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Soil composition and properties: a case study of Shilovsky Upland Oak Forest (Russia)

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Abstract. The paper deals with environmental properties of the soil cover taken from the Upland Oak Forest (Voronezh region, Russia). Morphological structure, physical and chemical properties, humus content and nutrients in urban forest soils are important for assessing their ecological status. Forest soils are characterized by a low degree of disturbance and close to the morphological structure to of the natural analogs outside the cities. Dark grey forest-steppe soils have the most favorable environmental properties. The low contents of total forms of heavy metals allows for the consideration of these soils in the category of environmentally friendly. The highest contents are characterized by the humus horizons of dark grey and grey forest-steppe soils, which maximum content is for Mn 754, Zn 49, Cu 13, Pb 16, Ni 25, Cd 0.26, Cr 60, Co 9, As 0.1, and for Hg 0.1 mg/kg. The content of mobile forms of heavy metals reaches Mn 105, Zn 0.9, Cu -5, Pb 1.8, Ni 2.6, Cd 0.08, Cr 0.2, and Co 2.9 mg/kg. The obtained data can be used to assess the degree of disturbance and anthropogenic impacts on anthropogenic-altered urban soils. The study area may be used as a background in assessment of the urban environment.

1. Introduction

Urban environment is a peculiar area evolving and maintaining natural, technological and social subsystems. Qualitative and quantitative characterization of industrialized urban environment remains highly relevant in large cities due to constant and widespread anthropogenic influence [1].

Soils are an indicator of the ecological state of the urban environment since it accumulates and transit of all pollutants came from occupational and natural sources [2]. The problems of studying forests and forest soils in cities are of interest to scientists around the world. The using of native and exotic invasive seedlings in urban forests [3], potential indicators of soil quality in temperate forest ecosystems [4], forest soil condition database links soil physicochemical and hydraulic properties [5], effects of soil preparation methods and plant types on the establishment of poplars on forest land [6] and other problems have been investigated.

Voronezh is the capital of the Central Chernozem region of the Russian Federation and a major administrative, industrial, social and cultural center with a population of over 1 million people. It is an example of a major center with a complex urban ecosystem, where a considerable area is occupied by forests of different sizes, which are included in the ecological framework of the city and largely determine the quality of its environment. Conventionally, natural ecosystems within the city can be considered green infrastructure. The main component is a forest area of over 1200 hectares. Forests can be used as a background of areas with natural soil types. Usually small forests interspersed with commercial facilities of the city and their soils are experiencing intense human pressure. In large forest



areas forest management is sporadic. Therefore the soils are natural and are considered to be background components of the urban environment.

The green belt of Voronezh city has scientific interest. We have studied in detail the composition and chemical properties of grey forest soils of the Voronezh region [7], conducted research by Voronezh scientists of chemical pollution of coppice oak forests in the green area of Voronezh [8,9], the productivity and the longevity of Voronezh highland oak forest [10, 11]. Much attention is paid to the study of oak vegetation [12]. However the chemical, physical properties of forest soils, the content of heavy metals in them remain hardly studied. The purpose of our research is to monitor composition and properties of the soil cover of oak trees that grow within the territory of the city of Voronezh with a million population.

2. Materials and methods

In our work we characterized the urban forest soil taken from the Shilovsky Upland Oak Forest (51°57'29.54" N 39°17'15.23" E to 51°59'71.43" N 39°18'08.25" E, Voronezh, The center of the European part of Russia) having the area of 1200 hectares. The Shilovsky forest was incorporated into the urban system at the end of the 20th century. Therefore, this forest had a minimal infrastructure. The study area clearly defined boundaries on top of the slope. The area has considerable slope and is crossed by numerous ravines. The difference in elevation of bottom of the slope and adjacent watershed is 40-60 m.

