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SUITMA 9: URBANIZATION — CHALLENGES AND OPPORTUNITIES FOR SOIL FUNCTIONS AND ECOSYSTEM SERVICES

Evaluation of environmental health of the Kolomenskoye Park under anthropogenic pressure from Moscow City

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Abstract

Purpose The purpose of this paper is to evaluate the environmental state of the territory of the famous Russian landscape-architectural museum Kolomenskoye. This park reserve is located on the left bank of the Moscow River in very close proximity to a heavy industrial area of Moscow and a major highway. The museum's territory is of a concern to the environmental state, and our data is a part of the monitoring program.

Materials and methods Assessments of snow, snow run-off, and soils were carried out to describe the current state of the environment. Analyses of the pH, major cations, conductivity, heavy metals (Pb, Cd, Zn, Ni, Cu), and bioassay techniques were used to assess Kolomenskoye's area.

Results and discussion The content of acid forms of heavy metals (HM) in soils varied widely (Cu—1.3–21.6; Zn—2.7–30.2; Cd—0.07–3.48; Pb—2.21–15.64 mg kg^{-1}). High concentrations of Cd (3.48 mg kg^{-1}) were found at a distance from the highway, while the other parameters were at an accepted level. Meltwaters significantly increased the "leaching" of almost all soluble components, especially Na^+ ions (1–70 mg l^{-1}) and Ca^{2+} (10–340 mg l^{-1}) ones. The total load of HM (the sum of HM: Pb, Cd, Zn, Ni) near the road (2 m from the fence to the park) was 470 mg kg^{-1} and at the control plot (150 m from the fence)—it was 590 mg kg^{-1}, i.e., almost 20% more. The toxicity determined by different test objects was observed near the road.

Conclusions The data indicate a real threat of the pollution, not only for the territories adjacent to the highway but also to the remote areas. The intensity of pollutions is associated with the distance from the road and migrations of heavy metals. Their intensive penetration into the territory is mainly connected with small dust fractions.

Keywords Bioassay · Heavy metals · Kolomenskoye museum-reserve · Snow samples

1 Introduction

Kolomenskoye, a residence of Moscow Grand Princes and Russian Tsars, was first mentioned in the fourteenth century. Its unique architectural complex is of great art and historical value (Nashokina 2016). The ancient royal country residence of Kolomenskoye includes the Tsar's Courtyard complex (notably, a UNESCO site—the unique tent-roof sixteenth century Church of the Ascension), an open-air Museum of Wooden Architecture, and age-old gardens and parks, all the landmarks dating back from the fourteenth to nineteenth century. The complex of Kolomenskoye art and architectural museum-reserve occupies 254.6 ha. The unique landscape of Kolomenskoye bears traces of the life and activities of many generations (The Moscow State Integrated Art and Historical Architectural and Natural Landscape Museum-Reserve 2017). The preservation and restoration of the natural environment is one of the most important tasks of the museum-reserve in Kolomenskoye; there is a large number of old plants with historical, ecological, and esthetical values, which are the rarities not only for the museum-reserve, but also for Moscow City. The park and six gardens have always given a special beauty to the estate. The English oak trees planted here in the sixteenth century, fragments of the landscape park "Lipki,"

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the alley of linden trees planted at the beginning of the nineteenth century, the only European ash grove in the city, and the famous gardens of Kolomenskoye (Kolomenskie Sady) have survived until now (The Moscow State Integrated Art and Historical Architectural and Natural Landscape Museum-Reserve 2017). Alongside fruit trees, there are also berry shrubs, a lot of medical and spice herbs, fodders, and ornamental plants. The flora and fauna of the museum-reserve are extraordinarily rich and diverse. It includes a large number of rare and endangered species, including insects registered in the Red Data Book of Moscow City, 2011 (Samoilov and Morozova 2011). Of the plant world, the rarest are the species of *Dactylorhiza*, often called "Northern orchids," *Cota tinctoria*, *Dianthus deltoides*, *Thymus marschallianus*, and others.

