyc.org/) or My Street in Moscow (https://www.mos.ru/city/projects/moscow2020/) as a universal recipe to reach C neutrality. However, none of these or similar projects consider C stocks in and emission from urban soils. In comparison with natural soils, which are considered in C accounting as achieved stocks (Mikhailova et al. 2021), urban soils shall be also considered as potential C sources due to artificial origin (i.e., importing C with materials for urban soil's construction, Vasenev and Kuzyakov 2018) and high soil respiration further intensified by UHI (Vasenev et al. 2021).

The role of urban soils in C balance of UGI remains overlooked, and this *knowledge gap* increases uncertainty in C accounting and probably overestimates the real potential of UGI for C sequestration and therefore their role in climate mitigation and adaptation measures. Although high net primary production (NPP) of urban trees was reported (Nowak and Crane 2002; Elmqvist et al. 2015), high CO_2 emissions from soils will likely change some UGI ecosystems from sinks to sources, like it was shown for managed lawns (Shchepeleva et al. 2016). Under the climate change, the role of urban soils in UGI C balance will likely increase considering high sensitivity of soil C emissions to changes in temperature and moisture regimes. Risks of further intensification of soil CO_2 emissions are especially high in cities with hot and arid climate where high soil temperature results in intensive heterotrophic respiration during a considerable part of the season. Projecting C dynamics in urban soils and UGI under climate change shall also consider the effects of land cover, soil management, and maintenance of UGI (e.g., mowing, pruning, or irrigation), e.g., Zirkle et al. (2011) showed higher C stocks and potential C sequestration in unmanaged lawns in comparison with intensively managed lawns due to limited C input (grass clips were removed) and higher temperature contributing to intensive soil respiration. Higher soil temperature and moisture were the main abiotic factors, which determined an increased biodegradation coefficient (ratio between CO_2 emissions and topsoil C stocks) in urban soils of Kursk in comparison with the virgin steppe (Sarzhanov et al. 2015, 2017). Preliminary studies in Moscow in summer 2019 also showed that higher average soil temperature (+4.5 °C) and moisture (+20%) under lawns compared to soils under green stands increased soil CO_2 emissions by 40% (Vasenev et al. 2021).

Grozny city is an interesting case study to observe C stocks and fluxes in soil of UGI under hot and dry summer conditions. An average air temperature is above 15 C° from April to October, reaching + 35 C° in July. Based on the remote sensing data, green areas including trees, shrubs, and lawns cover up to 70% of the city area. A considerable part of these green areas comprises natural or semi-natural meadows and forests, where the management effect is minimal. However, several urban parks in Grozny are well-managed that allows studying microclimatic and management effect on C stocks and fluxes in UGI. In 2021, Chechen Republic was selected among the pilot regions in Russia, where experimental stations for C monitoring (C polygons) were set-up. However, so far C stocks and fluxes in urban soils were not observed (Markova et al. 2022). Our research aimed to fill this knowledge gap by investigating C stocks and CO_2 emissions in soils of the urban park "Mothers' Glory" in the center of Grozny city.

13.2 Materials and Methods

13.2.1 Research Area

Grozny city (43.3°N, 45.7°E) is the administrative center of Chechen Republic and of the biggest city in the North Caucuses region of Russia. Although a considerable part of Chechen Republic is dominated by mountainous landscapes, Grozny city is located on a relatively flat area on the banks of Sunzha River. Chechen Republic exhibits a huge diversity of bioclimatic conditions ranging from semi-desert landscape on the North to alpine meadows on the South. Grozny city locates in steppe conditions, and therefore, natural vegetation is dominated by grasses, and most of the tree species used in urban greening are introduced. Natural soils in the area are dominated by Calcic Chernozems and Kastanozems; however, in the city, Anthrosols and Technosols are widely spread. Grozny city was almost completely redeveloped in early 2000-s that resulted in establishment of new green areas or reorganization of the existing ones. One of them is an urban park "Mothers' Glory" (hereinafter MG Park) located in center of Grozny. The park contains of the two areas: area of attractions and a landscape area. Area of attractions is almost completely sealed, and therefore, its contribution to biogenic C balance is minimal (or difficult to assess). The landscape area, in contrast, is more than 90% unsealed and includes lawn areas, ornamental trees, and shrubs. The area is maintained, but maintenance practices vary between the plots (e.g., not all green lawns are irrigated) resulting in a patchy structure of land cover (Fig. 13.1). This patchiness is likely reflected in the spatial patterns on soil C stocks and CO_2 emissions.

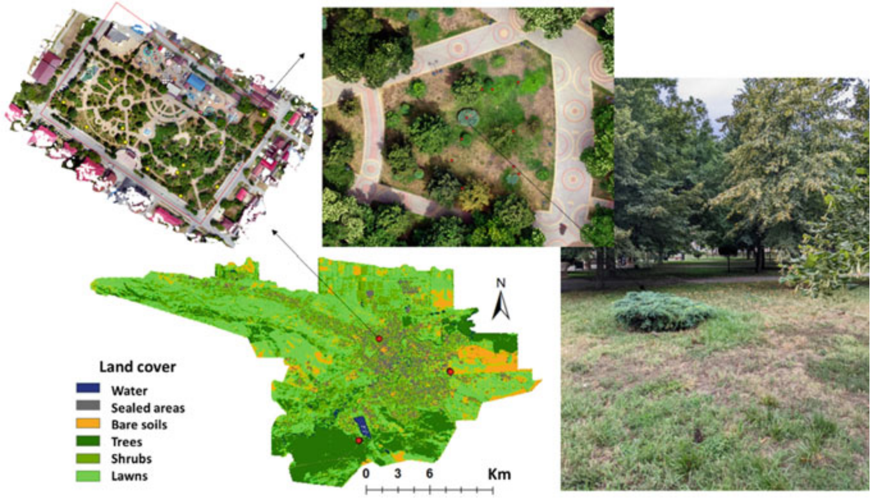

Fig. 13.1 MG Park as a part of urban green infrastructure of Grozny and location of the observation locations (yellow points are the soil sampling locations and red points are locations where soil samples were collected and CO_2 was monitored)

13.2.2 Measuring Soil C Stocks and CO_2 Fluxes

Soil survey in the park was performed in July 2022. Sampling points were randomly selected within the landscape part of the park. Topsoil (0–10 cm) samples were collected at irrigated lawns (MG-1), non-irrigated lawns (MG-2) and non-irrigated lawns with trees (MG-3) sites. Additional samples from top 50 cm and top 100 cm were collected at the sites. All the subsoil samples were collected based on the distinguished horizons that allowed describing profile distribution of soil properties. Bulk density was measured and further used to estimate soil C stocks. All the collected samples were processed in the laboratory (roots and rock fragments were removed), and the following chemical properties were analyzed: pH_{H2O}, total and inorganic carbon (TC and SIC, respectively) contents. Soil organic carbon (SOC, %) was calculated by following: TC - SIC. Soil C stocks (kg m^{-2}) were calculated by the formula BD × h × C / 10, where BD is the soil bulk density (g cm^{-3}); h is the thickness of the soil layer (cm); C is the content of carbon in the soil (%). Soil respiration was measured in situ by infrared gas analyzer Li-7810SC during the period April–October 2022 with an average time step 2–3 weeks. In parallel, soil temperature and moisture were observed. Total C emission for the season was estimated based on extrapolating the daily measurements for the observation period. Ratio between C emissions extrapolated for the season and topsoil C stocks were estimated to approximate the biodegradation coefficient and resistance on soil C stocks. Relationship between soil respiration and temperature was analyzed by multiple regression.

13.3 Results and Discussions

13.3.1 Soil C Stocks: Total, Organic, and Inorganic Components

Based on the description of 100 cm deep soil profiles (MG-1, MG-2, and MG-3), soils of the park have anthropogenic genesis or have experienced considerable anthropogenic effect. Profile MG-1 is a constructed Technosols with a clear RAT horizon comprised from the introduced organic material. The underlying UR horizon also exposes features of urban pedogenesis such as inclusions of bricks and other artifacts. Profiles MG-2 and MG-3 also contain anthropogenic subsoils horizons (TCH and UR); however, organic material was not added to topsoil artificially (at least, it is not evident in contrast to MG-1 profile). The identified AY horizon was likely formed in result of a gradual carbon input with leaves, grass clips, and fine roots residuals. All the profiles include buried horizons of natural Calcic Chernozems (Fig. 13.2). All soil had basic pH, which did not differ significantly along the profile. Land cover and management (mainly, irrigation) were the main factors which determined topsoil C stocks. Topsoils' SOC stocks under irrigated lawns (MG-1) were 35% higher than under non-irrigated sites (data not shown). Among non-irrigated site, topsoil C stock in MG-2 (3.04 kg Cm^{-2}) was slightly higher than in MG-3 (3.00 kg Cm^{-2}) that can be likely explained by more intensive C input with above- and belowground biomass residuals from lawns. An opposite pattern was shown for topsoil inorganic C stocks, which were 0.4, 0.5, and 0.7 kg Cm^{-2} for MG-1, MG-2, and MG-3, correspondingly. Profile distribution for SIC showed a gradual increase of SIC content in deeper horizons. High SIC stocks in subsoil could be partly inherited from the carbonate soil formations of the buried horizons. Dust deposition with further migration down the profile is another possible source of SIC in subsoil. An opposite profile distribution was shown for SOC content, which were more than two times higher in top 50 cm in comparison with the depth 50–100 cm (Table 13.1). TC stocks in 0–100 cm ranged from 18 kg Cm^{-2} for MG-2 to 32 kg Cm^{-2} in MG-1. This outcome is comparable to C stocks under green lawns in cities located in Chernozemic zone, such as Kursk (Sarzhanov et al. 2017) or Rostov-on-Don (Dvornikov et al. 2021) and considerably higher than in Moscow (Vasenev et al. 2013) or northern cities (Korneykova et al. 2021). Fraction of SIC in total C stocks ranged from 11 to 64% that is significantly higher than for Moscow. Such a considerable SIC fraction in total C stocks could contribute to a higher resistance to biodegradation as it was proposed by (Lorenz and Lal 2015). However, monitoring and assessment of CO_2 emissions are needed to check this assumption.

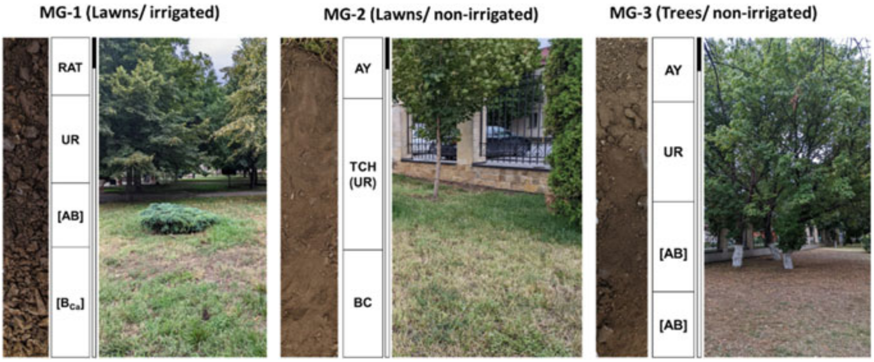

Fig. 13.2 Soil profiles under different land cover types and management regimes

Table 13.1 Profile distribution of soil properties (BD, bulk density; TC, total carbon; SOC, soil organic carbon; SIC, soil inorganic carbon content)

Horizon	Depth	Texture	BD (g cm^{-3})	pH$_{H2O}$	TC (%)	SOC (%)	SIC (%)
MG-1 (lawns/irrigated)							
RAT	0–20	Loam	1.2	8.5	3.9	3.5	0.43
Ur	20–50	Clay loam	1.2	8.7	3.9	3.4	0.55
[AB]	50–75	Clay loam	1.1	8.8	1.3	1.0	0.29
[Bca]	75–100	Clay loam	1.1	8.8	1.9	1.0	0.95
MG-2 (lawns/non-irrigated)							
AY	0–20	Sandy loam	1.0	8.6	3.4	2.8	0.62
Ur	20–50	Loam	1.0	8.4	2.7	1.8	0.92
TCH (Ur)	20–50	Sandy loam	1.0	8.8	2.3	1.8	0.53
BC	50–80	Loam	1.0	8.8	1.6	0.6	1.03
MG-3 (trees/non-irrigated)							
AY	0–20	Loam	1.1	8.8	2.9	2.1	0.85
[AB]	50–80	Clay loam	1.2	8.6	3.6	2.9	0.68
[B]	80–100	Clay loam	1.2	8.7	1.8	0.8	0.98

13.3.2 Seasonal Dynamics in Soil Temperature and CO_2 Emissions

During the observation period, soil temperature varied between 12 and 30 °C with an average + 20.2 °C. For more than six months of observation, temperature never dropped below 10 °C, which is much warmer than in many other cities where soil respiration was previously measured, e.g., Moscow (Goncharova et al. 2019), Kursk (Sarzhanov et al. 2015), or Boston (Decina et al. 2016). Therefore, favorable climatic conditions for soil microbial activity were observed for at least 210 days during the

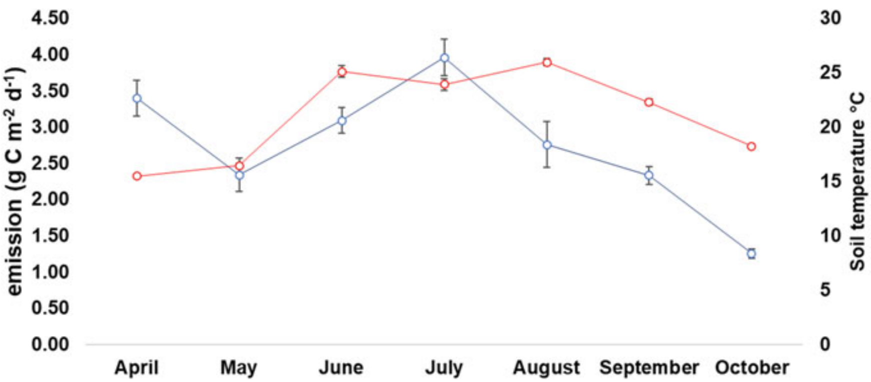

Fig. 13.3 Seasonal dynamics in soil temperature (red line) and CO_2 emissions (blue line) at the irrigated site (MG-1)

season that could result in intensive heterotrophic soil respiration. June and August were the hottest months with soil temperature above 25 °C, whereas the lowest monthly average temperature was reported in October. Soil respiration exposed a similar seasonal dynamic with the highest monthly values in July and the lowest in October (Fig. 13.3). However, we did not find significant positive linear or exponential relationships between soil temperature and soil respiration which is usually reported for urban and natural soils in temperature climate (Shchepeleva et al. 2016; Sushko et al. 2019; Kurganova et al. 2020). Moreover, during the summer months, relationship between soil respiration and temperature was negative, indicating limitation of microbial activity by high temperatures under conditions of the water scarcity. Apparently, even at the irrigated sites, water content in summer is not enough to stimulate gradual growth of soil respiration by increasing temperature. Indirectly, this outcome is confirmed by high soil respiration in April, when soil temperature was almost 10 °C lower than in July, but water content was abundant. In result, observed average emissions were 20 to 50% lower than in green areas of Moscow or Kursk and comparable to green lawns in Rostov-on-Don, where climatic conditions are comparable and water scarcity remains the main limitation factor.

13.3.3 Comparison Between C Stocks and Fluxes

Extrapolation of monthly average CO_2 emissions results in total outflow of 573 g Cm^{-2} for the period between the beginning of April and end of October 2022. This outcome can be considered a minimal estimate of the annual emission, since respiration in November–March is highly likely more than zero. This emission is comparable to the estimates obtained for urban lawns in Moscow and Kursk (Shchepeleva et al. 2016) and Kursk (Sarzhanov et al. 2015; Sushko et al. 2019).

The estimated soil SOC stocks at the MG-1 site where soil respiration was monitored were 4.6 kg Cm^{-2} in top 10 cm and 26 kg Cm^{-2} in top 100 cm. Based on the approach proposed by (Sarzhanov et al. 2017) for Kursk, almost 15% of the total topsoil C stocks can be emitted annually by heterotrophic soil respiration. This value is considerably lower than at the industrial site in Kursk, where the ratio was above 50%. When a more advanced approach to estimate biodegradation coefficient (k) and half-life time ($T_{0.5}$) proposed by (Smagin et al. 2018) is used, an average half-life time of 5.5 years is obtained. This outcome is comparable to the average values obtained for Moscow (Vasenev et al. 2021) but considerably lower than for most of the natural biomes. A short half-life time indicates low resistance of soil C stocks to biodegradation, which can further decrease with ongoing climate change.

13.4 Conclusion

For the first time, soil C stocks and CO_2 emission were estimated for UGI in Grozny city, Chechen Republic. C stocks under managed (irrigated) lawns were considerably higher than under non-irrigated lawns and trees, and therefore, management and maintenance are important factors contribution to C balance in urban soils under hot and arid climatic conditions. The contribution of inorganic C to total C stocks was high and increased down the profile. Although C stocks in irrigates sites were considerable, at least 15% of the topsoil stocks could be released annually by heterotrophic respiration. The estimated half-life time of topsoil C stocks was just 5.5 years that indicate low resistance of C stocks to biodegradation and shall be considered in soil management strategies and maintenance practices.

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Chapter 14
Water Table and Dissolved Organic Carbon Seasonal Dynamic at the Different Ecosystems of the Ombrotrophic Bog (Mukhrino, West Siberia)

Evgeny A. Zarov, Anastasiia V. Meshcheryakova, Viktoria S. Shanyova, and Vitaliy Yu Khoroshavin

Abstract Peatland streams have repeatedly been shown to be responsible for the high amounts of produced in the soil ecosystems dissolved organic carbon (DOC) exported to the Arctic rivers. They contribute to the global carbon budget and remove carbon amounts equal to 50% of the net ecosystem exchange at the peatland. This study aimed to examine the patterns of DOC concentration dynamics for the different vegetation types and to estimate the total amount of DOC loss over the warm season for the typical ombrotrophic peatland in western Siberia. The greatest seasonal averaged DOC concentration (72.0 mg l^{-1}) was found at the driest ecosystem (ryam), while the smallest seasonal averaged concentrations (31.3 and 37.8 mg l^{-1}) were found at the wettest ecosystems (pool and stream). The highest seasonal DOC variation was found for the ridge (range 31–154 mg l^{-1}) and ryam (range 38–107 mg l^{-1}) sites; the DOC concentration at the pool site did not change significantly during the whole season (range 27–53 mg l^{-1}). A seasonal DOC concentration dynamic was discovered, increasing from the beginning of June until the end of August with a subsequent decrease to the initial values. Most of the DOC losses (42.5%) during the spring freshet with the subsequent decrease in the water discharge and DOC loss. The amount of 9.8 tons of carbon has been lost from the catchment area for the spring–autumn season 2021, i.e., ~ 11.14 g C m^{-2} $year^{-1}$.

Keywords Dissolved organic carbon · Peatland · West Siberia · Seasonal dynamic · Carbon loss

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14.1 Introduction

Numerous studies highlight the importance of the dissolved organic carbon (DOC) transfer between soil and freshwater systems (Shirokova et al. 2013). Arctic rivers featured the highest concentrations of organic matter (Dittmar and Kattner 2003) coming from the carbon-rich soils spread on the watershed area. In the peatland carbon cycle, the DOC is accounted for 30–50% of net ecosystem exchange fixed carbon (Roulet et al. 2007; Nilsson et al. 2008; Dinsmore et al. 2010). Increasing export of the DOC from the peatlands to the streams causes an increased flux of organic carbon to the oceans (Freeman et al. 2004; Frey and Smith 2005), where it turns to carbon dioxide and methane, which returns to the atmosphere that could contribute to significant positive feedbacks to climate warming (Field et al. 2007).

The West Siberian plain is the most waterlogged area in the world, where peatlands occupy ~ 600,000 km^2, i.e., ~ 25% of the whole area (Sheng et al. 2004; Smith et al. 2004). Thus, the catchment area of two main West Siberian rivers mostly covers the carbon-rich soils storing at least 70.2 Pg C (Sheng et al. 2004; Smith et al. 2004) where during decomposition under waterlogged conditions, part of the litter and peat converts to a dissolved form and is flushed out by surface runoff. It was estimated that the average stream DOC concentration of ~ 16 mg l^{-1} in West Siberia will possibly rise up to ~ 21–24 mg l^{-1} by 2100 (Frey and Smith 2005).

Numerous global drivers affecting the DOC concentration have been suggested, such as air temperature (Freeman et al. 2001; Clark et al. 2009), elevated carbon dioxide concentration in atmosphere (Freeman et al. 2004; Fenner et al. 2007a, b) and hydrological regime (Tranvik and Jansson 2002; Clark et al. 2009). Additionally, the number of local factors controlling the DOC export from the peatlands to the streams are presented: the catchment area size (Olefeldt et al. 2013; Pokrovsky et al. 2015), water table depth (Strack et al. 2015), air and soil temperature (Bonnett et al. 2006), and vegetation type (Armstrong et al. 2012).

Thus, the DOC export might be expressed as a function of DOC production and hydrological pathways by which water flows in the peatland (Waddington and Roulet 1997). In addition, the peatland vegetation reflects the integrated properties of the habitat, such as the geochemistry of soil water (Kuhry et al. 1993), the peat physical properties (McNamara et al. 2008; Dyukarev et al. 2021a, b), the micro-biota, the quality and quantity of plant and litter input (Wickland et al. 2007), amount of DOC (Armstrong et al. 2012). Summarizing all the above, the vegetation type might be taken into account for predicting changes in DOC loss. Finally, it might be used to estimate the DOC export using remote access data, such as a landuse thematic map.

In this paper, we aim to study the patterns of DOC concentration dynamics for the vegetation types of the typical ombrotrophic bog in West Siberia and to estimate the total amount of DOC loss over the warm season.

14.2 Materials and Methods

14.2.1 Mukhrino Location Map and Measurement Points

Mukhrino field station is located in West Siberia belonging to the middle taiga zone (55–65 N latitude, the Russian Federation). The station occupies the left terrace of the Irtysh River, about 20 km to the west from Khanty-Mansiysk city and about 20 km to the south from the confluence point of the Irtysh and Ob' Rivers.

Most measurements are concentrated at the Mukhrino peatland, a vast pristine ombrotrophic (rain-fed) bog. The most dominant ecosystems are ridge-hollow complexes and ryams. The vegetation consists of a mix of sedges (*Carex limosa*, *Eriophorum vaginatum*) covering a *Sphagnum* mosses mat in hollows, which may become submerged after a snow-melting period. Ridges (30–40 cm height, 10–100 m length) are elongated across water flow, dominated by a mix of *Pinus sylvestris*, dwarf shrubs (*Chamaedaphne calyculata*, *Ledum palustre*, *Andromeda polifolia*) and *Sphagnum fuscum*. Ryams are dense treed by *Pinus sylvestris* together with the dwarf shrubs similar to the ridge vegetation diversity (Filippov and Lapshina 2008). The peatland was initiated ~ 12 kyr ago as a minerotrophic fen with brown mosses, sedges, and wood dominance. The average thickness of the peat deposits is ~ 3.3 m mostly composed of oligotrophic peat (dominant remains are *Sphagnum* mosses and shrubs) (Zarov et al. 2021).

The environmental monitoring system is organized at the station. The main measured properties are the air pressure, radiation balance, precipitation, water level, air and soil temperatures, greenhouse gas fluxes (methane and carbon dioxide), as well as geobotanical surveys (vegetation and fungus) and hydrochemistry (major ions and DOC). The environmental monitoring data are available since 2010 (Dyukarev et al. 2019, 2021a, b).

14.2.2 Precipitation (Rain, Snow)

Precipitation was monitored using a tipping-bucket rain gauge (Hobo RG3-M, resolution 0.2 mm) located in the two sites—ryam and ridge-hollow complex. First, the amount of snow was measured at the end of the snow season (end of March–beginning of April). Then, the snow depth was measured using a measuring rod, and the amount of water stored in the snow was estimated using a metal tube (24 cm diameter, 1.2 m height) and a weighing scale. For this, the exact volume of the snow was cut off by the metal tube and weighted in the field. Totally, forty points was visited during the snow-measurement session.

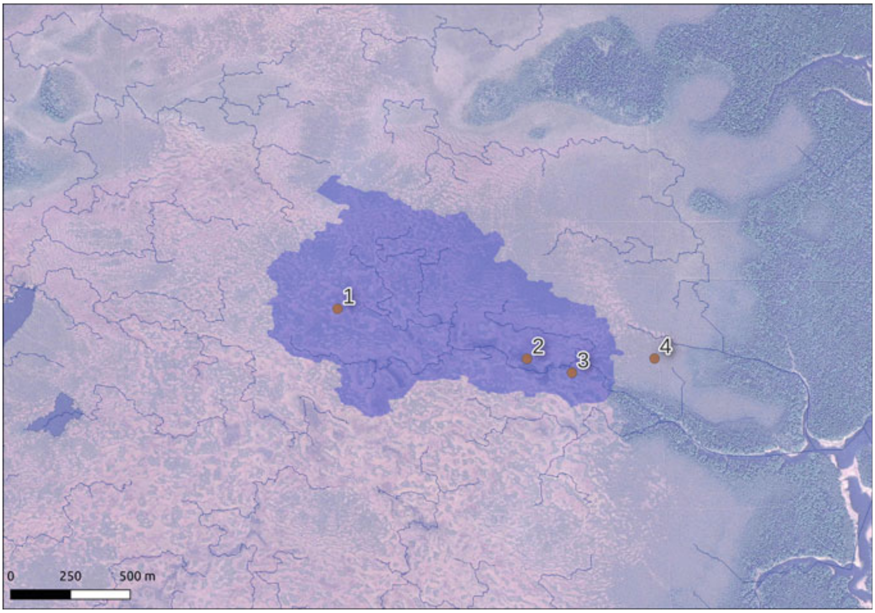

Fig. 14.1 Stream catchment area (blue shade) and piezometer location (1—hollow, 2—ridge-hollow ecotone, 3—pool, 4—ryam)

14.2.3 Water Levels and Air Temperature

A pressure logger (Mini-Diver D1501, accuracy ± 5 mm of water, frequency measurement 30–180 min) was installed in groundwater observation tubes (5 cm diameter) with a filter at 100–250 cm below the peat surface. The groundwater wells were fixed in the mineral soil (at a depth of 350–550 cm below the peat surface, depending on the location) to have a fixed reference datum and avoid vertical changes of position due to peat volume expansion or compression. For barometric compensation, the air pressure and temperature were recorded with a pressure sensor (Baro-Diver, accuracy ± 5 mm of water, frequency measurement 30–180 min) placed in the center of the mire 2 m above the surface. Location of the loggers is shown in Fig. 14.1.

14.2.4 Mapping (DEM and Landunit)

A digital elevation model (DEM) was created based on the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010). The initial model was converted to the

ASCII-formatted file and processed via Python environment (version 3.9.7) integrated with PcRaster (Karssenberg et al. 2010). The flow direction was calculated using the function «*lddcreate*» on its base, and a catchment area was calculated using the function «*catchment*».

Six land units (hollow, ridge, ryam, pool, forest, and stream) (Filippov and Lapshina 2008) were delineated by visual classification of ESRI Satellite (2 m spatial resolution), Resource P (0.5 m spatial resolution) and field survey data. Classification was preformed within the QGIS software (v. 3.24).

14.2.5 DOC Analysis

Water was sampled once a month in three replications from the most typical ecosystems (hollow, ridge, ryam, pool and stream) located at a distance of 100–200 m from each other to cover a spatial variation. The water samples were collected from the plastic pipes (perforated from the surface to the depth 20 cm for the hollows and pools, to the depth 50 cm for the ridges and to the depth 80 cm for the ryams) installed at each point and directly from the stream mouth. The water were sampled into a glass bottle (made of black glass, 70 ml) at the upper water level (10–25 cm depending on the season). All bottles were transported to the lab (Yugra State University), stored in the fridge (no more than 1 day, temperature 4 °C).

In the laboratory, all water samples were filtered through the membrane filter (Whatman©, 0.45 μm pore-size, polyethersulfone) and immediately analyzed on the elemental analyzer Thermo Scientific (Flash© 2000, Germany) equipped with the autosampler for the liquid substrates (AS1310) to define DOC concentration. Calibration was done using urea standard (C = 22.56%, N = 7.84%, H = 15.01%, O = 18.59%).

14.2.6 Discharge and DOC Loss Calculation

Discharge from the study area was measured at the beginning of the stream, where the underground flow turns to the visible stream and forms a small waterfall, by collecting overflow in a bucket of exact volume (12 l) and measuring a filling time. Additionally, the APIK (atmosphere-soil measurement complex, produced by Institute of Monitoring of Climatic and Ecological Systems, Tomsk city) device was installed downstream to measure the water level and electroconductivity every 30 min. Finally, the water levels for the APIK were converted to the discharge values by matching the integrated function "time vs water level" to the annual water discharge volume (catchment area multiplied by the sum of snow and rain precipitation).

Loss of DOC was calculated as the daily water discharge (l day^{-1}) multiplied by the monthly average DOC concentration in stream water (kg l^{-1}). The cumulative DOC loss was calculated as a sum of daily DOC losses over the season (from April 15, 2021 to October 31, 2021) and is the estimated value.

14.3 Results

14.3.1 General Hydrology

The amount precipitation for the study period (April–October) was 429.4 mm, whereas average annual precipitation is 470 ± 68 mm (¼ is snow) (Dyukarev et al. 2021a, b). Precipitation events were not evenly distributed during the study period: most rain falls in May–June and September. Short-term and light rainfalls characterized the mid-summertime.

Snow melting starting at the beginning of April caused a rapid and dramatic water level increase. During this period, water is kept on the surface creating ponds since the peatland is frozen with the lack of infiltration. When the surface thaws, all the water rapidly infiltrates into the peatland profile, increasing the water level. The wet period lasts up to 2.5 months (April–the first decade of June), and then the water level drops. The subsequent temporal variation in precipitation is reflected in the position of the water table, causing a short-term rise. Due to autumn rainfalls and a decrease in evapotranspiration, the water level again increases in September. Discharge stops completely at the end of October when the peatland freezes.

The water table fluctuation range was featured exactly to the studied ecosystems (Figs. 14.1 and 14.2). At the ridge-hollow ecotone located at the central part of the catchment area, the water level was sustained through the summer, varying at a depth of ~ 10 cm and rising above the surface only at the end of May because of snow-melting water. The highest fluctuation was found for the ryam ecosystem where water flow had been blocked by hummocks during the snow-melting period and stayed 30 cm above the surface. The water level was continuously decreasing during the summer and autumn to the lowest value of ~ 90 cm below the surface in September. Pools were covered by water until the first decade of July; further, the water level dropped down the surface and stayed 5–7 cm below until the mid of September when the active rains occurred. The hollow site, located at the far edge of the catchment area, showed around-surface water table position until the mid of June, then the water level dropped until the end of September, with the short-term rising as a response to the heavy rain event.

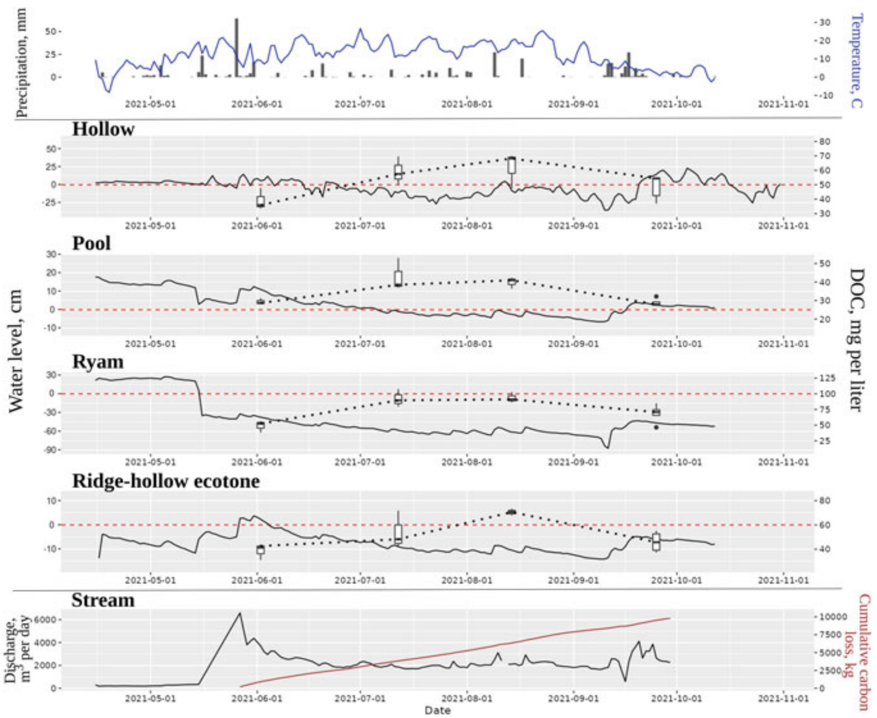

Fig. 14.2 Seasonal DOC concentration dynamics for the different ecosystems (boxes with whiskers), air temperature, precipitation amount (bars), stream water discharge, and cumulative DOC loss

14.3.2 The Seasonal DOC Dynamic

Concentrations of DOC are generally increasing in the summer because of higher evapotranspiration rates and plant tissue decomposition (Moore 1987). However, pore-water dilution occurs during the snow-melting period (April–May) and autumn rainfall events, which cause the DOC concentration to decline.

DOC concentrations in the peatland ranged from 23.5 to 153.5 mg l^{-1} for the whole season (Fig. 14.2), with the lowest seasonal average concentrations for the pool (31.3 mg 1^{-1}) and stream (37.8 mg 1^{-1}) sites, and the highest seasonal average concentration for the ryam (72 mg 1^{-1}) site. During the lowest water level period in mid-August, DOC concentrations for all sites were 10–60 mg l^{-1} higher than in the highest water level period (end of May–beginning of June). The highest seasonal fluctuation was found for the ridge (range 31–154 mg l^{-1}) and ryam (range 38–107 mg l^{-1}) sites. At the same time, the DOC concentration at the pool site did not change significantly during the whole season (range 27–53 mg 1^{-1}).

14.3.3 Catchment Area, Water Flowing Direction, Discharge, and Carbon Loss

The bog flow drains into the stream, which is a 0.88 km^2 catchment (Fig. 14.1), with a span of 1.5 km from the west to the east and 0.4–1 km from the north to the south, characterized by ridge-hollow complex (30.5 and 49.3% of the catchment area, correspondingly), ryam (12.9% of the catchment area), and pools (7.3% of the catchment area). The eight main water flows form a beaded stream; an additional flow contributes to the main stream ~ 300 m to the river mouth. The water flow is directed south-east to the stream that is a confluence to the Mukhrina River.

The DOC loss is directly dependent on the water discharge rather than the DOC concentration. Even the smallest DOC concentration (28.95 mg l^{-1}) during the spring freshet causes high DOC loss because of the highest discharge, i.e., a massive flush of the DOC. Since end of May (May 27) till the end of June (June 28), while the snow melt water discharging, the amount of ~ 45% of DOC is flushed and 32.5% of seasonal discharge (94,978.7 m^3) occured. Totally, an amount of 9.8 tons of carbon has been lost from the catchment area for the spring–autumn season 2021, i.e., ~ 11.14 g C m^{-2} $year^{-1}$.

14.4 Discussion

In this paper, we studied a seasonal dynamic of the DOC concentration for the different ombrotrophic peatland ecosystems and estimated a total seasonal loss of DOC with the surface runoff. The highest concentrations of DOC are associated with the driest ecosystems with the high tree coverage—ryam and ridge (the average seasonal water table is 41 and 30 cm below the surface, correspondingly) (Dyukarev et al. 2021a, b), where after spring freshet the thick aerobic zone (acrotelm) creates favorable environmental conditions and promotes the active organic matter decomposition and increased amount of DOC. There is evidence that peatland tree cover has been dynamic with greater cover during warmer periods in the Holocene (Velichko et al. 1998; Ratcliffe et al. 2017). Thus, expecting global warming may increase tree coverage at the omrotrophic bogs and, together with the same or increased amount of precipitation, trigger higher DOC export to the streams.

At the same time, there was not found any significant increase of DOC concentration during the whole season in the ecosystems collecting water from all catchments—pool and stream. Despite the similar proportion of the hollows, ridges, and ryams in the catchment area, the DOC concentration in the pools and stream did not exceed 55 mg l^{-1} while the ridge and ryam showed concentrations over 100 mg l^{-1}. It looks like the DOC loss to a large extent is controlled by the water table rather than the amount of produced DOC—in the time of high water (beginning of spring and autumn), the DOC concentrations are low, causing the low DOC export; but in the time of low water level, warm temperatures, and corresponding high DOC concentration, the role of ryam and ridge ecosystems decreased. When the water table drops to the lowest level, active water flow stops, and water hold in the peat pores, these ecosystems do no contribute much to the increased amounts of DOC in the pools and stream.