Complete soil profiles were laid out at the top (near the watershed) and middle parts of the slope. The samples of grey and dark grey forest-steppe soils were selected from each genetic horizon using a soil knife in the summer at $+24 \pm 2^\circ\text{C}$. The maximum depth of soil profiles was 150 cm. After that, samples were dried to an air-dry state within 2 weeks at $+22 \pm 1^\circ\text{C}$. Then the soil samples were crushed prior to take the fraction with particles size of 1 mm for further analyses.

The granulometric composition was determined by the pipette method (Kaczynski method) using a Stokes pipette. The pH of soil solution with KCl was determined by potentiometric method on a set pH-meter/ion meter S500 Seven Excellence (S500-Fluoride) (Mettler Toledo, USA). Also we measured the sum of exchangeable bases (Ca^{2+} and Mg^{2+}) by complexometric Giedroyc's method using the reaction with $\text{C}_{10}\text{H}_{12}\text{N}_2\text{O}_8\text{Na}_4 \cdot 4\text{H}_2\text{O}$ (Spektr-Him, RF). Hydrolytic acidity of soils was determined by titration method (Kappen's method) with NaOH (Vekton, RF). The wet ashing method (Tyurin's method) we used to find humus content in the samples. $\text{K}_2\text{Cr}_2\text{O}_7$ (Spektr-Him, RF) solution was used as an oxidizer. Mobile forms of phosphorus were determined by photoelectrocolorimetry method on a KFK2 (ZOMZ, RF) (Chirikov's method). Exchangeable potassium was determined by atomic emission spectroscopy method on a PFA 378 (Uniko, RF) (Chirikov's method). Hydrolyzable nitrogen was determined by titration (Kornfeld's method) (1N NaOH) (Vekton, RF) [13].

Before to measure heavy metals (gross forms) soil samples are treated with acids such as HNO_3 (5 ml), HF (4 ml), HCl (1 ml) and finishing on the atomic absorption spectroscopy Kvant-2A (Kortek, RF) [14].

3. Results and discussion

More than 70% of the forest surface slope of the area is occupied by the wet oak forest of bonitation class III – IV with different variations of gray forest-steppe soils. The upper portion of the slope is 1-2°. Soil cover is represented by dark gray forest-steppe soils. The humus horizon here (A1+A1B) is 50-60 cm thick. These soils are replaced by their eroded counterparts on elongated areas with 2-3° slopes. In these soils the humus horizon is thinner (A1+A1B = 33-43cm). Some areas in this part of the slope are characterized by a distribution of gray forest-steppe soils. In them the thickness of horizons A1+A1E varies from 35 to 40 cm or from 15 to 27 cm, depending on the steepness of the slope. In the middle part of the slope, the steepness is more than 10-15°, rarely 3-5° or 5-7°. Here the basic compounds (humus and nutrient elements, exchangeable bases) of the soil are washed out of the soil. Their humus horizon is strongly washed away. These soils exhibit a regular alternation in the degree of flushing. The slope was just above the reservoir. There is a narrow, weakly expressed

microzone here of reclaimed soils, up to 70-90 cm deep. They play a minor role in the soil cover structure of the forest ecosystems of the Upland Oak Forest.

Это наши результаты исследований, прежде чем переходить к результатам анализа, важно показать морфологическое строение почв.

The complex tree structure of the soil cover is formed by elements of the hydrographic network, such as the ravines. Reclaimed soils are distributed at the bottoms of ravines. On the slopes there is a high degree of variability in the soil cover due to differential erosion rates within a single slope. The complexity and contrast of soil conditions is enhanced by high moisture at the bottoms of slopes and groundwater. The soil profile of dark grey forest soils has a morphological structure:

O 3...5 cm: a litter represented by leaves of oak, maple, pears of different degrees of decomposition.

Ad 0...6 cm: dry, gray with a brownish tint, fine-grained, medium loamy, on the faces of structural separations marked whitish plaque silica powder, densely intertwined roots of herbaceous vegetation, slightly compacted, the transition is noticeable.

A1 6...30 cm: fresh, gray, finely nutty structure, light loamy, the roots of herbaceous vegetation, the abundance of moves the worms, sealed, transition noticeable by color.