Currently, Kolomenskoye, the monument of the cultural and historical Heritage, is under technological threat. Being in the vicinity of a large city creates a great recreational pressure, therefore, air and soil pollution, deterioration of the living conditions, and development of the plant world pose a threat to the preservation of valuable flora and integral cultural and historical monument.

The territory of the Kolomenskoye museum-reserve, located at the right bank of the Moscow River, in the south-eastern part of the city, is under a significant anthropogenic pressure, due to being in the proximity of the industrial zones and the overflow of tourists (Fig. 1). The environmental situation in the district is greatly influenced by the industries and the road traffic complex. Enterprises emit more than 30 types of harmful substances annually (16% of all Moscow enterprises). The emissions of carbon monoxide, nitrogen oxides, hydrocarbons, sulfur dioxide, and solids (dust) make up about 95% of the total emissions (Kuznetsov et al. 2017). The main sources of air pollutants are combined electric-power, heat-generating plants, and local heat stations. Enterprises in the energy complex account for about 39.4% of all the county's emissions. The environment is heavily damaged by road traffic with emissions exceeding 85% of the gross emissions of the enterprises' active and stationary sources. The main contaminants from road traffic emissions are carbon dioxide, nitrogen oxide, and hydrocarbons, as well as soot, sulfur dioxide, and lead (Evans et al. 2000).

2 Materials and methods

In order to carry out the analytical work, several plots were installed (Kazanskiy Garden, alley of linden trees in park "Lipki," Old Oaks, wasteland, territory of the administration building), where mixed soil samples and snow samples have been selected and analyzed for 2 years (soil samples) and one season (snow samples).

2.1 Chemical analyses of soil and snow samples

The studied soil properties are as follows: pH, mobile phosphorus (P) with colorimetric method by Deniges, potassium (K) by flame photometer, microelements, and heavy metals (HM) (Cu, Zn, Cd, Pb, Ni) by atomic absorption spectrophotometer Hitachi 180-80. In order to assess HM in the Park, several open plots were selected at different distances (2, 7, 25, and 50 m) from Andropov Avenue (Fig. 1) to depict the diversity of the landscape's heterogeneity and encompass various forms of relief. A compared control sample was collected at a distance of 150 m. Ten samples were selected from each plot by a soil sampler. The HMs were extracted with 1 n nitric acid and ammonium acetate buffer solution at pH 4.8.

Taking into account that along the highways, peculiar anthropogenic anomalies appeared, a further analysis of the snow cover from that zone was carried out. The melted snow and its solid balance (provisionally dissolved in the mixture of 10% HCl and 5% HNO_3) were analyzed as follows: pH (water, salt); cation exchange capacity; humus content; mobile P; cations: K^+, Ca^{2+}, Mg^{2+}, Na^+; mineralized dry residue; water extract; electrical conductivity; and HM content (Cu, Zn, Cd, Pb, Ni). Chemical analyses were carried out by standard methods (Mineev 2001).

2.2 The bioassays

The environmental health was assessed with bioassay. In the present work, the studies were conducted through three bioassays on infusoria, daphnias', and radish seeds. The phytotesting is based on methods developed and modified by the Department of Agricultural Chemistry and Biochemistry of Plants of Lomonosov Moscow State University (MSU) with the radish seeds (*Raphanus sativus*) (Cheremnykh and Voronina 2007). The phytotest is based on the seeds' high sensitivity to toxic substances (ISO 11269-2: 2012). The reduction in the length of the sprout roots was accounted for in the experiment to control (in percentage). The studies were supplemented by accounting the change of the coleoptile height (epicotyledonary burgeons) in the plants.

The bioassay on protozoa was measured by the survival response of infusoria *Paramecium caudatum*. The acute toxic activity of the sample was determined by the mortality (lethality) of the infusoria after a certain exposure period. The criterium of the acute toxicity is the death of 50% or more of paramecium in 24 h (Venkateswara Rao et al. 2007).