The short-term blast DOC flush from the ridge and ryam ecosystems might be expected when the heavy rain event occurs after the protracted period without precipitation (Tiwari et al. 2022), but in this study, it has not been discovered due to the monthly sampling period. Therefore, to increase the precision of DOC monitoring, the high-frequency hydrochemical survey must be organized in the study area. It was shown that this monitoring type improves annual flux calculations, reveals seasonal relationships between discharge and DOC concentrations, and improves discharge measurements during low flow periods (Gandois et al. 2021).

The calculated annual specific DOC flux for the same area was 11.14 g C m^{-2} $year^{-1}$ and comparable with our previous estimations of 7.7 g C m^{-2} $year^{-1}$ (Bleuten et al. 2020). The difference in the results is caused by using the DOC concentration data for different years (2011–2016 in the last estimates vs 2021 in this paper) and the modeled discharge data in the (Bleuten et al. 2020) and the in-situ water discharge monitoring data in the current research. The DOC flux for the Mukhrino peatland is higher than this value for the Central Siberian Plateau (2.8–4.7 g C m^{-2} $year^{-1}$) (Prokushkin et al. 2011). The differences are likely related to the peat chemical composition, but this analysis has not been carried out for our site.

The carbon accumulation rate for the Mukhrino peatland ranged from 5.66 to 189.52 g m^2 $year^{-1}$ for the last 9500 years (Tsyganov et al. 2021). Thus, the annual specific DOC flux is equal to 6–196% of the carbon accumulation rate, i.e., sometimes it exceeds the amount of carbon sequestrated in the peat and acts as a carbon source. The role of DOC loss with the surface runoff increases in case of warming and droughts where the low carbon accumulation (12 g m^2 $year^{-1}$) (Tsyganov et al. 2021) and the high DOC concentrations (till 153.5 mg l^{-1}) occur.

14.5 Conclusion

In this paper, we summarized the first-year results of systematic monitoring for the DOC concentrations and stream discharge at the Mukhrino peatland. We discovered the DOC seasonal variation for the different ecosystems at the ombrotrophic peatland, estimated the stream catchment area based on a digital elevation model and calculated the total amount of DOC loss with the surface runoff. The results discovered the seasonal pattern of DOC behavior: a massive DOC loss with the spring freshet, and further evenly distributed losing till October; the DOC concentrations at the different ecosystems reach their maximum in August with the highest values for the dry ecosystems and the lowest values for the wet ecosystems.

The future directions of research are: (1) the high-frequency DOC and discharge monitoring; (2) to elucidate control on temporal variability in DOC considering drought and storm flow events; (3) studying DOC concentration vertical distribution; (4) studying the organic isotopic compounds of the DOC to estimate the role of different ecosystems to the annual DOC loss.

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Chapter 15
Specifics of Accumulation and Profile Distribution of Organic Carbon in Soils of Park and Recreational Areas of Rostov Agglomeration

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Abstract Artificial tree plantations of different ages in the city limits of Rostov-on-Don, Aksai and Bataysk were studied. In total, 22 monitoring sites were studied on the territory of park and recreational zones of the Rostov agglomeration. Geobotanical and soil research was carried out for each monitoring site. The study shows a statistically significant increase in the organic carbon content in the 0–10 cm layer of calcic chernozems of city recreational zones. There was on average of 4.23 ± 0.88% regarding to the chernozems of reserved and native areas of the Rostov agglomeration, where the content of C org. was 2.86 ± 0.63%. The comparison of the C org. content in the surface 10-cm layer for studied forest parks was concluded that, regardless of the location and floral composition features, the difference in the organic matter content is small: C org. = 4.23 ± 0.88%. It was possible to identify a pattern associated with the planted forests age and the accumulated organic carbon amount in the surface horizon. In forest phytocenoses aged 70–90 years, the content of C org. in the surface layer was significantly higher (4.40 ± 0.78%) than in younger ones (3.42 ± 0.76%), whose age was 30–50 years. The profile distribution of organic carbon under woody vegetation has specific features. Some monitoring sites demonstrate a sharp decrease in the content of C org. (by 2–2.5 times) during the transition from the A horizon to the underlying horizon. The rest are characterized by a smoother distribution of organic carbon throughout the humus-accumulative strata, which is associated with a larger total biomass of herbaceous plants forming under the canopy of trees at these monitoring sites.

Keywords Calcic chernozems · Urban forest parks · Organic matter · Humus · Natural soils

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15.1 Introduction

The woody vegetation planting in the steppe zone is one of the manifestations of anthropogenic interference in the functioning of natural ecosystems, correcting the steppe biocenoses circulation (Canedoli et al. 2020; Huot et al. 2017; Morel et al. 2015; Yang et al. 2014). Therefore, the research of soil cover of urban forest parks is an important object for of long-term anthropogenic impact studying on steppe ecosystems (Velts and Lupova 2013). Overall, the landscaping development in cities is one of the factors that ensure the soil organic matter accumulation (Kimpe and Morel 2000). This tendency is especially observed in native treeless areas and cities developing in unfavorable conditions, for example, in the arid zone (Vodyanitskii 2015). Woody phytocenoses affect the temperature and hydrological soil regimes, the atmospheric precipitation composition, the number and activity of various organic matter destructors, form a sub-morphological flora which is different from the steppe and provide additional dead vegetation to the soil (Demakov et al. 2017; Gorbov and Bezuglova 2014; Vysotskiy 1962). It leads to organic matter accumulation changes and also increases the intensity of carbon inorganic forms migration and part of the water-soluble organic matter in the soil profile. However, the impact of the same plant species on the soil manifests itself differently in different biogeocenoses and largely depends on the physico-geographical conditions (Karpachevskiy 1981). The purpose of this work is to study the influence of the change of plant formations on the features of the accumulation and profile distribution of organic carbon in the conditions of a large agglomeration of the steppe zone.

15.2 Objects and Methods

The objects of the study were the natural soils of the parks and recreational zones of the Rostov agglomeration, applying to one subtype-ordinary carbonate chernozems (calcic chernozems), experiencing minimal influence of the anthropogenic factor (the soil cover has been preserved since the period of agrogenic use, the absence of modern human economic activity). The internal spatial structure of recreational zones at the monitoring sites (with an area of 100 m^2) allocated considering the dominant tree species, and their age was studied; visual assessment of the condition of tree and shrub plantations was carried out, also floral and geobotanical descriptions were carried out. Monitoring sites were laid on watershed areas to minimize the impact of the relief factor on soil properties. In the selected recreational areas, 16 full soil profiles were made, and surface soil samples were additionally taken from a ten-centimeter layer in ten-fold repetition for each monitoring site. As a control site, the sites on the territories of the exposition of the Botanic Garden of the Southern Federal University "Priazovskaya Steppe" (sites 3.4–3.5) were selected. It represents a 60-year-old old reservoir that was artificially subjected to the repatriation of steppe and red book species, as well as a virgin plot on the territory of a natural monument

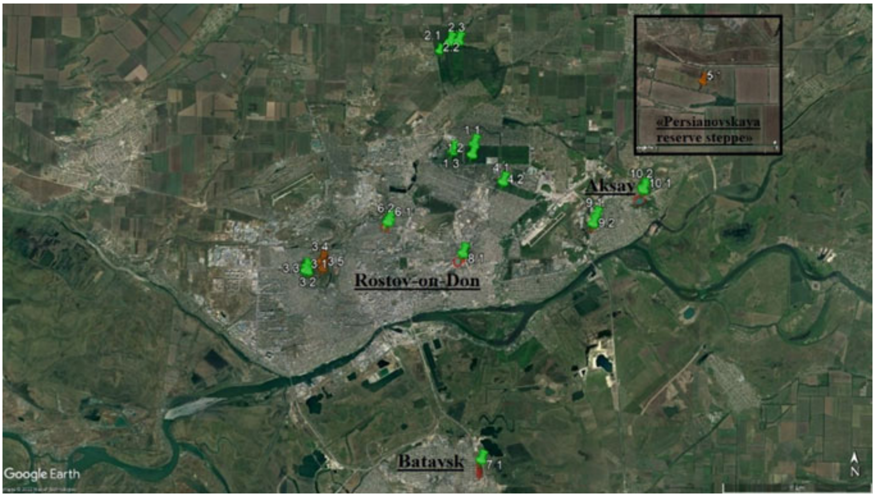


Fig. 15.1 Map of the location of monitoring sites

with a reserved regime "Persianovskaya reserved steppe" (site 5.1) 10 km from the city of Novocherkassk (Yu and Myasnikova 2014). In total, 22 monitoring sites were investigated (Fig. 15.1 and Table 15.1).

Visual assessment of the state of tree and shrub plantations was carried out according to the method of Alekseyev (1989), which allows interpreting the habitus of the plant as an indicator of environmental conditions. With an indicator from 100 to 80%, the vital state of the tree stand is considered as healthy, at 79–50% is weakened, at 49–20% is severely weakened and at 19% and below is completely destroyed.

Geobotanical descriptions were carried out for each park to assess species biodiversity. The projective coverage of a single geobotanical description site was determined visually and expressed as a percentage. The taxation (forestry) indicators of the tree tier were determined by eye, and the diameter and height of each tree under study were determined using a tape measure. The abundance of herbaceous plant species is indicated on the Brown-Blank scale (Braun-Blanquet 1951):

The biomorphological structure of the flora was determined by the system of life forms of K. Raunkier and the ecological and morphological classification of biomorphs of I. G. Serebryakov. In the distribution of species by ecological-cenotic groups (ECG) and geographical element, the indications of the "Flora of the Lower Don" (Zozulina and Fedyayevoy 1984), the "Summary of the flora of the Exposition of the Botanic Garden of the SFU "Priazovskaya Steppe" (Shmarayeva et al. 2021) and the Internet version of the database "Flora of vascular Plants of Central Russia" were considered". The criterion for the distribution of the species of the studied flora by ecological groups is the ratio to the degree of moisture and salinity of soils. The nomenclature of vascular plant species is given according to the regional determinant of flora (Zozulina and Fedyayevoy 1984, 1985). The species diversity

Table 15.1 Characteristic of studied monitoring sites

Monitoring sites	Number of site	Coordinates	Characteristic
Temernitskaya grove	1.1	N 47.294859° E 39.762646°	Large artificial forest plantation on the north-eastern outskirts of the city
	1.2	N 47.289895° E 39.761479°	
	1.3	N 47.291334° E 39.747751°	
Shchepkinsky forest	2.1	N 47.343712° E 39.744084°	Large artificial forest plantation on the north-eastern outskirts of the city
	2.2	N 47.340411° E 39.737190°	
	2.3	N 47.344121° E 39.750227°	
Botanic Garden of the Southern Federal University	3.1	N 47.232851° E 39.645382°	Coniferous nurseries
	3.2	N 47.233300° E 39.648200°	
	3.3	N 47.236400° E 39.645800°	Forest belt of oak near arable land
	3.4	N 47.237514° E 39.656652°	Control fallow plot
	3.5	N 47.234234° E 39.657186°	Control fallow plot
Ordzhonikidze village	4.1	N 47.277120° E 39.783838°	Large artificial forest plantation on the north-eastern outskirts of the city
	4.2	N 47.277600° E 39.784600°	
«Persianovskaya reserve steppe»	5.1	N 47.504655° E 40.152729°	Control fallow plot
K. Chukovsky Park	6.1	N 47.258397° E 39.704121°	Old city park
	6.2	N 47.256614° E 39.702811°	
Forest plantation of Bataysk	7.1	N 47.256614° E 39.702811°	Forest belt near the cemetery
N. Ostrovsky Park	8.1	N 47.242500° E 39.756389°	Old city park
Forest plantations of Aksai	9.1	N 47.261178° E 39.850075°	Independently arisen forest area
	9.2	N 47.257851° E 39.848214°	
	10.1	N 47.274444° E 39.883333°	Forest belt on the south-western border of Aksay

(continued)

Table 15.1 (continued)

Monitoring sites	Number of site	Coordinates	Characteristic
	10.2	N 47.275556° E 39.883056°	

of plant communities and their complexes were evaluated according to the indicators proposed in the works of Whittaker (1972), which have become classic in modern ecology: α-diversity – (internal diversity of habitat for a description representing a homogeneous community), β-diversity (diversity between different communities along the gradient of the environment).

The organic carbon content was determined by two methods:

(1) a method for determining humus in soil according to Tyurin in the Nikitin modification with a colorimetric ending according to Orlov-Grindel (Mineyev 2001). The method involves the oxidation of humus with an excessive amount of chromium mixture ($K_2Cr_2O_7 + H_2O + H_2SO_4$) in a drying oven heated to 150 °C, followed by considering the trivalent chromium formed during the reaction. Accounting is carried out at a wavelength of 590 nm, providing maximum absorption of Cr^{3+} ions, in 10 mm cuvettes.

(2) high-temperature catalytic combustion on the carbon analyzer TOC-L CPN Shimadzu in the console for dry samples SSM-5000A. This method is based on high-temperature catalytic combustion of the sample and subsequent detection of the released carbon dioxide. The analysis of the sample realizes in two stages: Total carbon is determined by burning the sample at a temperature of 900 °C, inorganic—at 200 °C with the addition of orthophosphoric acid. Organic carbon is determined by subtracting from total—inorganic (Tagiverdiev et al. 2020). The advantage of this method is that the "side" result of the analysis is the determination of the amount of inorganic carbon in a dry sample.

The calculation of soil organic carbon reserves is carried out based on data obtained during laboratory analyses according to the following formula: reserve of carbon of C org. t/ha = $C * H * d$, where C is the content of organic matter, %; d is the thickness of the horizon (layer), cm; H is the density of the soil, g/cm^3.

Statistical data processing was performed using the software Statistica for Windows 10.0, MS Excel.

15.3 Results and Discussions

In the study of vegetation, 94 species of woody and herbaceous plants from 39 families belonging to 78 genera and three classes were identified: coniferous Pinopsida, dicotyledonous Magnoliopsida and monocotyledonous Liliopsida.

Shchepkinsky Forest is characterized by a very uneven distribution of herbaceous vegetation, depending on which species of trees and shrubs were planted. In total, 17 species from 15 families of flowering plants were noted here. *Glechoma hederacea* L. is abundant in the herbaceous tier and *Geum urbanum* L. (Table 15.2).

The highest species diversity of plants was noted in the Temernitskaya grove: 50 species of flowering plants from 28 families. The tree and shrub layers are dominated by representatives of the Fabaceae and Sapindaceae families (*Robinia pseudoacacia* L., *G. triacanthos*, *Acer negundo* L., *A. tataricum* L., *A. fruticosa*) (Table 15.3). In the grove, the plots represent a stage of a succession series, transitional to wheatgrass (background species—*Elytrigia repens* Desv.). The herbaceous tier is dominated by representatives of weedy-shrubby, weedy-meadow and shrub-forest vegetation.

Exclusively *Picea abies* (L.) H. Karst and *Pinus pallasiana* D. Don. grow in the nursery of the Botanic Garden of the Southern Federal University. The floral composition of the remaining tiers is almost identical and includes 28 species of herbaceous plants, shrubs and lianas from 19 families. The herbage is dominated by a representative of shrub-forest vegetation *Viola odorata* L. In addition, representatives of weed

Table 15.2 Dominant species of the tree tier of the studied monitoring sites

Monitoring sites	Species	Abundance	Projective cover, %
«Shchepkinsky forest»	*Glechoma hederacea*	3	30
Botanic Garden SFU	*Viola odorata*	5	75
«Temernitskaya grove»	*Elytrigia repens*	5	90
K.Chukovsky Park	*Poa bulbosa, Stellaria media*	5	85
N. Ostrovsky Park	*Alliaria petiolata*	5	85
Ordzhonikidze park	*Poa bulbosa*	4	55
Forest plantations of Aksai	*Chaerophyllum temulum*	5	90

Table 15.3 Dominant species of the grassy tier of the studied monitoring sites

Monitoring sites	Species	Average diameter (m)	Average height (m)
« Shchepkinsky forest»	*Quercus robur*	0.18	12.1
Botanic Garden SFU	*Picea abies, Pinus pallasiana*	0.17	3.6
« Temernitskaya grove»	*Robinia pseudoacacia*	0.17	8.1
K.Chukovsky Park	*Fraxinus excelsior*	0.15	6.6
N. Ostrovsky Park	*Morus alba*	0.09	4.2
Ordzhonikidze park	*Robinia pseudoacacia*	0.25	10.6
Forest plantations of Aksai	*Robinia pseudoacacia*	0.19	7.6

communities are noted in the herbage: *Chelidonium majus* L., *Physalis alkekengi* L. (abundance from 1 to 2 b.). Weed-psammophilic, weed, synanthropic, sun-meadow, meadow-steppe, weed-fringe-meadow and characteristic of the communities that have developed in this area were found: *Bromus tectorum* L., *Fumaria schleicheri* Soy. -Will, *Cirsium setosum* (Willd.) Besser, *C. canum* (L.) All., *Clematis recta* L., *Cynoglossum officinale* L. and *Securigera varia* (L.) Lassen. On another site mainly plantings of such woody plants as *Quercus robur* L., *A. campestre* L. and *A. pseudoplatanus* L. are presented.

Monitoring sites in the parks of Chukovsky and Ordzhonikidze are floristically like each other. The herbaceous cover is represented by dominant species such as *Poa bulbosa* L., *Stellaria media* (L.) Vill. and *Taraxacum officinale* Webb. Mixed woody vegetation dominates on the sites of the N. Ostrovsky Park and forest plantations in Aksai. In all the above-mentioned artificial plantings, such species as *Fraxinus americana* L., *F. excelsior* L., *A. pseudoplatanus*, *A. tataricum*, *A. negundo*, *Sorbus hybrida* L., *Morus alba* L., *G. triacanthos*, *R. pseudoacacia*, *Prunus domestica* L., *Syringa vulgaris* L., *Ulmus pumila* L., *Sambucus nigra* L., *Juglans regia* L., *C. coggygria, Cornus sanguinea* L. and *Euonymus europaeus* L. were planted. In the park named after N. Ostrovsky, seedlings of *Celtis occidentalis* L. (abundance of 4 b.) and *Alliaria petiolata* (Bieb.) Cavara et Grande (abundance of 5 b., in bulk) are represented in the mass.

As a control site, a site was selected on the territory of the exposition of the Botanic Garden of the Southern Federal University "Priazovskaya Steppe", on which steppe vegetation grows naturally for the zone with the dominance of species of the Poaceae and Asteraceae families. Studies were also carried out on the territory of the protected area "Persianovskaya Steppe", which is a virgin area where such families as Asteraceae, Poaceae and Fabaceae occupy a leading place in the flora.

The results of the assessment of the vital condition of trees showed that the highest indicator of the vitality of trees was found at the sites of the Shchepkin Forest—95.27%. The lowest indicator of tree vitality was recorded in Ordzhonikidze Park. Here, tree stands grow near the highway, which can significantly affect their condition (Table 15.4).

The soils of forest parks, compared with soils under steppe vegetation, have increase the humus-accumulative stratum thickness. These soils were characterized by pronounced agronomically valuable structure formation of the soddy horizon and decrease the effervescence depth in the B and BC illuvial horizons. Chemical analysis of soil samples of the 0–10 cm layer showed the following results. There is a statistically significant (U-criterion, $p < 0.05$) increase in the content of organic carbon in soils under woody vegetation, and on average it is $4.23 \pm 0.88\%$ ($N = 200$) relative to the chernozems of reservoir and virgin areas of the Rostov agglomeration, where the content of C org. is $2.86 \pm 0.63\%$ ($N = 25$) (Fig. 15.2).

Comparing the monitoring sites for the content of C org. in the surface layer, it can be concluded, that, regardless of the spatial position and features of the floral composition, the content of organic carbon shows similar values and does not show statistically significant differences among themselves. The highest median values in organic

Table 15.4 Vital condition of trees

Monitoring sites	Number of trees, %				Ln, %*	The vital state of the plantings
	Healthy	Weak	Severely weak	Completely destroyed		
« Shchepkinsky forest»	89.5	5.2	5.3	0	95.27	Healthy
Botanic Garden SFU	31.6	7.7	26.4	34.3	49.35	Severely weak
« Temernitskaya grove»	30	50	20	0	80	Healthy
K.Chukovsky Park	62.1	27.6	6.7	3.6	84.32	Healthy
N. Ostrovsky Park	38.5	46.1	7.7	7.7	74.23	Weak
Ordzhonikidze park	6.1	18.2	36.3	39.4	35.4	Severely weak
Forest plantations of Aksai	30.8	17.3	15.4	36.5	50.9	Weak

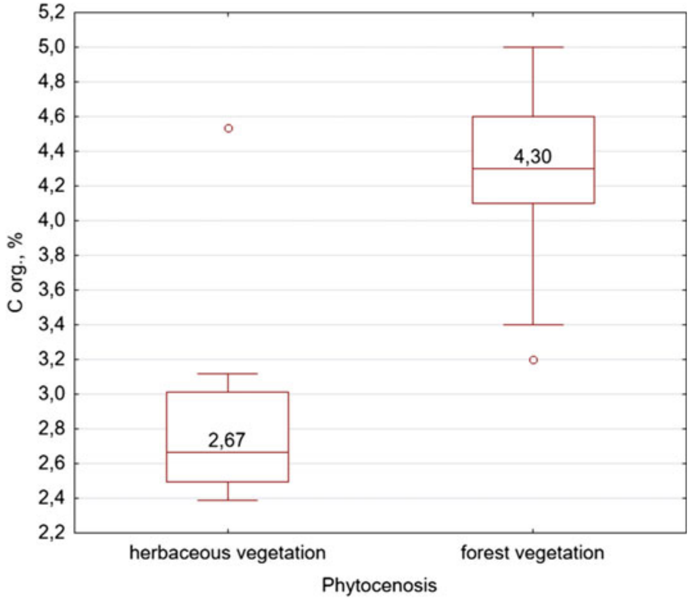


Fig. 15.2 Characteristics of median and interquartile range for C org., % for the surface ten-centimeter layer of soils under herbaceous and woody phytocenoses

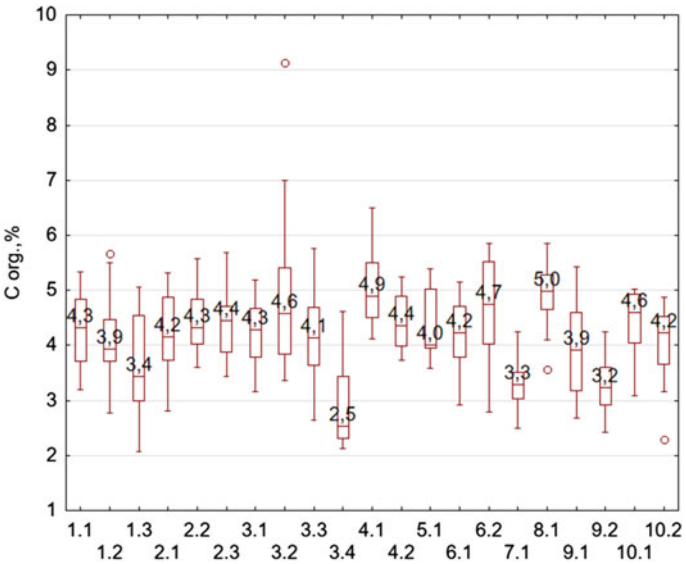


Fig. 15.3 Characteristics of median and interquartile range for C org., % at the studied monitoring sites in the surface ten-centimeter layer (Temernitskaya grove: 1.1–1.3, Shchepkinskiy forest: 2.1–2.3, Botanic Garden: 3.1–3.2—softwood nurseries, 3.3—oak grove, 3.4—reservoir, Ordzhonikidze: 4.1–4.2, Persianovskaya steppe: 5.1, K. Chukovsky Park: 6.1–6.2, N. Ostrovsky Park: 8.1, Aksai: 9.1–10.2)

carbon content were found in Ordzhonikidze (4.1)—4.9%, K. Chukovsky (6.2)—4.7%, N. Ostrovsky (8.1)—5.0% and the nursery of the Botanic Garden (4.6)—4.6% (Fig. 15.3). Two of the above-mentioned monitoring sites, namely Ordzhonikidze 4.1 and Park N. Ostrovsky 8.1, have a statistically significantly higher content of C org. compared with all other studied sites. The content of organic carbon at the monitoring sites in Temernitskaya grove (1.3) and Aksai (9.1, 9.2), on the contrary, is significantly lower than in other forest parks of the Rostov agglomeration.

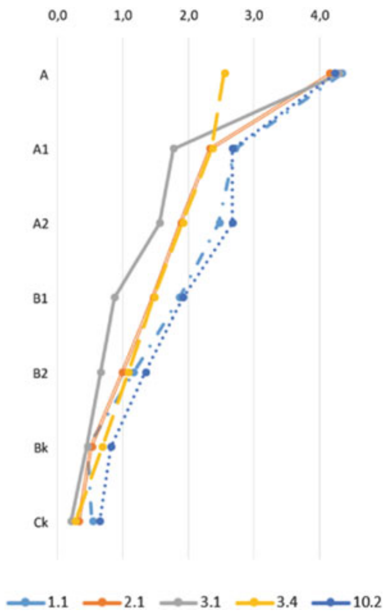
Such a low content of C org. can be explained by the later formation of woody vegetation here, as evidenced by the age of *Robínia pseudoacácia*, which is the dominant tree layer in these areas. Thus, at the first stage of development of a forest area, a small amount of dead ground and root mass of plants enters the soil. It is due to the youth of the forest phytocenosis, and part of the humus formed before forest reclamation measures is mineralized. It should also be considered that for a long time (until the mid-70s of the last century) the plot 1.3 of the Temernitskaya grove belonged to the state farm and was used in agricultural activities, which could lead to a decrease in humus reserves and depletion of the soil with organic carbon. The totality of data on the history of the formation of woody vegetation, as well as geobotanical surveys at sites 9.1 and 9.2 of Aksai allow us to determine the age of trees in this forest area in 20–30 years. Interestingly, this site was formed spontaneously, without carrying out forest reclamation measures. Thus, it can be concluded that the age of forest parks plays a decisive role in the accumulation of organic matter in the surface layer.

The profile distribution of total organic matter demonstrates two trends. On the one hand, peaks of humus accumulation in the surface turf horizon are possible, followed by a relatively sharp decrease in its content in the underlying thickness. It is demonstrated by soil profiles laid on the territory of coniferous nurseries of the Botanic Garden 3.1–3.2, Park N. Ostrovsky 8.1 and Aksai monitoring site 9.1. In the horizon AU content C org. decreases by 2–2.5 times compared to the turf horizon and further along the profile, and the distribution of organic matter of the studied sections has similar values. On the other hand, individual monitoring sites (Temernitskaya grove, Ordzhonikidze Park and Shchepkinskiy Forest sites, virgin and reservoir areas) are characterized by the absence of such a sharp decrease in C org. There are characterized by a smoother profile distribution of organic matter throughout the humus-accumulative strata. The graph of the profile distribution of organic carbon for the most representative sections is shown in Fig. 15.4. This distribution is associated with a higher total biomass of herbaceous plants forming under the canopy of trees, since the dying root system of weeds and meadow grasses provides direct entry of dead roots into the soil thickness and, therefore, a gradual decrease in humus content with depth. The different nature of the entry of dead plant into the soil leads to changes in the reserves of organic carbon. The largest reserves of organic matter in the meter thick were found in the parks of the Eastern Protective Ring: Shchepkin forest 2.2 = 284 t/ha, Temernitsky grove 1.1 = 280 t/ha and Ordzhonikidze = 270 t/ha. The lowest indicators were recorded in areas with young forest phytocenosis: Temernitskaya grove 1.3 = 178 t/ha Aksai 9.1 = 176 t/ha, as well as in the control reservoir chernozem of the Botanic Garden 3.4 = 175 t/ha (Fig. 15.5).

15.4 Conclusions

The data obtained now cannot entirely confirm the assumptions that the factor of different floral composition of forest parks is crucial in the process of accumulation of organic matter in the surface horizon. Thus, all the plant communities studied by us differ significantly in species diversity, the composition of the dominant species, both specially planted tree and shrub species and spontaneously appeared grasses and also in the degree of projective coverage and abundance. The presence of well-developed herbaceous vegetation does not always lead to an increase in this indicator in the turf horizon, which indicates the relevance of this study and the need for an integrated approach to assess the interrelationships of various components of recreational areas. Nevertheless, it was possible to identify a pattern associated with the age of planted forests and the content of organic carbon. In forest phytocenoses aged 70–90 years, the content of C org. in the surface layer is significantly higher ($4.40 \pm 0.78\%$) than in younger ones ($3.42 \pm 0.76\%$), whose age is 30–50 years. The difference between the soils of forest parks and steppe areas is also obvious in almost all the studied indicators. In forest phytocenoses, the content of organic carbon in the turf horizon

Fig. 15.4 Profile distribution of C org., % in the studied soil profiles. Temernitskaya grove 1.1, Shchepkinsky forest: 2.1, nursery of coniferous trees of the Botanic Garden 3.1, reservoir plot 3.4, Aksai 10.2



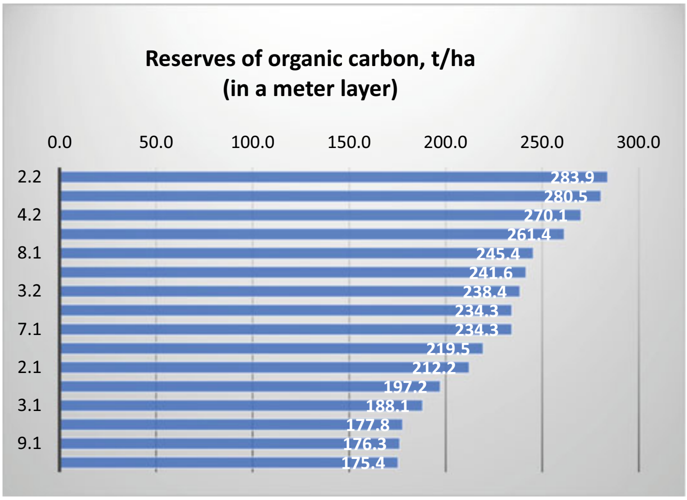


Fig. 15.5 Reserves of organic carbon in the meter layer, t/ha. (Temernitskaya grove: 1.1–1.3, Shchepkinskiy forest: 2.1–2.3, Botanic Garden: 3.1–3.2—softwood nurseries, 3.3—oak grove, 3.4—reservoir, Ordzhonikidze: 4.1–4.2, Persianovskaya steppe: 5.1, K. Chukovsky Park: 6.1–6.2, N. Ostrovsky Park: 8.1, Aksai: 9.1–10.2)

significantly increases. The humus profile of chernozems acquires the features of dark gray forest soil, which is expressed in a sharp decrease in humus with depth compared to the upper horizons.

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Chapter 16
Microbial Activity of Technosols Based on Peat-Sand Mixtures in Different Climatic Zones

Maria N. Vasileva, Maria V. Korneykova, Ekaterina V. Kozlova, Viacheslav I. Vasenev, and Yulia L. Sotnikova

Abstract The microbiological parameters of technosols based on peat-sand mixtures, made in cities of different bioclimatic zones: Apatity (subarctic), Moscow (temperate humid), Rostov-on-Don (temperate dry), were determined for the first time. Such properties as microbial biomass, activity and specific respiration of technosols were evaluated by the technics of substrate-induced and basal respiration, as well as the physiological profile and functional diversity of soil microbial communities by the MicroResp technic. Fungal biomass was assessed using light luminescence microscopy. In technosols from different climatic zones, microbial biomass carbon and microbial activity (basal respiration) values were found to be lower compared to natural (background) reference soils. Fourteen months after the beginning of the experiment, the microbial biomass in Moscow and Rostov-on-Don decreased by around 1.5 and 2 times, respectively, compared to background soils, whereas in Apatity, on the opposite, it increased. Microbial respiration in the conditions of the north increased by 1.2 times, while in temperate climate it decreased by 1.2 (Moscow) and 3.4 times (Rostov-on-Don). The specific respiration (microbial metabolic quotient) qCO_2 was found to be sufficiently high (3.5–4.5 CO_2-C μg-1 Cmic h^{-1}) for the first two years of the study for all experimental stations. Alterations in the microbial community physiological profile of technosols in different bioclimatic zones were discovered, most noticeably demonstrated in Moscow. In terms of fungal biomass, the technosols of Rostov-on-Don are closest to the background soil, while in Moscow it is lower by 2 times and almost 3.5 times in Apatity. After 14 months in the technosols, created in temperate humid and temperate dry conditions, tended to change the functional diversity of microbial communities towards

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natural reference. Under northern conditions, the physiological profile of the microbial community changed insignificantly. Alterations in the microbiological characteristics of technosols in various bioclimatic conditions revealed over a period of 14 months demonstrate a significant impact of the climatic factor on the formation of stable soil systems.

Keywords Human-made soil constructions · Bioclimatic gradient · Microbial specific respiration · Green infrastructure · Community level physiological profile

16.1 Introduction

Soil, as a main base of urban green infrastructure, strongly linked to the sustainable development goals, by providing the recreational and aesthetic function for comfort living (O'Riordan et al. 2021; United Nations 2019; Vasenev et al. 2016). The development of new construction technologies for urban soils and the adaptation of old ones can ensure the sustainability of technosols and at the same time support the functioning of the Urban Green Infrastructure.

With the increasing rate of urbanization, land use is changing and human impact on soils is growing (Chien and Krumins 2021; Demina et al. 2018; Ivashchenko et al. 2019). Urban soil remains crucial ecological asset and important component of the urban ecosystem. Due to the high dynamic and diversity, man-made soil constructions are an attractive object for assessing properties and functions for the purpose of further modelling (Hazelton et al. 2021). The analysis of the functioning of soil constructions in regions with different environmental conditions and the level of development of urban green infrastructure is especially relevant (Deeb et al. 2020; González-Méndez and Chávez-García 2020).

Soil is a source of ecosystem services—one of the carbon stores and a contributor to carbon emissions to the atmosphere through soil respiration (O'Riordan et al. 2021; Vasenev et al. 2017; Wang et al. 2011). The microbial component provides the main flux of CO_2 from the soil to the atmosphere (Saccá et al. 2017). The microbial community is highly sensitive to anthropogenic influences and is therefore an indicator of environmental change and is often used in assessing the health of terrestrial ecosystems (Ivashchenko et al. 2015; Sarzhanov et al. 2015; Wang et al. 2011).

Various materials are used for the construction of technosols, depending on the functions that they are required to perform and on the availability of materials (Fabbri et al. 2021; Smagin and Sadovnikova 2015). Natural materials with different organic matter content (in different proportions), such as sand, peat, displaced topsoil is used to create technosols. At the same time, technologies exist to create technosols based on mining waste to mitigate the effects of industrial pollution (Fabbri et al. 2021; Ivashchenko et al. 2021a; Slukovskaya et al. 2019; Uzarowicz et al. 2020). However, to fully evaluate the effectiveness of constructions, it is necessary to analyse materials comparable between regions that would be available and similar in properties.

Universal in design soil constructions could become a representative background for explaining the changes in the functioning of technosols in various bioclimatic zones.

The aim of the study is a comparative analysis of universal soil constructions for the creation of lawns with similar properties in different bioclimatic zones of Russia, based on microbiological indicators. The results of the study will identify the degree of influence of the factors determining the functioning of soils, and on this basis, adapt existing technologies for creating technosols to support sustainable urban development.

16.2 Research Area

The research area was carried out in cities located in different climatic zones: subarctic (Apatity), temperate continental with humid climate (Moscow) and temperate continental with dry climate (Rostov-on-Don) (Fig. 16.1).