A1B 30-43 cm: fresh, gray with a brownish tint, nutty-prismatic, slightly loamy, roots of herbaceous vegetation, compacted, the transition is noticeable in color.

B 43-66 cm. Fresh, light brown, lumpy-prismatic structure, medium-loamy, the roots of woody vegetation, denser than the previous, the transition is gradual.

BC 66-85 cm: fresh, non-uniform, brown spots of different intensity, coarse, medium-loamy, roots of woody vegetation, denser than the previous, the transition is gradual.

C 85 cm and deeper: fresh, non-uniform, brown spots of different intensity, lumpy, medium-loamy, roots of woody vegetation.

Thus, the morphological structure of grey forest soils in urban oak forests is similar to their analogues in natural forests.

Many of dark grey and grey forest soils formed on the surface loam. They were land by fluvioglacial sediments at shallow depth. In these soils, the morphological and genetic traits are expressed most fully.

Grey forest medium loam soils contain 35-42 % of physical clay (sum of soil particles smaller than 0.01 mm). The proportion of clay fraction is 14-25 % (table 1). Humus and humus-eluvial horizons are well-structured. The proportion of structural units with size 10-1 mm is 75-85 %. They have high water stability. The amount of humus in the 0-20 cm layer is 5.1-6.6 % in dark grey soils and is 3.2-4.8 % in grey soil (table 2). The humus content gradually decreases to 1.0-1.5% at a depth of 50-60 cm. The sum of exchangeable bases is in the range 22-30 mEq/100 g throughout the soil profile. The value of hydrolytic acidity is 2-7 mEq/100 g up to 1 m depth and sharply decreases to 0.4. deeper than 1 m. The degree of saturation of the bases gradually increases with depth from 82-88 % in the layer of 0-20 cm to 90-98% in the layer of 140-150 cm. Reaction of the soil environment is weakly acid ($\text{pH}_{\text{KCl}} = 4.5-5.5$) in the A1 horizon or close to neutral ($\text{pH}_{\text{KCl}} = 5.6-5.8$). It changes to acidic in the A1E horizons (there is no EB horizon, and the pH increases in the B). The reaction of the soil environment is neutral at depths below 120 cm (table 3). The content of mobile forms of phosphorus (6.0-9.1 mg/100 g) and exchangeable potassium (16.4-18.9 mg/100 g) corresponds to the average of their provision in the humus horizon. The content of exchangeable potassium (K₂O) changes little with depth, and the content of phosphorus (P₂O₅) increases (table 2).

The eroded grey forest soils on the slopes are characterized by a short humus horizon and a pronounced light horizon. "Nut" structure is present in the middle part of the soil profile. Unfavorable physical and physico-chemical properties in these soils include little humus and nitrogen, and a low content of the mobile forms of phosphorus and exchangeable potassium. They have low rates of forest productivity. Although herbaceous and woody vegetation largely inhibit erosion, some water erosion occurs due to the low quality of the granulometric composition (a small content of particles less than 0.01 mm). Average dust fraction (particle size of 0.01-0.001 mm) dominates in the composition of

physical clay. Medium sand fraction predominates in the composition of the physical sand (sum of soil particles larger than 0.01 mm). Small thickness of well-structured layer and poor water stability of soil structural aggregates contribute to the manifestation of water erosion.

The soils in the bottoms of ravines are forms under conditions of intense inflows of material that was eroded from the upper parts of the slope. Inflow, transit and accumulation of talus define the basic and additional soil-forming processes. The profile is characterized by depositional layering, a thickened humus layer, and a lack of soil structure. Among them are available eroded (30 cm), medium eroded (30-60 cm) and strongly eroded (60 cm) soils.

Table 1. Particle size distribution of gray forest-steppe soils.