The bioassay on *Daphnia magna* Straus daphnias was conducted according to the method of assessment of the water extracts' toxicity from soils, sewage sludge, wastewater and natural water, and the mortality of the test object *Daphnia magna* Straus (ISO 6341: 2012). The daphnias

Fig. 1 Kolomeskoye layout

⟹ The trend of the located experimental plots

1 - Kazanskiy Garden

2 - Linden Trees

3 - Old Oaks

4 - Territory of the administration building

5 - Wasteland

were exposed for up to 96 h. The number of dead daphnias was compared between different samples and the control (cultivated water). At the end of the experiment, the number of living daphnias was visually accounted for in each of the receptacles (i.e., maxillopods, which move freely in the water or float from the bottom of the receptacle after a light shaking) (Method of determining the toxicity… 2011). Furthermore, the concentration of dissolved oxygen, pH, and temperature was measured in the control and in the experimental samples. Calculation of the dead daphnia percentage in the experiment in relation to control (A, %) was done using the equation $A = (Sc - Sw) \times 100/Sc$, where Sc is the arithmetic mean of the survivors in the control and Sw is the arithmetic mean of the survivors in the studied water.

3 Results and discussion

The soil monitoring is essential for the preservation and maintenance of valuable tree species in protected historical-cultural and natural territories. The soil analysis allows the measuring of the content of nutrients available to plants, the study of soil properties that have a direct influence on plant development, and the use of soil elements (Gerasimova and Stroganova 2003; Vasenev 2017).

Of particular interest is the study of soil profile and its development over time on the historical reserve's territory. In accordance with the description of soil profile, the museum territory's soils belong to the Albic Retisol (Table 1) (WRB 2014).

Soil is the main source of nutrition for plant growth and development. The soils of cultivated areas (gardens) belong to Horbic Antrosol (WRB 2014). Deficiency or excess of nutrients can lead to physiological disorders of plant growth and development.

3.1 Chemical analyses of soil

The agrochemical characteristics of the soils in the old tree areas are presented in Table 2. The obtained data is the evidence of a high variety of agrochemical properties that

Table 1 Description of the Albic Retisol (Siltic, Aric) soil unit. Museum-reserve "Kolomenskoye"

Ad (0–8 cm)	Brownish-dark gray, small spots of whitish material. Medium blocky grainy powder-like structure, sandy loam. Many roots (sod layer), inclusions of anthracite. Dusty crumbs, porcelain. Noticeable by color and wavy horizon boundary.
A, old-arable (8–40 cm)	Grayish-brown. Crumbly powder-like structure, sandy loam. Many small and medium roots, inclusions of anthracite. Packed soil, brick. Noticeable by color and wavy horizon boundary.
EB (40–62 cm)	Uneven color: there are whitish spots on the light brown background. Medium blocky, powder-like structure, silty loam. Average number of roots, white silica powder. Small worm tunnels. Noticeable by color and smooth horizon boundary.
Bt1 (62–104 cm)	Uneven color: there are whitish spots on the red-brown background. Medium blocky structure, silty loam. Roots, inclusions of anthracite, light loamy mottles. Whitish and wavy horizon boundary.
Bt2 (104–110 cm)	Red-brown, separate whitish spots. Prismatic structure. Layer of clay, small worm tunnels. Wavy horizon boundary.