In 2020, universal constructions (Unified Technosols) based on sand, peat and 'cut-off' (the surface fertile soil layer removed during construction) in a 1:1:1 ratio were created at the experimental sites in each city in three replicates. These types of substrates are used quite often for soil construction, especially for Moscow

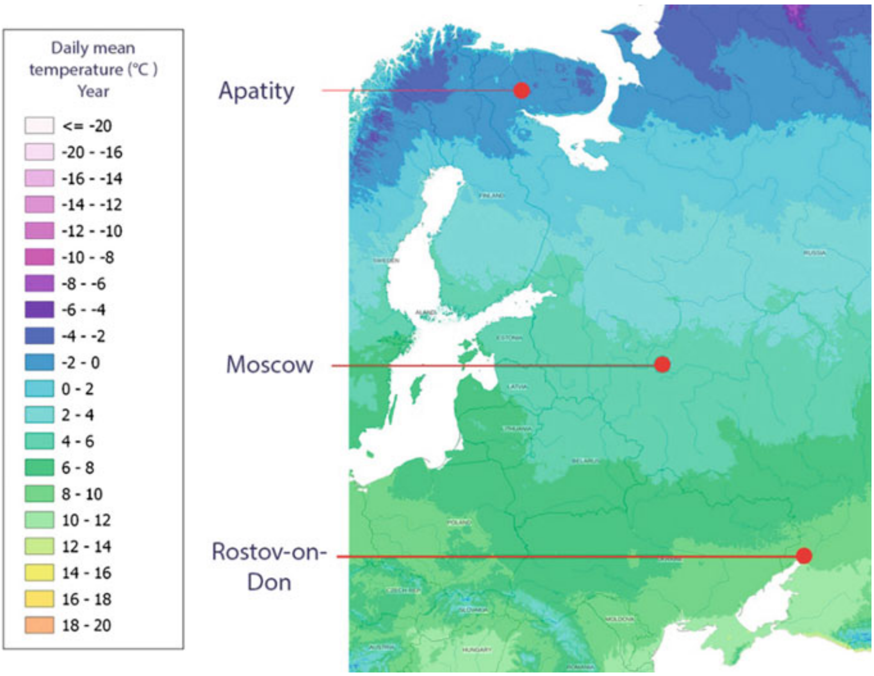

Fig. 16.1 Research area

region, which is more studied regarding technosols design (Brianskaia et al. 2020; Ivashchenko et al. 2021a). The sizes of the experimental plots at the Apatity station were 1 by 2 m, in Moscow—3 by 3 m, in Rostov-on-Don—2 by 2 m. As a lawn covering, a grass mixture with a seeding rate of 60 g/m^2 was used. In Apatity, a grass mixture with a seeding rate of 160 g/m^2 and a technology for pre-growing seedlings was additionally used.

Before establishing the soil constructions, the following chemical characteristics were determined for the mixtures composing them. Total carbon at the northern station was 3.05, 2.25% at the Moscow station, and 1.75% at the southern station. The content of total nitrogen in the mixtures in Apatity was 0.05%, in Moscow—0.02%, in Rostov-on-Don—0.04%. pH_{H_2O} was 6.24, 7.21 and 8.45, respectively.

A grass mixture of perennial ryegrass (*Lolium perenne*) 30%, red fescue (*Festuca rubra*) 35% and meadow bluegrass (*Poa pratensis*) 35% with a seeding rate of 60 g/m^2 was used to create lawn cover. Agrotechnical measures included the application of the mineral fertilizer Azophoska at a rate of 60 g/m^2 and active irrigation at all sites. In northern conditions, dolomite flour was applied in an amount of 300 g/m^2 to reduce soil acidity while creating soil constructions. Regular mowing was carried out at a frequency of once every 1–2 weeks between May and October, depending on the region.

16.3 Materials and Methods

The microbial biomass carbon in soil (C_{mic}) was measured by the substrate-induced respiration (SIR) method, based on capturing the respiratory response to the addition of a readily available substrate–glucose. Substrate samples (1 g) were placed in a 15 ml vial, glucose solution (0.1 ml/g soil, 0.5 mg/g) was added dropwise, the vial was sealed, and time was recorded. The vials were incubated (3–5 h of incubation, 22 °C), and the gas sample was collected with a syringe and injected into a gas chromatograph (KrystaL 2000 M, 'Meta-Chrom' manufacturer, Yoshkar-Ola, Russia) equipped with a thermal conductivity detector for measuring CO_2 concentration. Soil Cmic (μg C g-1 soil) was calculated from the equation SIR (μl CO_2 g g^{-1} soil h^{-1}) × 40.04 + 0.37 (Anderson and Domsch 1978; Ananyeva et al. 2008; Anderson and Domsch 2010).

Basal (microbial) respiration was determined in the native (not enriched) soil (24 h of incubation, 22 °C). The BR was measured as for SIR, but water (0.1 mL/g soil) was added to the soil samples instead of a glucose solution. The BR rate was expressed in μg CO_2–C/g soil per hour. The specific respiration of the microbial biomass, or the microbial metabolic quotient (qCO_2), was calculated as the ratio BR/C_{mic} = qCO_2 (μg CO_2–C/mg $C_{mic/}$h).

The community level physiological profile was assessed using the MicroResp technique (Creamer et al. 2016). The physiological profile of the soil microbial community is assessed using the MicroRespTM technique. Soil samples are placed in a well (945 μl volume) of a special 96-well plate and nutrient substrates belonging to the groups of amino acids, carbohydrates, carboxylic acids, and phenolic acids are added to each well. Each substrate is added to the wells of the plate in three replicates. In addition, a specially prepared indicator gel (agar, cresol red, potassium chloride and sodium hydrogen carbonate) was placed in the 450 μl wells of the other corresponding plate. The soil plate is covered with the indicator gel plate, separated by a membrane and incubated for 6 h at 25 °C. During incubation CO_2 is released from the soil, changing the pH and the colour of the gel (pink to yellow). The colour change is measured on a microplate reader ('Uniplan', 450λ nm filter). The absorbance units are converted into substrate-induced soil respiration, expressed in $\mu g\ C\ g^{-1}$ soil h^{-1} (Chapman et al. 2007).

Fungal biomass was determined by light luminescence microscopy using white calcofluor. Accounting for spores and the length of the mycelium was carried out on a Biomed 5 PR LYUM luminescent microscope (Russia). Cells were desorbed from the soil using an MSV-3500 Vortex (Latvia) at a speed of 3500 rpm for 10 min. Fungal biomass (mg/g soil) was calculated assuming the spore density equals 0.837 g/cm^3, and the mycelium density equals 0.628 g/cm^3 (Polyanskaya and Zvyagintsev 2005). The content of fungal biomass per gram of dry soil was calculated considering its moisture content.

All studied parameters of soil constructions were measured twice, in 2020 and 2021 years. The results of samples analysis were compared with their natural analogues (forest ecosystem) in the respective cities and the results of the previous year.

16.4 Results and Discussion

During the first year of the experiment, the microbial biomass of technosols in the studied cities ranged from 150 to 230 μg C g-1 and was 2.8–5.3 times lower than its natural analogues (Fig. 16.2). After 14 months in Moscow and Rostov-on-Don, it decreased by more than 1.5 times, and in Apatity, the values showed a tendency to increase. However, in comparison with natural reference the microbial biomass values remained low. The trend of biomass values distribution in the climatic gradient differed for unified soil constructions and background soils. Thus, in technosols, the microbial biomass decreased in the 'north–south' direction, whereas in natural reference samples it decreased in the 'south–north' direction.

Basal respiration of natural references exceeded that of technosols by 1.8–2.3 times in different regions. After 14 months from the beginning of the experiment, it decreased by more than 3 times in Rostov-on-Don. In Moscow and Apatity, the values have not changed significantly. In general, in technosols, there was a tendency like natural ecosystems—decrease of basal respiration in climatic gradient Apatity–Moscow–Rostov-on-Don. Values of specific respiration of soil constructions in the first year of observations exceeded natural analogues by 1.5–3.2 times. The microbial metabolic coefficient qCO_2 remained high at 3.5–4.5 CO_2-C mg^{-1} C mic h^{-1} and did not differ significantly from the results of the previous year. The high values of

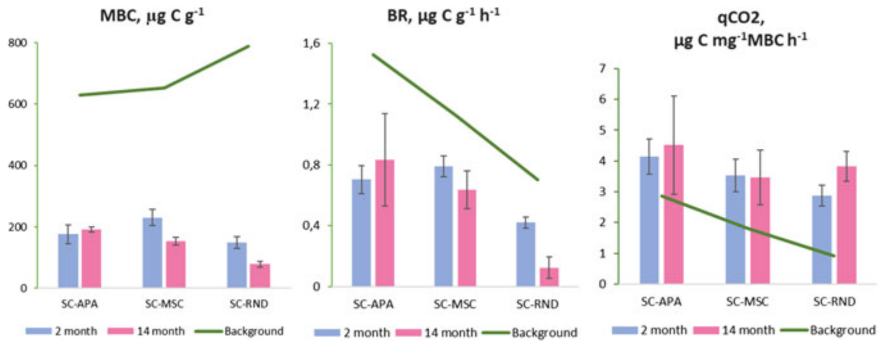

Fig. 16.2 Microbial indicators of soil constructions: MBC—microbial biomass carbon, BR—basal respiration, qCO_2—specific respiration of microbial biomass (microbial metabolic coefficient); SC—soil constructions: SC-APA—Apatity, SC-MSC—Moscow, SC-RND—Rostov-on-Don; BG—background soil

this coefficient may indicate adverse conditions for the development of the microbial community in the soil (Ivashchenko et al. 2015).

The soil constructions of the studied towns showed a rather high level of carboxylic acid mineralization, from 32 to 69%, as in their natural analogues, where the contribution ranged from 47 to 62% (Fig. 16.3). The group of microorganisms that decompose carbohydrates in the technosols ranged from 15 to 35%.

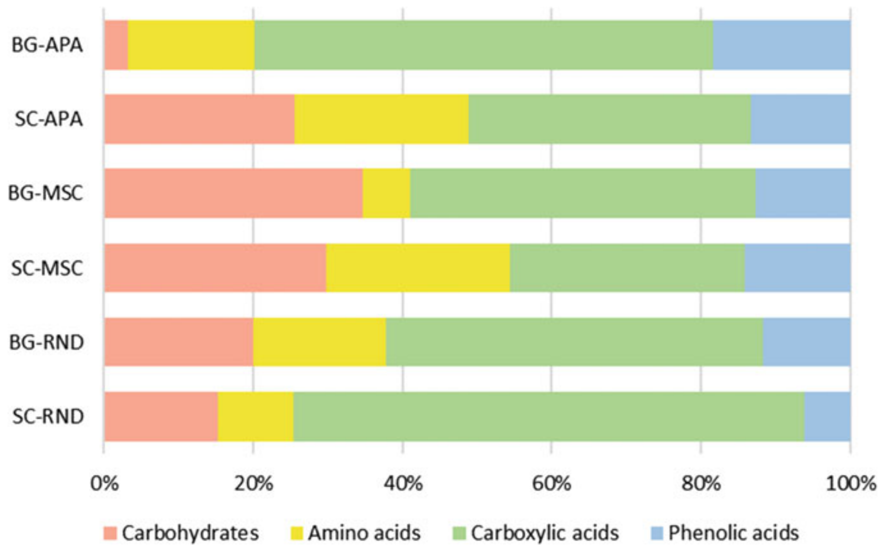

Fig. 16.3 Community-level physiological profile of technosols in comparison with natural analogues in climatic gradient. SC—soil constructions: SC-APA—Apatity, SC-MSC—Moscow, SC-RND—Rostov-on-Don; BG—Background soil

In Rostov-on-Don and Moscow, their amount was only 1.2–1.3 times lower than in natural reference. For natural ecosystems of Apatity, the contribution of this group to the total respiration of microorganisms was only 3%, while for technosols, it was closer to that in Moscow and Rostov-on-Don and reached 26%.

After 14 months, the contribution to total respiration of the microorganisms decomposing carboxylic acids decreased, most notably in Moscow—by more than 2 times (Fig. 16.4), in Rostov-on-Don—by 12% and in Apatity—by 20%. There is a general trend for all stations to increase the proportion of microorganisms reacting to carbohydrate application—by 1.5–2.2 times. In Moscow, the response to the application of substrates of the amino acids group increased significantly, from 9 to 25%, as well as of difficult to decompose phenolic acids, from 1 to 14% of the total contribution to respiration.

According to the similarity of the functional structure of the microbial community of technosols, it can be noted that the technosols of Moscow were the closest to the background soils in 2020 year (they were in one large cluster). Soil constructions of Apatity were also quite close to their natural analogues (Fig. 16.5). In Rostov-on-Don, technosols differed comparatively sharply from soils of natural references.

The prevalence in the consumption of easily available substrates cannot be claimed with certainty to be a direct indication of the inefficiency of the microbial community. Despite some changes in the structure, the dominance of microorganisms decomposing carbohydrates and carboxylic acids remains, which is characteristic of both natural and urban ecosystems (Ivashchenko et al. 2021a, b).

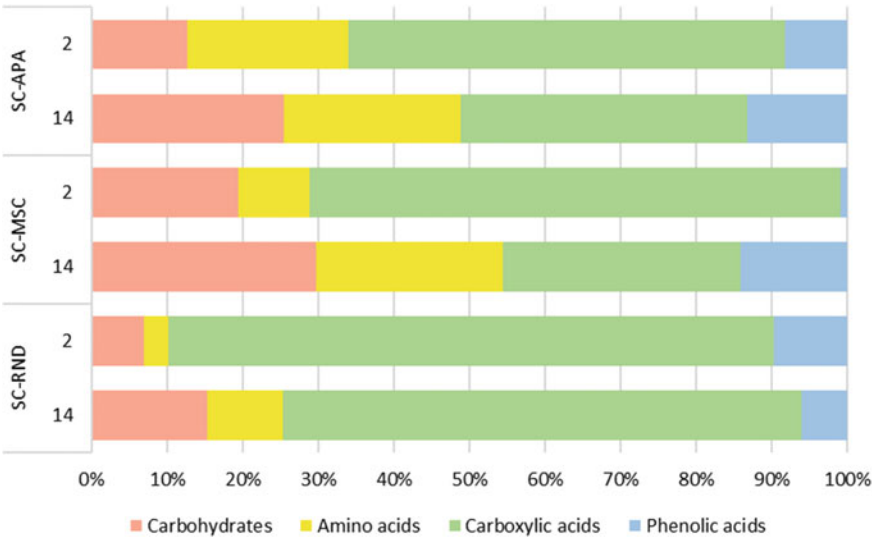

Fig. 16.4 Community-level physiological profile in temporal dynamic. SC—soil constructions: SC-APA—Apatity, SC-MSC—Moscow, SC-RND—Rostov-on-Don; BG Background; 2–2 months after creation, 14–14 months after creation

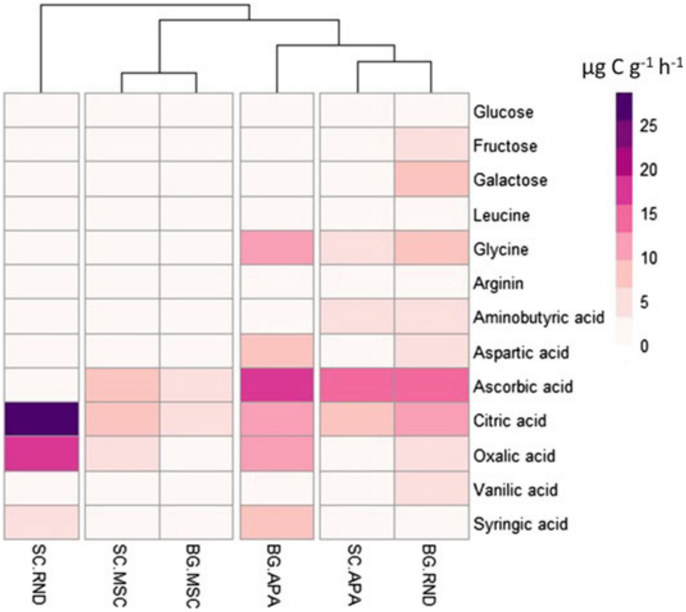

Fig. 16.5 Similarities in the functional structure of the microbial community of technosols in 2020 year. SC-APA—Apatity, SC-MSC—Moscow, SC-RND—Rostov-on-Don; BG—background soil

In 2021, the similarity in the physiological profile of microbial communities of the soil constructions laid in Moscow and the background soils remained (Fig. 16.6). The physiological profile of technosols in Rostov-on-Don has become much closer to the structure of community of the background soils. The functional structure of the microbial community of the soil constructions in Apatity has deviated from its natural analogues but has become closer to the physiological profile of the microbial community of the Moscow stationary.

In summary, the most significant changes in the physiological profile of the microbial community of technosols were observed in Moscow compared to Apatity and Rostov-on-Don. However, in the second year of the experiment in Moscow and Apatity similarities in the functional profile of microbial communities can be noted. Rostov-on-Don and Moscow were also characterized by a tendency to change the functional structure towards natural communities.

The biomass of fungi varied from 0.073 to 0.790 mg/g of soil. The lowest biomass (0.078 mg/g soil) was noted in technosols of Rostov-on-Don, and the highest biomass reached 0.2473 mg/g soil in Apatity. For background soils, the maximum biomass of 0.790 mg/g of soil was also noted for the subarctic zone. In terms of biomass, the technosols of Rostov-on-Don were closest to the background, for the Moscow region, the biomass of fungi is 2 times lower, and in Apatity it is almost 3.5 times lower than in the background plot.

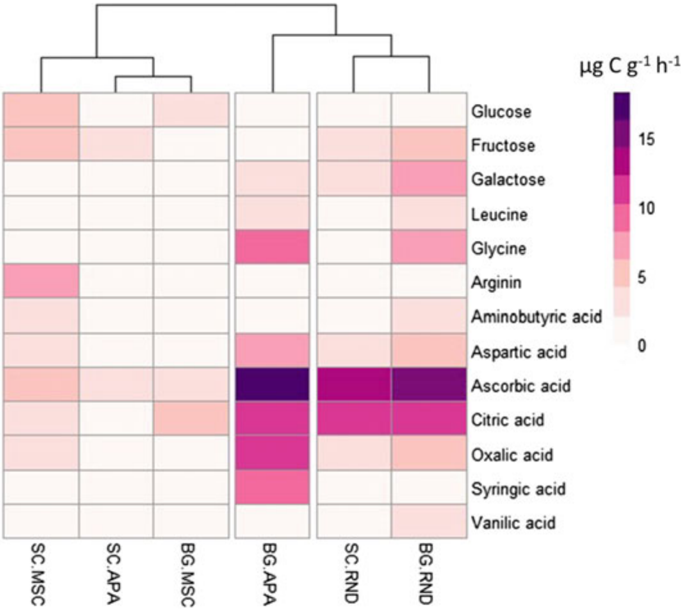

Fig. 16.6 Similarities in the functional structure of the microbial community of technosols in 2021 year. SC-APA—Apatity, SC-MSC—Moscow, SC-RND—Rostov-on-Don; BG—Background

The smallest proportion of mycelium (43–45%) was noted for the soils of Rostov-on-Don and the largest (60–87%) for the soils of Apatity. The proportion of mycelium in the biomass of fungi for Moscow soil varied from 55 to 69%. The length of fungal mycelium varied from tens to hundreds of meters per gram of soil. A minimum of mycelium (25–27 m/g of soil) was also found in the soils of Rostov-on-Don and a maximum (118 and 544 m/g of soil) in the soils of Apatity.

The average length of the mycelium was equal to 41 and 105 m/g in Moscow soils. The dominance of mycelial forms in the north and its minimum amount in the south can be explained by the type of natural zone in which the objects of study are located (northern taiga and steppe, respectively), the prevailing vegetation and soil moisture. The proportion of thin (less than 3 μm in diameter) mycelium of fungi in the studied soils was relatively high (up to 41%) in the soils of Rostov-on-Don.

The proportion of thin fungal hyphae in the soils of Moscow and Apatity was significantly lower: 20 and 32%, respectively. For all studied samples, the number of unicellular fungal propagules (spores and yeasts) was 10^4 cells/g of soil. However, in the technosols of Apatity, their number reached 10^5 cells/g of soil. A high proportion of fine mycelium in soils may indicate a stressful state of the mycobiota community under extreme climatic conditions (Marfenina et al. 2016). The basidiomycete buckle mycelium of fungi was found rarely (about 7–10% of all hyphae), and only in the subarctic zone.

The majority of mycobiota propagules (from 79.6 to 100%) was represented by specimens of small size, 2–3 μm. The studied soils of Moscow and Rostov-on-Don had approximately the same proportion of small mycobiota propagules: 93.3–100% and 95.6–100%, respectively. The proportion of small propagules in Apatity was lower and amounted to 79.6–86.9%. The number of large propagules (5 and more μm) was about 103 cells/g of soil in Apatity and hundreds of cells in samples from Moscow and Rostov-on-Don.

16.5 Conclusion

The sensitivity of microbiological indicators to disturbances makes it possible to assess changes in the functioning of soil microorganisms. Over a period of 14 months, the soil constructions created in different climatic zones differed considerably from their natural analogues in terms of quantitative parameters and functioning of microbial communities. They are characterized by low content of microbial biomass as well as its high respiratory activity and high specific respiration value. This state of microbial communities of soil constructions indicates the instability of ecosystems at this stage of development. However, the tendency to change the properties of microbial communities towards their natural analogues is clearly visible. For example, the microbial biomass content and basal respiration have increased in soil constructions located in Apatity. Probably, microbial communities of northern ecosystems, having a shorter life cycle, adapt faster to changing environmental conditions and as a result, over the period under study are more similar in their properties to their natural analogues. In the technosols of Moscow and Rostov-on-Don, despite the decrease in the values of the indicators mentioned above, the microbial metabolic coefficient is more stable over time. These cities are also characterized by a trend towards a change in the physiological profile of microbial communities towards their natural analogues, with similarities in the structure of microbial communities noted for Apatity and Moscow. The quantitative indicators of soil fungal communities showed an ambiguous result, currently demonstrating only trends in the formation of a microbial community in technosols: the soils of the subarctic zone are characterized by the highest biomass and length of the fungal mycelium, while the soils of the southern region are characterized by the minimum values.

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Chapter 17
Strategies for Phytoremediation of Polluted Sites in the Subarctic

M. A. Pistsova, A. V. Gromova, M. V. Slukovskaya, Yu. A. Dvornikov, and A. L. Gurinov

Abstract Pollution by potentially toxic elements (PTE) leads to the formation of industrial barrens. Remediation of polluted sites located in the Subarctic is hampered by unfavorable climatic conditions. Soil erosion results in considerable loss of topsoil and is also an important pathway for lateral migration of sediment-associated PTEs. Here, phytoremediation is considered as an appropriate management to reduce these risks. The strategy is tested to an area impacted by a Cu/Ni smelter in the Kola Peninsula. Soil properties and, in particular, susceptibility to water erosion are determined using the RUSLE equation. Annual soil losses in the territory are 4–10 mm; the values are related to the conformation of the terrain. From the calculated soil loss values, three strategies (for hilltops, slopes, and depressions) are proposed to protect the territory from degradation by limiting the mobilization, transport, and accumulation of metals.

Keywords Industrial barren · Phytoremediation · Soil erosion assessment · Environmental pollution

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17.1 Introduction

Environmental protection (and mainly pollution control) is always an important problem for industrialized regions, and it is especially acute in the Russian Subarctic, where industrial pressure affects vulnerable ecosystems. Long-term pollution of soils by potentially toxic elements (PTE) not only increases the potential toxicity of soils, but also the contamination levels of waterbodies. In polar regions, long-term intensive pollution of soils by PTE has resulted in the formation of industrial barrens (IB)—open, desolate landscapes (projective vegetation cover less than 10%) that have developed around point sources of industrial pollution (Kozlov and Zvereva 2007). In the current paper, we analyzed a case of an IB in the vicinity of the town of Monchegorsk (Murmansk region).

The IB formed by the impact of the Cu/Ni smelter (Kola Mining and Metallurgical Company (MMC), formerly «Severonickel») in Monchegorsk (Kola Peninsula, NW Russia) is one of the most extensive. The MMC plant remains active nowadays, and its annual emissions are estimated to be up to 40,000 tons which can be deposited over vast areas up to 300 km away from the source (Moore 1978; Simms et al. 2003). The PTE content in the topsoil can reach extremely high values which are comparable to the processed Cu/Ni ore (Ni—0.24–4.2%, Cu—0.36–5.8%) (Kashulina 2017) and exceed the threshold limit value by 1–3 orders of magnitude (Kashulina 2018).

Despite an ecological policy aimed at reducing the environmental effect, revegetation in the Subarctic takes decades and centuries. Migration and accumulation of PTEs are associated with soil erosion and are controlled by landscape characteristics (e.g., slope steepness and vegetation). Soil erosion and PTE transit predominate on elevated surfaces and slopes, while topographic depressions act as reservoirs of polluted sediments.

We propose a specific phytoremediation strategy for each type of landscape. These strategies are based on the qualitative and quantitative assessment of the landscape (inc. soil erosion rates) as well as the specific ecological properties of plant species: attitude to light, humidity (flooding and draught), soil chemical composition, and wind resistance (based on the root system).

17.2 Study Area

The study area (Fig. 17.1) is located on the Kola Peninsula beyond the Arctic Circle. The climate is characterized by cold with no dry season and cold summers (Dfc by Köppen-Geiger classification) (Beck et al. 2018). The indigenous vegetation cover is formed mainly by plants of northern taiga species: *Picea abies* (L.) H. Karst and *Pinus sylvestris* L. (Manninen et al. 2015), *Salix sp.*, and *Betula pubescens* Ehrh. (Koptsik et al. 2016). Leptic Albic/Entic Podzol is the dominating soil type in the area (Dvornikov et al. 2022). Wetlands are also common—they occupy the low

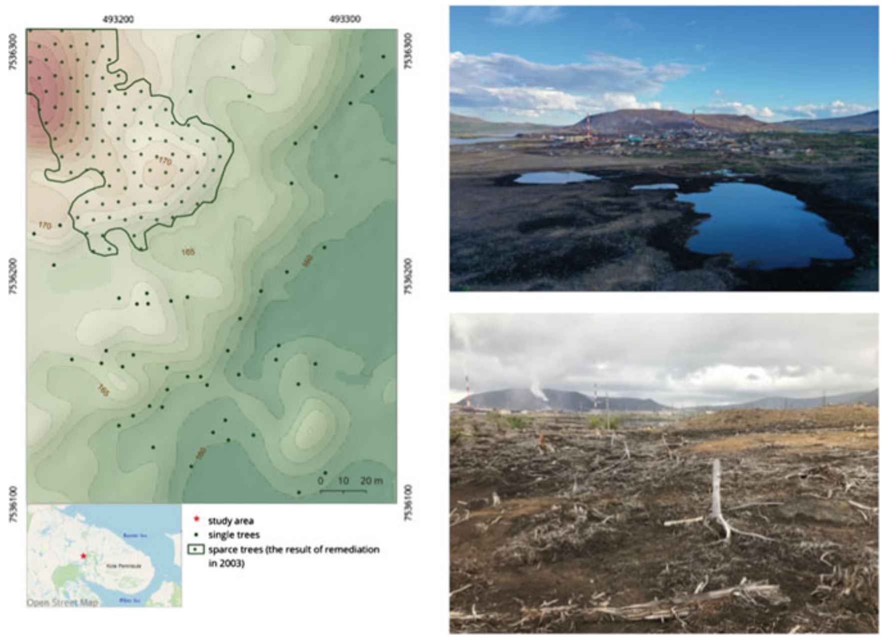

Fig. 17.1 Monchegorsk industrial barren: topography (DTM was obtained as a result of photogrammetric UAV data processing (Dvornikov et al. 2022))

hypsometric levels and act as a place of peat accumulation; Histosol is the most typical soil type here.

Quaternary sediments are represented by moraine sandy loams with pebbles and boulders, as well as anthropogenic sediments (Smirnova et al. 2017a). The study area is in the suburban area and is characterized by an irregular semi-natural bumpy topography of glacial origin: small, partly isolated depressions, and hollows alternating with moraine crests and hummocks. The elevation varies from 159 to 177 m above sea level.

Soil type and topography explain up to 80% of the variance in the Cu/Ni content distribution (Fernandez et al. 2003). But it should be noted that the entire territory is extremely polluted: high acidity or alkalinity, poor vegetation, lack of the nutrients (Ca, Mg, Mn K, and P), and high concentrations of Ni and Cu (Slukovskaya et al. 2017).

The northwestern part of the site was managed with phytoremediation in 2003. On the part of the site, the degraded Podzol subsoils were covered by peat (Koptsik et al. 2016).

17.3 Materials and Methods

Geochemical studies were carried out during the field work. A field-portable XRF analyzer was used to assess the content of nickel, copper, and other chemical elements in soils (Dvornikov et al. 2022). PTE concentrations (Zn, Cd, Pb, Hg, Cu, Co, Ni, As, and Mn) were then estimated by soil indices: Average single pollution index (PIavg) (Inengite et al. 2015), Nemerow pollution index (PI Nemerow), and the total pollution index (Zc) (Romzaykina et al. 2020) to define more and less polluted areas.

$$\mathrm{PIAvg} = \frac{1}{m}\sum_{i=1}^{m}\mathrm{PI}i \tag{17.1}$$

$$\mathrm{PI} = \frac{Ci}{B} \tag{17.2}$$

where

PIi single pollution index of a particular PTE,
n number of studied PTE,
B background content of the PTE (Rossii 1997).

Contamination level is considered as the following: $\mathrm{PI}_{\mathrm{avg}} \leq 1$—low, $1 \leq \mathrm{PI}_{\mathrm{avg}} \leq 3$—moderate, $\mathrm{PI}_{\mathrm{avg}} \geq 3$—heavy.

$$\mathrm{PI\ Nemerow} = \sqrt{\frac{(\frac{1}{n}\sum_{i-1}^{n}\mathrm{PI})^2 + \mathrm{PI}_{\mathrm{max}}^2}{n}} \tag{17.3}$$

where

PI single pollution index of a particular heavy metal,
$\mathrm{PI}_{\mathrm{max}}$ maximal value of the single pollution index of all PTEs,
n number of studied PTE.

Contamination level is considered as the following: PI *Nemerow* ≤ 0.7—clean, $0.7 \leq$ PI *Nemerow* ≤ 1—warning limit, $1 \leq$ PI *Nemerow* ≤ 2—slight pollution, $2 \leq$ PI *Nemerow* ≤ 3—moderate pollution, $3 \leq$ PI *Nemerow*—heavy pollution.

$$\mathrm{Zc} = \sum K_{ci} - (n-1) \tag{17.4}$$

$$K_{ci} = \frac{Ci}{Cb} \tag{17.5}$$

where

K_{ci} concentration coefficient of the i-th PTE,
n number of PTEs,
Ci an actual content of the i-th PTE in soils, mg kg^{-1}.

Contamination level is considered based on Methodology guidelines "Hygienic evaluation of soil in residential areas" from 1999-04-05:

> $Zc < 16$-permissible, $16 \leq Zc \leq 32$—moderately dangerous, $32 \leq Zc \leq 128$ dangerous, $Zc > 128$—extremely dangerous (Hygienic evaluation of soil in residential areas).

We used the well-known and commonly used (mostly for arable lands) empirical model Revised Universal Soil Loss Equation (RUSLE) to calculate soil erosion rates [Revised Universal Soil Loss Equation (2001), 53]. The Revised Universal Soil Loss Equation (RUSLE) estimates soil loss from erosion (A) caused by rainfall and associated surface runoff. RUSLE considers six parameters: climatic erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practices (P) to calculate soil loss (Renard et al. 1997; Revised Universal Soil Loss Equation 2001).

$$A = R * K * \mathrm{LS} * C * P \tag{17.6}$$

R-factor is a measure of the total annual erosive rainfall for a specific location, as well as the distribution of erosive rainfall throughout the year. According to global rainfall erosivity dataset (Nikolova 2016), R-factor for the research area is 191 (MJ mm)/(ha h yr).

K-factor is the soil erodibility factor—the susceptibility of soil particles to detachment and transport by rainfall and runoff. Soil texture is the principal factor affecting K, but structure, organic matter content, and permeability are also important. Williams and Renard (1983) as cited in Chen et al. (2011) proposed the following equation for K-factor calculating (Benavidez et al. 2018):

$$\begin{aligned} K = {} & 0.2 + 0.3 \exp\left(0.0256 * \mathrm{Sa} * \left(1 - \frac{\mathrm{Si}}{100}\right)\right) * \left(\frac{\mathrm{Si}}{\mathrm{Cl} + \mathrm{Si}}\right)^{0.3} \\ & * \left(1.0 - \frac{0.25 * \mathrm{C}}{\mathrm{C} + \exp(3.72 - 2.95\mathrm{C})}\right) \\ & * \left(1.0 - \frac{0.7 * \mathrm{SN}}{\mathrm{SN} + \exp(-5.51 + 22.9\mathrm{SN})}\right) \end{aligned} \tag{17.7}$$

The correction factor converting K-value into SI units of metric ton hours per MJ per mm equals to 0.1317. We used averaged granulometric composition to calculate the factor according to Eq. 17.2. We used K-factor values that characterize typical soils in the study area: 0.013 for Podzol and 0.1 for Histosol. The *K*-factor value for Histosol was chosen according to Moore (1978) based on: (i) the similarity of natural environment with the Northwest Territories in Canada and (ii) the idea that *K*-factor value for the European Histosols should exceed 0.03 (Nikolova 2016).

The LS (slope length-gradient) factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22.13 m. The steeper and more prolonged the slope is, the higher are the erosion risks. The LS-factor was calculated based on DTM derivatives (slopes and float accumulation). The high-resolution (1.5 m) DTM was obtained as a result of photogrammetric UAV data processing (Dvornikov et al. 2022; Zhang et al. 2017).

C-factor is the crop or land cover management factor and is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. RUSLE was developed for agricultural areas; however, it can be adapted for non-agricultural conditions. The study area is almost devoid of vegetation. Forest stand density is ensured in the northwestern part of the site only, where remediation was carried out in 2003. According to May and Place (2005), these sites were assigned a value of 0.13, which is typical for transitional woodland and shrubs. Outside this area, no protection of soil from erosion is ensured. Therefore, the value of the C-factor here is 1.0 (despite the presence of individual trees).

P is the support or land management practice factor, e.g., contouring, terracing, and strip cropping. For areas where there is no support practice (as in our area) the P factor is set to 1.0 (Simms et al. 2003).

For the selection of plant species, we have created the database with attitude of plant species to environmental controls (attitude to light, hardiness zone, moisture resistance, and draught tolerance) considering the accumulation capacity of Ni and Cu. For the selection of plant species, specific criteria for each strategy are defined (environmental controls and the erodibility factors), and the list of plants for each strategy reflects compliance with the chosen criteria.

17.4 Results

17.4.1 Soil Loss Estimated by RUSLE

The value of the LS-factor varies from hundredths of a unit to nearly 8 (Fig. 17.2). The maximum values are confined to the steepest slopes, and the minimum values characterize sub-horizontal and gently sloping surfaces. The minimum LS-values act as a lowering factor in the equation (values less than 1). Maximum values indicate areas of maximum soil loss and exceed minimum values by 1–2 orders of magnitude. By the coincidence of the visual pattern of the LS and A images, it is also clear that geomorphological factors determine the spatial variability of erosion rates in the study area.

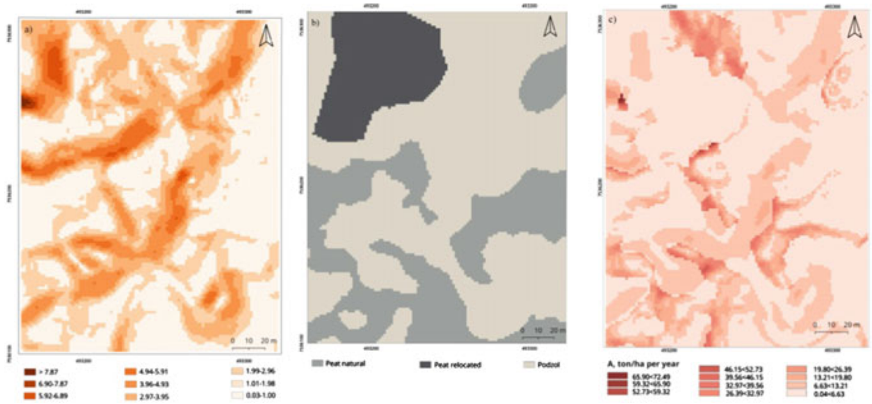

Fig. 17.2 LS-factor (**a**), soil types (**b**), and soil loss values (**c**)

As a result, the maximum values of A (up to 72 tons/ha per year) characterize the steepest and longest slopes where soils are classified as Podzols, and the vegetation cover is reduced.

When converting A (t/ha per year) to erosion rates (mm per year), it was found that 4–10 mm of soil layer is washed away from the area per year. Due to the lack of vegetation cover, the soil has neither the time nor the opportunity to condense, being constantly devoid of organic matter source and exposed to external aggressions.