Horizons	Depth, cm	The contents of fractions, %; particle size, mm						
		1-0.25	0.25- 0.05	0.05- 0.01	0.01- 0.005	0.005- 0.001	<0.001	<0.01
Dark grey forest-steppe medium loam soils								
A ₁	0-10	3.8	6.7	51.1	12.0	12.8	13.6	38.4
A ₁ B	35-45	4.0	5.6	50.2	12.5	13.1	14.6	40.2
B	70-80	2.0	2.5	49.4	15.0	15.8	15.3	46.1
BC	105-115	5.2	4.0	48.8	11.9	14.0	16.1	42.0
C	125-135	7.0	4.2	47.1	11.3	13.2	17.2	41.7
Grey forest-steppe light loam soils								
A ₁	3-13	44.4	14.2	15.3	6.1	6.0	14.0	26.1
A ₁ E	25-35	39.8	22.7	16.7	6.8	4.4	9.6	20.8
EB	45-55	38.8	23.1	15.2	7.9	5.0	10.0	22.9
B	75-85	32.6	10.4	19.1	10.6	9.3	18.0	37.9
BC	95-105	40.5	20.2	17.0	7.7	6.1	8.5	22.3
C	125-135	50.6	34.5	5.6	2.8	2.4	4.1	9.3
Grey forest-steppe eroded soils								
A ₁	3-13	45.5	25.0	10.8	5.0	4.5	9.2	18.7
A ₁ E	18-28	46.3	24.4	12.6	4.8	3.2	8.7	16.7
B	40-50	46.8	14.9	15.2	2.2	3.0	17.9	23.1

Table 2. Chemical indicators of the humic and eluvial horizons of grey forest-steppe soils (Xmin - Xmax).

Depth, cm	Humus, %	Carbon stocks, t/ha	Nitrogen, %	Content of oxides, mg/100 g	
				P ₂ O ₅	K ₂ O
Dark grey forest-steppe medium loam soils					
0-20	5.1-6.6	124-160	0.25-0.33	8.0-9.0	17.7-21.4
Grey forest-steppe light loam soils					
0-20	3.2-4.8	78-117	0.13-0.18	4.5-11.8	12.5-19.4
Grey forest-steppe eroded soils					
0-20	1.4-2.5	34-61	0.06-0.08	3.0-5.0	1.8-4.0

The genetic horizons are represented by several layers varying in thickness, color, granulometric composition, structure, chemical composition and density. They are powerful diluvial sediments of different granulometric composition. In their properties they are similar to soils of the watershed. For example, the soils at the foot of the eastern slope (at the reservoir) contains 5.6-7.3 % of humus in the upper part of the profile. The nitrogen content is still 0.3-0.4 %. These soils are well provided with phosphorus, hydrolyzable nitrogen and exchangeable potassium. The sum of exchangeable bases is 25-31 mEq/100 g. Soil environment is slightly acidic.

The results of the research show that the dark gray and gray forest soils from loam granulometric composition are the best for the growth of oak forests. These soils formed on loess loam cover with favourable physical–chemical and chemical properties. Here grow oak forests of bonitation classes II–III. Indicators of the composition and properties of these soils should be used as a base when assessing the ecological status of urban anthropogenically-modified soils.

The high content of heavy metals in urban soils is an indicator of anthropogenic impact and leads to the deterioration of the ecological properties of soils. The study of the content of total key heavy metals in the grey forest-steppe soils of the Upland Oak Forests showed that in all soil samples the content of heavy metals is below the maximum allowable concentrations. The highest contents are characterized by the humus horizons of dark grey and grey forest-steppe soils, which maximum content is for Mn 600–754, Zn 33–49, Cu 7–13, Pb 14–16, Ni 22–25, Cd 0,22–0,26, Cr 48–60, Co 7–9, As 0,1, Hg 0,1 mg/kg (table 4). The content of mobile forms of heavy metals is Mn 96–105, Zn 0,7–0,9, Cu 1,2–1,5, Pb 1,4–1,8, Ni 2,9–2,6, Cd 0,08, Cr 0,16–0,2, Co 2,6–2,9 mg/kg (table 5). The amount of heavy metals according to all indicators is reduced by a factor of 2 in the upper horizons of the flushed varieties of grey forest-steppe soils. The obtained results allow us to classify the investigated soils to the category of environmentally friendly.