determine the fertility of these areas. The soil acidity of the plots near and under the Old Oaks was neutral. In the "Lipki" Park, the environment's response was close to neutral. The neutral reaction of the environment is characterized by the soil in the wasteland and in the Kazanskiy Garden. The organic carbon content (2.3%) in the samples was evidence of a good state of soil cultivation. The mobile P content decreased with the years (from 168 to 67 mg kg^{-1}) and especially with the depth from 282 to 60 mg kg^{-1} (25–60 cm). Apple trees are quite undemanding to mineral supply. They thrive and fruit where field crops produce very low yields. This is because the roots of the fruit trees continue to consume nutrients after vegetation dies, even in winter when the soil freezes, and then this process begins well before spring vegetation. The main service that these gardens provide is esthetics rather than fruit yields. Observing the change in content of the nutrients in the soil allows us to adjust their levels. Trees also need periodic fertilizing with nutrients. Thus, whereas in 2013, the studied soils were categorized in the group of soils with high P (> 250 mg kg^{-1}), in 2014, these soils could be characterized as soils with medium P (150–200 mg kg^{-1}). Potassium content was correlated with P content ($r = 0.85, p < 0.05$). Very high K contents were found in the wasteland (1122 mg kg^{-1}—upper layer), which may be associated with the die-away and decomposition of plant residues. The high content in the soil samples from the alley of linden trees (533 mg kg^{-1}) may be associated with the use of deicing substances. Furthermore, at the plot under Old Oaks, it was high (163–178 mg kg^{-1}) and steadily increased in the lower horizon. In the Kazanskiy Garden, potassium content in the upper horizon was very high and decreased in the lower horizon. This element was taken out with the plant biomass, as well as through the migration, resulting in a noticeable decrease of the active K in the soil samples in 2014.

Throughout all territory of the museum, the content of acid forms of HM in soils varied widely (Cu—1.3–21.6; Zn—2.7–30.2; Cd—0.07–3.48; Pb—2.21–15.64 mg kg^{-1}) (Table 3). The content of the plant available forms of HM compounds

Table 2 Agrochemical characteristics of soil samples at the fixed plots

Points	Depth, (cm)	pH	Carbon (%)	P_2O_5 (mg kg^{-1})		K_2O (mg kg^{-1})	
				1*	2*	1*	2*
Kazanskiy Garden	0–25	5.89	2.3	168	87	311	120
	25–60	5.60	1.8	282	60	206	150
Linden trees	0–25	5.75	1.9	192	180	533	474
	25–60	6.00	1.6	168	150	336	340
Old Oaks	0–25	4.65	2.8	68	58	163	122
	25–60	5.00	2.2	68	40	178	143
Wasteland	0–25	5.72	3.4	292	210	1122	921
	25–60	5.75	2.5	392	250	632	542
Territory of the administration building	0–25	6.62	2.8	322		410	
	25–60	6.96	2.3	212		212	

*Years of experiments: 1—2013; 2—2014

Table 3 Heavy metal content in various extracts, in milligrams per kilogram

Points	Depth (cm)	Cu	Zn	Cd	Pb
1 n HNO3					
Kazanskiy Garden	0–25	21.6	30.20	3.44	16.25
	25–60	8.9	3.37	1.08	2.69
Linden trees	0–25	2.28	4.75	3.48	5.88
	25–60	2.22	4.60	0.14	3.29
Old Oaks	0–25	0.96	2.70	3.46	2.21
	25–60	0.94	2.89	3.03	2.61
Wasteland	0–25	1.72	3.23	0.08	3.11
	25–60	1.28	4.59	1.24	1.97
Territory of the administration building	0–25	2.99	3.66	0.07	5.25
	25–60	2.04	4.78	2.98	4.56
AAB, pH = 4.8 (ammonium acetate buffer)					
Kazanskiy Garden	0–25	1.93	4.85	1.06	0.90
	25–60	0.57	3.6	0.84	0.41
Linden trees	0–25	1.2	1.69	1.31	0.89
	25–60	0.07	1.34	2.59	0.76
Old Oaks	0–25	> 0.01	0.49	1.53	0.75
	25–60	0.05	0.57	3.62	18.9
Wasteland	0–25	> 0.01	2.34	> 0.01	0.05
	25–60	> 0.01	1.64	0.01	0.05
Territory of the administration building	0–25	> 0.01	2.20	> 0.01	0.39
	25–60	0.01	1.74	0.01	0.25