17.4.2 Soil Pollution by PTE

Based on the calculations of the soil pollution indices (average single pollution index (PIavg), Nemerow pollution index (PI Nemerow), and the total pollution index (Zc), the following results were obtained (Fig. 17.3).

There are lower concentrations of heavy metals on hilltops compared to the topographic depressions represented by all three indices. In some cases, the concentrations of heavy metals on hilltops are five times lower than concentrations of the topographic depressions considering the Average single pollution index and the Nemerow pollution index. Regarding the total pollution index, the difference in heavy metal concentration reach up to 95 times and can be explained by the migration of heavy metals from the upper surfaces to depressions due to the factors of erodibility and the higher capability of Histosols to accumulate heavy metals compared to Podzols (Paltseva et al. 2022).

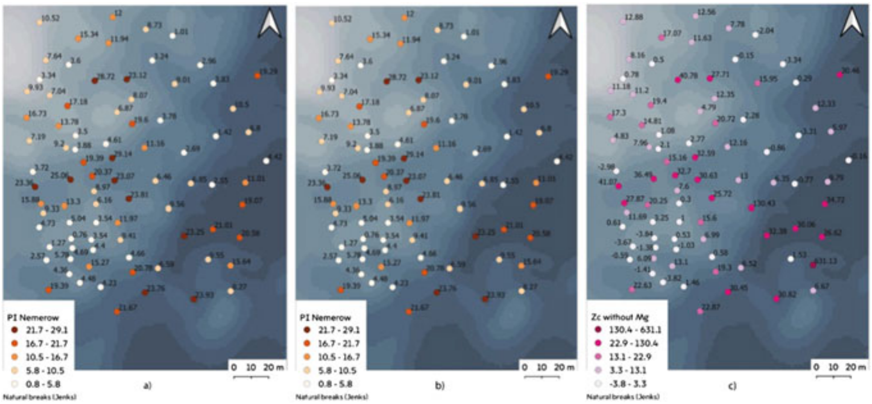

Fig. 17.3 Spatial representation of the soil pollution of the IB estimated by three soil pollution indices (Average single pollution index (PIavg) **a**, Nemerow pollution index (PI Nemerow) **b**, the total pollution index (Zc) **c**) considering the heights of the relief

17.4.3 Phytoremediation Strategies

While considering the issue of remediation of the industrial barren on the Kola Peninsula, it is important to consider (i) the high content of PTE (Cu and Ni), (ii) soil erosion, and (iii) climate conditions. Based on the data obtained on soil loss values, three phytoremediation strategies were developed: for hilltop areas, for slopes, and for depressions. Due to the harsh climate conditions on the Kola Peninsula (Dvornikov et al. 2022), only local plant species can be used, metal-hyperaccumulating plant species have not been implemented for phytoremediation strategies, as no suitable plant species was identified so far in the area. Phytoremediation strategies are chosen based on factors which are used in RUSLE: K-factor, LS-factor, C-factor, and P-factor. Were also considered hardiness zone, sun exposure, moisture resistance, and draught tolerance.

Local species able to cope with soil pollution are used for different remediation strategies on the Monchegorsk IB. In order to create more sustainable ecosystems for phytoremediation, it is more beneficial to use different forms of plants. However, the use of trees only or perennials is also possible depending on the area (m^2) and steepness. The database containing plant species that are tolerant to pollution and arctic climate conditions was proposed (Table 17.1).

Phytoremediation of Hilltop Areas. Hilltop areas are characterized by flat to gently undulating terrain (up to 5–7° steep) with an elevation ranging from 165 to 177 m a.s.l. Rain and snowmelt water transfers soil mass from the upper surfaces to the bottoms of depressions. Therefore, the values of the PTE content increase from top to bottom. Soil moisture in hilltop areas is generally lower than in the rest of the territory. However, the substrate (soil type) is an important factor in this case.

The A-value is higher near the edges which require plant species with strong root systems. For the unvegetated plots with a higher LS-factor (higher than 4.94)

Table 17.1 Plant species for the industrial barren remediation strategies. *Legend* Attitude to light: shade-tolerant (s-t), heliophyte (h); attitude to flooding and draught: resistant (r), non-resistant (n-r), hardly withstands (hw), short flooding (sf), short draught (sd); root system strength: relatively strong (rs), strong (s); root system type: surface (s), deep (d)

Plant species name	Accumulated elements	Height (max) (m)	Crown diameter (max) (m)	Attitude to light	Attitude to flood	Attitude to draught	Root system strength	Root system type (WUR collection)	References
Picea abies (L.) Karst	Ni, Co, Zn, Cu	5	0.6	s-t	r	r	rs	s	Orlova et al. 2013)
Picea obovata Ledeb	Ni, Co, Zn, Cu	5	0.6	s-t	r (sf)	r	rs	s	Chernen'kova et al. 2014)
Pinus sylvestris	Ni, Cu, Pb, Cd	5	0.6	h	r	r	s	d	Golubeva and Glukhova 2015)
Betula nana	Ni, Cu, Pb, Cd	0.5	0.5	h	r	r (sd)	rs	s	Orlova et al. 2013)
Betula pubescens	Cu, Pb, Zn	4	1	h	r	hw	rs	s	Koptsik et al. 2016)
Betula pendula Roth	Cu, Pb, Zn	5	0.5	h	r	r	rs	s	Pfadenhauer and Klötzli, 2020)
Populus tremula	Pb, Cd, Co, Zn, V, Sr	6	0.5	h	r (sf)	r	rs	s	Kozlov and Zverev 2022)
Salix arctica	Cd, Zn	0.3	0.5	s-t	r	hw	rs	s	Orlova et al. 2013)
Salix schwerinii	Cd, Zn	5	5	s-t	r	hw	rs	s	Terebova et al. 2014)
Larix sibirica	Ni, Cu	5	1	h	r	hw	rs	s	Renard et al. 1997)

(continued)

Table 17.1 (continued)

Plant species name	Accumulated elements	Height (max) (m)	Crown diameter (max) (m)	Attitude to light	Attitude to flood	Attitude to draught	Root system strength	Root system type (WUR collection)	References
Alnus incana	Ni, Cu, Pb	5	2	h	r	hw	rs	s	Smirnova et al. 2017a)
Salix polaris	Ni, Cu, Cd, Zn	0.1	3–6	s-t	r	hw	rs	s	Pfadenhauer and Klötzli, 2020)
Salix phylicifolia L	Ni, Cu, Cd, Zn	0.5	0.5	s-t	r	hw	rs	s	Koroleva and Kopeina 1937)
Salix glauca L	Ni, Cu, Cd, Zn	0.5	0.5	s-t	r	hw	rs	s	Koroleva and Kopeina 1937)
Salix caprea	Cd, Co, Cr, Ni, Cu, Al, Fe, As, S, Ca	3	3	s-t	r	hw	rs	s	Koroleva and Kopeina 1937)
Salix cinerea L	Ni, Cu, Cd, Zn	2	2	s-t	r	hw	rs	s	Koroleva and Kopeina 1937)
Festuca rubra L	Zn, Cu, Pb, Ni, Fe	0.2	–	h	r	hw	s	d	Slukovskaya et al. 2017)
Festuca pratensis Huds	Zn, Cu, Pb, Ni, Fe	0.2	–	h	r	hw	s	d	Koroleva and Kopeina 1937)
Bromopsis inermis (Leyss.) Holab	F, Cu, Ni	0.7	–	h	r	r	s	d	Koroleva and Kopeina 1937)
Dactylis glomerata (L.)	Cu, Ni	0.6	–	h	hw	r	s	d	Koroleva and Kopeina 1937)

(continued)

Table 17.1 (continued)

Plant species name	Accumulated elements	Height (max) (m)	Crown diameter (max) (m)	Attitude to light	Attitude to flood	Attitude to draught	Root system strength	Root system type (WUR collection)	References
Elytrigia repens (L.)	Cu, Ni	0.5	–	h	r	r	s	s	Koroleva and Kopeina 1937)
Calamagrostis lapponica	Cu, Ni	0.5	–	s-t	r	r	s	d	Koroleva and Kopeina 1937)
Calamagrostics phragmitoides Hartm	Cu, Ni	0.5	–	s-t	r	r	s	d	Kozhin and Sennikov 2016)
Deschampsia caespitosa	Cu, Ni	0.3	–	h	r	r	s	d	Koroleva and Kopeina 1937)
Poa arctica	Cd, Pb, Cu, Zn	0.1	–	s-t	n-r	r	rs	s	Pfadenhauer and Klötzli, 2020)
Lolium perenne	Cd, Pb, Cu, Zn	0.2	–	h	r	r	s	d	Tarasova et al. 2020)
Calamagrostis epigeios (L.) Roth	Ni, Pb, Cu	0.8	–	h	r	r	s	d	Smirnova et al. 2017a)
Chamaenerion angustifolium (L.) Scop	Pb, Zn, Cd, Cu, Ni	0.8	–	h	hw	r	rs	s	Koroleva and Kopeina 1937)

denser perennial plantings are needed combined with trees and bushes. The plants-heliophytes resistant to winds and draught with a strong root system, that are able to grow on Histosols, can be used for phytoremediation. The tree species that are more tolerant to specific conditions on such landforms are *Pinus sylvestris* and *Populus tremula. Populus tremula* is highly recommended for the polluted sites as it gives shoots even without any improvement of the soil quality (Kozlov and Zverev 2022). The perennials for the hilltop surfaces are *Bromopsis inermis* (Leyss.) Holab, *Dactylis glomerata* L., *Elytrigria repens* L., *Deschampsia caespistosa* L., *Lolium perenne* L., *Calamagrostics epigeios* (L.) Roth., and *Chamaerion angustifolium* (L.) Scop.

Phytoremediation of Slopes. The slopes are the most dynamic areas on the territory and diversified both in steepness and exposure. However, most of the slopes are about 15–20° steep. Therefore, it is important to consider when choosing plants their root systems which must be able not to gain a foothold and develop on the slope only, but also to maintain their stability in the future. By stabilizing slopes, root systems decrease erosion, PTE mobility, and availability (Koptsik et al. 2016).

The slope remediation strategy may include plants of different life forms. For example, grass vegetation reduces the A-value by about 20 times (Morel et al. 2015), based on CP-factors in RUSLE (with a constant $P = 1$). However, the grass cover is characterized by seasonality, so erosion become active during spring snowmelt.

Exposure to the sun influences the moisture of the slope. However, the elevation changes do not provide much shadow from one hill to another one. Therefore, sun exposure is not the main factor considering strategies. Slopes are exposed to higher winds and erosion rate than depressions. Plant species for slopes are *Picea abies (L.) Karst*, *Picea obovata* Ledeb., *Pinus sylvestris*, *Betula pendula Roth*, *Betula nana*, *Betula pubescens, Populus tremula*, *Salix caprea, Salix cinerea L., Salix schwerinii, Larix sibirica, Elytrigia repens* (L.), *Poa arctica*, *Dactylis glomerata L., Lolium Perenne, Chamaenerion angustifolium* (L.) Scop., *Calamagrostis epigeios (L.) Roth.,* and *Festuca rubra. Festuca rubra* prevents the migration of Cu and Ni if it is grown on the substrate whose toxicity module equals 0.01 (Slukovskaya et al. 2017). Hence, it is a beneficial plant for slope stabilization; however, the initial soil should be covered by another layer of less toxic substrate (it is relevant to each phytoremediation strategy).

Phytoremediation of Depressions. Moraine depressions and hollows occupy elevations below 160 m above sea level and are the wettest areas. Accumulation predominates here, and it leads to a hyperconcentration of PTE transferred by lateral migration. The plants used here must be resistant not only to high PTE concentrations, but also to almost constant waterlogging. Limiting factors will play a decisive role in the selection of plants. The ability of root systems to limit erosion does not matter here. Thus, in depressions a wetland ecosystem can be obtained with plants capable of absorbing PTE. Such plants include: *Betula pendula* Roth., *Betula pubescens*, *Salix arctica*, *Salix shwerinii*, *Salix polaris*, *Salix phylicifolia* L., *Salix glauca* L., *Salix cinerea* L., and *Salix caprea. Betula pubescens* and *Salix caprea* are able to maintain their chemical composition even under the extreme conditions of an IB (Koptsik et al. 2016). Perennials meeting the depression criteria are *Calamagrostics lapponica*, *Calamagrostics phragmitoides*, *Calamagrostics epigeios* (L.) Roth., *Deschampsia caespitosa*, *Poa arctica*, *Elytrigia repens (L.), and Lolium perenne* (Fig. 17.4).

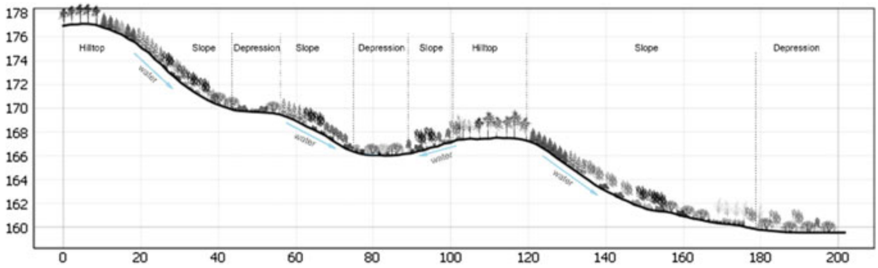

Fig. 17.4 Phytoremediation strategies visualization

17.5 Discussion

The K-factor showed little variability because the averaged data of the composition of the Podzols was used. In addition, a problem was detected in determining the K-factor for soils saturated with organic content (Revised Universal Soil Loss Eq. 2001; Wall et al. 2002). The values of K-factor offered for different regions and types of land-use are sometimes several times different (Fernandez et al. 2003; May and Place 2005).

Soil loss values corresponded to the average values for European Part of Russia or slightly exceeded them. The exceedances of the average values were obtained due to the absence of vegetation cover in most of the territory, as well as relatively low values of soil density (we have 0.4–1.0 g/cm^3 for Histosols and 1.0–1.6 g/cm^3 for Podzols).

In fact, there is no natural vegetation on the territory, and the result of remediation is a sparse forest stand. The C-factor used (May and Place 2005) successfully characterizes the territory. However, there are other estimates of the C-factor (e.g., (Fernandez et al. 2003)), which are used for natural vegetation and urban areas. During the existence of a modern copper-nickel smelter (25 years), erosional truncation in different parts of the study area ranged from 10 to 25 cm. The average values of soil losses (A-value) are similar to the results of other researchers (Li et al. 2018; Tsymbarovich et al. 2020)—the order of magnitude, as well as variability. Despite the opinion (Gorbacheva 2011) that the RUSLE gives an overestimate, our results reflect the relationship between soil erosion and pollution rates.

Plant species for remediation strategies are chosen based on their natural areal, tolerance to soil pollution and criteria for the specific conditions of each type of landforms. However, there are still other factors that influence plants liveability, i.e., nutrient supply, air quality, soil quality, interrelationship between different plants of a particular plot, biotic stress, etc. (Schulze et al. 2019).

Probably, there is not only lateral migration down the slope, but also deep into the soil. Hence, the PTE concentrations do not only depend on the location of erosion and accumulation sites.

The presence of IB in the suburbs of Monchegorsk strongly affects the quality of life of residents. Remediation of the site and long-term effect of management should consider the provision of ecosystem services (Morel et al. 2015). Such services include the benefits for the biodiversity and for the health of population resulting from the restoration and protection of the landscape (foremost vegetation cover and soils). Currently, the quality of these ecosystem services is very low, but well-chosen phytoremediation strategies in line with environmental monitoring are very much in demand.

17.6 Conclusions

The maximum rates of soil erosion within the territory (on steep slopes devoid of vegetation cover) exceed 10–12 times the rates of erosion on very gentle slopes and subhorizontal surfaces and 3–4 times—on slopes of medium steepness. Vegetation further reduces the rate of erosion, sometimes even by 1–2 orders of magnitude (on the highest flat-topped hills). Intensive soil erosion is associated with the absence of vegetation cover. In addition, slow revegetation rate in subarctic conditions and under industrial pollution leads to continued soils degradation.

The geomorphological characteristics of the territory are decisive for the erosion process, due to the high variability of the LS-factor. Therefore, when choosing a remediation strategy, it is necessary to take into account the features of the topography of the territory. The full RUSLE equation or the LS-factor (for an approximate estimate) can be used for small areas with low variability of soil types and other factors. The use of local plant species or plant species that are able to survive in arctic climate conditions allows them to spread throughout the territory with low additional plants care measures. The suggested species could be recommended for phytoremediation strategies in the Kola Peninsula IB territory. Providing suitable phytoremediation strategies will decrease the erosion processes and stabilize the slopes, as well as slow down PTE migration gradually to acceptable PTE concentrations. In addition to pollution mitigation, which is the priority of these sites, phytoremediation strategies should improve the ecosystem services provided by the area, including biodiversity, carbon storage, and landscape. However, these services must be evaluated to attest to their effectiveness.

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Chapter 18
Remediation of Urban Soils with Nitrogen and Microbiological Fertilizers when Contaminated by Oil, Gasoline and Fuel Oil

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Abstract Rostov-on-Don is a major agro-industrial center in the South of Russia and one of the key points on the way to the Black Sea coast of Russia. At the same time, the share of motor transport (passenger cars) is 88%, trucks (small and medium-sized)—7% of the total transport, respectively. Commercial oil and its derivatives are regularly transported by road and rail through the territory of the city as a transport hub. Considering that diesel fuel and gasoline are used as fuel for cars and trucks, and the transportation of commercial oil often passes through the territory of Rostov-on-Don, remediation of oil-polluted urban soils is necessary. The work objective was to assess the impact of nitrogen and microbiological fertilizers on the ecological state of urban soils in Rostov-on-Don. To assess the ecological state of soils, an experiment was modeled under controlled laboratory conditions. For the experiment, the level of oil pollution of 5% of the soil mass was studied; the incubation period was 30 days. The ecological state was assessed by indicators of phytotoxicity, enzymatic activity, and the total number of soil bacteria. It was found that oil, fuel oil and gasoline pollution caused inhibition of biological parameters by 23–49%. When applying complex mineral fertilizer as nitrogen fertilizer and "Baikal EM-1" as microbiological fertilizer, a decrease in phytotoxicity of contaminated soils with fuel oil and gasoline was observed by 7–75% compared to no treatment soil. In the soil with gasoline, the introduction of complex mineral fertilizer and "Baikal EM-1" caused stimulation of catalase activity, dehydrogenases and the number of soil bacteria by 9–55% compared to contamination with gasoline alone. As a result of the study, it was found that the introduction of complex mineral fertilizer and "Baikal EM-1" into haplic chernozem contributed to the restoration of the soil ecological state when contaminated with light fraction petroleum products such as gasoline, and for fuel oil and oil, it is necessary to adjust the exposure period and doses of ameliorants.

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Keywords Haplic chernozem · Rostov-on-Don · Pollution · Complex mineral fertilizer · "Baikal EM-1" · Enzymatic activity · Phytotoxicity · Total number of bacteria

18.1 Introduction

Rostov-on-Don is a major agro-industrial center in the South of Russia and one of the key points on the road to the Caucasus and the Black Sea coast of Russia. More than 267.3 million people are projected to be transported through Rostov-on-Don in 2022, with the length of the network of dedicated lanes for route vehicles in 2021–2022—93.0 km (The Program… 2021). At the same time, the share of motor transport (passenger cars) is 88%, and trucks (small and medium-sized)—7% of the total number of vehicles. Commercial oil and its derivatives are regularly transported through the territory of the city as a transport hub (Al'bekov 2011; Sablina 2020). Diesel and gasoline are used as fuel for cars and trucks; fuel oil is used as boiler fuel for sea and river transport, in heat generators in agriculture, for various heating systems, furnaces, technological installations and steam heating systems. Pollution with oil and petroleum products occurs in any city or settlement (Gospodarek et al. 2021). In the case of an oil leak in an abnormal mode and in an emergency, contamination of surface waters and soil occurs, and the sanitation or remediation of oil-polluted soils is necessary. Petroleum products such as diesel fuel, gasoline and motor oil have a negative impact on soil biochemical processes and increase phytotoxicity (Caravaca and Rodán 2013; Gürtler et al. 2022; Kolesnikov et al. 2010; Rusin et al. 2017, 2018; Swapna et al. 2021; Wyszkowski et al. 2020, 2022). Restoration of soils with this type of pollution is complicated by a number of parameters: physico-chemical properties of oil and petroleum products (viscosity, density, octane number, impurity content, etc.), quantitative characteristics of oil and petroleum products (volume and concentration), soil buffering capacity and is also directly related to the biological properties of the soil (Ahmad et al. 2020). Therefore, bioremediation is the most effective method of restoring oil-contaminated soils. Within the framework of bioremediation measures, several main directions are used: stimulation of native hydrocarbon-oxidizing biota by applying organic and mineral fertilizers, bioaugmentation when other hydrocarbon-oxidizing microorganisms are added to soil native biota, phytoremediation when plants are planted in contaminated soil (Alori et al. 2022; Sales da Silva et al. 2020). Humic and nitrogen fertilizers were previously used effectively when the soil was polluted with oil of various concentrations (Minnikova et al. 2019). These fertilizers acted as stimulators of the native biota: nitrogen fertilizers equalized the ratio of C:N, and humic substances stimulated the native biota. In addition, mineral sorbents (glauconite) and organic sorbents (biochar) affect the soil condition during oil pollution along with bacterial preparations (Hazim and Al-Ani et al. 2019; Koshlaf and Ball 2017; Minnikova et al. 2021, 2022a, b, c; Ruseva et al. 2022).

In this regard, it is relevant to study the ability of oil-polluted urban soils (for example, in Rostov-on-Don) to remediate after the use of nitrogen fertilizers and microbiological preparations combining strains of various microorganisms (bacteria, fungi and actinomycetes).

The aim is to assess the ecological state of urban soils after bioremediation with nitrogen and microbiological fertilizers when contaminated with oil, gasoline and fuel oil.

18.2 Materials and Methods

Soil. To assess the ecological state of soils during remediation of contamination of haplic chernozem by oil, fuel oil and gasoline, an experiment was modeled under controlled laboratory conditions. Soil samples were taken from the top layer of 0–5 cm of arable land located in experimental plots of the Botanical Garden of the Southern Federal University (Fig. 18.1).

The soil was dried to an air-dry basis; organic and inorganic residues (roots, stones and other debris) were removed. Then, the soil was sifted through a sieve with a cell size of 3 mm.

Experiment simulation. For the experiment, 300 g of pre-prepared air-dry soil was moistened, and oil 5% of the soil weight and ameliorants were added. Complex mineral fertilizer and microbiological preparation—"Baikal EM-1"—were used in

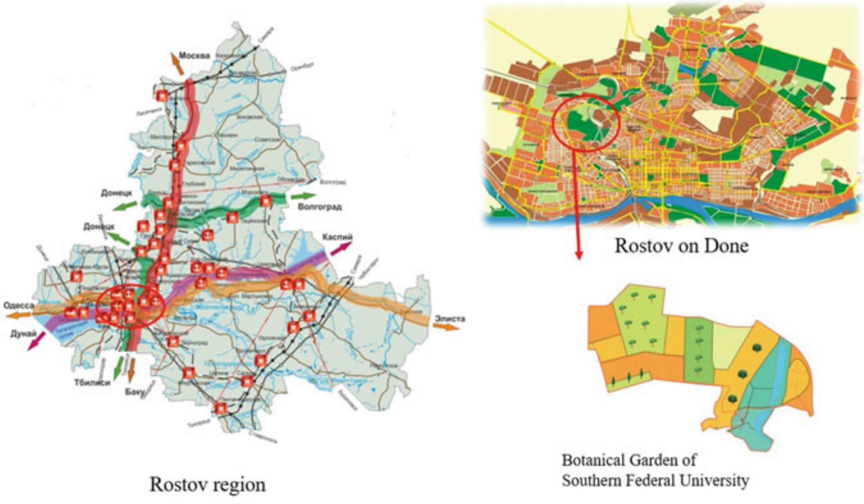

Fig. 18.1 Map of the location of the soil sampling site (Botanical Garden of the Southern Federal University (Rostov-on-Don)

the study. Complex mineral fertilizer was applied to the soil after wetting and oil contamination, and "Baikal EM-1" was applied to dry soil, and then, oil was applied.

Complex mineral fertilizer (CMF) contains N, P, and K in approximately equal proportions (15:15:15). The fertilizer manufacturer is the "Nov-Agro" manufacturing and trading company (Novaya Melnitsa, Novgorod Region). Complex mineral fertilizer was introduced into the soil in an amount equivalent to compensate 0.75 g for the lack of nitrogen in the oil-contaminated soil and equalize the ratio between carbon and nitrogen.

The composition of «Baikal EM-1» includes bacterial strains (*Paenibacillus pabuli, Azotobacter vinelandii, Lactobacillus casei, Clostridium limosum, Cronobacter sakazakii, Rhodotorulla mucilaginosa and Cryptococcu*), hybrid yeast (*Saccharomyces, Candida lipolitica, Candida norvegensis and Candida guilliermondii*) and fungi (*Aspergillus, Penicillium and Actinomycetales*). "Baikal EM-1" produced by LLC "Scientific and Production Association EM-CENTER" was used in this study (Ulan-Ude, Republic of Buryatia). One-percent solution "Baikal EM-1" with a volume of 100 ml was introduced into the soil. When adding the solution, we achieved soil moisture content of 25–30%.

The incubation period of soils contaminated with oil, fuel oil and gasoline after the introduction of nitroammophos and "Baikal EM-1" at a temperature of 24–25°C, and a humidity of 25–30% was 30 days long. The experiment scheme and the stages of work are shown in Fig. 18.2.

Measurement. The ecological state was assessed by indicators of phytotoxicity, enzymatic activity, and the total number of soil bacteria (Table 18.1) (Kazeev et al. 2016). Measurements were taken after 30 days of soil incubation. When assessing the phytotoxic properties of the soil, garden radish (*Raphanus sativus* L. var. *sativus*) of the "Zhara" variety was used as a test object.

As a result of the determination of biological indicators, the integral indicator of the biological state (IIBS) was evaluated as an average to show the reflective response of all biological indicators to the state of the soil.

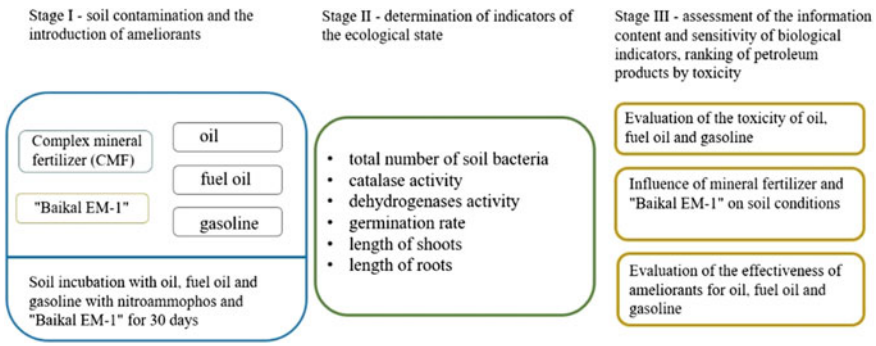

Fig. 18.2 Scheme and stages of the experiment

Table 18.1 Methods for assessing the ecological state of oil-contaminated soils

No.	Indicator	Units of measurement	Method of measurement	References
	Total number of bacteria	10^9 in gram of soil dry weight	Luminescent microscopy with solution of acridine orange, 40X	(Zvyagintsev 1991)
	Catalase activity (H_2O_2: H_2O_2—oxidoreductase, EC 1.11.1.6)	ml O_2 per gram of soil dry weight in 1 min	By the rate of decomposition of 3% hydrogen peroxide, after contact with the soil (temperature, 20–22 °C)	(Galstyan 1978)
	Dehydrogenases activity (substrate: NAD (P)—oxidoreductase, EC 1.1.1)	mg of triphenylformazane (TPF) per gram of soil dry weight for hour	According to the rate of conversion of triphenyltetrazolium chloride (TPC) to TPF PE 5800VI spectrophotometer at a wavelength of 540 nm	(Khaziev 2005)
	The germination rate of radish seeds (*Raphanus sativus L.* var. sativus)	% of germination seeds of control	Germination of radish (*Raphanus sativus* L.) after 7 days of the experiment	(Zvyagintsev et al. 2005)
	The length of the radish shoots (*Raphanus sativus* L. var. sativus)	10^{-3} m	Of length of the shoots in radish (*Raphanus sativus* L.) after 7 days of the experiment	(Zvyagintsev et al. 2005)
	The length of the radish roots (*Raphanus sativus L.* var. sativus)	10^{-3} m	Of length of the roots in radish (*Raphanus sativus* L.) after 7 days of the experiment	(Zvyagintsev et al. 2005)

Statistical Processing. Significance was tested at the $p < 0.05$, ** $p < 0.001$, *** $p < 0.0001$ level (using the software package STATISTICA 12.0). Statistics (mean values, dispersion) were determined, and the reliability of different samples was established by using dispersion analysis (Student's *t*-test).

18.3 Results

It was found that oil, fuel oil and gasoline pollution caused inhibition of biological parameters by 34–92%. The change in the total number of bacteria in the soil contaminated with oil, fuel oil and gasoline is shown in Fig. 18.3. In clean soil without pollutants, complex mineral fertilizer and "Baikal EM-1" did not have a significant effect on the number of bacteria.

The introduction of oil, fuel oil and gasoline caused inhibition of the bacteria number by 64, 77 and 62%, respectively. Complex mineral fertilizer and "Baikal EM-1" did not have a significant effect on the number of bacteria in oil-contaminated soil. In the soil with fuel oil, complex mineral fertilizer and "Baikal EM-1" caused stimulation by 14 and 27%. In the soil with gasoline, the introduction of complex mineral fertilizer and "Baikal EM-1" caused a stimulation of the number of soil bacteria by 17 and 12%.

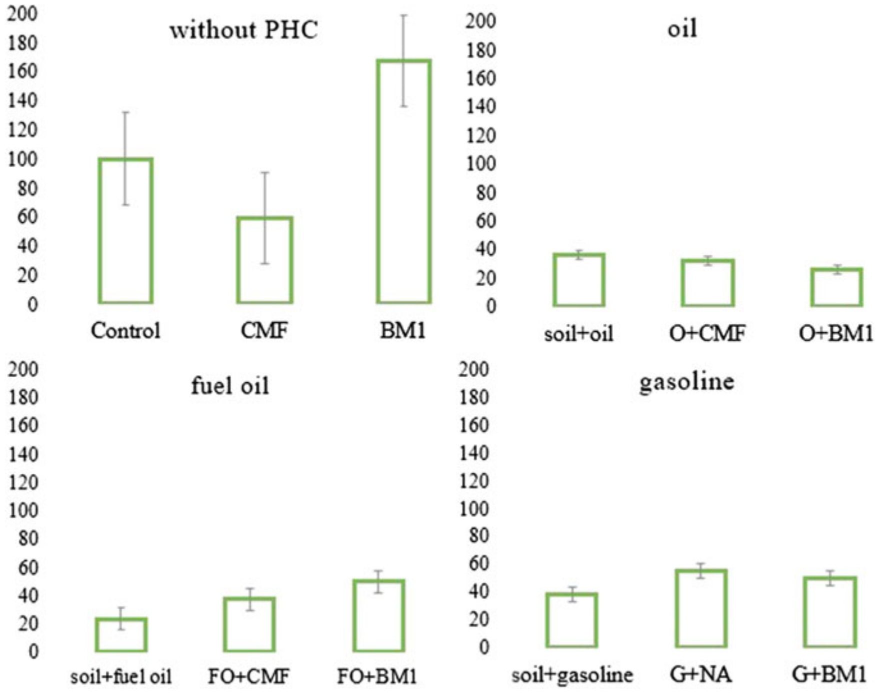

Fig. 18.3 Total number of bacteria in haplic chernozem when contaminated with oil, fuel oil and gasoline after the introduction of complex mineral fertilizer and "Baikal EM-1", % of control. PHC—petroleum hydrocarbons; O—oil; FO—fuel oil; G—gasoline; CMF—complex mineral fertilizer; BM1—"Baikal EM-1"

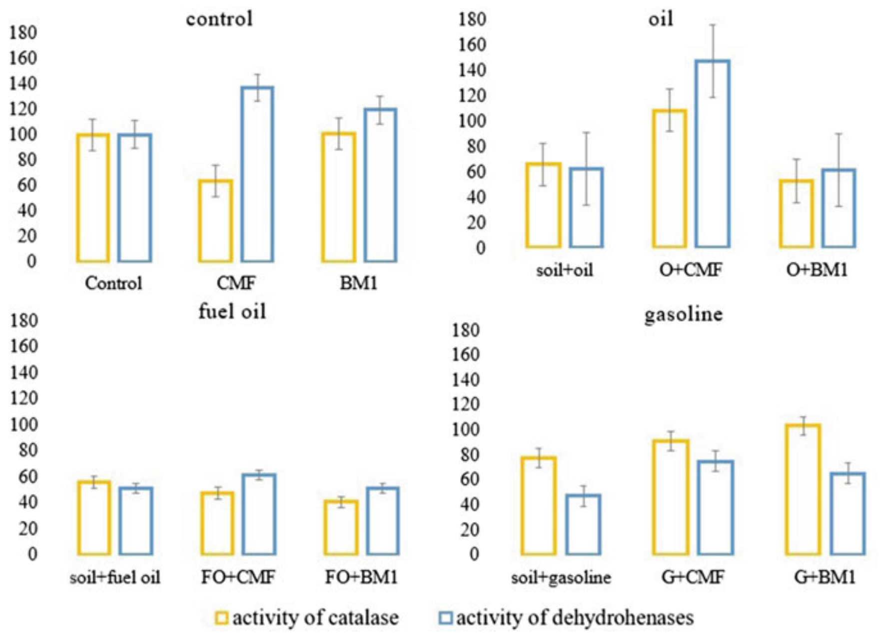

Fig. 18.4 Changes in the activity of catalase and dehydrogenases of haplic chernozem when polluted with oil, fuel oil and gasoline after the introduction of complex mineral fertilizer and "Baikal EM-1", % of control. PHC—petroleum hydrocarbons; O—oil; FO—fuel oil; G—gasoline; CMF—complex mineral fertilizer; BM1—"Baikal EM-1"

The activity of catalase and dehydrogenases during the introduction of complex mineral fertilizer and "Baikal EM-1" varied unequally (Fig. 18.4). If the catalase activity during the introduction of complex mineral fertilizer was inhibited by 37%, then the dehydrogenases activity was stimulated by 37% in control. In addition, stimulation of dehydrogenase activity was detected when introducing "Baikal EM-1".

Oil, fuel oil and gasoline inhibited enzyme activity by 23–49%. When complex mineral fertilizer was introduced into oil-contaminated soil, catalase and dehydrogenase activity was stimulated by 43 and 85%. "Baikal EM-1" had no effect on the activity of enzymes in oil-contaminated soil. In the case of contamination with fuel oil, the stimulation of dehydrogenases activity was established with the introduction of complex mineral fertilizer (10%). With gasoline contamination and the introduction of complex mineral fertilizer and "Baikal EM-1", catalase activity was stimulated by 12 and 26%. The activity of dehydrogenases was also stimulated by 28 and 18% with the introduction of complex mineral fertilizer and "Baikal EM-1".

Changes in phytotoxic parameters such as germination, length of shoots and roots are shown in Fig. 18.5. Complex mineral fertilizer in pure soil inhibited germination and slowed down the growth of the radish root system by 66 and 64% relative to the control. At the same time, "Baikal EM-1" did not have a significant impact. Oil

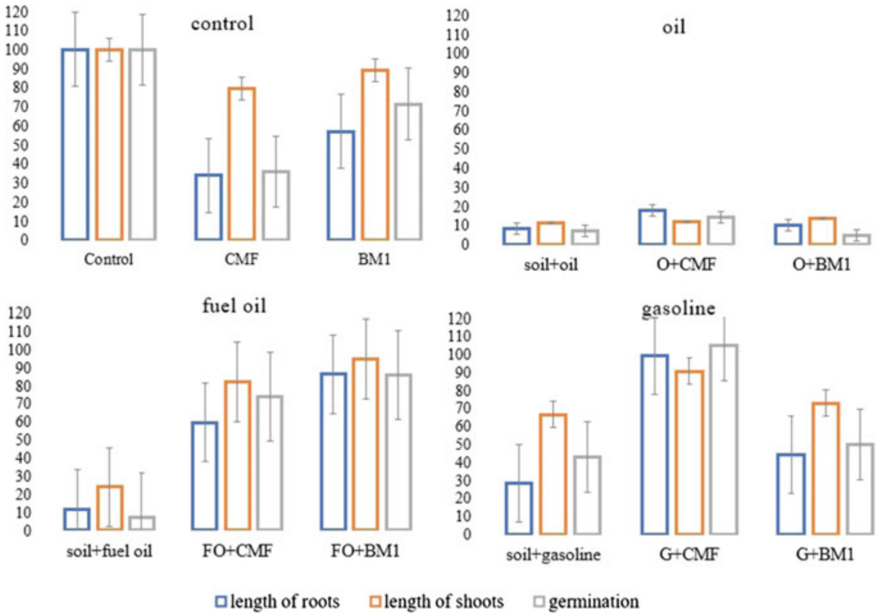

Fig. 18.5 Changes in phytotoxic indicators of haplic chernozem when contaminated with oil, fuel oil and gasoline after the introduction of complex mineral fertilizer and "Baikal EM-1", % of control. PHC—petroleum hydrocarbons; O—oil; FO—fuel oil; G—gasoline; CMF—complex mineral fertilizer; BM1—"Baikal EM-1"

causes the greatest inhibitory effect on germination rate, and the length of shoots and roots of radish were decreased by 89–92%. At the same time, fuel oil also reduced germination by 93%, as well as oil, but the length of shoots and roots was longer. Gasoline reduced germination of radish by 57%, length of shoot—by 34%, and length of root—by 72%.