Table 3. A range of physical and chemical properties of grey forest steppe soils (Xmin - Xmax).

Horizons	pH _{KCl}	Content of ions, mg-eq/100 g of soils			Hydrolytic acidity	Degree of saturation with bases (V), %
		Ca ⁺²	Mg ⁺²	Ca ⁺² + Mg ⁺²		
Dark grey forest-steppe medium loam soils						
A ₁	5.6–5.8	25.8–27.0	2.0–3.4	28.8–30.0	4.3–6.8	82-87
A ₁ B	6.0–6.3	23.0–24.2	2.6–3.2	25.6–27.4	3.8–5.0	84–87
B	6.4–6.6	22.6–23.8	1.8–2.0	24.4–25.8	2.6–3.3	89–90
C	6.8–7.0	21.2–22.0	1.6–2.4	22.8–24.4	0.4–0.6	90–97
Grey forest-steppe light loam soils						
A ₁	4.5–5.5	22.0–23.4	2.8–4.0	24.8–25.5	3.4–5.3	83–88
A ₁ E	4.4–5.0	19.1–20.3	2.0–3.6	21.6–22.2	3.0–4.0	85–87
B	5.6–6.0	21.2–22.1	1.7–3.3	23.9–24.8	1.8–2.8	90–93
C	6.2–6.5	18.0–21.0	2.2–4.1	22.0–23.0	0.4–1.0	96–98
Grey forest-steppe eroded soils						
A ₁ E	5.1–5.3	15.3–17.8	2.0–4.1	18.4–20.6	3.8–4.0	83–84
B	5.5–6.0	18.8–23.0	3.3–4.4	22.7–25.1	2.0–2.5	90–91
BC	6.6–6.8	16.9–21.5	2.0–3.8	21.3–23.2	1.0–1.5	94–95
C	7.0–7.2	17.0–20.4	1.5–2.4	18.2–20.5	0.0–0.6	97–100

Features of Genesis, structure, composition and soil properties of forest ecosystems of the city of Voronezh were first studied on the example of the island forest. The most significant quantitative results of the study are such conservative indicators of forest soils of the natural block as acidity, exchangeable bases and organic matter. Changes in these properties show the degree of anthropogenic changes in soil technogenic block of the urban environment.

The results showed that the basis of the soil cover of Upland Oak Forests is the grey forest-steppe loamy soil. They possess the most fully expressed morphogenetic features is characteristic of this type. They have favorable environmental properties and the oak forest high performance of bonitation classes II–III. The eroded grey forest-steppe soils of the slopes with a sparse herbaceous cover are characterized by a shortening of the humus horizon. They contain less humus and nitrogen, have low contents of available phosphorus and exchangeable potassium, and generally have poor quality physical and chemical properties and low forest productivity.

Table 4. The content of total forms of chemical elements (the maximum).

Horizons	Concentration of element, mg/kg									
	Mn	Zn	Cu	Pb	Ni	Cd	Cr	Co	As	Hg
Dark grey forest-steppe medium loam soils										
A ₁	754	49.2	13.4	16.4	25.3	0.26	60.7	9.7	0.10	0.13
A ₁ B	569	40.4	12.8	14.8	20.1	0.18	43.5	6.4	0.10	0.12
B	480	38.0	10.0	13.5	13.5	0.15	40.0	5.9	0.06	0.09
C	539	56.0	15.2	17.2	26.4	0.16	65.0	11.4	0.10	0.10
Grey forest-steppe light loam soils										
A ₁	600	33.5	7.7	14.3	22.0	0.22	48.8	7.0	<0.1	<0.1
A ₁ E	600	30.9	6.8	12.6	18.2	0.17	46.7	4.6	<0.1	<0.1
B	495	29.1	5.9	11.7	17.6	0.15	45.9	4.0	<0.1	<0.1
C	510	31.8	12.6	13.7	23.1	0.24	35.0	10.5	0.12	0.14
Grey forest-steppe eroded soils										
A ₁ E	461	22.6	5.5	12.3	17.1	0.11	31.1	4.5	<0.1	<0.1
B	435	22.0	4.0	11.5	16.6	0.10	30.6	4.0	<0.1	<0.1
C	518	30.2	11.4	14.9	21.5	0.18	29.5	9.3	<0.1	<0.1
The maximum permissible concentration	1500	100	55	32	80	1.0	-	-	10.0	2.1