extracted with the acetate ammonium buffer solution exceeded the background values and ranged from 0.01 to 1.93 mg kg^{-1} for Cu, from 0.49 to 4.85 mg kg^{-1} for Zn, from 0.01 to 3.62 mg kg^{-1} for Cd, and from 0.05 to 18.9 mg kg^{-1} for Pb. It should be noted that the variability of HM content in the soils of the museum-reserve was high. The highest concentrations were indicated in the upper humus horizons due to the high accumulation of HM by the organic part of the soil. The level of HM content (Cu, Zn, Cd, Pb) on surveyed territory was low (Methodical Recommendations for the Detection of Dehydrated and Contaminated Lands 1995). The cadmium content was an exception. The main load was observed in the Linden Alley area. The distribution of plant available forms of compounds was closely related to the distribution of their acid forms. In the early stages of pollution, the content of available HM forms is assumed to be more informative. For these forms, the total loads of HM did not exceed the approximate acceptable levels, which may be explained by the precautionary and competent approach in protecting the reserved area, as well as by the abiotic factors such as neutral or close to neutral soil environment and a protective role of plants. Data on the analysis of the content of the potentially mobile HM forms indicate their significantly increased amount, especially in the Kazanskiy Garden area, in the topsoil. It shows that in the topsoil, forms of HM were probably linked to organic formations.

High Cu content can be caused by the cultivation of the garden with plant protection chemicals. The presence of Zn, in case of its presence in the lower horizon (25–60 cm) in the plant available forms, can be regarded as a positive factor as it is an essential micronutrient for trees.

3.2 Chemical analyses of snow samples

The loaded highway (Andropov Avenue) is adjacent to the park, causing a risk of pollution to the reserve complex. An analysis of snow cover, in the plots located at different distances from the highway, was carried out. The snow cover accumulates almost all of the substances from the atmosphere, showing the dynamics of pollution. This makes it a useful pollution indicator, not only of the precipitation itself, but also of atmospheric air composition and of subsequent contamination of the soil and water. In the formation of the snow cover, due to dry and damp impurity processes, the concentration of contaminants in the snow is two to three orders higher than that in the ambient air (Kim and Kannan 2007; Sorokina et al. 2013). That is why the analysis of snow meltwaters highlights the nature and the process of pollution (Zajac and Grodzińska 1982). The main focus of the study on the geochemistry of snow cover in cities is the transformation of the physical and chemical properties of the snow (pH and mineralization of melt water, content of suspended particles and phosphorus) compared to the background territories (Sorokina et al. 2013; Nikiforova et al. 2014) and the accumulation of its organic and inorganic pollutants, which include HM, metalloids, petroleum products, and polycyclic aromatic hydrocarbons. The increased pollution of snow along the roads is caused by the reduced efficiency of motor vehicles below 0 °C (Engelhard et al. 2007). In the snow cover of cities, Cu (emitted by road braking at the gates and lights), Zn (rubber-coated), and Pb (use of leaded gasoline) are the most intensively accumulated. The content and amount of HM in the solid residue, and in the small dust fraction adsorbed on the snow cover, were assessed. It is important to emphasize that at a 50-m distance from the highway, there is a risk of soil and plant contamination, but the characteristics provided in Table 4 indicate a sharp braking of many negative processes. The concentration of H^+ ions was reduced near the highway, while the alkalinity of snow cover increased, but this factor stabilized with distance. The snow-water's pH (7.3) can be explained by the dissolution of the mineral dust accumulated in the snow cover, as the mineral dust has a highly carbonate composition (Ca^{2+} 268 mg l^{-1}). Meltwaters significantly increased the "leaching" of almost all soluble components, especially Na^+ ions (1–70 mg l^{-1}) and Ca^{2+} (10–340 mg l^{-1}) ones. High concentrations not only of cations but also of anions were observed in the solution, with some elements (Cl^-) maintaining high at a distance of up to 50 m (83.3 mg l^{-1}). As it was to be expected, the concentrations of ions correlated with the indicator of mineralization (0.09–1.67 mg l^{-1}) and the electrical conductivity (100–2500 ms cm^{-1}) ($r = 0.76$, $p < 0.05$).