The introduction of complex mineral fertilizer stimulated germination, shoot and root length in fuel oil-polluted soil by 67, 58 and 48%. "Baikal EM-1" with the same type of pollution stimulated germination, the length of shoots and roots by 79, 71 and 75%. In the soil with gasoline, the introduction of complex mineral fertilizer made it possible to reach the level of uncontaminated soil (control group), causing stimulation of germination, length of shoots and radish roots by 62, 64 and 71%. The introduction of "Baikal EM-1" stimulated the germination of radish on soil contaminated with gasoline by 16%.

The integral indicator of biological state (IIBS) was calculated based on six indicators of soil biological activity (Fig. 18.6). It was established that complex mineral fertilizer in uncontaminated soil at a dose applicable to oil, fuel oil and gasoline pollution had a toxic effect on biota. This is due to the fact that with the optimal functioning of the soil, the balance of C:N is in the ratio of 1:9–1:12 (Kurganova

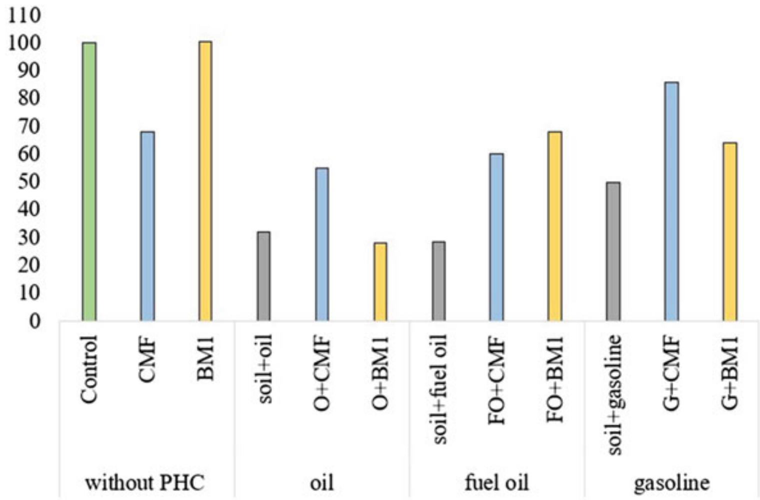

Fig. 18.6 Integral indicator of the biological state of haplic chernozem when contaminated with oil, fuel oil and gasoline after the introduction of complex mineral fertilizer and "Baikal EM-1". Note: PHC—petroleum hydrocarbons; O—oil; CO—crude oil; G—gasoline; CMF—complex mineral fertilizer; BM1—"Baikal EM-1"

et al. 2021; Lukin 2016; Terpelets and Plitin 2015), and with the addition of petroleum hydrocarbons, an increase in C with respect to N is observed (Degtyareva et al. 2020; Slyusarevsky et al. 2018; Timergazina and Perekhodova 2012).

Complex mineral fertilizer should compensate for the lack of nitrogen in the soil and optimize the microbiological and enzymatic activity of the soil. In oil-contaminated soil, the application of complex mineral fertilizer was 27% more effective than when applying "Baikal EM-1". The greater efficiency of applying complex mineral fertilizers to oil-contaminated soil compared to bacterial preparations is because in soil with a disturbed C:N ratio, even the introduced microorganisms cannot grow and multiply (Minnikova et al. 2019; Tereshchenko et al. 2004).

In the soil with fuel oil, the difference between the efficiency of using "Baikal EM-1" and complex mineral fertilizer was only 8%. The use of Baikal EM-1 for soil with fuel oil and gasoline is possible, but when the soil was contaminated with oil, the biological indicators of the soil were not restored to the control level and were more inhibited. Thus, several petroleum products according to the effectiveness of complex mineral fertilizer use (% of control): gasoline (86) > fuel oil (60) > oil (55). Several petroleum products according to the effectiveness of the "Baikal EM-1" use (% of control): fuel oil (68) > gasoline (64) > oil (28).

Remediation of fuel oil (heavy fraction of oil) is also associated with several difficulties due to its high viscosity and density, which directly affects the growth and development of plants and the functioning of soil biota (Odukoya et al. 2019). Compared with oil and fuel oil, gasoline (light fraction of oil) is a mixture of hydrocarbons with different evaporability and less toxic effects on soil biota (Vasilyeva et al. 2013, 2020). In this regard, even if the C:N ratio is normalized (after complex mineral fertilizer use) and the native biota is stimulated with the help of "Baikal EM-1", it is not possible to restore the ecological state for every oil product. Thus, the effectiveness of the use of complex mineral fertilizer and "Baikal EM-1" in soil contaminated with oil and petroleum products depends on the chemical nature of the contaminant.

18.4 Conclusion

As a result of the study, it was found that when the soil was contaminated with oil and gasoline, the application of complex mineral fertilizer was 27 and 22% more effective than when applying "Baikal EM-1". When contaminated with fuel oil, it is advisable to use both "Baikal EM-1" and complex mineral fertilizer. Petroleum hydrocarbon products form the following series according to the effectiveness of complex mineral fertilizer application (% of control): gasoline (86) > fuel oil (60) > oil (55); petroleum hydrocarbon products form the following series according to the effectiveness of "Baikal EM-1" application (% of control): fuel oil (68) > gasoline (64) > oil. "Baikal EM-1" into haplic chernozem helps to restore the soil when contaminated with gasoline and fuel oil, and when soil is contaminated with oil, a longer incubation period is required, and it is also necessary to adjust the doses of ameliorants.

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Chapter 19
Tree Health of *Betula Pubescens* L. for Sustainable Urban Ecosystems (in the Railway Impact Zone on Kola Peninsula)

Natalya V. Saltan and Ekaterina A. Sviatkovskaya

Abstract The environmental conditions on Kola Peninsula are affected by industry and transport with substantial consequences for tree health. The research aimed to assess the resistance of *Betula pubescens* in the railway impact zone in five settlements: Murmansk, Olenegorsk, Apatity, Polyarnye Zori, and Kandalaksha. The methodology included determining the state of plants, content of photosynthetic pigments in leaves, fluctuating asymmetry, and morphological parameters of the leaf lamina. Tree health assessment of *B. pubescens* showed state deterioration in 2021, which is associated with sanitary care for plantings. On forecourt areas revealed increase of photosynthetic pigments in the leaves birch not associated by railway transport activity. An assessment of changes in the stability of plant development using FA index revealed that the largest deviations from the norm were observed in Olenegorsk in 2018–2019 (FA = 0.058–0.062) and Kandalaksha in 2021 (FA = 0.060). Leaf size did not depend on the level of railway load. The correlation analysis showed a general trend for most cities is the negative dependence FA index on the size of morphological features. Based on the research outcomes, *B. pubescens* can be recommended for introduction to the protective plantings along the railway track and used for greening railway stations due to high resistance to pollution and long lifetime.

Keywords The rail station areas · Murmansk region · *B. pubescens* · Ecological features · Greening

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19.1 Introduction

The urban environment is formed under the influence of various factors, both natural and anthropogenic. Anthropogenic factors (increased dustiness, gas pollution, changes in temperature, water, light regimes, pollution, etc.) determine the specificity of the ecological environment of the city, which differs sharply from the natural one, where the biological and ecological features of plants used for urban greening were formed (Kulagin and Shagieva 2005). The toxic effects of pollution on the tree health can be expressed through plant injury, morphological changes, decrease of vegetative and reproductive growths, early senescence, and even mortality (Dorsey et al. 2015; Viehweger 2014).

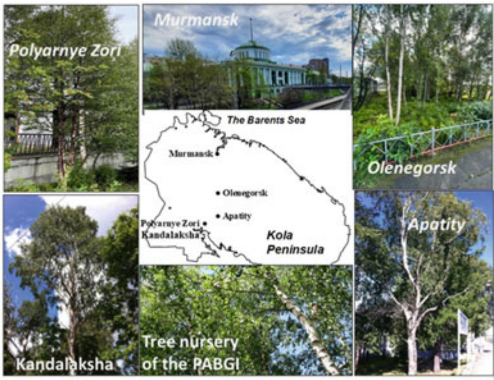
The vulnerability of urban ecosystems of the subarctic region of Russia (Murmansk region) is due to harsh soil and climatic conditions and an intensively developed industrial complex including heavy metals pollution. Mining and industrial enterprises are local sources. Most of the extracted raw materials and products are transported by rail. In addition to transporting chemicals, the maintenance and operation of rolling stock use hazardous materials that, if leaked, lead to environmental pollution (Borda-de-Agua et al. 2017; Kazantsev 2015). The problem of improving the urban environment is very relevant for the Kola Arctic. Green spaces that perform health-improving, environmental, and aesthetic functions optimize the urban environment (Gontar et al. 2010; Supuka 1997). A properly selected assortment of resilient plants allows you to decorate the urban landscape while maintaining sanitation and environmental efficiency. Railway transport's influence on plants growing in the right-of-way remains poorly understood. The study of plants used for landscaping railway stations located near cities is relevant to identifying resistant species. In urban plantings, a typical representative is a native species—*B. pubescens*.

The purpose of this work was to assess the resistance of *B. pubescens* to railway transport's impact using numerous indicators (e.g., tree state, the content of photosynthetic pigments in leaves, fluctuating asymmetry, morphological parameters of the leaf lamina) from different locations of the Kola Peninsula.

19.2 Objects and Method

19.2.1 Location

The research was carried out in 2018–2021 at observation plots located in areas adjacent to railway stations, in the immediate vicinity of the tracks in Murmansk, Olenegorsk, Apatity, Polyarnye Zori, and Kandalaksha (Fig. 19.1). The tree nursery of the Polar-Alpine Botanical Garden-Institute (PABGI) (1 km from the city of Apatity) was selected as a natural reference (control).



Location	Coordinates
Murmansk	68°58′N 33°04′E
Olenegorsk	68°08′N 33°18′E
PABGI	67°34′N 33°18′E
Apatity	67°33′N 33°22′E
Polyarnye Zori	67°22′N 32°29′E
Kandalaksha	67°09′N 32°25E

Fig. 19.1 Location and view of observation plots

19.2.2 Characteristics of Site

The Oktyabrskaya railway has been operating in the Murmansk region for more than 100 years (Transport 2008). The Murmansk region of service of the Oktyabrskaya railway includes 5 main railway stations (Murmansk, Olenegorsk, Apatity, Polyarnye Zori, Kandalaksha). The largest nodes are located in Murmansk and Apatity; Olenegorsk and Kandalaksha are junction stations with an average traffic load; Polyarnye Zori—with a minimum.

19.2.3 Experimental Species

Middle-aged (40–50 years) plantations of *B. pubescens* growing on the territory of railway stations in 5–10 m from the railway tracks.

19.2.4 Data Collection and Data Analyzes

In August 2018, 2021, the state of *B. pubescens* was evaluated at each site according to the study's methodology, Table 19.1 (Nikolaevskiy and Yakubov 2008).

To determine the pigment fund at the end of the growing season (August) 2018, 2019, 2021 birch leaves were sampled. The content of leaf plastid pigments was determined in alcohol extracts (96%) by optical density at the absorption maxima of chlorophylls *a* and *b*, carotenoids using a UV-1800 spectrophotometer from Shimadzu, Japan at wavelengths $\lambda = 665$, 649, and 470, respectively; all calculations were made for raw samples (Lichtenthaler and Wellburn 1983).

Table 19.1 Description of classes of the tree state

Classes of the tree state	Main signs	Additional signs
Without signs of weakening	The needles are green, dense canopy, the foliage is 100%	
Weakened	The needles are green, up to 25% of dry branches	Local damage to branches, trunk
Middle-weakened	Crown thinning, dry branches 25–50%, the needles are smaller	Local damage to branches, trunk, presence of stem pests
Highly weakened	The crown is very thinned, dry branches 50–75%, the needles are smaller than the previous class	Local damage to branches, trunk, presence of stem pests, water shoots on the trunk and branches
Shrinking	In crown more than 75% dry branches, the needles are small, light yellow, falls off prematurely	The trunk and branches are inhabited by pests and diseases, a partially withered tree
Deadwood	No needles, 100% dry branches	The trunk and branches are affected by pests and fungi

Phytoindication methods are widely used to assess technogenic pollution (Mandra et al. 2019; Neverova 2009). One of these methods is the determination of fluctuating asymmetry (FA) to assess the state of ecosystems (Zakharov 2000). Fluctuating asymmetry is a deviation from ideal bilateral symmetry caused by developmental instability and genetic problems during development under the influence of environmental stress, primarily of anthropogenic origin (Kozlov et al. 1996). The strength of the impact of the stress factor contributes to the deviation of the FA index from the norm (Zorin and Korosov 2007), as a result of which the FA index at the macroscopic level is used to assess the stability of the development of the organism (Zakharov 2001). To assess fluctuating asymmetry, vegetative organs (f. e., leaf lamina) of woody plants are often used.

Birch leaf samples were collected at the end of the growing season in July 2018, 2019, and 2021. For the study, 100 leaves were selected from each site. Measurements of the main leaf parameters (length, width, and area) were performed. To estimate fluctuating asymmetry of leaves set of five biometric traits, which characterize that the stability of leaf formation in ontogenesis was applied (1—the width of the half of the sheet (the measurement was carried out in the middle of the leaf blade; 2—length of the second vein from the base of the leaf of the second order; 3—distance between the bases of the first and second veins of the second order; 4—distance between the ends of these veins; 5—the angle between the main vein and the second vein from the base of the leaf of the second order) (Guidelines for the implementation of quality assessment environment as living beings (stability assessment development of living organisms on the level of asymmetry of morphological structures) 2003). All measurements were carried out manually. The calculation integral index of fluctuating asymmetry of the morphological traits of leaf lamina has been produced using normalized difference algorithm (Zakharov 2000):

Table 19.2 Point scale for assessing the quality of the environment by indicators of a violation of the stability of development

FA index	Environment state	Point
< 0.04	Conditional norm	I
0.04–0.044	Initial, minor deviations from the norm	II
0.045–0.049	Average level of deviations from the norm	III
0.050–0.054	Significant deviations from the norm	IV
> 0.055	Critical state	V

$$FA = \frac{1}{m * n}\sum_{i=1}^{m}\sum_{j=1}^{n}\frac{|(Lij - Rij)|}{|(Lij + Rij)|}$$

where *Lij* and *Rij* are values of the *j*-th character in the *i*-th leaf to the left and right side of the plane symmetry; *m*—number of leaves; $n = 5$ (morphological traits).

A 5-point system was developed to assess the degree of disturbance of plant development stability, Table 19.2 (Zakharov 2000). The FA values corresponding to the first point are observed, as a rule, in a sample of plants from favourable growing conditions. The fifth point characterizes the critical state of the environment when the plants are in a very depressed state.

Mathematical processing of the results was done using standard software packages for statistical calculations (Microsoft Office Excel 2016). The correlation coefficient (r) was calculated by the square method (Pearson's method) for the significance level of 0.05.

19.3 Results and Discussion

Over a three-year observation period tree, health assessment of *B. pubescens* showed its state deterioration in 2021 (Fig. 19.2). In 2018, healthy plants without signs of weakening were found in all cities except Murmansk. Weakened plants prevailed in Apatity (50%) and Olenegorsk (48%). Middle-weakened plants prevailed in Murmansk (57%). The maximum number of deadwoods was found in Kandalaksha (14%).

In 2021, there was a lack of healthy plants in Polyarnye Zori, and vice versa, its appearance in Murmansk (29%). In other cities, this indicator has not changed much. In Apatity, due to the state deterioration of birch, weakened plants were absent, the proportion of highly weakened plants (from 16 to 33%) increased, shrinking plants (17%), and dead wood (17%) appeared. In Kandalaksha, the proportion of middle-weakened plants increased; dead wood was not observed due to its removal. In Olenegorsk, the indicator of middle-weakened plants increased, in the absence of highly weakened ones. Shrinking plants were transformed into dead wood. In Murmansk, despite the appearance of plants without signs of weakening, middle-weakened plants turned into highly weakened ones.

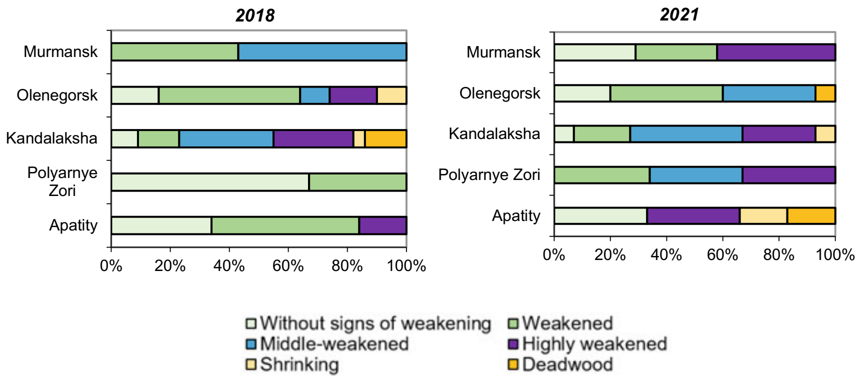


Fig. 19.2 State of *Betula pubescens* in the cities

A high level of chronic air pollution by technogenic emissions has a negative impact on the whole complex of physiological processes in plants, including photosynthesis (Biswal et al. 2011; Vass and Aro 2007). There are several opinions about the effect of anthropogenic pollution on the photosynthetic activity of plants. Some authors point to its suppression under conditions of pollution (Balandaykin 2014; Bukharina et al. 2013). Others, on the contrary, show an increase in the content of green pigments in plant leaves in response to pollution, or the absence of changes (Voskresenskaya et al. 2014; Yashin and Zaitsev 2015). This is due to different types and levels of pollution, with the heterogeneity of environmental conditions of growth and the plant species specificity.

Our research has shown that the content of photosynthetic pigments in birch leaves varied significantly depending on the location and year of the study (Fig. 19.3). In the control plot, the content of chlorophyll *a* was higher than in some cities only in 2018; in all other years, the content was lower. The dynamics of pigment distribution over the years in the forecourt areas differed. In Apatity and Kandalaksha, the content of chlorophyll *a* increased yearly to the maximum values in 2021 was observed. In Polyarnye Zori, this indicator did not change significantly. In Murmansk and Olenegorsk, same dynamics was revealed, while in Murmansk in 2018–2019, content of chlorophyll a was higher than in other locations.

The distribution of the amount of chlorophyll *b* differed from that of chlorophyll *a* (Fig. 19.3). In 2018, the excess chlorophyll *b* content compared to the control was noted in Apatity and Kandalaksha. In other years, this parameter (as well as chlorophyll *a*) in the control was lower than in the railway station areas. In 2021, in all cities, an increase in chlorophyll *b* was detected to the maximum values over a three-year observation period. The amount of chlorophyll *b* was stable in Polyarnye Zori.

Carotenoids perform a protective function, shielding chlorophyll from photooxidation. Therefore, an increase in the content serves as a signal of an unfavourable state of plants. The content of carotenoids significantly correlated with chlorophyll

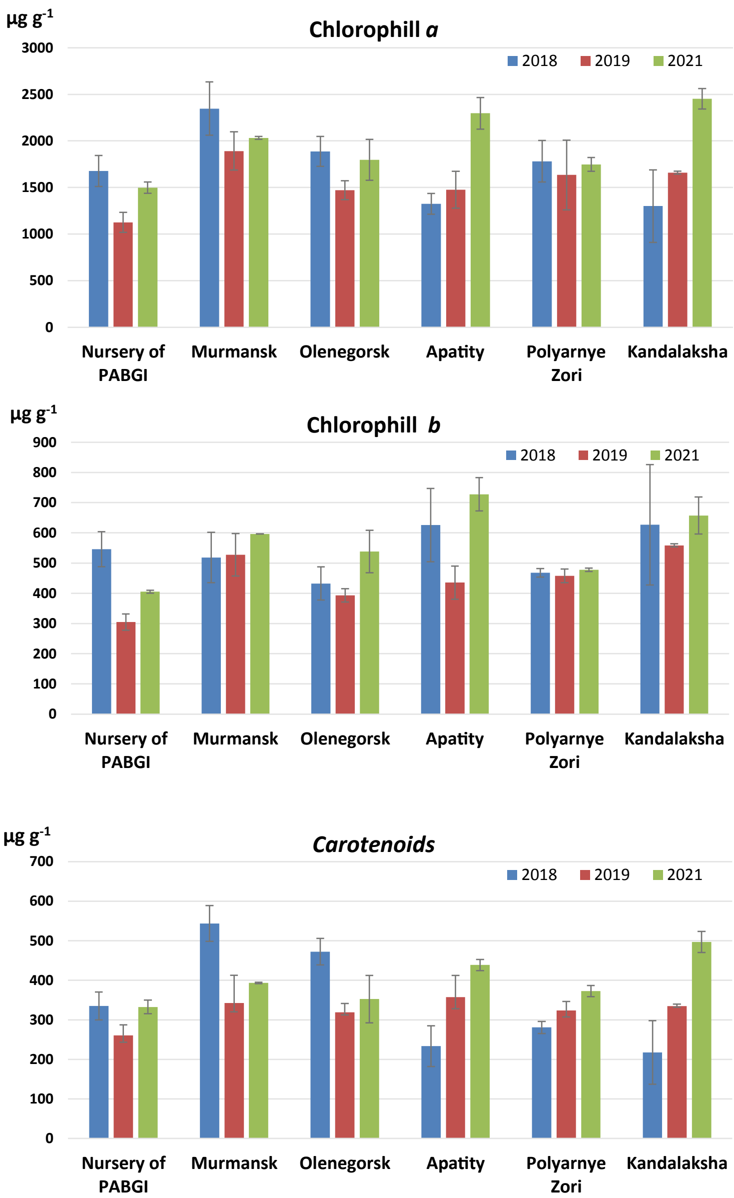


Fig. 19.3 Mean content (µgg^{-1} fresh weight) of chlorophyll *a*, *b*, carotenoids in leaves of *B. pubescens*

a ($r = 0.81$–0.99, except for Polyarnye Zori) and did not correlate with chlorophyll *b* ($r = -0.38$–0.53 ($p < 0.05$), except for control). The content of carotenoids was higher—compared to Apatity, Polyarnye Zori, and Kandalaksha—in the control only in 2018. In 2019, the content of carotenoids in the territories near the railway station did not differ significantly; in 2021, an increase in carotenoids was detected, especially in Apatity and Kandalaksha (what could be a warning sign).

Thus, in the territories near the railway stations, a predominant increase in photosynthetic activity was observed. In some studies, two trends in the change in the content of green pigments under the influence of an urbanized environment have been identified: an increase in resistant plants and a decrease in moderately resistant species (Sarsatskaya 2017). Thus, we can conclude about the stability of *B. pubescens*.

An assessment of the sustainability of birch development based on the FA index in the studied areas with varying degrees of impact of railway transport showed significant differences (Fig. 19.4). During the study period, the most stable FA was found for trees growing in the city of Polyarnye Zori (0.041–0.044), corresponding to a slight deviation from the development norm and indicating low-level environmental pollution. Low variability was also shown in the three-year dynamics of the photosynthetic pigments' content here. In Apatity, the FA index varied slightly compared to other locations, but due to growth in 2021, it corresponded to the average level of deviation from the norm. At the control site in 2018–2019, FA approached critical values, but in 2021, it significantly decreased and reached the conditional norm. In Murmansk and Kandalaksha, FA increased, while in Kandalaksha, it reached a critical level. In Olenegorsk, this parameter dropped sharply in 2021, despite high values in 2018–2019.

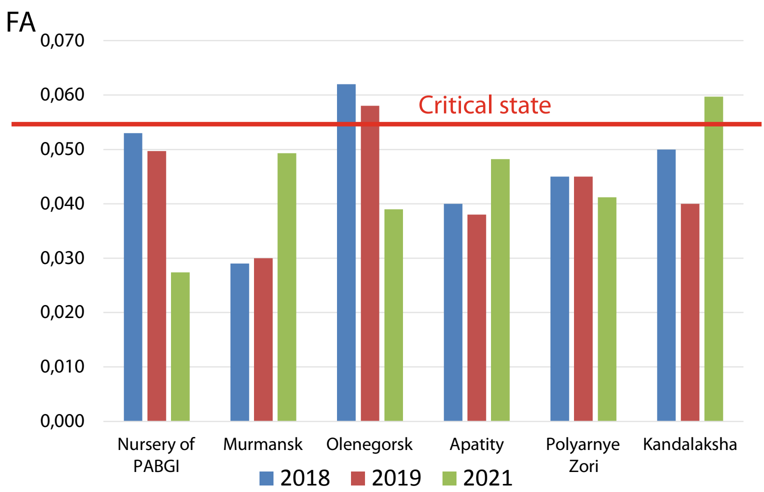


Fig. 19.4 Integral index of fluctuating asymmetry of leaves of *B. pubescens*

Some researchers found that leaf fluctuating asymmetry does not serve as sensitive indicator of environmental stress, because it is influenced by many factors, including weather conditions (Kozlov et al. 2022; Sandner and Matthies 2017).

An assessment of changes in the morphological parameters of the leaf lamina showed that in the period 2018–2019, the minimum values of length, width, and area are typical for birches growing in Olenegorsk and Polyarnye Zori (Table 19.3). In 2021, they grew noticeably, approached the indicators in other cities and even exceeded them in leaf length. As a result, in 2021, the differences in morphological parameters between the plots were insignificant.

The level of changes in the anatomical structure of the assimilation organs of plants depends on the concentration and toxicity of pollutants, on the duration of exposure and also on the sensitivity of the species. Some researchers have shown that in the process of adaptation to negative environmental conditions in plants, leaf parameters can change, both upwards (Sokolova and Tingaeva 2008) and downwards (Bukharina and Dvoeglazova 2010). As our studies have shown, leaf size did not depend on the level of anthropogenic load, but rather associated with the characteristics of the place of growth (weather conditions, soil conditions, etc.)

The correlation analysis of all the studied parameters of *B. pubescens* leaves demonstrated the heterogeneity of the obtained dependences. Trees growing in

Table 19.3 Dynamics of leaf morphological parameters of *B. pubescens* in 2018–2021

Place of selection	Year	Leaf length, cm	Leaf width, cm	Leaf area, cm^2
Murmansk	2018	6.06 ± 0.12	4.52 ± 0.08	17.39 ± 0.61
	2019	6.20 ± 0.11	5.04 ± 0.13	18.51 ± 0.86
	2021	5.53 ± 0.10	4.54 ± 0.09	17.33 ± 0.48
Olenegorsk	2018	**4.45 ± 0.15**	**3.69 ± 0.09**	**11.05 ± 0.63**
	2019	**4.41 ± 0.09**	**3.29 ± 0.06**	**8.18 ± 0.29**
	2021	6.09 ± 0.17	4.23 ± 0.14	16.65 ± 0.36
Apatity	2018	5.91 ± 0.13	5.08 ± 0.14	21.59 ± 0.98
	2019	5.47 ± 0.19	5.06 ± 0.16	18.49 ± 1.10
	2021	5.23 ± 0.14	4.46 ± 0.14	16.03 ± 0.86
Polyarnye Zori	2018	**4.53 ± 0.09**	**3.46 ± 0.08**	**10.71 ± 0.48**
	2019	**4.18 ± 0.08**	**3.44 ± 0.09**	**9.19 ± 0.38**
	2021	5.49 ± 0.01	4.42 ± 0.09	14.32 ± 0.61
Kandalaksha	2018	5.90 ± 0.13	4.97 ± 0.06	20.52 ± 0.46
	2019	6.10 ± 0.10	4.63 ± 0.10	16.60 ± 0.55
	2021	5.54 ± 0.10	4.13 ± 0.07	14.88 ± 0.49
The tree nursery PABGI	2018	6.03 ± 0.25	5.14 ± 0.26	20.86 ± 1.66
	2019	5.52 ± 0.17	4.21 ± 0.13	14.04 ± 0.76
	2021	6.01 ± 0.23	4.59 ± 0.17	16.44 ± 0.89

Low values are in bold

Olenegorsk and Polyarnye Zori have similar functional relationships: an FA index with morphological parameters and chlorophyll *b* content (high significant negative correlation coefficients), and accordingly, high significant positive coefficients between the length, width, and area of the leaf plate and the amount of chlorophyll *b*. In the control plot, significant positive relationships were obtained between the content of photosynthetic pigments (to a lesser extent, carotenoids) and morphometric features; that is, the content of pigments increased in proportion to the leaf size.

In Apatity and Kandalaksha, the distribution of correlation coefficients was similar to the previous locations in terms of the ratio of FA to metric indicators. The difference was a high negative correlation between the content of chlorophyll *a* and leaf parameters. A positive dependence of the FA index on chlorophyll *b* was obtained, and in Apatity, there was a positive dependence also on chlorophyll *a*. Thus, for these areas, the synthesis of the main chlorophyll *a* increased with a decrease in the leaf lamina. No significant patterns were found in Murmansk, except for single high correlation coefficients.

Thus, the pollution level caused by rail transport did not significantly affect the studied parameters. It can be stated that in most cities, the FA index negatively correlates with the size of morphological features leaves (length, width, and area) (Table 19.4).

Thus, the conducted studies have shown that the native species (*B. pubescens)* was resistant to the impact of railway transport. The dynamics of changes in the parameters of the birch was not related to the activities of the railway transport. Thus, in birches growing in Murmansk (the highest traffic load), no deviations in development were revealed based on the FA index, leaf size varied slightly over the study period. According to the state of plants, two different qualitative transitions were noted: the appearance of healthy plants and highly weakened ones. The content of photosynthetic pigments showed no significant dynamics, except for carotenoids, which decreased compared to 2018. While the content of carotenoids increased in Apatity and Kandalaksha, the FA index also increased. Railway services were advised to pay attention to this. The birches growing in Polyarnye Zori had the lowest variability of the studied parameters, with the exception of morphological parameters.

19.4 Conclusion

Monitoring the state of *B. pubescens* for the observation period 2018–2021 showed that the proportion of healthy plants remained almost unchanged at the railway stations of Apatity (33–34%), Olenegorsk (16–20%), and Kandalaksha (7–9%). At the same time, dramatic changes took place in Polyarnye Zori and Murmansk. In Murmansk, an increase in the number of healthy plants (up to 25%) was noted, whereas in Polyarnye Zori, deterioration in the state of this species was revealed (this category is absent), which is associated with sanitary care for plantings (timely

Table 19.4 Correlation coefficients between studied parameters in leaves of *B. pubescens*

Parameter	FA	Chlorophill *a*	Chlorophill *b*	Carotenoids
Murmansk				
Leaf length	**−0.97**	0.02	**−0.95**	0.08
Leaf width	−0.43	−0.76	−0.37	−0.72
Leaf area	−0.50	−0.71	−0.44	−0.66
FA index	1.00	−0.26	**1.00**	−0.32
Olenegorsk				
Leaf length	**−0.98**	0.33	**0.97**	−0.29
Leaf width	**−0.82**	0.68	**0.99**	0.12
Leaf area	**−0.88**	0.61	**1.00**	0.02
FA index	1.00	−0.15	**−0.91**	0.46
Apatity				
Leaf length	−0.64	**−0.85**	−0.18	−1.00
Leaf width	**−0.98**	**−0.99**	−0.75	−1.00
Leaf area	−0.71	**−0.90**	−0.28	−1.00
FA index	1	**0.95**	**0.87**	0.68
Polyarnye Zori				
Leaf length	**−0.97**	0.53	**0.97**	0.73
Leaf width	**−1.00**	0.31	**0.87**	**0.88**
Leaf area	**−0.96**	0.55	**0.97**	0.71
FA index	1.00	−0.29	**−0.87**	**−0.88**
Kandalaksha				
Leaf length	**−0.99**	−0.78	**−0.93**	**−0.70**
Leaf width	−0.58	**−0.99**	−0.40	**−1.00**
Leaf area	−0.29	**−0.91**	−0.09	**−0.95**
FA index	1.00	0.67	**0.98**	0.57
The tree nursery of PABGI				
Leaf length	−0.36	**0.96**	**0.83**	**1.00**
Leaf width	0.22	**0.95**	**1.00**	0.83
Leaf area	0.28	**0.93**	**1.00**	0.79
FA index	1.00	−0.08	0.21	−0.37

Note Correlation coefficients were shown in bold for the significance level of 0.05

in Murmansk and absent in Polyarnye Zori). The determination of photosynthetic pigments in the leaves of *B. pubescens* in areas near railway stations revealed a predominant increase in photosynthetic activity not associated with the level of the anthropogenic load caused by railway transport activity. An assessment of changes in the stability of plant development using the FA index revealed that the largest deviations from the norm were observed in Olenegorsk in 2018–2019 (FA = 0.058–0.062) and Kandalaksha in 2021 (FA = 0.060). In 2018–2019 in control, this parameter was relatively high, close to critical. It has showed that the FA index in plants is quite variable, with the exception of trees growing in the city of Polyarnye Zori. An analysis of the dynamics of the morphological parameters of the leaf lamina of *B. pubescens* showed that the minimum values were noted in Olenegorsk and Polyarnye Zori in 2018–2019. In 2021, the differences between locations decreased due to an increase in leaf size in the cities. The correlation analysis of all studied parameters of *B. pubescens* leaves showed photosynthetic pigments' significant positive dependence on leaf size in the control; in Olenegorsk and Polyarnye Zori, high correlation coefficients were obtained only for chlorophyll *b*. In Apatity and Kandalaksha, these indicators correlated negatively. A general trend for most cities is the negative dependence of the FA index on the size of morphological features. In general, the native species *B. pubescens* is stable in these environmental conditions of growth and can be recommended as landscaping objects for railway stations.

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Chapter 20
Ecological Revitalization Master Plan of Lipetsk City Based on the HBV Hydrological Modelling of a Small Ungauged Lipovka River (Russia)

Pavel Terskii, Anatoly Tsyplenkov, Artem Gurinov, Anna Antoniuk, Igor Shchukin, and Aleksey Sayanov

Abstract Water discharge fluctuations in ungauged rivers, especially in the face of climate change and urban sprawl, can be dangerous and destructive. The water discharge dynamics of small urban rivers are highly variable and complex. Understanding these dynamics and their underlying causes is necessary for public awareness. Our work is focused on the small ungauged river Lipovka (Lipetsk, Russia). It has a 50.1 km^2 urbanized watershed with an outlet in Komsomolsky Pond in Lipetsk's city center. We used several independent methods to study the hydrological regime of the Lipovka River. Based on in-situ measurements in spring 2022, we estimate the water discharge with a 1% annual exceedance probability according to the regulatory document SP 33-101-2003. Furthermore, we used data from the Lipetsk meteostation to run a Hydrologiska Byråns Vattenbalansavdelning model (HBV) to simulate a daily hydrograph for the 2005–2022 period. We found that the reduced runoff of the Lipovka River was mainly caused by a decline in the effective catchment area, a littered channel, and increased evaporation and filtration into the groundwater. To reestablish the river's natural flow and catchment area, we propose constructing and maintaining a culvert to enable upstream feeding of the Lipovka River by Syrsky Pond. In the context of smart urbanization, our study can be used to design and revitalize small urban rivers that form a crucial component of a city's water-green framework.

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20.1 Introduction

The biodiversity and quality of water bodies are negatively affected by human-induced landscape changes, nutrient cycling regulation, water purification, and waste treatment (Malhotra et al. 2020; Guo et al. 2022; Pastor et al. 2022). Several techniques, including hydrological stabilization, water filtration, and biodiversity restoration, have been developed to improve the quality of urban rivers (Primo et al. 2022). However, restoration and revitalization cannot be conducted without studying the hydrological regime of a river (Muhar et al. 2018).