Table 5. The content of mobile forms of chemical elements (maximum).

Horizons	Concentration of element, mg/kg							
	Mn	Zn	Cu	Pb	Ni	Cd	Cr	Co
Dark grey forest-steppe medium loam soils								
A ₁	105	0.9	1.5	1.8	1.7	0.08	0.07	2.6
A ₁ B	91	0.7	1.4	1.4	1.2	0.06	0.03	0.6
B	60	0.4	0.6	1.1	0.8	0.05	0.08	0.8
C	70	0.6	0.9	1.6	2.6	0.06	0.20	2.9
Grey forest-steppe light loam soils								
A ₁	96	0.6	1.2	1.4	1.1	0.07	<0.1	2.1
A ₁ E	70	0.3	1.1	0.9	1.0	0.04	<0.1	0.4
B	62	0.2	0.7	0.6	0.9	0.04	0.16	0.6
C	74	0.5	0.8	2.0	1.9	0.05	0.20	1.4
Grey forest-steppe washed away soils								
A ₁ E	52	0.4	0.9	0.7	0.5	0.03	<0.1	0.4
B	50	0.3	0.5	0.5	0.8	<0.01	<0.1	0.7
C	54	0.5	0.6	1.4	2.9	<0.01	0.2	1.5
The maximum permissible concentration	140	23.0	3.0	6.0	4.0	0.5	6.0	5.0

4. Conclusion

Forest ecosystems of the right bank Upland Oak Forest dominate in the natural complex of the city of Voronezh. They are the basis of the ecological frame of the city and perform water conservation, erosion control, recreation and other environmental functions. They stretch as a strip along the right bank of the Voronezh river. The Upland Oak Forest is a part of the high fourth terrace and the steep slope down to the river. Ravines covered with forests. The oak forest is located within a typical forest-steppe of the Oka-Don plain, on the watershed of the Don and Voronezh Rivers. The right bank of the Voronezh river is a sandy-clay left bank of the Don river, in which are embedded the valley of the river Voronezh. Therefore, there are growing indigenous types of oak forests on clay soils and mixed

forests on sandy soils. Oak forests account for 85% of the forests. They became part of the green areas of the city and its forested parts. Shilovsky forest soils are similar to other forest soils, which are included in the ecological framework of the Voronezh city. Forest soils have weak recreational load. The residential area is close. However, the industrial zone is far away and the studied area of the Shilovsky forest does not experience the influence of air masses from the industrial zone. The dominant wind direction is Northwest.

Thus, the results indicate favorable environmental properties, which allow these urban forest soils to be classified as environmentally friendly and recommended for further use as the background when assessing the ecological status of urban anthropogenically modified soils. The experimental data obtained serve as an analytical basis for assessing the current level of transformation and ecological-geochemical state of the soil of the technogenic block of the urban environment. They make it possible to monitor changes in the quantitative and qualitative parameters of anthropogenic soil change and assess the risk to public health. The performed works marked the beginning of complex researches of monitoring of forest ecosystems of the city of Voronezh. Further research will continue on the biological activity of forest soils, the study of forest litter, the degree of recreational load on forest ecosystems within a large city.

The obtained data can be useful for environmental services and design organizations of Voronezh and other major cities in the organization of measures to improve the system of environmental monitoring of the urban environment and ensure its sustainable development. The results obtained on the current state of forest soils of cities will add to the scientific database of the Voronezh region, Russia and the world.

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