In the filtered water, the contents of HM were low (Table 5), indicating that the HM presented in the aerosols, the dust, and the colloidal particles had mostly been adsorbed on the surface of the particulates, saturating the snow cover. The table shows the results of HM content on the filter, that is, in solid precipitation after filtering. Metal concentrations are very significant, with the distribution depending on distance, sediment mass, and HM concentration. The toxicants' maximum pollution occurred in the small dust fraction (< 2 μm) of the particle size (Förstner and Salomons 1980; Wang et al. 2006; Ladonin and Karpukhin 2008). They have lower density, so they spread over considerable distances and the concentration of HM increased.

Table 5 Content of the trace elements in the filtrates of snow samples, in milligrams per liter

Distances from the highway (m)	Pb	Cd	Zn	Ni
2	0.0002[a]	0.0014[a]	0.13[a]	0.003[a]
7	0.0002[a]	0.0010[a]	0.02[b]	0.003[a]
25	0.0002[a]	0.0014[a]	0.02[b]	0.003[a]
50*	–	–	–	–

Values within a column followed by the same letter are not significantly different based on LSD ($p < 0.05$)

*Less than the detection limit

This data shows a real threat of pollution not only to the areas adjacent to the highway but also to the remote areas. The total load of HM (the sum of HM: Pb, Cd, Zn, Ni) near the road (2 m from the fence to the park) was 470 mg/kg and at the control plot (150 m from the fence)—it was 590 mg/kg, i.e., almost 20% more (Fig. 2).

At the plots away from the road (Kazanskiy Garden, wasteland, Linden Alley, administration building), the results of the snow cover analysis can be used to estimate the pollution intensity of the territory. pH levels were not substantially different from the above. In the open territory, the pH was < 8.0 and the concentration of Ca^{2+} ions decreased. The sum of Ca^{2+} and Mg^{2+} cations was very small, and in the area of the museum-reserve, it ranged from 5 to 10 mg/l. The concentration of anion chlorine was small. The sum of cations (Ca^{2+}, Mg^{2+}) was represented in small quantities (6.7–9.8 mg/l), and its maximum concentration was found at the administration building plot. An increase in electrical conductivity was detected at this plot. The deicing products were likely to have been used in winter, near the administration building. The results of the snow analysis in this area are quite different from the snow data near the highway, on the open area (Table 6).

The ecological state of the territory under investigation was also characterized by the concentration of HM in the soil, determined with 1 n HNO_3 and ammonium acetate buffer (AAB, pH = 4.8). The extract with 1 n HNO_3 characterizes the entire supply of potentially available HM compounds. Nitric acid extracts of metal ions were either included into the soil

Table 4 The results of the snow cover analysis

Distances from the highway (m)	pH	Conductivity (ms cm^{-1})	Solid residue (mg)	Mineralization (g l^{-1})	K^+ (mg l^{-1})	Na^+ (mg l^{-1})	Ca^{2+} (mg l^{-1})	Mg^{2+} (mg l^{-1})	Cl^- (mg l^{-1})
2	7.5	2102[a]	27.3[a]	1.53[a]	20.5[a]	43.0[a]	268.0[a,c]	59.2[a]	415.3[a]
7	7.0	848[b]	5.8[b]	0.39[b]	6.0[b]	1.5[b]	69.6[b]	15.9[b]	154.4[b]
25	6.9	117[c]	2.3[c]	0.14[c]	1.0[c]	–	13.6[c]	11.7[c]	103.0[b]
50	7.1	84[d]	1.4	0.08	–	–	16.4[c]	10.2[c]	83.3[b]

Values within a column followed by the same letter are not significantly different based on LSD ($p < 0.05$)