The water discharge dynamics of small, urban rivers can be highly variable and complex (Taylor and Owens 2009; Sokolov et al. 2021). Understanding these dynamics and their underlying causes is essential for our awareness of streamflow fluctuations in ungauged basins, especially in the face of climate change and intensified urbanization (Gurnell et al. 2007). Modern Russian regulatory documents (e.g., SP (Handbook) 33-101-2003) on river discharge calculations and their probability analyses are based on regional empirical relationships built for Soviet streamflow data, as presented in SNiP (Construction Rules and Regulations) 2.01.14-83 (Ayzel et al. 2020). Thus, the methodology for estimating streamflow characteristics has not been updated for almost 40 years, raising numerous questions regarding its applicability to contemporary cases (Makarieva et al. 2017; Klimenko and Kharlamova 2019). Therefore, developing and applying alternative methods for streamflow assessment is important, especially for ungauged basins (Nesterova et al. 2019). Although hydrological modelling could tackle this research gap (Pool et al. 2017), streamflow predictions in data-sparse regions remain challenging (Hrachowitz et al. 2013). However, the development of global parameter maps, i.e., hydrologic parameter regionalization (e.g., Beck et al. 2020), could significantly improve the model accuracy by transferring data from data-rich regions (Ma et al. 2021).

In recent decades, the use of hydrological models has grown dramatically, and today, they are standard tools for an increasing number of applications. The Hydrologiska Byråns Vattenbalansavdelning (HBV) model follows this trend (Bergström 1992; Lindström et al. 1997). There are many applications that cover hydrological forecasting, spillway design, studies of the effects of climate change, synoptic water balance mapping, and simulations of groundwater response. (Hundecha and Bárdossy 2004; Shrestha and Solomatine 2008; Thielen et al. 2009; Bergström and Lindström 2015).

The goal of our study was to develop an ecological revitalization strategy for the Lipovka River and Komsomolsky Pond, located at the outlet (Lipetsk, Central Russia). We aimed to determine the flooding stages in Komsomolsky Pond with various annual exceedance probabilities (AEP), considering the anthropogenically disturbed watershed and climate change. The results of the hydrological assessment served as a background for the Lipovka River eco-revitalization master plan. Water budget estimation was used to calculate the water inflow to Komsomolsky Pond during the low-water periods.

20.2 Study Area

The small Lipovka River runs through the city of Lipetsk (Fig. 20.1). It is a right tributary of the Voronezh River (a part of the Don River basin). Lipovka is a 3-km-long river, and the total catchment area is 51 km^2 in the outlet of Komsomolsky Pond. Downstream, the Komsomolsky Pond Lipovka flows along Skorokhodova Street in an artificial canal created by the Lipetsk ironworks as a bypass along this section of the river at the beginning of the eighteenth century. At present, the Lipetsk springs have dried up, and water intermittently disappears in the source owing to the intensive water removal of the Zadonsk-Yelets horizon. The Lipovka River has a channel of about 6–15 m in width and 0.2–0.3 m in depth (Anichkina et al. 2017).

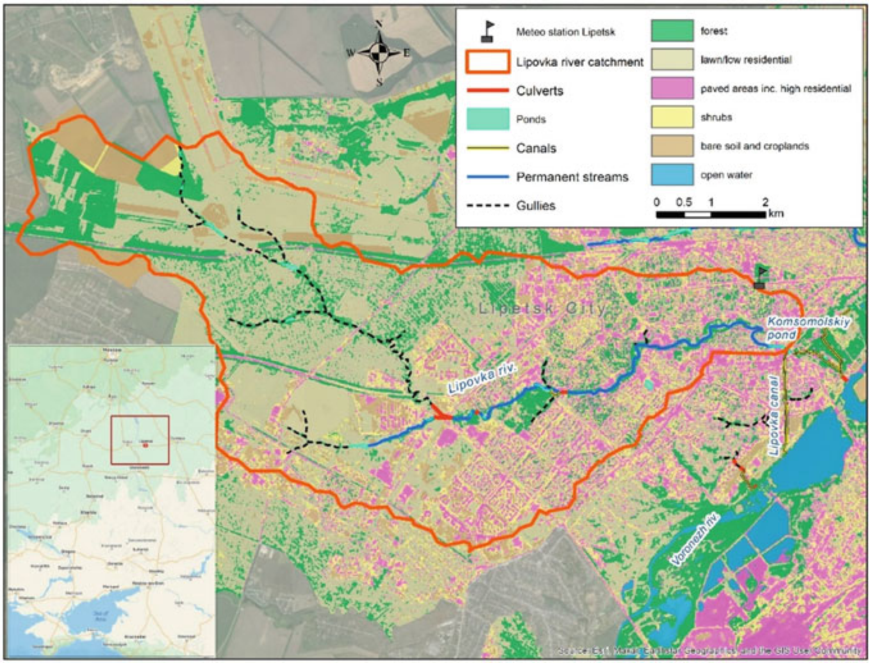

Fig. 20.1 The land use/land cover (LULC) map of the Lipovka River basin based on Sentinel-2 satellite image classification

20.2.1 Landscape Setting

The central part of Lipetsk is located on the right bank of the Voronezh River at the confluence of the Studenovka and Lipovka Rivers. The small valleys of the Voronezh tributaries and gullies are deeply incised into the interfluves, thus forming the natural boundaries of the city's historic center. The city lies at the edge of two major geomorphological domains: the Oksko-Donskaya Lowland and the Srednerusskaya Upland. The two main complexes of forms represent the topography of the city territory. The first is the glacial and fluvioglacial landforms of the interfluves formed during the Middle Pleistocene glaciation, which were further transformed by erosion, mass movement, and karst processes. The second is the fluvial landforms presented by the Voronezh River valley, its tributary valleys (Lipovka and Studenovka Rivers), and small erosional landforms (gullies, arroyos, and dry washes).

On the Lipovka River valley slopes, there are massive rock outcrops of Devonian limestone up to 15 m in height, which are of natural and cultural heritage value. However, locals often use gullies and small valleys as unauthorized storage sites for construction and domestic waste. Thus, small erosional landform slopes and bottoms are heavily littered, significantly affecting the hydrological connectivity of the Lipovka basin.

The land cover map (see Fig. 20.1) was constructed using Sentinel-2 maximum likelihood classification. The Lipetsk city land cover is mainly residential. Most paved lands are situated in factory territories and modern residential districts. There are some areas with destroyed and sliced soil layers in the northern part of the city. The forested areas are situated in the upper third of the Lipovka catchment and city center.

20.2.2 Hydrometeorological Setting

The climate of Lipetsk is temperate continental with warm summers and moderately cold winters. The mean January (the coldest month) air temperature is −8.6 °C. The snow–water equivalent can exceed 100 mm. Annual precipitation sums area 480–500 mm, evapotranspiration ranges from 350 to 370 mm, and the potential evapotranspiration is 570–580 mm. Precipitation varies from season to season, with the lowest amounts in winter, with a minimum in February of 20–25 mm. Monthly and daily maxima occur in June and July, and can exceed 50–100 mm, caused by heavy rainfall.

Rivers in the Lipetsk region are mainly snow-fed, have a pronounced spring freshet, and have an Eastern-European hydrological regime. Such hydrological regimes are characterized by pronounced spring snowmelt freshets, summer–winter low-water periods, and rain floods during summer and autumn. The period of the frozen rivers is approximately 120–130 days in winter. Ice cover usually cracks at the end of March. Small rivers have rapid snow-fed freshets because of compact catchments, developed gullies, and relatively narrow floodplains.

The Lipetsk city water bodies include rivers, streams, gullies (with temporary runoff), and artificial water bodies, such as ponds, canals, culverts, and reservoirs. Natural surface runoff in city areas has been transformed substantially through the construction of buildings, road infrastructure, and land reclamation. The catchment area was strongly modified by deforestation; almost all forests were removed, except for several parks upstream and within the floodplain along the streams. Several streams were buried underground in pipes to serve as drainage arteries in the city's sewer system, whereas others were filled by ground. In the lower reach, after Komsomolsky Pond, the Lipovka River is a channelized stream discharging into the Voronezh River 1.5 km downstream from its natural mouth.

In this study, we examined the Lipovka River along its entire watercourse, with the most downstream point in Komsomolsky Pond. It was built in the middle of the eighteenth century to meet factory needs. Historically, ponds have been filled with water from the Voronezh River through a system of pumps and channels. Reconstruction work has now taken place at Komsomolsky Pond: treatment facilities have been rebuilt, new locks have been installed to regulate the water level, new fountains have been installed, and a pipeline has been laid along the bottom of the reservoir.

20.3 Materials and Methods

20.3.1 Field Surveys

The field survey was conducted in April 2022. During the field survey in April 2022, we examined the entire river valley and channel, particularly the ecological conditions in the control cross-sections. Topographic surveys were conducted by using a DGPS receiver (EFT M2). Accurate measurements of the reference points of the water surface and valley landforms (shoulder and footslope breakpoints of the channel, floodplain, terraces, etc.) were performed to obtain a longitudinal water surface profile and cross-sectional elevation profiles. Water discharge measurements were performed using the floating method (John et al. 1978). The water temperature and conductivity were measured using a YSI Pro1030 portable probe at 32 control points.

20.3.2 Water Discharge Assessment (Regulatory Documents)

The freshet water discharge ($Q_{1\%}^{\mathrm{freshet}}$) with a 1% AEP was estimated using the so-called reduction equation according to SP 33-101-2003. The maximum water discharge was calculated as follows:

$$Q_{1\%}^{\text{freshet}} = \frac{K_0 h_{1\%} \mu_{1\%} A}{(A+c)^n} \delta \delta_1 \delta_2, \tag{20.1}$$

where $h_{1\%}$ is a specific water discharge with a 1% AEP, mm; A is a catchment area, km^2; K_0 is freshet coefficient; n is a regional reduction coefficient set to 0.25; c is a regional declining reduction coefficient describing the reduction decline in a small sub-basin, set to 2; δ, δ_1, δ_2—area empirical coefficients describing the basin lake cover, forest cover, and wetland cover.

We used the so-called equation of peak intensity from SP 33-101-2003 to estimate rain flood water discharge with a 1% AEP ($Q_{1\%}^{\text{rain}}$). This equation also uses several empirical coefficients when the overall formula is:

$$Q_{1\%}^{\text{rain}} = q_{1\%} \varphi H_{1\%} \delta A, \tag{20.2}$$

where $q_{1\%}$ is a relative maximum specific water discharge; φ is the empirical streamflow coefficient; $H_{1\%}$ is a maximum daily rainfall amount, mm; A is a catchment area, km^2. The $q_{1\%}$ and $H_{1\%}$ were taken from eponymous maps (Kopilov 1986).

20.3.3 Water Discharge Modelling

The HBV is a lumped conceptual catchment model (Lindström et al. 1997) that has relatively few model parameters (see Table 20.1) and minimal forcing input requirements—daily air temperature (T), precipitation (P), and potential evapotranspiration (PET). A daily time step was used in the model, which had an unsaturated zone store, two groundwater stores, and 15 parameters that could be calibrated (see Table 20.1). We selected the HBV model because it is low in complexity, agile, and computationally efficient (Beck et al. 2020).

Meteorological data (T and P) for the 2005–2022 period was taken from the Lipetsk meteostation (WMO code 27,930) located 9 km north of Komsomolsky Pond (i.e., study outlet). The daily air temperature, precipitation, and snow depth data were obtained from 2005 to 2022 (https://www.rp5.ru). Daily PET was calculated using the Oudin equation (Oudin et al. 2005) for a latitude of 52.5°, based on the daily station air temperature (T). Because the Lipovka River is ungauged, we could not use water discharge data to calibrate the free parameters. Therefore, we used the HBV global parameter maps created by Beck et al. (2020). In their dataset, ten alternative sets (folds) of parameters exist for every 0.05° cell. We ran all scenarios to study the water discharge variability (Fig. 20.2).

The final parameter set (Table 20.1) was manually chosen based on measured water discharges in 2022 and by comparing simulated and published water yield regional means (Kopilov 1986). Snowmelt runoff was calibrated by comparing the simulated snow water equivalent (SWE) accumulation and measured snow depth at Lipetsk meteostation (cf. Fig. 20.1 for location). Model performance was measured

Table 20.1 HBV model parameters were calibrated for the Lipovka River (2005–2022)

Parameter	Description	Process	Unit	Adjusted value
TT	Temperature threshold determining snowfall or rainfall, and melt or refreezing	Precipitation/melt/refreeze	°C	0.1
CFMAX	Degree-day factor of snow melt and refreezing	Melt/refreeze	mm $°C^{-1}$ day^{-1}	6.4
SFCF	Snowfall correction factor	Snowfall	—	0.55
SP	Seasonal variability of degree-day factor	Melt/refreeze	—	0.9
CFR	Coefficient of refreezing of melted snow	Refreeze	—	0.05
CWH	Maximum water-holding content of the snowpack	Excess flow	—	0.1
FC	Maximum soil moisture storage	Infiltration/recharge	mm	360
LP	Soil moisture value above which Ea reaches Ep (wilting point)	Evaporation	—	0.9
BETA	Nonlinearity coefficient of upper zone recharge	Infiltration/recharge	—	3.7
K_0	Runoff coefficient for quick flow (from the upper zone)	Quick flow	1 day^{-1}	0.1
K_1	Runoff coefficient for normal flow (from the upper zone)	Normal flow	1 day^{-1}	0.1
K_2	Runoff coefficient for base flow (from the lower zone)	Base flow	1 day^{-1}	0.25
UZL	The threshold for quick flow	Quick flow	mm	60.9
PERC	The maximum rate of percolation to the lower zone	Percolation	mm day^{-1}	0.5
MAXBAS	Flow routing delay	Routing	day	2

using the Nash–Sutcliffe coefficient (NSE; Nash and Sutcliffe 1970) and coefficient of determination (R^2).

20.3.4 Flood Stage Estimation

The highest water stage of a certain AEP for the free-of-ice conditions for each cross-section was calculated based on the maximum discharge of the relevant AEP and stage–discharge curve, which was constructed considering the hydraulic and morphometric properties of the channel and floodplain. The maximum capacity of the channel in each design segment is computed using the curve.

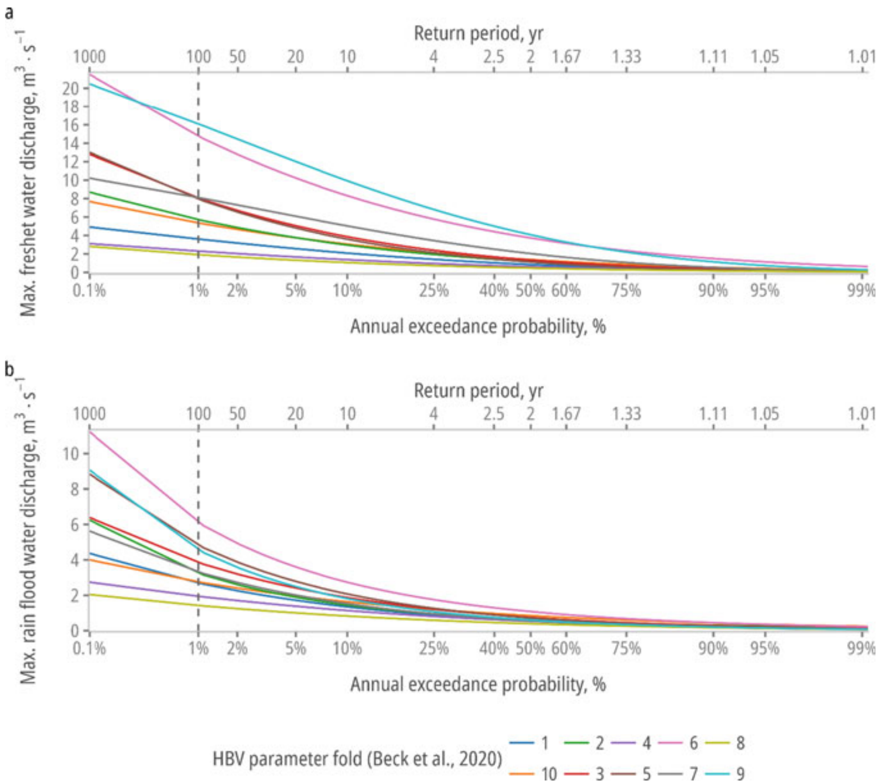

Fig. 20.2 Water discharge variability in HBV modelling according to various parameter sets for freshet (**a**) and rain (**b**) floods

Hydraulic radius, width, and cross-sectional area were calculated based on the water level. Subsequently, the Chézy–Manning formula (Chanson 2004) was used to obtain the average velocity in the section for each piece of the channel cross-section. As a result, the stage–discharge curve was estimated for each cross-section.

20.4 Results

20.4.1 Field Surveys

The Lipovka River watershed area is 50.1 km^2 (with an outlet in Komsomolsky Pond). It has only one tributary on the left, with a watershed area of 21.4 km^2. The catchment of the unnamed river is fully developed, and streamflow is regulated. During the field survey in April 2022, no streamflow was observed. Before the conflux, the streamflow of Lipovka was also regulated by Syrsky Pond. Therefore, we hypothesized that the effective catchment area begins only after confluence (A = 22.6 km^2).

The measured discharges in April 2022 were approximately 5–10 l s^{-1} at the beginning of the river directly downstream of Syrsky Pond, 80–100 l s^{-1} in the middle, 180–200 in the Kamenny Log, 250–270 l s^{-1} through the Komsomolsky Pond, and 320–350 l s^{-1} in the outlet of the Lipovka Canal running into the Voronezh River.

20.4.2 Regulatory Documents

The study area's rivers belong to the watercourses group with an indicator of the expected annual specific water discharge of 3.8 l s^{-1} km^2. The regional mean annual water discharge of Lipovka watershed (Kopilov 1986) should be 190 l s^{-1} for the entire catchment and *ca.* 90 l s^{-1} for the lower part of the catchment.

According to the reduction equation (Eq. 20.1), the maximum freshet water discharges with a 1% AEP is 520 l s^{-1} for the effective catchment (A = 22.6 km^2) and 1311 l s^{-1} for the whole area (A = 50.1 km^2). Equation 20.2 suggests that the maximum rain flood discharges with a 1% AEP should be 570 l s^{-1} and 910 l s^{-1}, respectively.

20.4.3 Hydrological Modelling

The run of tenfold parameter sets from the 2020th study (Beck et al. 2020) for the whole catchment area suggested that the mean annual freshet discharge with a 1% AEP varied from 1939 to 15 095 l s^{-1} with a mean of 6927 l s^{-1} (see Fig. 20.2). The rain flood discharges were significantly lower, ranging from 1514 to 5648 l s^{-1} with a mean of 3379 l s^{-1} (1% AEP). It should be noted that these results correspond to an uncalibrated model and serve only descriptive needs.

The HBV model was calibrated based on the regional surface/ground runoff relationship and snow water equivalent (NSE = 0.86, R^2 = 0.90). This allowed us to adapt the 8th CV-fold (from Beck et al. 2020) for local conditions. Therefore, in the case of the gauging station's absence, we decided that the HBV model represents snow melting runoff satisfactorily and generally corresponds to measured discharges (see Sect. 4.1). The simulated streamflow and snow cover time series (compared to the observed snow cover values) are shown in Fig. 20.3; Table 20.2.

Simulated mean annual hydrograph is shown on the Fig. 20.4. The mean annual specific water discharge for the inlet to Komsomolsky Pond was 104 mm during 2005–2021, whereas the mean annual precipitation was 540 mm. The average inflow into Pond is 6200 m^3 from mid-March to early April. The annual inflow into Pond is 22,000 m^3. Calculated using the Oudin method, 10.9 m^3 of water evaporates annually. The computation of the maximum levels of the pond was based on fieldwork of the

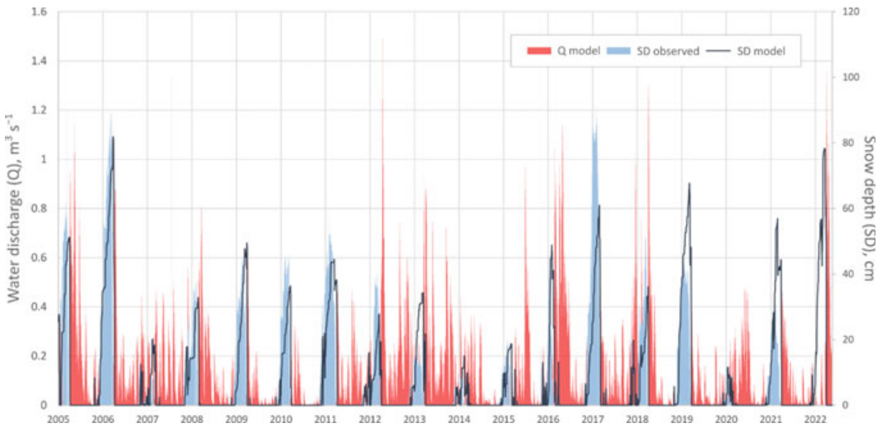

Fig. 20.3 Simulated water discharge (Q, $m^3\ s^{-1}$) and snow depth (SD, cm) time series for the Lipovka River for 2005–2022. The observed snow depth is indicated by blue bars

Table 20.2 Long-term water budget components of the Lipovka River catchment for 2005–2022

Runoff characteristic	Units	Value
Annual total runoff	mm	105
Annual precipitation	mm	483
Annual Evapotranspiration	mm	365
Annual Potential Evapotranspiration	mm	581
Snowmelt (freshet) runoff	mm	16
Rainwater runoff	mm	89
Surface runoff	%	39
Lateral, soil, and groundwater runoff	%	61
Mean maximum freshet water discharge	$m^3\ s^{-1}$	0.91
Mean maximum rain flood water discharge	$m^3\ s^{-1}$	0.63
Maximum freshet water discharge	$m^3\ s^{-1}$	1.50
Maximum rain flood water discharge	$m^3\ s^{-1}$	0.97

locks located in the southern part of the pond. The water level at which overflow occurred through the locks was taken as 110.12 m a.s.l. The discharge overflowing through the walls of the locks will be 0.3 $m^3\ s^{-1}$, provided that the water stage increases by 0.1 m.

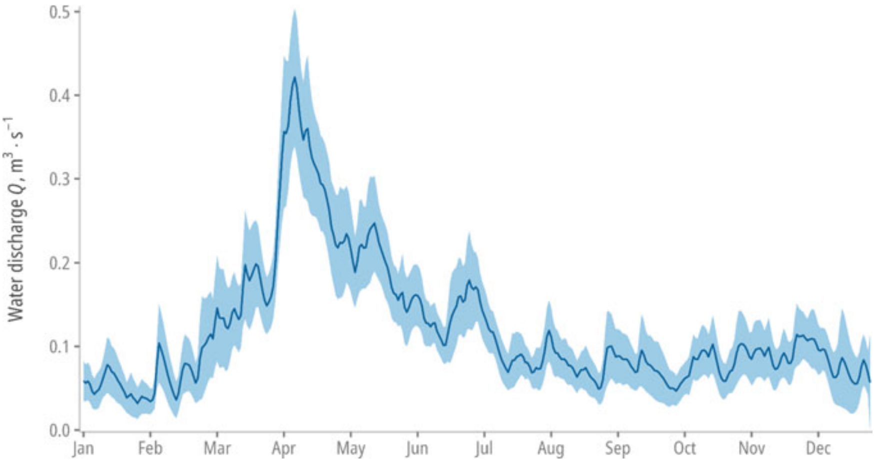

Fig. 20.4 The mean daily water discharge (Q, m^3 s^{-1}) at the inlet at Komsomolsky Pond. The colored shaded areas represent the range corresponding to ± SE. The mean values and standard errors were estimated using the HBV model for 2005–2022

20.4.4 Komsomolsky Pond Water Stages

At an average water stage of 110.12 m, the pond had a volume of approximately 22 000 m^3. This volume is filled in 4–6 days during low-water periods with a water discharge *of ca.* 50 l s^{-1}. The daily inflow volume reaches six pond volumes during extreme floods, with a daily discharge of approximately 1.5 m^3 s^{-1}, as opposed to the ordinary flood of 500 l s^{-1}. In any case, floods completely pass through Komsomolsky Pond. Approximately 8 m^3 s^{-1} is the gate opening's maximum capacity (*ca.* 700,000 m^3 day^{-1}).

According to the calculated water discharge curves, the Lipovka Canal could pass a short-term flood with a discharge of up to 9 m^3 s^{-1}. The hazard of water spilling over the Lipovka Canal edges arises in the event of a lengthy rain flood or spring flood owing to the filling of the channel network and inflow from the surrounding areas below Komsomolsky Pond. It is advisable to create a pond water-level management system to avoid floodplain inundation.

20.5 Discussion

20.5.1 Water Balance

The long-term maximum water discharge calculated based on regulatory documents (SP) and the HBV model are as follows: Spring freshet (mainly snowmelt) discharges with a 1% annual exceedance probability are 1.5 (HBV) and 1.31 (SP) $m^3\ s^{-1}$, while rain flood discharges are 0.97 (HBV) and 0.91 (SP) $m^3\ s^{-1}$. Global parameter maps for the HBV model showed highly diverse results in both hydrograph estimation and water balance, especially in low AEP discharges (Fig. 20.3). However, calibrating the model with SWE significantly improved its prediction power.

Applying the HBV model to several small Swedish catchments, Seibert and Beven (2009) showed that even a few field measurements can effectively constrain prediction uncertainties. In the case of the Lipovka River, hydrological modelling was the only method used for hydrograph reconstruction. Even with several discharge measurements, it was possible to set up the HBV model and obtain relatively reliable water balance results.

At the same time, there are many unaccounted local factors that reduce reliability and bring uncertainties to the discharge calculation results. These factors are mainly culverts, small dams across the riverbed, sewers, and clutter of the river valley. The maximum spring freshet discharges and rainwater discharges of the Lipovka River are of the same order. However, daily snowmelt discharge is usually higher owing to the daily time step in the modelling. Heavy rain causes short-term floods that might be much higher than daily discharges because high-intensity rains usually have one–two hours peak amount, and the actual maximum short runoff peak cannot be modelled with daily time step.

The regulatory document approach (SP 33-101-2003) was based on regional and outdated relationships (Ayzel et al. 2020). Therefore, without gauged analog rivers, the approach cannot account for both local synoptic situations (rainfall and temperature) and particular catchment features, such as ground and surface water interaction and anthropogenic disturbance of the river valley. Modelling, on the contrary, may address these features by adjusting the parameters.

20.5.2 Ecological Revitalization Master Plan

Komsomolsky Pond is one of the critical components of the hydrological balance of the Lipovka River. It is situated in the city center and acts as a barrier between surface runoff from the city's central area and water from the upstream Lipovka. The pond is continuously filled in the summer with water from the Voronezh River. Maintaining an average water level in the pond, releasing the minimum sanitary discharge into the Lipovka Canal, removing sediments and pollutants delivered by the river from the upstream, and flood protection for the downstream surrounding areas are the requirements of the pond water balance management system.

Even though the pond only has a small capacity and primarily serves as a transit container during floods, it is nevertheless crucial to be ready for them to avoid the lengthy discharge of water into the Lipovka Canal. Shield gates control the pond's water level and the amount of water that drains into the Lipovka Canal, preventing floods. On the other hand, efficient congestion management can optimize the water consumption from the Voronezh River and reduce the electricity costs of pumping.

It is advisable to develop and install an automatic system to regulate streamflow to control the water stage in the Komsomolsky Pond and to provide consistent runoff into the Lipovka River's artificial channel (canal) downstream of the Komsomolsky Pond. Figure 20.5 illustrates an example of the calculated water levels in Komsomolsky pond during the operation of the automatic level maintenance system.

These levels are maintained by managing the water pumps at the water intake station of the Voronezh River. The shield gates are located at the outlet of the pond. Shield gates are remotely and automatically controlled in response to signals from water-level sensors. The automatic level maintenance system uses the following algorithm. Existing pumps fill the pond with water from the Voronezh River until it reaches its highest water level (Lv. 1), at which point they are shut off. Through the shield gate, water runs continuously from the pond downstream into the canal.

Fig. 20.5 Water stages of Komsomolsky pond while the automatic level maintenance system operates. Lv. 1 represents the highest calculated water level in the pond (turning off the pump), Lv. 2 represents the lower calculated water level in the pond (turning on the pump), Lv. 3 illustrates the level at which the shield gate opens, Lv. 4 represents the water level with an unfavorable precipitation forecast, and Lv. 5 represents the stable water level with the mean annual discharge

The pumps are turned on when the water level reaches a lower calculated level (Lv. 2), and remain on until Lv. 1 is reached. When a lot of rain and water from the Lipovka River entered the pond, the water level increased to Lv. 3. The shield gate was opened slightly to allow the water to flow smoothly into the canal. The shield gate closes when Lv.1 is reached.

To avoid inundation downstream of Komsomolsky pond, it is advisable to perform a preliminary lowering of the water level in the pond in case of considerable precipitation. To do this, the shield gate is gently opened, and the water level is lowered to Lv.4 when warnings about the probability of extremely heavy precipitation are received from meteorological services or the Ministry of Emergency Situations. As a result, the Komsomolsky Pond water level is automatically controlled, and the overflow into the Lipovka Canal is managed to prevent flooding of the city's residential districts. To perform water purification through the Lipovka River downstream and Komsomolsky Pond, it is recommended to settle aquatic plants in gabion structures for biofiltration against organic and mineral pollutants, as well as for decorative purposes. With the help of gabion structures filled with substrate, plants can be settled at certain artificial heights (cf. Figure 20.6). Aquatic planting zones in Komsomolsky Pond should be close to the stormwater sewer points. Another local biofiltration treatment facility should be constructed directly opposite to the stormwater sewers.

Gabion structures similar to aquatic plants can be placed at the lower Lipovka Canal, where a series of complex landscaping and shoreline reconstruction projects are planned. Biofiltration zones installed along the canal are frequently at a stable minimum permanent water level. Recreational zones along the river are designed to not be inundated at a water stage with a 10% AEP and are constructed of water-invulnerable materials (stones, gabions, and composite boards).

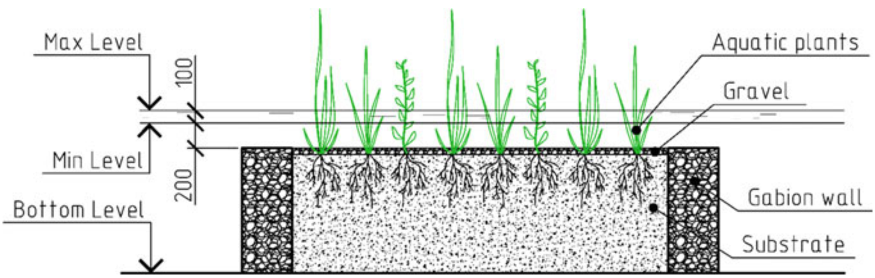

Fig. 20.6 An illustration of how gabion construction is used for sowing aquatic plants in Komsomolsky Pond

20.6 Conclusion

Water discharge dynamics of small urban rivers are highly variable and complex. Understanding these dynamics and their underlying causes is essential for our awareness of water discharge fluctuations in ungauged basins, especially in the face of climate change and urban sprawl. To study the hydrological regime of the small urban Lipovka River, we used two methods: empirical equations recommended by regulatory documents, and hydrological modelling. The anticipated freshet discharges with a 1% AEP are 0.69 (HBV) and 0.52 (SP 33-101-2003) $m^3 s^{-1}$. In contrast, rain flood discharges are 0.45 (HBV) and 0.57 (SP 33-101-2003) $m^3 s^{-1}$. However, we believe that HBV is a better predictor of maximum water discharge. However, more precise modelling is still required for extreme event forecasting and accurate assessment of their effects on the urban environment.

The reduced runoff of the Lipovka River was mainly caused by a decline in the effective catchment area, a littered channel, and increased evaporation and filtration into the groundwater. To reestablish the river's natural flow and catchment area, we propose constructing and maintaining a culvert to enable upstream feeding of the Lipovka River by Syrsky Pond.

The following are some recommendations for urban planning and water management based on the suggested approach to modelling the runoff of a small urban river:

- To install a system of automatic water level control in Komsomolsky Pond to manage the discharge downstream and prevent flooding in downstream areas.
- Use the pond's estimated water balance to determine the amount of pumping water running through the pumping station, which provides the required water level during the warm season.

Our study can serve as the basis for designing and revitalizing small urban rivers, as they are a crucial component of the city's water-green framework, providing a variety of ecosystem services in the context of smart urbanization.

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Chapter 21
Development of Environmentally Safe Concentration of Silver Content in Soils of Different Resistance to Chemical Pollution

Natalia Tsepina, Sergey Kolesnikov, and Tatiana Minnikova

Abstract To manage the quality of urban soils effectively, it is necessary to develop maximum permissible concentrations of various pollutants in the soil. This list includes pollution with heavy metals, such as silver (Ag). At the moment, neither in Russia nor in the world, maximum permissible concentrations of silver in the soil have been developed. Therefore, it is relevant to establish environmentally safe concentrations of silver in soils with different resistance to chemical pollution, which can later be used in soil pollution normalizing. The work objective is to develop environmentally safe concentrations of silver in soils with different resistance to chemical pollution. The following are selected as research objects for the development of environmentally safe concentrations of silver Haplic Chernozems Calcic, Haplic Arenosols Eutric, and Haplic Cambisols Eutric. Environmentally safe concentrations of Ag in soils were developed based on the degree of violation of ecosystem functions of the soil under the influence of silver pollution. Quantitative guidelines for the development of these standards are proposed. The environmentally safe concentration of Ag in Haplic Chernozems Calcic, Haplic Arenosols Eutric, and Haplic Cambisols Eutric is 4.4, 0.9, and 0.8 mg of Ag/kg of soil. The developed environmentally safe concentrations of Ag can also be used to regulate the quality of similar soils in other regions of the world.

Keywords Normalizing · Haplic chernozems calcic · Haplic Arenosols Eutric · Haplic Cambisols Eutric · Length of roots · Enzymatic activity · Ecosystem functions

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21.1 Introduction

In recent years, silver has increasingly become a polluting element as a result of anthropogenic activity. Silver (Ag) enters the environment from industrial sources, which include coal burning at thermal power plants, metal smelting at non-ferrous metallurgy enterprises, cement production, as well as synthesis, processing, and disposal of products based on silver nanoparticles (Künniger et al. 2014; Michels et al. 2017; Xing et al. 2004). The silver content in polluted soils can reach up to 35.9 mg/kg (Yildirim and Sasmaz 2017). The negative effect of Ag is manifested in a decrease in the length of roots and biomass of plants, suppression of the growth and reproduction of earthworms, a decrease in the number of soil bacteria, and inhibition of the activity of soil enzymes (Rahmatpour et al. 2017; Samarajeewa et al. 2017; Shoults-Wilson et al. 2011). As a result of the interaction of silver with humans, toxicity to the respiratory and gastrointestinal systems of humans, skin, liver, and brain cells was noted (Dziendzikowska et al. 2012; Hussain et al. 2001; Oberdorster et al. 2005). To manage the quality of soils, including urban soils, effectively, it is necessary to develop maximum permissible concentrations (MPCs) of various pollutants in the soil. This list includes pollution with heavy metals, such as silver. Now, neither in Russia nor in the world, MPCs of silver in the soil have been developed. Therefore, it is relevant to establish an environmentally safe concentration of silver in soils with different resistance to chemical pollution. The developed environmentally safe concentrations of silver can later be used for soil standardization with the help of biological indicators (Kolesnikov et al. 2000, 2013). The presented set of indicators provides an informative picture of the biological processes occurring in the soil and its ecological state.

The work objective is to assess environmentally safe concentrations of silver in soils with different resistance to chemical pollution.