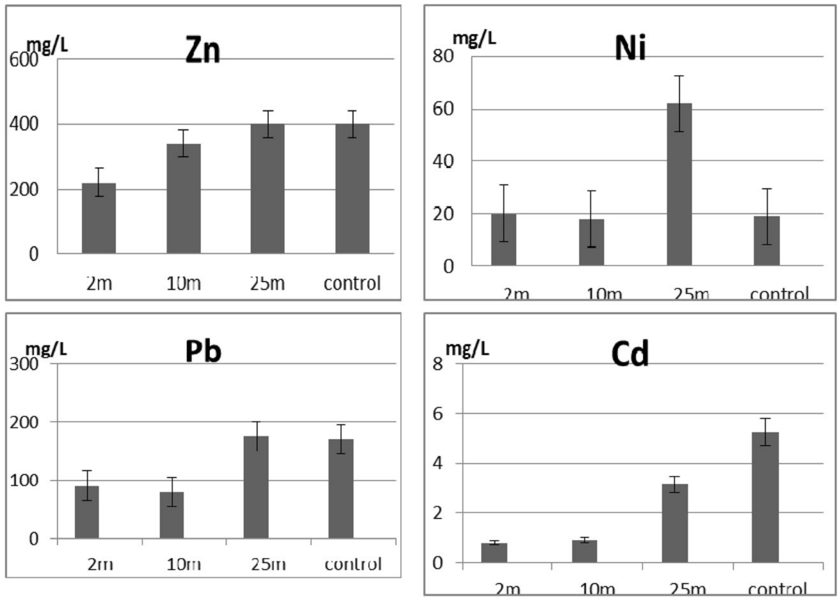

Fig. 2 Content of the trace elements in the solid residue of snow samples, in milligrams per kilogram (the control is the point at a distance of 150 m from the highway)

absorption complex in the form of exchange cations, occluded by mineral soil components, or formed a part of integrated soil organic compounds. In addition, nitric acid contributes to the dissolution of carbonates and other HM soluble compounds. The calculation of the mobile metal compounds in AAB allowed to assess micronutrients available for plant uptake, as well as to evaluate the ecological state of soils with heavy metal contamination. The data is provided in Fig. 2.

3.3 The bioassays

An ecotoxicological approach using biological tests on target organisms at different trophic levels has been recommended for the sophisticated assessment of environmental hazards to complement chemical analyses (Cheremnykh and Voronina 2007; Boluda et al. 2011). The method of biotesting in conjunction with the bioindication and both chemical and analytical methods has a number of undeniable advantages. Bioassay can capture negative changes with relatively weak anthropogenic loads. The total toxicity in samples from plots (Kazanskiy Garden, linden trees, Old Oaks, wasteland and territory of the administration building) was not established.

These results confirm the low level of HM content in the reserve soils which is comparable to the level of HM content in the soils of foreign cities' reserves, such as the Albufera Natural Park in Valencia (Spain); Glasgow (Great Britain), Warsaw (Poland) (Gil-Sotres et al. 2005; Lehmann and Stahr 2007; Sujetoviene and Griauslyte 2008).

At a distance of 50 m from the road, phytotest parameter (root length) was the highest which may evidence the lowest toxicity in this plot. The toxicity was established to be the highest at the road (2 m from the road), where the decrease in root length made up more than 20%. At a distance of 150 m, the growth of roots declines again (10% less comparing to the maximum).

The bioassays' results with the test object *Paramécium caudátum* and the test object *Daphnia magna* correlated with the phytotest's results with the test object radish seeds ($r = 0.85–0.95$, $p < 0.05$). The lethality was found to be 30–35% at a distance of 2 m from the road down to 10% at a distance of 50 m from the road. The lethality of the organisms was lower at a distance of 150 m (control) than that in the plots close to the road but higher than that at a distance of 25–50 m (15–25%).

The ecological state of the territory was also determined by bioassay of soil samples from different "alarm" or "fiducial"

Table 6 The results of the snow cover analysis at the fixed plots

Fixed plots	pH	Conductivity (ms cm^{-1})	Solid residue (g)	Mineralization (g l^{-1})	Ca^{2+} mg l^{-1}	Mg^{2+}	Cl^{-}
Linden trees	7.10	43.1	0.0014	0.093	6.0	0.7	26.6
Wasteland	8.00	34.0	0.0014	0.093	4.0	0.5	21.3
Territory of the administration building	6.99	51.9	0.0009	0.060	8.4	1.4	37.3

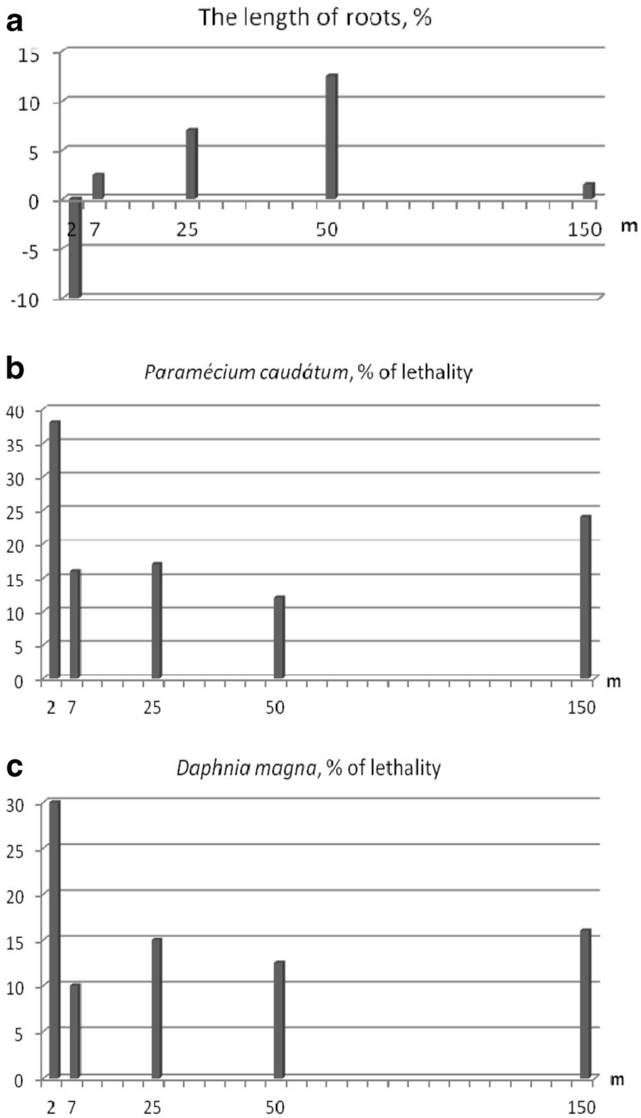

Fig. 3 The bioassays. The samples were taken from the plots at different distances from the highway: 1–2 m, 2–7 m, 3–25 m, 4–50 m, and 5–150 m. **a** Test object: radish seeds; test parameter: the length of roots, %. **b** Test object: *Paramécium caudátum*; test parameter: lethality, %. **c** Test object: *Daphnia magna*; test parameter: lethality, %

points within the reserve. The results for some of the test crops used for estimating the total toxicity are presented in Fig. 3a–c). The toxicity determined by phytotest (*Raphanus sativus*) was observed in the samples selected near the Andropov Avenue. The toxicity determined by other test objects (*Paramécium caudátum*, *Daphnia magna*) was confirmed by the increased lethality of the test parameters.

4 Conclusions

Soil acidity changes towards the alkalization, which is typical to urban soils. Studied areas are characterized by high soil fertility; however, there is a downward trend of mobile P and K content, as well as a rise of soil acidity, in the soil of Kazanskiy Garden and the "Lipki" alley. A preliminary evaluation of soils by HM pollution indicates that the maximum acceptable concentrations are not exceeded in potential available forms. An increase of Cd of the active HM forms was found in the area under the Old Oak and in the alley of linden trees.

The results of the snow water analyses showed alkalinization. The increased mineralization and high content of base cations and anions were found in the areas near the Andropov Avenue, mainly due to the use of deicing products. Solid residues of snow in the museum-manor are characterized by significant pollution of HM (Pb, Cd, Zn, and Ni), with maximum pollution observed at the areas located between 2 and 50 m from the highway.

Monitoring studies are needed to detect changes in the ecosystem's state. Preliminary studies using bioassay are an alarm of possible negative processes. The research shows that the territory of the Kolomenskoye museum-reserve is a self-contained ecosystem structure and has barriers against urban pollution. Despite this, the intensity of pollution from the highway is a real threat.

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