21.2 Materials and Methods

Soils with different resistance to chemical pollution were selected as research objects for the development of environmentally safe silver concentrations. Soils differed in their texture, soil acidity, and organic matter content: Haplic Chernozems Calcic, Haplic Arenosols Eutric, and Haplic Cambisols Eutric (World Reference Base for Soil Resources. International Soil Classification System for Naming Soils and Creating Legends for Soil Maps 2022). The concentrations recorded by the authors in uncontaminated soil for Ag were 0.01–1 mg/kg (Alekseenko and Alekseenko 2013; Jones et al. 1986). The soil samples were selected from the top layer of 0–10 cm since silver is usually accumulated in the surface layers of the soil. In polluted soils, silver content ranged from 8 to 35.9 mg/kg according to Kabata-Pendias (2010); Yildirim and Sasmaz (2017), up to 7000 mg/kg in the soils of ore deposits (Druzhinin and Karelina 2008). The study was conducted under laboratory conditions. The doses were calculated based on the background concentrations of silver. Since the MPC of silver has not been established, its content can be expressed as a derived concentration, which for heaviest metals is about three to four background concentrations in the soil (Kolesnikov et al. 2019). The background silver content in Haplic Chernozems Calcic, Haplic Cambisols Eutric, and Haplic Arenosols Eutric is 0.303, 0.282, and 0.215 mg/kg, respectively. The soil was incubated in vegetative vessels in 3 replications in the climatic chamber Binder for 30 days. The mass of soil in each vessel is 200 g. Favorable conditions for soil biota were set up in the climatic chamber: 25–30% humidity, temperature 24–25 °C, change of lighting (day and night). The silver background content in soils was determined by ICP MS method at the All-Russian Scientific Research Geological Institute named after A.P. Karpinsky (St. Petersburg, Russia). Soil samples were dried and sieved through a 0.25-mm sieve, packed in thick paper bags and transported to the laboratory.

The biological properties of the soil were investigated first, because they were the first to react to external influences and are much more sensitive and informative compared to other soil properties. The change in biological parameters of soils was evaluated 30 days after contamination. Silver was introduced into the soil in the amount 1, 10, and 100 mg/kg, respectively. In this experiment, silver nitrate, which is quite soluble in water, was used to achieve maximum silver toxicity. It is also worth noting the high ecotoxicity of silver nitrate in studies conducted earlier (Cvjetko et al. 2017; Tripathi et al. 2017).

Silver ecotoxicity was assessed using biological methods (Kazeev et al. 2016). The total number of bacteria, catalase and dehydrogenases activity, and phytotoxic properties of the soil (length of root) were determined. To assess the soil state according to biological indicators, the result of calculating the integral indicator of the biological state (IIBS) of the soil was used (Kolesnikov et al. 2000). The calculation of IIBS allows comparing different biological indicators with different units of measurement and making a conclusion about the state of soils after pollution. To calculate environmentally safe concentrations of silver, regression equations were used describing the dependence of the decrease in IIBS values on silver concentration in the soil.

To verify the obtained data for significance, variance analysis was carried out, followed by the determination of the least significant difference (LSD). Variation statistics (mean values, dispersion) was determined, and reliability of different samples was established by using dispersion analysis (Student's t test).

21.3 Results and Discussion

The integral indicator of biological state of soils (IIBS) is used just for a holistic assessment of the degree of violation of ecosystem functions. As can be seen from Fig. 21.1, with an increase in silver concentration, the degree of the IIBS decrease for Haplic Chernozems Calcic, Haplic Cambisols Eutric, and Haplic Arenosols Eutric increases.

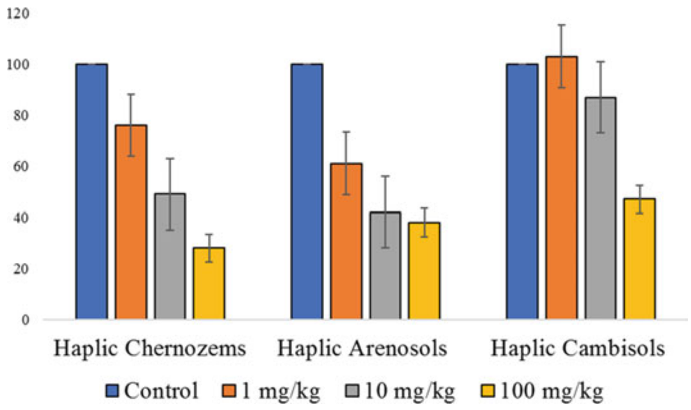

Fig. 21.1 Integral indicator of the biological state of soils with different resistance to silver pollution, % of control

At a dose of 1 mg/kg of silver, the decrease in IIBS of Haplic Chernozems Calcic by 3%, at 10 mg/kg—by 10%, and at 100 mg/kg—by 27% relative to the control values, respectively, was observed. A dose of 1 and 10 mg/kg of silver caused an IIBS decrease in Haplic Cambisols Eutric by 13 and 27% relative to the control, respectively. At a dose of 100 mg/kg, IIBS of Haplic Cambisols Eutric decreased by 39% relative to the control. IIBS of Haplic Arenosols Eutric decreased at a dose of 1 mg/kg of silver by 15%, at 10 mg/kg—by 30%, and at 100 mg/kg—by 42%, relative to the control, respectively.

To calculate environmentally safe concentrations of silver, regression equations were calculated describing the dependence of the decrease in IIBS values on silver content in each type of soil (Table 21.1). Functional violation is directly related to the silver concentration in the soil. First, a violation of information, then—biochemical, physicochemical, chemical, and holistic, and then physical functions was observed (Kolesnikov et al. 2019, 2002).

Ecological functions of the soil are not violated when the IIBS of the soil is reduced by 5%, and the silver concentration is less than 0.5 mg/kg. The function of soil

Table 21.1 Regression equations for soils with different tolerance to silver pollution and ecologically safe silver concentrations

Soil type	Regression equation	Ecologically safe concentration, mg/kg
Haplic Chernozems Calcic	$y = -4.704 \ln(x) + 96.955$, $R^2 = 0.99$	4.4
Haplic Arenosols Eutric	$y = -7.138 \ln(x) + 88.803$, $R^2 = 0.98$	0.8
Haplic Cambisols Eutric	$y = -6.664 \ln(x) + 90.101$, $R^2 = 0.98$	0.9

information is violated when the IIBS is reduced by 5–10%, and silver concentration is in the range from 1.5 to 4.4 mg/kg. The biochemical, physicochemical, chemical, and the complete function of the soil are validated if a decrease in IIBS occurs by more than 25%, while the silver concentration in the soil is more than 106 mg/kg. A decrease in IIBS by more than 10% indicates serious violations in soil functioning. The dose of silver, which causes a violation of the holistic functions responsible for soil fertility, can be considered an environmentally safe concentration of silver in this soil, the excess of which is unacceptable.

The authors have proposed the quantitative guidelines for the development of these norms for three soils that differ greatly in resistance to chemical pollution in Haplic Chernozems Calcic, Haplic Cambisols Eutric, and Haplic Arenosols Eutric. An environmentally safe concentration of silver in Haplic Chernozems Calcic is 4.4 mg/kg of silver in the soil, in Haplic Cambisols Eutric—0.9 mg/kg, and Haplic Arenosols Eutric—0.8 mg/kg.

The higher the silver concentration in the soil, the more effective and efficient the method of sanitation should be. When the silver concentration in Haplic Chernozems Calcic is less than 0.5 mg/kg, there is no violation of environmental functions, and soil sanitation is not required. When the silver concentration is in the range of 4.4–106 mg/kg, the application of organic and mineral fertilizers (phosphorous fertilizers, lime, etc.) and adsorbents (ion exchange resins, zeolites, etc.) is already required as part of chemical recultivation. The developed environmentally safe concentrations of silver can also be used in the normalizing of soils and other geographical areas.

The series of informativeness (averaged for all types of soils) of biological indicators is the following sequence: length of radish roots (−0.86) > dehydrogenases activity (−0.81) > catalase activity (−0.76) > total number of bacteria (−0.71).

Of the four biological indicators, the most informative was the length of roots, and the least informative was the total number of bacteria. But at the same time, all indicators have high correlation coefficients with a silver content of more than (−0.70).

When studying the effect of silver pollution on the biological properties of soils, it was found that all bioindicators had high sensitivity and informative value. This indicates the expediency of their use in monitoring, diagnostics, and normalizing of silver-contaminated soils. Environmentally safe concentrations of silver in soils were developed based on the degree of violation of ecosystem functions of the soil under the influence of silver. When soils are polluted with silver biogeocenotical functions of the soil are violated.

21.4 Conclusion

The increasing trend of soil pollution with silver, as well as the absence of the MPC of silver in soils, determines the necessity for its normalizing. The environmentally safe concentration of silver in soils was developed based on the degree of violation of ecosystem functions of the soil under the influence of silver. The IIBS was used for a holistic assessment of the degree of violation of ecosystem functions. The dose of soil-polluting silver, which causes a violation of the holistic functions responsible for soil fertility, can be considered an environmentally safe concentration of silver in this soil, the excess of which is unacceptable. The authors have proposed the quantitative guidelines for the development of these norms for three soils that differ greatly in resistance to chemical pollution. The high resistance to silver contamination is due the following parameters: the high content of organic matter which is about (3.7%), the neutral reaction of the soil medium pH (7.8), and heavy-loamy granulometric composition of Haplic Chernozems Calcic. The high in both mobility and ecotoxicity of silver in the following soils is due to the light granulometric composition (sandy loam) of Haplic Cambisols Eutric and the acidic reaction of the medium (pH = 5.8) in Haplic Arenosols Eutric furthermore the low humus content (1.8 and 2.3%, respectively). It can be concluded that each type of soil, has its own environmentally safe concentration of silver. The environmentally safe concentration of silver in Haplic Chernozems Calcic, Haplic Cambisols Eutric, and Haplic Arenosols Eutric is 4.4, 0.9, and 0.8 mg of silver/kg of soil, respectively.

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Chapter 22
Cost–Benefit Assessment for Maintenance of Urban Green Infrastructure at the University Campus in Moscow: Application of GreenSpaces and TreeTalker Technologies to Regulating Ecosystem Services

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Abstract Trees are a key element of urban green infrastructure (UGI). They supply a wide range of benefits—ecosystem services—from air purification to places for recreation. UGI is also an expenditure item in the budget due to the investments required for its establishment and maintenance. Accounting for ecosystem services in monetary terms allows considering direct and indirect benefits of green spaces together with costs, has not only implications for decision-making but also could be instrumental in changing landowners' perceptions of UGI and its importance. In this paper, we used the data from advanced tree monitoring technologies to compare monetary values of regulating ecosystem services to maintenance costs for the case of campus of the People's Friendship University of Russia (RUDN) in Moscow, Russia. Inventories of UGI elements were conducted by means of a field survey and remote sensing, that resulted in GIS project in GreenSpaces software. The same program was used to keep track of costs of the different types of maintenance work based on information from Greening Department of RUDN. Biophysical parameters of tree functioning were obtained from more than 60 TreeTalker sensors installed on the major species during the two years. The monetary value of four major regulating

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ecosystem services (air purification, climate regulation, water transpiration, carbon sequestration) of the trees was then assessed, allowing a comparison of the costs for maintenance and some of the benefits derived. The results show that even when considering just monetary value from regulating services, it outweighs the costs for maintenance of the UGI in the amount of 1.5 million rubles or about a quarter of the costs.

Keywords Ecosystem services · Value · TreeTalker · R3GIS · Green area maintenance

22.1 Introduction

Urban green infrastructure (UGI) plays a crucial role in ensuring good quality of life and human well-being, as well as in the sustainable development and functioning of urban environment (Gómez-Baggethun and Barton 2013; Haase et al. 2014; Kondo et al. 2018), especially at the times of crisis (Fagerholm et al. 2022). One of the most substantial components of UGI are trees, growing on roadsides, in backyards, as well as in the parks, gardens and urban forests and are even included in vertical greening. Urban trees provide a wide range of benefits, referred to as ecosystem services (ES), such as supporting, regulating, provisioning and cultural (Burkhard et al. 2018; Klimanova and Illarionova 2020). Carbon sequestration as part of climate mitigation, provision of shade and cooling effect, aesthetic and recreational values, habitat for birds and other species is the most widely studied ecosystem services provided by urban trees. Many of these services fall under the category of so-called non-market services (e.g., recreation in a park), i.e., not traded on markets and often they are also not easy to quantify / determine value both in biophysical and socio-economic terms (Small et al. 2017). This is also partly linked to the challenge of stakeholders often not realizing the full range of services and values provided by the UGI and its components.

At the same time, having trees in cities coincide with costs that include not only those for planting and maintenance, but also a long list of potential indirect costs, such as damage to buildings and pavements by tree roots, damage and injury from falling trees, disruption to traffic during maintenance, carbon emissions through operating machinery, blockage of drains by leaf litter and air pollution by volatile organic compounds emitted by foliage, to name but a few (Vogt et al. 2015). Calculation of costs is also not a straight-forward exercise, as it involves specific rates for labor and other components, technologies and materials to be used, all set by the official documents.

This complex balance of understanding and valuation of UGI's benefits and costs is the reason why planting trees in the cities can be and often is a controversial issue, involving many stakeholders with different interests and preferences, as well as more importantly with differences in awareness of the entirety of the costs and benefits associated with urban trees. Therefore, in order to support decision-making, it is paramount to investigate benefits and costs and explore ways to better quantify them. In recent years, a number of studies devoted to the question have emerged (Bolund and Hunhammar 1999; Russo et al. 2017), including reviews (e.g., Song et al. 2018). Many of them have quantified the benefits, while the costs have received less attention. Suggesting that understanding of the balance between costs and benefits (namely, which way it lies) remains poor.

At the same time, advanced GIS-based technologies for monitoring tree health and greenery maintenance allow considering these costs and aim to minimize them. One of such systems is GreenSpaces, developed by R3GIS company (https://www.r3gis.com/greenspaces). Its main tasks include inventory of current state and changes of main elements of UGI, management and control of maintenance activities. The company is also developing features for valuation of ES integrated in the app along with TreeTalker integration (Valentini et al. 2019; Matasov et al. 2020). This company entered the Russian market relatively recently and thus the app is still undergoing the process of adaptation to the institutional, biophysical, climatic and economic conditions of Russian cities.

Aim of this study was to determine whether the costs of maintaining urban trees outweigh the benefits they provide in order to support decision- and policy-makers. Benefits were represented through four main regulating ecosystem services measured in real time with TreeTalkers. Data on costs for their establishment and maintenance of trees have been collected from the authorities managing the site—the campus of the Peoples' Friendship University of Russian (RUDN) in Moscow, Russian Federation.

22.2 Materials and Methods

22.2.1 Study Site

Founded in 1960, the RUDN University campus (No 1 in Russia and No 42 in World University Green Metrics Ranking) (GreenMetric 2023) is situated in southwestern Moscow, in the Konkovo and Obruchevsky districts. The southwest of Moscow is located within the Teplostan upland, making the territory much higher than the rest of the city (Fig. 22.1). That, together with the prevailing western winds, an abundance of greenery, and a lack of big industrial areas, makes the territory one of the most favorable places to live in the capital. The campus occupies 0.34 km^2 of land and includes 20 teaching blocks and 14 dormitories.

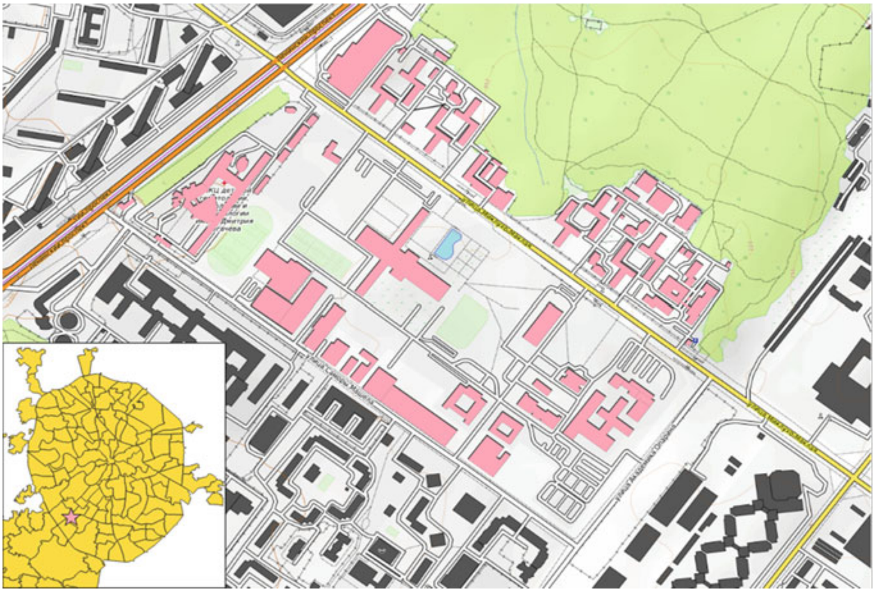

Fig. 22.1 Location of the study site (in Moscow)

22.2.2 Assessment of Costs and Benefits

Our study was conducted in three steps:

(1) We carried out inventory on campus and identified the structure of green infrastructure as well as the number of trees and their parameters.
(2) We gathered data on costs for establishment and maintenance of the trees using several calculation methods and primal information from RUDN Greenery Department, which were then compared to the benefits.
(3) Based on findings from the previous steps and using TreeTalker data, we have calculated the value of regulating ecosystem services provided by the trees on campus.

22.2.2.1 Inventory of Green Infrastructure

We used basic classification of green spaces in R3GIS, which is represented by four groups: trees, shrubs, lawns, flower beds. Trees can be a linear object or a point object. Shrubs can be designated as a single object, a line (hedge) if work is estimated per meter in length, and a polygon (shaped/unshaped) if work calculations are estimated per square meter. Lawns are polygonal objects and are represented by several types (by grass composition and type of care). Flowerbeds represent different variations of mixborders, flowerbeds and modular flowerbeds. Differences in classification are due to the longevity of plants: perennials and annuals. There are also ampelous plants that decorate the front entrances of buildings.

To describe the structure of green spaces, we used field observations with georeferencing using the GPS receiver GarmineTrex 32 and visual description of elements of green infrastructure with fixation of attributes. For trees, we described: species, trunk diameter, canopy diameter and tree height. For shrubs—species, height, length for hedges in addition. Green infrastructure elements with complex shapes were digitized in QGIS using DJI Mavic 2 PRO images (Hasselblad and Mapir DJI Inspire 2 Survey 3 near-infrared (NIR) and visible spectrum (RGB) camera on board, flying altitude 50 m). The images were taken in September 2019. The resulting images (with a resolution of 3–4 cm per pixel) were combined into a single georeferenced image and DEM. We used ForestTools package algorithms in R to obtain a shape file with the exact canopy shapes and georeferencing of each tree (R Core Team 2014).

22.2.2.2 Assessment of Regulating Services and Their Monetary Value

In order to conduct assessment of regulating services and their value, we have chosen four biophysical indicators, which can be measured in real time with TreeTalker (Matasov et al. 2020): carbon sequestration, water transpiration, PM_{10} absorption and energy use for climate regulation. We installed about 60 devices on major species of trees to collect their biophysical functioning data during 3 vegetation seasons in 2019–2021 to make extrapolation possible for the whole number of trees on campus.

To value biophysical flows in terms of money, we made such suggestions. To estimate, carbon deposition was used world prices for CO_2 emissions (40$ per ton—(World Bank 2021). Transpiration was estimated through the cost of drainage in prices of GUP Mosvodostok (https://мосводосток.рф/subscriber-service/rates/—14 rubles/m^3). The energy spent on transpiration was estimated as the work of a climate-conditioning system in rubles at prices of GUP Mosenergosbyt (https://www.mosenergosbyt.ru/individuals/services/pricelist.php—5.5 rubles/kWh). Literature data were used to estimate PM_{10} air purification—$4500/ton (Nowak et al. 2018).

22.2.2.3 Costs for Green Infrastructure Maintenance

The documents of RUDN Greenery Department for 2019 and 2020, job descriptions of the gardener and florist, the calendar of work on the maintenance of green areas were used to determine the costs of maintaining green areas. The data on the costs of planting material, its quantity and types of plants, garden tools and consumables were also obtained from the documents and interviews.

To compare real costs of the maintenance in RUDN campus with norms of maintenance for the Moscow City, we used Government Regulation No. 743-PP dated September 10, 2002 "On Approval of the Rules of Creation, Maintenance and Protection of Green Plantations and Natural Communities of the City of Moscow" (Decree of the Moscow City Government No 2002). We used information on the number of necessary «man working hours» and «machine working hours» for different types of work dedicated to trees and lawns care processes. Thus, the total amount of working hours per year was calculated in accordance with the regulations. These values were recalculated to cost equivalents based on average market prices and salaries.

22.3 Results

22.3.1 Green Infrastructure Composition of the Study Site

As a result of the inventory, a map of RUDN campus green infrastructure was created (Fig. 22.2), the areas of all existing objects of green infrastructure presented in Table 22.1. Open lawns (33%) and lawns under crowns (13%) dominate the structure of green areas. The share of sealed areas on campus is a bit over 50%. These include parking lots and roadways, 33%, and buildings, 18%.

The RUDN campus has 1707 trees. The four most common species here are *Tilia cordata, Betula pendula, Salix caprea* and *Populus tremula*. They account for 64.7%

Fig. 22.2 RUDN campus green infrastructure

Table 22.1 Share of land cover types and green infrastructure elements

Green elements	Area, sq. m	Share of area, %	Number, pcs
The entire territory	347,314	100	
Sealed:	179,502	51	
Roads and parking slots	116,099	33	
Buildings	63,402	18	
Green area:	167,812	48	
Lawns:	163,235	47	
Open lawns	115,465	33	
Lawns under the canopy	47,770	13	
Bushes:	4100	0.6	260
Artificial shapes	3522	1	
Natural shapes	578	0.16	
Flower beds:	402	0.12	
Annuals	234	0.07	
Perennial	168	0.05	
Trees:			1707
Trunk area	74	0.02	

of all trees. The distribution of tree diameters, heights and canopy areas by species is shown in Annex 1. Rare individuals exceed the height of 20 m, the most typical height is about 10–13 m. Trunk diameters in most cases range from 10 to 30 cm.

22.3.2 Costs for Maintenance

Actual spending consists of three main categories—employee salaries, supplies for planting, and equipment purchases or repairs (Table 22.2). In 2020, lawn seeds, seedlings for flower beds, soil and fertilizers were purchased for a total of about 1 million rubles, which amounted to 18% of the total cost. Among the equipment used are all kinds of soil drills, lawn mowers, long pruners and other stuff. There were spent on them about 10% of the total amount, i.e., about 0.5 million. Other 72% went on salaries of employees according to their employment by months and types of work (see Annex 2). Thus, the total costs amounted to 5.5 million rubles.

Compared to regulation norms (Decree No. 743-PP) on the man-hours for different types of work care for 1700 trees and an area of 34 hectares, we get the total number of man-hours about 21,035. Based on average salaries and the number of working days in 2020, we get an estimated amount of 213 rubles per working hour of a gardener which in total gives an amount of about 3.5 million rubles.

Table 22.2 Amount and types of the costs

Type	Category	Units	Quantity	Costs, rub	Costs, %
Flower seedling	Consumables	pieces	36,000	829,056.00	17.90
Soil and fertilizers		cubic meter	100	142,800.00	
Grass seeds		kg	60	24,000.00	
Equipment repair	Equipment	-	-	36,000.00	10.74
Petrol brush		pieces	3	192,000.00	
Lawn mower		pieces	2	144,000.00	
Gas shears		pieces	1	67,200.00	
Pole cutter		pieces	1	60,000.00	
Office equipment		pieces	4	14,400.00	
Soil drill echo $d = 12$ cm		pieces	1	10,022.84	
Soil drill echo $d = 20$ cm		pieces	1	10,051.37	
Soil drill echo $d = 25$см		pieces	1	10,517.42	
Soil drill echo EA-410		pieces	1	53,273.42	
Personnel of service jobs	Personnel	person	7	3,823,012.05	71.37
Personnel of planning jobs		person	1	95,333.33	
Personnel of planting jobs		person	1	52,962.96	
			Total	5,564,629.41	100

22.3.3 Benefits Obtained from the Trees: Regulating Ecosystem Services

According to the results of the analysis, we can conclude that the RUDN campus trees produces regulating ecosystem services worth about 7.2 million rubles per year (Table 22.3), with most of it being climate regulation through transpiration (1144 MWh/yr). The second most valuable is air quality regulation (2263 kg/yr), slightly less valuable is rainwater removal through transpiration (11,185 m^3/yr) and carbon deposition (14.8 t/yr) is valued the least.

To sum up, with this estimate, we get that the balance of benefits to the territory due to regulating ecosystem services at the RUDN campus is more than 1.5 million rubles.

Table 22.3 Biophysical volume of ES and their cost estimation

Ecosystem service	Biophysical flow, units	Cash flow, thousand rubles
Tree carbon accumulation	14.8 t/yr	6.2
Energy absorbed	1144 MWh/yr	6292.2
Total transpiration	11,185 m^3/yr	156.6
Total PM absorbed	2263 kg/yr	712.8

22.4 Discussion

Our assessment of costs and benefits associated with the maintenance of trees as part of the UGI concludes that the latter even based on regulating services value only slightly outweighs the former. Similar findings have been reached by Song et al. (2018): these estimates are often within the same range if not the same. Regulating services are the most common to be used in such cost–benefit assessments (Song et al. 2018). Of the differences, it can be noted that several studies have concluded water retention to be more valuable than air purification, which is probably due to the large number of studies conducted in the subtropical climate zone, where there is significantly more precipitation than in Moscow. Carbon sequestration has the least effect most of the time. And microclimate regulation through shading and transpiration turns out to be the most significant of all regulatory services.

At the same time, trees provide other benefits than regulating services, such as cultural services. (Song et al. 2018) In their review demonstrated that benefits from the latter (for example, aesthetics) are often larger than those of water purification and carbon sequestration. Authors of another review of cultural services provided by the UGI have concluded that while parks, gardens and forests have been examined in studies often, more comprehensive assessments of services from other components of UGI (such as trees, tree lines) as well as network as a whole are needed (Cheng et al. 2021). In line with the call to assess various components of UGI is the fact that lawns, while being one of the most common components of open green spaces and UGI, their importance for the human well-being and urban sustainability is still underestimated in many parts of the world, including Russia (Ignatieva et al. 2020). Their transpiration and PM10 removal rates, especially microclimate regulation, could be similar or even higher than trees due to the larger area they occupy. Moreover, as with trees, cultural services of lawns have not been represented in our valuation. Other studies have demonstrated their importance for people as well as a whole range of preferences toward their composition (Ignatieva et al. 2017; Yang et al. 2019).

Methodologically, we tested a combination of hardware and software: TreeTalkers and GreenSpaces. We discovered that while they have potential for application in such assessments, first a few limitations need fixing. For example, R3GIS didn't contain some of the management functions inherent in Moscow climate (like snow drilling in spring) and some of the elements of UGI that are present in Moscow, such as stone flowerbeds. Moreover, it became evident that there is a need for development of similar sensors for lawns (LawnTalker) which will be able to assess the biophysical processes in such important green infrastructure elements and translate them into ecosystem services numbers to be used in the decision support.

22.5 Conclusion

The results show that even when considering just monetary value from regulating services, it outweighs the costs for maintenance of the UGI by about a quarter of the former. Findings from such studies could play a major role in transforming a decision-maker's perspective of an urban tree, as the most typical element of UGI, from a liability on the landowner' balance sheet into an asset. This outcome could add to the current understanding of the value of a tree among decision-makers, that is largely determined by the value of a felling ticket or the value of a cubic meter of its timber, and the necessary costs of its valuation are forced by the need to avoid the risks of damage to someone else's property in the event of a possible fall of a tree. This study presents the foundation for future research, which needs to conduct more comprehensive assessments of UGI and its components. Moreover, as suggested by previous studies, decision-making could benefit largely from findings and process of the transdisciplinary research involving stakeholders (Ignatieva et al. 2017; Willcock et al. 2016). Such close engagement with among other decision-makers would be beneficial for the researchers and their studies in terms of knowledge and navigation of the currently applied procedures for calculation of costs.

22.6 Conflicts of Interest

The authors declare no conflict of interest.

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Annex 1

See Fig. 22.3.

Annex 2

See Table 22.4.

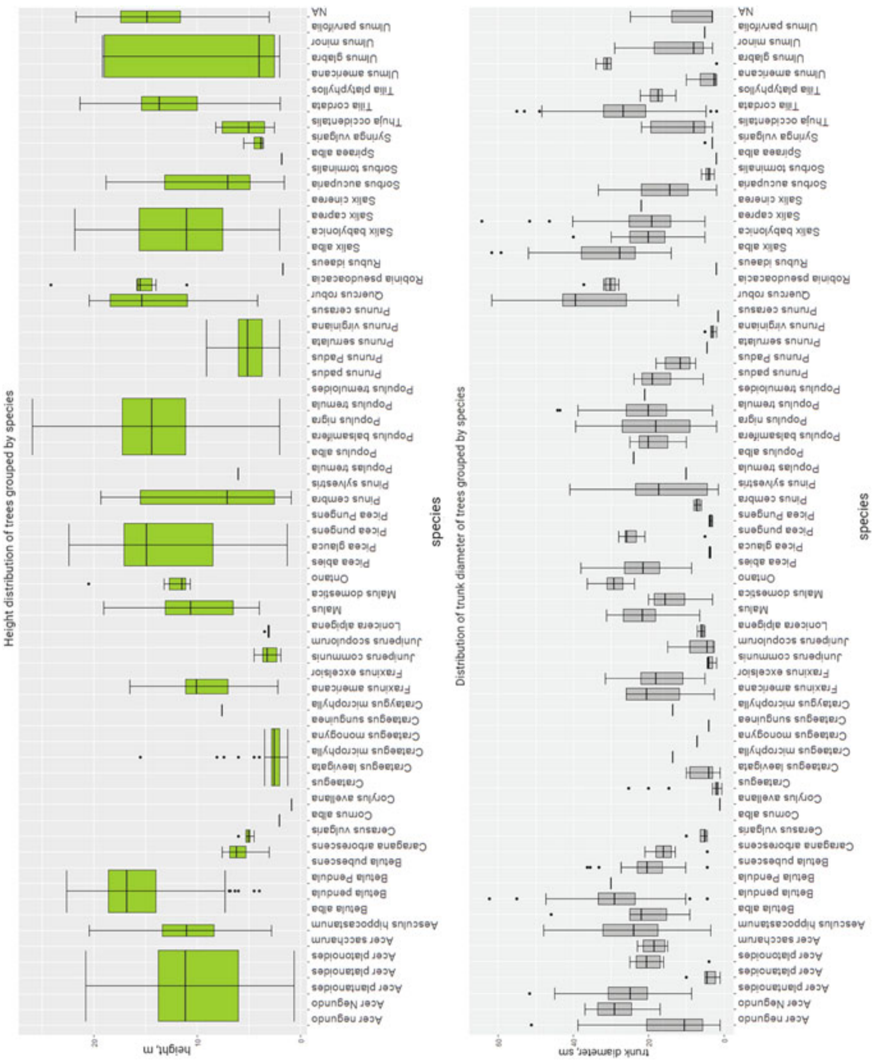

Fig. 22.3 Distribution of tree characteristics by species: height (**a**), diameter at breast height (**b**), canopy area (**c**)

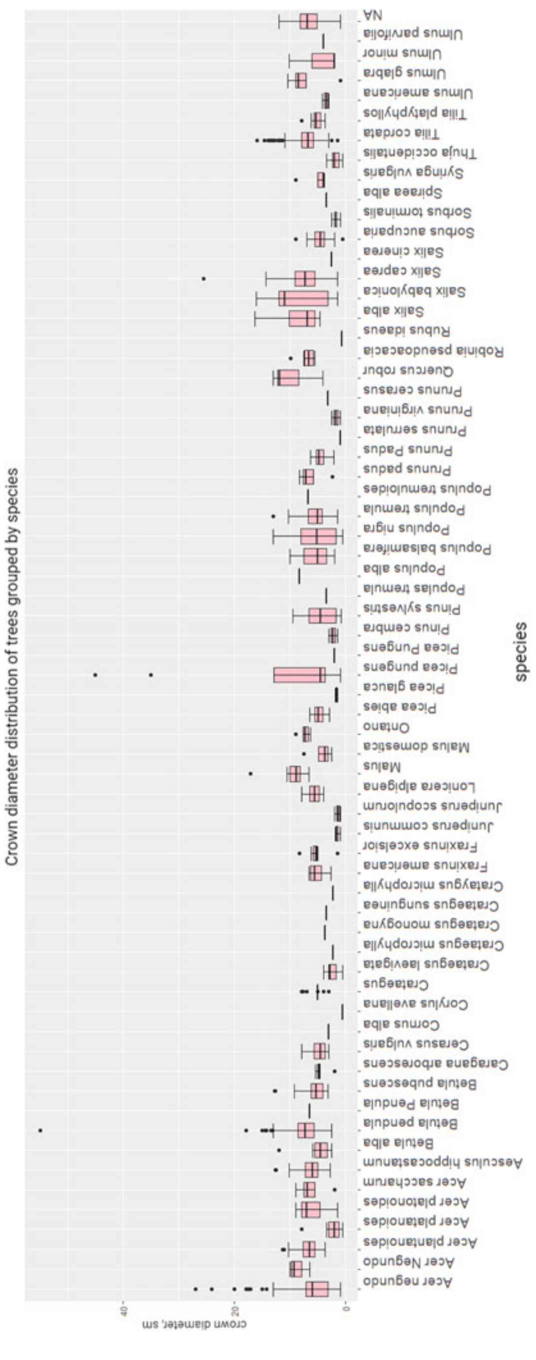

Fig. 22.3 (continued)

Table 22.4 Distribution of different work types across seasons and their working hours assessment

Type of jobs	Job category	Man-hours/ year	January	February	March	April	May	June	July	August	September	October	November	December
Snow removal	Service	2800	700	700	350								350	700
Equipment repair	Service	9			9									
Pruning trees and shrubs	Service	280			140	140								
Cleaning after winter	Service	240				240								
Addition of mineral fertilizers	Service	200				40	40	40	40	40				
Chemical protection of trees from pests and diseases	Service	120			20	20	20	20	20	20				
Chemical protection of shrubs from pests and diseases	Service	720			120	120	120	120	120	120				
Hedge trimming	Service	420						140	140	140				

(continued)

Table 22.4 (continued)

Type of jobs	Job category	Man-hours/year	January	February	March	April	May	June	July	August	September	October	November	December
Removing overgrowth on trees	Service	50					10	10	10	10	10			
Overseeding of lawn grasses	Service	120				60	60							
Flower garden care: watering	Service	3000					600	600	600	600	600			
Flower garden care: weeding	Service	600					120	120	120	120	120			
Lawn mowing	Service	3750					750	750	750	750	750			
Cleaning of flower beds and flower beds before winter	Service	175										175		
Removal of the territory from fallen leaves	Service	385									192.5	192.5		

(continued)

Table 22.4 (continued)

Type of jobs	Job category	Man-hours/year	January	February	March	April	May	June	July	August	September	October	November	December
Lawn reclamation (locally)	Service	0			1день/ 100 кв.м - 2 человека									
personnel management of service work	Service	1582	131.833	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5	169.5
conclusion of contracts	Planning	9			9									
Planting design development	Planning	63			31.5	31.5								
Planning new lawns	Planning	45				9	9	9	9	9				
Purchase of soil	Planning	9			9									
Purchase of perennial and annual plants	Planning	54					54							
Planting annual flower seedlings	Planting	125					125							

(continued)

Table 22.4 (continued)

Type of jobs	Job category	Man-hours/year	January	February	March	April	May	June	July	August	September	October	November	December
Planting annual perennial flowers	Planting	25					25							
Planting shrubs and trees	Planting	50					50							
		Total man-hours/year	January	February	March	April	May	June	July	August	September	October	November	December
Total		14,756	831.833	869.5	858	830	2152.5	1978.5	1978.5	1978.5	1842	537	519.5	869.5

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Chapter 23
Urban Livability: A Place of Environmental Compounds in a Mindset

Vitaly A. Kryukov and Elena I. Golubeva

Abstract Urban livability depends on a lot of compounds, including the environmental ones, most of them dependent on green infrastructure (GI) and its distribution. Two interviews of the public in Moscow and Saint-Petersburg ($N = 352$) and experts from Belgrade in the field of urban studies ($N = 27$) were conducted to assess the importance of 23 compounds of urban livability. Public respondents are more interested in social and economic issues (income rise, job creation, improvement of healthcare, education, housing quality, safety, etc.) than in environmental ones. The improvement of parks and public spaces (8th place), the design of new ones (12th) and pollution reduction (9th) are the most significant environmental compounds, while the conservation of secluded silent shelters (20th) and expansion of protected areas (18th) are the least demanded. The local environmental issues are not properly expressed in public answers. The most significant differences between respondents are related to the place of residence, not to demographic, education level or access to the GI. Saint-Petersburg citizens are more interested in the design of new parks and public spaces compared to Moscow citizens that are keener on pollution reduction and nature shelters for relaxation. Belgrade experts consider environmental compounds of livability as significantly more important. Local pressing issues of the urban environment are expressed in the opinion of experts from Belgrade (air pollution, public transportation, wastewater treatment and economic problems). Considerable gap between the professional community and public in terms of environmental compounds of livability is yet to be explored.

Keywords Livability · Well-being · Urban ecology · Sustainable cities · Mindset · GIS

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23.1 Introduction

Livability can be described as the ability to be and dwell in some physical spaces with the appropriate environmental and cultural prerequisites (Onnom 2018; Yassin 2019). At the same time, most researchers imply their definitions of livability depending on the aims and scope of surveys. One of the most popular and comprehensive methods of livability assessment is subjective well-being (SWB), which may be characterized as "people's evaluations of their lives, which include both cognitive judgements of one's life satisfaction in addition to affective evaluations of mood and emotions" (Diener et al. 1999), p. 213. The positive relation between livability and SWB has been revealed earlier (Florida 2008; Okulicz-Kozaryn and Valente 2019). SWB mostly depends on basic needs, according to Maslow's pyramid (Maslow 1987) like physiological and security ones, but the highest state of SWB is only possible by satisfying psychological and self-development needs. Urban livability may be defined as the unique type of livability at large (Kashef 2016). Besides architectural characteristics of human-made grey infrastructure (buildings, roads, utilities and other sealed surfaces), determining important dimensions of urban livability, a liveable environment also heavily depends on the ecosystems' state – the rate of transformation, fragmentation, and connectivity. One of the most significant compounds of urban livability is green infrastructure (GI), according to the World Health Organization (WHO) (2004), which can be characterized as "an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife" (Benedict and McMahon 2006, p. 1). GI properly designed with the main planning principles is capable of providing a livable environment: multifunctionality (useful for the environment, economics, and community), connectivity of landscape systems, habitability (for people and other living organisms), resiliency (ability to revive after some disturbances and changes), identity (defining a visual image of a place) and return to investments (reducing costs for citizens, businesses, government entities) (Rouse and Bunster-Ossa 2013). GI ecosystem services are varying widely and comprise most issues of urban SWB. Most SWB environmental compounds are strongly dependent on GI elements.

Meanwhile, GI is generally examined by case studies, covering parts of regions, cities, their districts or even residential blocks. From this perspective, it becomes evident that urban spaces provide a specific set of services related to geographical zonal features and peculiarities of environmental policy, spatial planning and conflicts of various stakeholders (Bush et al. 2021; Haase and Wolff 2022).

Therefore, urban GI protection fully corresponds with three UN Sustainable Development Goals – № 11 (sustainable cities and communities), № 14 (life below water) and № 15 (life on land) (United Nations 2017). The ecosystem services of urban GI are yet to be evaluated properly, especially cultural ones (Maes et al. 2016), but their effect usually might be comparable to huge financial costs to provide a healthy, safe and comfortable place of residence (Birtles et al. 2013). The emphasis is also placed on the blue infrastructure as evaluations of its services, protection of natural wetland systems and adequate design of water supply networks and runoff collectors will significantly mitigate the adverse effects of global climate change (Wong and Brown 2009). Since the understanding of unique green–blue infrastructure contribution to life-enabling, sustaining and fulfilling (Sydney Metropolitan Catchment Management Authority (SMCMA) 2012) is rising amongst the academic community, government and public, robust surveys of urban ecosystem services supplied by GIS comparative assessments and financial evaluations are emerging consistently but they are predominantly dedicated to the most developed cities (Boehnke et al. 2022; Haase and Wolff 2022; Kabisch et al. 2014; Klimanova et al. 2021). Such studies are accelerating the process of green transition to sustainable urban policies which should be based on the implementation of an ecosystem services approach (Burkhard et al. 2014; Hamel et al. 2021; McPhearson et al. 2015).

The urbanization rate is expected to increase mostly by an ambiguous expansion of cities in less developed countries (United Nations, Department of Economic and Social Affairs 2019) complicated by the great constellation of gaps in urban planning, which will require organizing a comfortable environment with a strong support of multidisciplinary teams. Besides, megapolises should be in the focus of livability surveys as their share of the world population is estimated to reach about 39% by 2035 (United Nations, Department of Economic and Social Affairs 2019).

This survey is aimed at revealing the ratio between various livability compounds in the mindset of urban residents. A huge variety of questions arise from this goal, but this study is focused on the place of ecological compounds determined by the natural peculiarities of study areas and human-caused impact on the environment. Moreover, the perceptions of these issues by various population groups in specific cities to organize a livable environment, according to the equity principle of sustainable development (Emas 2015), are yet to be explored.

A wide variety of various methods and techniques are used to contemplate public perception of livability issues: focus groups (Raymond et al. 2014), expert scores, narrative methods (Burkhard and Maes 2017), design of hypothetical scenarios of willingness to pay (West et al. 2006), photo-elicitation surveys (Burkhard and Maes 2017) and content analysis of surveys conducted earlier (Dennis and Bower 2008). Some approaches are considered to be integrating a few techniques and providing the most accurate and feasible imprint of the mindsets, e.g., Perceived Residential Environmental Quality – PREQ (Debek and Janda-Dębek 2015) or various international comparative ratings and indexes: The Global Liveability Index,[1] Mercer's Quality of Living Ranking,[2] Arcadis Sustainable Cities Index,[3] etc.

At the same time, objective quantitative indicators alone are insufficient to complete a livability assessment due to the need to consider subjective feelings and

[1] Global Liveability Report of The Economist Intelligence Unit (EIU) (2022). https://www.eiu.com/n/campaigns/global-liveability-index-2022/.

[2] Mercer's Quality of Living Ranking (2019). https://mobilityexchange.mercer.com/insights/quality-of-living-rankings.

[3] Arcadis Sustainable Cities Index (2018). https://www.arcadis.com/en/global/our-perspectives/sustainable-cities-index-2018/citizencentric-cities/.

emotions (Levent and Nijkamp 2006; Marans and Stimson 2011). The conjugation of public questionnaires and interviewing experts is considered to be the most reliable way of livability assessment (Debek and Janda-Dębek 2015). However, most researchers have applied their specific conceptual frameworks and techniques to gauge the quality of urban life (e.g. Marans and Stimson 2011), residential satisfaction (e.g. Ramkissoon et al. 2013), sense of place (Campelo et al. 2014) and other similar or almost identical aspects of urban livability. The essential problems caused by this variety are applicable to the specific projects and case studies only, insufficient efforts to compare to other surveys and extremely different sets of assessed indicators (Debek and Janda-Dębek 2015).

23.2 Data and Methods

23.2.1 Study Areas

The citizens of the two largest Russian megapolises, Moscow and Saint-Petersburg (13.0 and 5.6 million people, respectively), and respondents from the surrounding Moscow region (federal subject in Russian administrative division) and Leningrad region (8.5 and 1.9 million people, respectively)[4] have been interviewed. Both megapolises may be characterized as extremely polarized cities with highly dense urban cores and remote outskirts of New Moscow, towns within Saint-Petersburg or even pristine wetlands within Yuntolovsky or Pike Lake protected areas.[5] The choice of case study areas is explained by the fact that citizens of these regions have quite high rates of the Internet use (the share of active online users from Moscow is 87.7% and from Saint-Petersburg is 80.9%),[6] which makes it easier to carry out online interviews. Nearby regions beyond megapolises are strongly oriented towards these cities as the conjugations of jobs, social and transport infrastructure, and public life. Besides, these megapolises and nearby subjects are highly developed Russian regions, economically and socially,[7] which has made us suggest that these residents are strongly aware of urban environment quality and ecological compounds of livability, according to Maslow's pyramid.

Moreover, it has turned out that some citizens of nearby cities have been identifying themselves as Moscow or Saint-Petersburg residents while snowballing samples.

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[4] Mosstat, demographics (In Russian). https://mosstat.gks.ru/folder/64634.
Petrostat, demographics (In Russian). https://petrostat.gks.ru/storage/mediabank/Возраст-пол%20нас%20СПб%202019.pdf.

[5] The Directorate of Saint-Petersburg protected areas. https://oopt.spb.ru/.

[6] FinExpertiza. Survey on the activity of Internet users across Russian regions. https://finexpertiza.ru/press-service/researches/2022/kolich-inter-polz-vyrosl/.

[7] The Federal State Statistics Service (Rosstat). Social and economic indicators of Russian regions. https://rosstat.gov.ru/folder/210/document/13204.

Experts in the fields of urban planning, environmental management and architecture, residing in Belgrade (Serbia) with a population of around 1.7 million people[8] and its suburbs, have been interviewed during the scientific and professional conference[9] to reveal the professional perception of urban livability. Moscow and Saint-Petersburg professionals interviewed during such conferences had no appropriate experience in urban planning, which makes us incorporate Serbian results in this study and plan the further extension of the public interviews to Belgrade and expert interviews to Moscow and Saint-Petersburg, respectively.

23.2.2 Public Survey

Text individual mass social survey reflected in online questionnaire entitled "Comfort urban environment – what it is?" has been conducted in January and February 2022 via Google Forms (the number of respondents $N = 352$) using freelance workers to distribute the link. It has been decided not to involve respondents who have personal connections with authors to exclude additional bias in the results. Four classic questions represent the introduction: gender, age, education and city. Moreover, each respondent must specify his postal code to identify his approximate place of residence.

The core formalized interview question comprised 23 items representing the main compounds of urban livability (Table 23.1). This compounds' set did not constellate all of the possible particular features, but such a bunch may be applied to a wide range of cities across developing countries. Each respondent specified the importance of each compound through a 5-point Likert scale: from 0 («not important at all») to 4 («extremely important»). Moreover, the additional optional unformalized open question, suggesting to type their proposals to improve the urban environment, has been included in the interview.

23.2.3 Spatial Analysis

The second stage of results processing implied the use of postal codes obtained from respondents through the second open question of the interview. This approach has been already successfully implemented while accessing GI services (Dushkova et al. 2021; Rozzi 2021; Rushton et al. 2007). Accessibility of large (more than 100 and 500 ha) green cores and GI share of total area have been estimated according to barriers, such as highways and water objects through QGIS tools and OpenStreetMap

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[8] RZS Srbije. Statistical office of the Republic of Serbia. https://www.stat.gov.rs/en-US/oblasti/stanovnistvo/procene-stanovnistva.

[9] "Lokalna samouprava u planiranju i uredjenju prostora i naselja" ("Local self-governing in planning and organisation of space and settlement" in Veliko Gradište, Serbia, 16–18 June 2022).

Table 23.1 Urban livability compounds (orange—economic, blue—social, green—environmental)

№	Livability factor
1	Jobs creation
2	Income rise
3	Improvement of healthcare and education quality
4	Design of healthcare and education facilities
5	Improvement of sport facilities
6	Design of sport facilities
7	Design of new parks and public spaces
8	Improvement of parks and public spaces
9	Quality of housing
10	Design of religious facilities
11	Security improvement
12	Digitalization
13	Reducing air and water pollution
14	Expansion of protected areas
15	Control of environmental violations
16	Improvement of public transportation
17	Increasing convenience for private transportation
18	Expansion of leisure objects
19	Expansion of education programmes
20	Architectural design and conservation of historical sites
21	Modernization of utilities network
22	Conservation of secluded silent places
23	Reducing noise pollution

data. Openrouteservice API[10] has been harnessed to estimate the actual proximity areas of each respondent via QGIS ORS Tools plugin. Hence, 352 accessibility areas in the form of 1-h isochrone are represented by variously distorted circles. Such procedures of isochrones correction, significantly improving the accuracy of results, are already known from various surveys (Efentakis et al. 2013; Kaszczyszyn and Sypion-Dutkowska 2019; Lantseva and Ivanov 2016).

Landsat 8 imageries (2021) were used to assess the GI share of the total area occupied by 1-h proximity isochrone. Normalized difference vegetation index (NDVI) has been estimated to identify GI areas:

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED})/(\mathrm{NIR} + \mathrm{RED}) \tag{23.1}$$

where NIR – reflectance value of near-infrared light, RED – reflectance value of red visible light (Tarpley et al. 1984). NDMI has not been used for such analysis due

[10] Openrouteservice API. https://openrouteservice.org/.

to great variations during different weather conditions (Gao 1996), as well as EVI which is mostly used for natural areas with great leaf area and may be considerably distorted by some buildings, especially the multistorey ones (Huete et al. 2002). At the same time, deep-routed NDVI implementation in the field of urban ecology is quite successful for the demarcation of green and grey infrastructure (Aryal et al. 2022; Liu et al. 2015).

The threshold value NDVI = 0.18 was used for the delimitation of green and barren areas in QGIS, following to comparison of different values to Google Satellite images in natural colours. Further, raster images were transformed into vector data to gain intersections between GI polygons and 1-h isochrones. GI shares within 1-h proximity areas of each respondent have been estimated through QGIS spatial statistics.

23.2.4 Expert Interviews

Respondents to these interviews who attended the conference mentioned above have expressed willingness to participate in the social survey for 3 days. Most of the Serbian experts live in Belgrade and nearby towns ($N = 27$). This questionnaire has included the same items as the public survey but has been advanced by questions about the field of professional activity, affiliated institution, position and completion of doctoral degree.

The results of the public and experts' interviews have been checked via IBM SPSS v.27 using nonparametric tests (Mann–Whitney U and Kruskal Wallis) for ordinal data, which are widely common in Likert-scaled surveys (Dushkova et al. 2021).

23.3 Results

23.3.1 Public Survey

The age and gender sample structure is quite close to those published by Moscow and Saint-Petersburg statistical authority branches.[11] The near-zero prevalence of respondents who identified themselves as female has been gained through this interview. The citizens aged 40–49 prevail, while the share of respondents above 40 years is compatible with the younger respondents – 48.7% versus 51.3% (Fig. 23.1).

[11] Mosstat, demographics (In Russian). https://mosstat.gks.ru/folder/64634.

Petrostat, demographics (In Russian). https://petrostat.gks.ru/storage/mediabank/Возраст-пол%20нас%20СПб%202019.pdf.

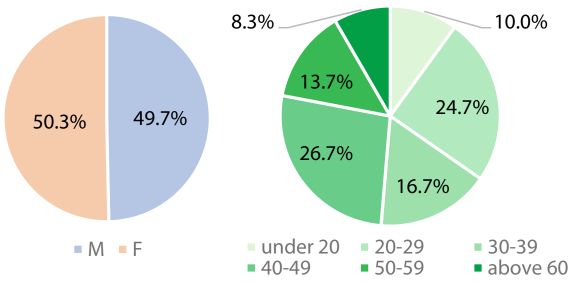


Fig. 23.1 Gender and age of respondents (public survey)

The citizens of Moscow and Moscow region amount to 63.3% of the total respondents' number. Nonetheless, two samples of respondents comprising (1) Moscow and Moscow region residents and (2) Saint-Petersburg and Leningrad region residents are comparable because of the sufficient respondents' number (Fox et al. 2007).

Only 14.3% of respondents have not completed either secondary professional education or a higher degree of education. Most of them (65.6%) are falling into the category of respondents aged below 20, which is making us able to assume the higher expected education rate. The share of respondents who completed higher education is quite similar to the opposite group (49.0% vs. 51.0%).

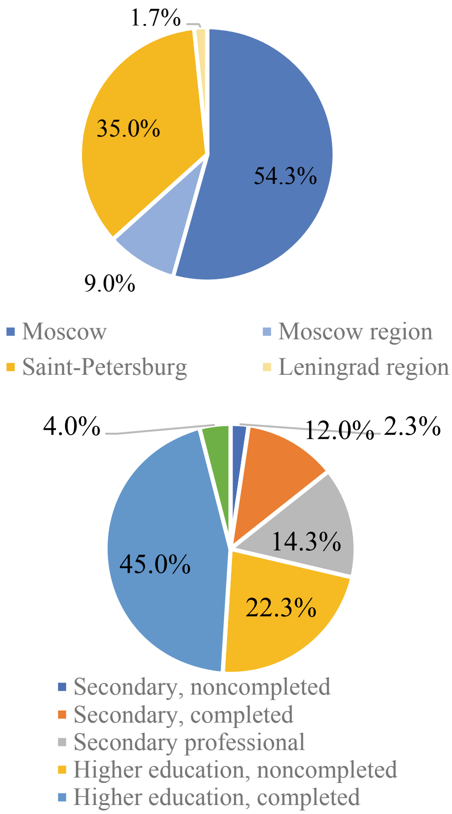
The public mindset of Moscow and Saint-Petersburg regions tends to be more economic- and social-oriented rather than ecologically inclined (Fig. 23.2). The leaders of public perception are income rise (№ 2), improvement of education and healthcare quality (№ 3), jobs creation (№ 1), housing quality (№ 9) and safety (№ 11), while conservation of secluded spaces for relaxation (№ 22), programmes of additional education (№ 19), design of sport (№ 6) and religious facilities (№ 10) are the least important.

The most important environmental issues are related to the design of new parks and public spaces (№ 7), their improvement (№ 8) and reduction of air and water pollution (№ 13). Meanwhile, the extension of protected areas took 18th place only, while the conservation of secluded silent places (№ 22) has become the least demanded compound. Besides this compound, some social ones make up the list of outsiders: programmes of additional education (№ 19), design of sport (№ 6) and religious facilities (№ 10).

Several patterns of public perception have been identified through the analysis of responses (Table 23.2):

- men are keener on the design of religious (№ 10) and sport facilities (№ 6), while women are more interested in the improvement of healthcare and education quality (№ 3).
- citizens above the age of 40 are more interested in religious facilities (№ 10).
- the large set of factors is considered by dwellers with higher education to be more important: improvement of education and healthcare quality (№ 3), development of public transport (№ 16), conservation of architectural and historic peculiarities

Fig. 23.2 The place of residence and education degree (public survey)



(№ 20) and upgrades of utilities (№ 21); while respondents without such education degree prefer religious facilities (№ 10).

- the citizens of Moscow and Moscow region are significantly more interested in three environmental compounds – pollution reduction (№ 13), nature shelters for relaxation (№ 22), noise pollution (№ 23) – as well as in the design and improvement of sport facilities (№ 5–6), upgrades of utilities (№ 21) and jobs creation (№ 1), whereas the citizens of Saint-Petersburg and Leningrad region are chiefly keen on the design of parks and public spaces (№ 7) and their improvement (№ 8). Such disparity may be related to the higher incomes of Moscow citizens and their psychological possibility to concentrate on the more comprehensive social and environmental issues. In the meantime, Saint-Petersburg does not possess such green spaces in the city centre as Moscow does.
- there are no significant disparities of the importance of protected areas expansion (№ 14) and control of environmental violations (№ 15) in the sample.

Table 23.2 Importance values of 1–23 urban livability compounds, their differences (*D*) in the various samples and *p* of null hypotheses (any differences between the samples of respondents are insignificant), according to the Mann–Whitney U test. Low (<0.05) *p* refuting null hypotheses are in bold

No. of compound	Gender				Age			
	M	F	*D*	p_U	Below 40	Above 40	*D*	p_U
1	3.39	3.26	0.13	0.056	3.34	3.31	0.03	0.312
2	3.40	3.54	– 0.14	0.099	3.49	3.46	0.03	0.373
3	3.30	3.48	**– 0.19**	**0.017**	3.38	3.40	– 0.03	0.399
4	3.05	3.21	– 0.15	0.398	3.12	3.14	– 0.01	0.395
5	2.83	2.62	0.21	0.364	2.75	2.69	0.05	0.394
6	2.79	2.43	**0.35**	**0.006**	2.60	2.61	– 0.01	0.399
7	3.14	3.03	0.11	0.333	3.02	3.16	– 0.14	0.200
8	3.13	3.17	– 0.04	0.281	3.14	3.16	– 0.03	0.391
9	3.28	3.32	– 0.05	0.291	3.32	3.28	0.04	0.300
10	2.11	1.58	**0.53**	**0.004**	1.56	2.14	**– 0.58**	**0.001**
11	3.12	3.28	– 0.16	0.082	3.23	3.17	0.06	0.282
12	3.06	3.05	0.01	0.399	3.11	2.99	0.12	0.215
13	3.17	3.13	0.05	0.394	3.25	3.05	0.20	0.084
14	2.79	2.75	0.04	0.395	2.77	2.78	– 0.01	0.390
15	3.03	2.95	0.08	0.372	2.99	2.98	0.01	0.397
16	3.22	3.09	0.14	0.283	3.12	3.19	– 0.07	0.278
17	3.19	3.13	0.07	0.389	3.13	3.19	– 0.06	0.267
18	2.94	2.80	0.14	0.255	2.99	2.74	0.25	0.073
19	2.66	2.56	0.09	0.260	2.49	2.74	– 0.25	0.120
20	2.94	2.85	0.09	0.332	2.80	2.99	– 0.19	0.116

(continued)

Table 23.2 (continued)

No. of compound	Gender				Age			
	M	F	*D*	p_U	Below 40	Above 40	*D*	p_U
21	3.17	3.03	0.13	0.325	3.09	3.11	− 0.02	0.399
22	2.65	2.58	0.07	0.346	2.73	2.50	0.23	0.110
23	2.97	2.83	0.13	0.237	2.90	2.64	0.26	0.397
Average	3.01	2.94	0.07		2.97	2.97	− 0.01	
No. of compound	Education				Place of residence			
	Without higher completed	With higher completed	*D*	p_U	Moscow and Moscow region	Saint-Petersburg and Leningradsky region	*D*	p_U
1	3.41	3.24	0.17	0.122	3.40	3.19	**0.21**	**0.048**
2	3.42	3.53	− 0.11	0.164	3.42	3.57	− 0.16	0.091
3	3.27	3.52	**− 0.25**	**0.030**	3.42	3.35	0.07	0.281
4	3.07	3.20	− 0.13	0.393	3.20	3.01	0.19	0.389
5	2.75	2.69	0.05	0.224	2.85	2.50	0.35	0.396
6	2.65	2.56	0.10	0.272	2.74	2.37	**0.37**	**0.014**
7	3.07	3.10	− 0.03	0.342	2.97	3.28	**− 0.31**	**0.025**
8	3.10	3.20	− 0.09	0.177	3.05	3.33	**− 0.28**	**0.044**
9	3.19	3.41	− 0.23	0.070	3.35	3.22	0.13	0.171
10	2.01	1.66	**0.35**	**0.048**	1.94	1.66	0.28	0.122
11	3.17	3.23	− 0.06	0.350	3.20	3.20	0.00	0.388
12	3.11	2.99	0.12	0.377	3.08	3.01	0.07	0.241

(continued)

Table 23.2 (continued)

No. of compound	Gender				Age			
	M	F	D	p_U	Below 40	Above 40	D	p_U
13	3.03	3.27	– 0.24	0.077	3.32	2.85	**0.47**	**0.000**
14	2.78	2.76	0.02	0.388	2.77	2.77	0.00	0.384
15	2.95	3.02	– 0.07	0.239	2.97	3.01	– 0.04	0.393
16	2.99	3.33	**– 0.34**	**0.002**	3.16	3.14	0.03	0.371
17	3.16	3.16	– 0.01	0.355	3.12	3.24	– 0.12	0.209
18	2.99	2.74	0.25	0.218	2.89	2.83	0.07	0.220
19	2.58	2.65	– 0.07	0.346	2.67	2.50	0.17	0.193
20	2.78	3.01	– 0.22	0.038	2.99	2.73	0.26	0.145
21	2.99	3.21	– 0.22	0.034	3.20	2.93	0.27	0.028
22	2.65	2.58	0.08	0.378	2.77	2.35	0.41	0.021
23	2.82	2.99	– 0.17	0.146	3.04	2.65	0.39	0.028
Average	2.95	3.00	– 0.05		3.02	2.90	0.12	

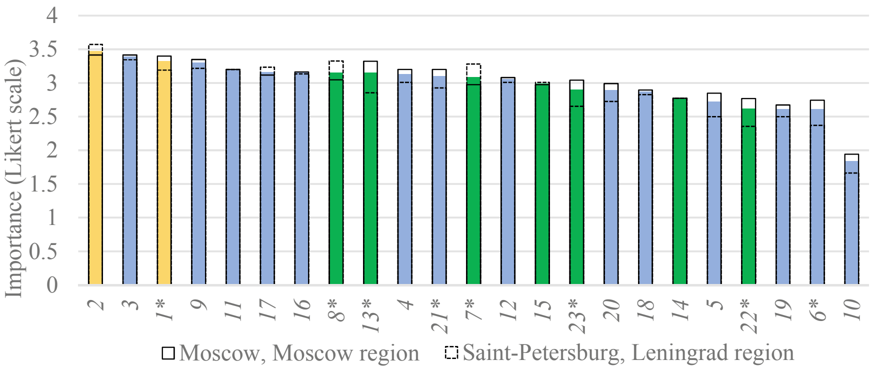


Fig. 23.3 Urban livability compounds, descending according to their importance: orange – economic, blue – social, green – environmental (public survey of Moscow, Moscow region, Saint-Petersburg, Leningrad region citizens). *Statistically significant differences

Therefore, the essential ecological issues (air pollution predominantly by mobile sources; stormwater retention; protection of wildlife habitats, coupled with reducing of free space due to ongoing urbanization of Moscow megapolis[12]) are not properly reflected in the residents' answers.

According to our results (Table 23.2), the distinctions of environmental compounds related to the place of residence (5 out of 7) are significantly more important than ones related to gender, age and education level (p of all compounds > 0.05). At the same time, no significant relation between the respondents' batches and the perception of economic issues (№ 1–2) has been revealed.

The hypothetical assumption about the less importance of 13–15 livability compounds for the respondents possessing GI most might be made (Fig. 23.3). However, most of the livability compounds have no significant relation to the GI share within 1-h proximity isochrones ($r_{s\ max} = 0.20$, negligible relationship) as well as to the access to the large GI cores ($r_{s\ max} = 0.17$, negligible relationship) (Fig. 23.4).

23.3.2 Expert Interviews

The respondents aged 20–29 make up most of the sample (Fig. 23.5). Any comparisons between the respondents aged below 40 and above 40 are unreliable due to the small sample. Therefore, two groups (below 30 and above 30) have been compared. Twelve experts received PhD degrees. Only three experts specialize in environmental

[12] Moscow Department of land use and nature protection (2016–2020) Reports on the environmental condition of Moscow city (In Russian). https://www.mos.ru/eco/documents/doklady/.

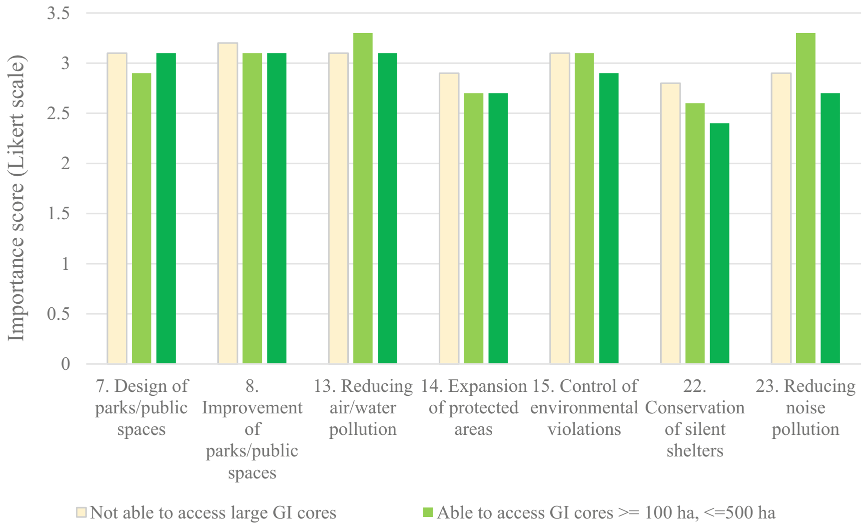


Fig. 23.4 The mean importance values of environmental compounds depending on GI access

protection and biogeography, while most of the respondents are focused on professional occupations in the field of spatial planning and architecture or social studies (regional, social, cultural geography and tourism).

The leaders of expert choices in Belgrade are: reducing pollution (№ 13), job creation (№ 1), improvement of public transportation (№ 16), income rise (№ 2), and design of new parks and public spaces (№ 7). Serbian experts are quite interested in the improvement of the ecological state (Fig. 23.6). The key differences between Moscow and Belgrade's perceptions are related to the local geographical peculiarities: common unfavourable weather conditions including high pressure, temperature inversions, smog in Belgrade (Đurić and Vujović 2020), even resulted in public protests[13]; lack of high capacity rail system, heavy reliance on buses, frequent traffic congestions due to motorization increase (Jovanovic 2013); inadequate, but improving waste management and wastewater treatment,[14] etc.

However, no significant relation between the perception of environmental factors and groups of respondents has been revealed (p_U of all compounds > 0.05). Jobs creation, improvement of healthcare and education quality (№ 3), and digitalization (№ 12) are more important for women experts, and expansion of leisure objects (№ 18) – for men experts. The experts aged below 30 are more interested in the

[13] N1 news. https://rs.n1info.com/english/news/hundreds-of-belgrade-citizens-in-protest-against-air-pollution/.

[14] Coalition 27 (2018) Chapter 27 in Serbia: No-Progress Report. https://rs.boell.org/sites/default/files/uploads/2018/06/izvestaj_k27_2018_eng_web.pdf.

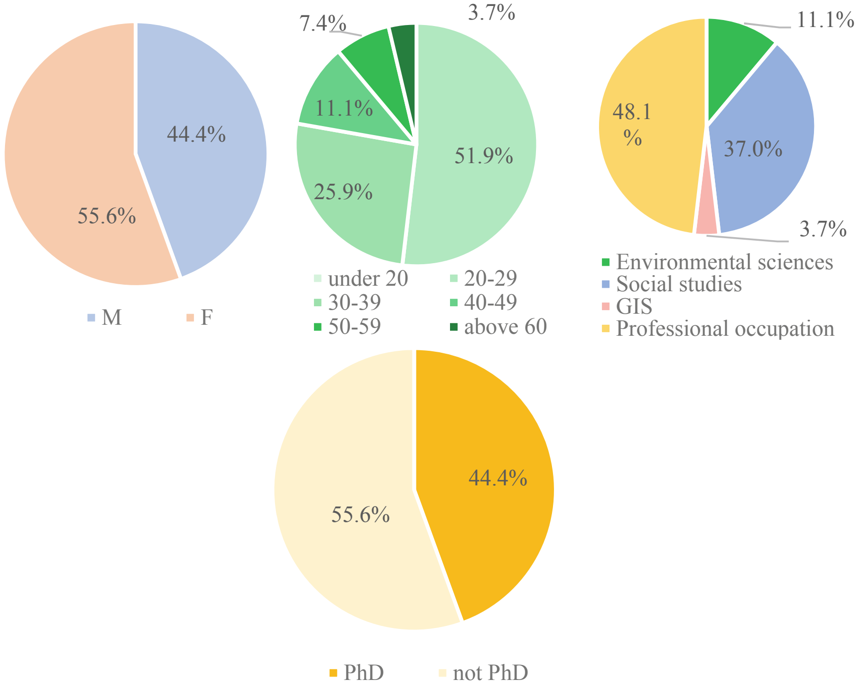


Fig. 23.5 From left to right: gender, age, field of the professional activity, position/academic degree of Serbian experts

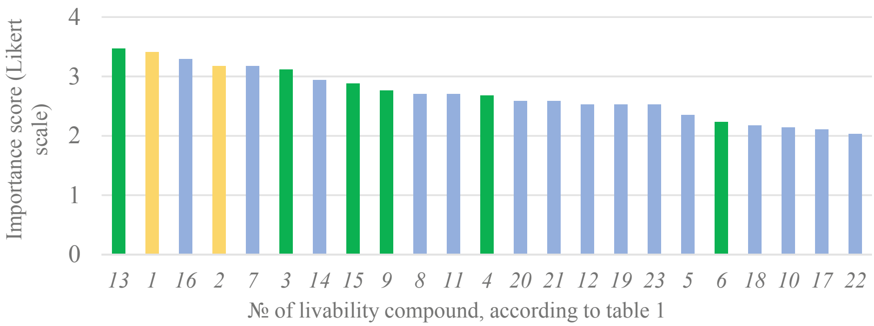


Fig. 23.6 Urban livability compounds, descending according to their importance: orange – economic, blue – social, green – environmental, interviews of Belgrade experts

development of sport facilities (№ 5). The experts without an academic degree tend to be keener on the problem of job creation (№ 1).

23.4 Discussion of Results

The environmental bunch of compounds could not be regarded as an essential factor of well-being, according to the interviews of Moscow and Saint-Petersburg citizens. Similar results of Moscow content analysis through the analytic hierarchy process (AHP) (Saaty 2004) have been obtained earlier based on pair-wised comparisons of each pair of urban livability compounds (Kryukov and Golubeva 2020). Content analysis of scientific and realty assessments surveyed earlier and expert interviews have been applied. The sum of environmental factors was estimated to be 2 times less important than the sum of social factors. Moreover, the economic elements of urban livability, such as income level, have not been assessed at that time.

No significant relation between the GI proximity within the specific city and reported SWB has been found earlier (Dushkova et al. 2021). Regardless of this fact, it has been repeatedly elicited that GI proximity, size and availability strongly influence the physical and mental health of dwellers (Ridder et al. 2004; Dennis et al. 2020; Hunter et al. 2019). Hence, the gap between objective GI value and its subjective perception by public should be considered significant and even alarming.

Possible limitations of this survey may be related to the inaccurate locations of post service areas, even though such procedure is widely used. Interviews within focus groups distinguished by demographic, education or answers to the main question may result in more reliable outcomes, but such a study seems to be less feasible as larger financial costs are required and rare respondents are ready to provide specific locations of their residence places. The spatial resolution of Landsat 7 imageries (30 m) has not brought significant inaccuracy compared to the maximum distances from post office locations to residents more than 2 km. Moreover, some preferences in the importance of specific livability compounds might have been determined by the place of interview attending, mostly at home. However, the role of environmental compounds seems to be not overstated as interviews have not been carried out within urban forests, parks or public gardens. At the same time, the demographic of residents is quite close to the official statistical data of Moscow and Saint-Petersburg.

However, it is crucial to implement an approach that combines both public and expert interviews in urban planning of green infrastructure, since the livability concept includes subjective evaluations of comfort based on feelings and objectively estimated compounds (Levent and Nijkamp 2006), such as harmful pollutant emissions, low proximity of education and healthcare facilities, high unemployment rate, outdated utilities, emergency housing conditions, etc. Hence, the experts related to urban studies and possessing a high level of awareness and consciousness have expressed their strong demand for the solving of environmental problems, even though most experts do not specialize in ecology and environmental studies. Such disparity between the grassroots and professional perceptions may be an important argument for changes in the system of spatial planning and environmental education.

The psychological linkage between the place of residence and green infrastructure is quite complicated, but it is considered to be more important than factors of gender and age, which corresponds to similar surveys conducted before (Lamond and Everett 2019). Besides, the essential problem of the low involvement of citizens in environmental design exists. The current demand for the preservation of the most valuable urban green infrastructure parts – protected areas – is rather distinct, but at the same time, it involves merely a small number of activists. The detected gap between livability compounds will likely become more significant as global and regional challenges are translating into great economic and social problems. Nonetheless, environmental issues and in particular the design of green infrastructure must remain at the core part of urban management. Most of the green and blue spaces are almost indispensable, and the recovery costs of commensurate ecosystem functions would be enormous, given actual economic transformations.

23.5 Conclusion

The inconsistency between public and expert mindsets in terms of environmental compounds' role should be surveyed further. Despite current international and regional economic and social challenges, environmental factors are still important to provide a comfortable urban space. This blueprint of expert opinions should be implemented not only in urban environmental policy but also unveiled to the public and embedded into environmental education and propaganda.

Besides questionnaires dissemination amongst public and experts, this survey may be continued in the following areas:

- comparing the results of online and on-site text individual mass interviews;
- dynamic interviews over several years to reveal responses to social, economic and environmental issues by different population groups;
- gathering focus groups of old timers/new settlers and residents with a standard 5-day on-site work week/residents working mostly online or attached by freelance contracts;
- narrative analysis of chosen respondents to identify the main points of interest in the areas of their residence;
- AHP (analytic hierarchy process) implementation into experts' interviews;
- design hypothetical scenarios of willingness to pay for the protection of the nearby environment – how much the different groups of residents are going to pay for it?

These issues are strongly linked to the applications of environmental policy and should be analysed to develop the new eco-oriented mindset of urban citizens. Nonetheless, it would seem that the ecological dimension may be neglected as basic needs satisfaction will decline over years due to economic and social shocks, according to Maslow's pyramid. But the place of environmental factors in livability should not be overstated, from our standpoint. On the contrary, the delicate programmes of environmental education should become one of the prior goals of urban environmental policy around the world, especially in developing countries substantially vulnerable to economic issues.

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