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To cite this article: A O Oznobihina and E V Gayevaya 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **272** 032062

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The Ecological State of the Soil Continuum of Urbanized Territories

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Abstract. The intense urbanization process has conditioned a significant number of ecological problems connected with a rapid deterioration of the quality of urban environment. All that calls for indication and an unbiased assessment of its current state. The distribution of heavy metals in the town's soils was in the following descending order: lead > zinc > nickel > copper > cadmium > mercury > arsenic. Largest values of contaminating substances were determined in the territories adjacent to motorways. The maximum value of oil products content in soils of the researched areas was determined on a motorway section and was 280.9 mg/kg which corresponds to an "acceptable" level. Researched soils had no express acute toxicity which is indicative of acceptable ecotoxicological state of the town's soils.

1. Introduction

The topicality of researches is conditioned by the determination of the level of sustainability of urban landscapes under the integrated anthropogenic effect.

Urban soils bear excessive anthropogenic impact and differ from natural ones by a number of properties. They are characterized by a high patchiness and diversity of the soil profile, alkaline media reaction, compaction, poly-elemental contamination; the biological activity is significantly limited. In result, the process of soils' degradation occurs, and their normal functioning becomes impossible [1, 2].

Along with stationary industrial enterprises, motor vehicles, the number of which increases year after year, plays especially significant role in such pollution [3].

As a result of strong technogenic pollution, full destruction of the vegetation mantle and washout of pedologic horizons take place [4, 5].

The analysis of relevant literature and documentary data shows that at present, during the assessment of the ecological state of urban territories, the issues of changes in a suite of metrics of soils' biological activity of soils contaminated by oil products, their ability of self-restoration and the contamination by moving forms of heavy metals may serve as early diagnostic indicators allowing to cognize negative changes at initial stages [1, 2].

The study of the suite of these metrics will allow to more accurately understand the direction of changes taking place in urban soils, and will enable local authorities to make managerial decisions aimed at sustainable development of urbanized territories.

In such a way, this paper presents the results of study of the ecological state of urbanized territories' soils of a large industrial center (Tyumen) having different impact on the vegetation and topsoil.



2. Materials and Methods

The collection of soil samples was carried out in administrative districts of Tyumen, in residential and recreational zones, and at road sections. The samples were collected with the use of soil sampling tube from the depths of 0-20 cm in conformance to GOST 17.4.3.01-83 Standard "Environmental Protection. Soils. Methods of Collection and Preparation of Samples for Chemical, Bacteriological, and Helminthological Analysis", and GOST 28168-89 Standard "Soils. Collection of Samples" [6, 7, 8].

The chemical analysis of the quantitative content of heavy metals in soil samples was carried out in conformance to PND F (Federal Regulatory Environmental Document) 16.1:2.2:2.3.36-02 "Quantitative Chemical Analysis of Soils. Methodology for Carrying Out Measurements of Total Content of Copper, Cadmium, Zinc, Lead, Nickel and Manganese in Soils, Bottom Sediments and Deposits of Waste Effluents Using the Flame Atomic Absorption Spectrophotometric Method", PND F 16.1:2.2:2.3.48-06 "Quantitative Chemical Analysis of Samples of Soil, Hothouse Soils, Silty Mud, Bottom Sediments, Bottom Ooze, and Solid Waste. Methodology for Making Measurements of Mass Concentrations of Zinc, Cadmium, Lead, Copper, Manganese, Arsenic, and Mercury Using the Stripping Voltammetry Method on Analyzers of TA Type", and PND F 16.1:2.3:3.10-98 "Quantitative Chemical Analysis of Soils. Methodology of Carrying Out Measurements of the Content of Mercury in Solid Objects Using the Atomic Absorption Spectrophotometric Method" [9,10,11]. The determination of oil products was carried out using the gravimetric method according to the methodology of PND F 16.1:2.2:2.3:3.64-10 [12]. The measurement of the acid-base medium was carried out using "HANNA" pH meter.

The content of sulfates was determined in conformance to GOST 26426-85 Standard [13], and that of chlorides was determined using Unico 2800 spectrophotometer.

The determination of acute toxicity was carried out on live test objects *Daphnia magna* Straus using the methodology of PND F T 14.1:2.4.12-06. T 16.1:2.3.3.9-06 [14].

The assessment of the soil in terms of contamination by heavy metals was carried out in relation to the values of maximum permissible concentration (MPC) and in comparison to background values. The level of soil contamination by oil products was determined according to the Methodology for Determination of the Harm to Environment in Cases of Accidents on Main Oil Pipelines (1995), with grading according to Yu Pikovskiy and gradation according to V Khomich [15, 16, 17].

3. Results and Discussion

Main soils in the town are transformed gray and light-gray forest soils, soddy-podzolic soils and leached chernozem. The soils are characterized by a not large thickness of the turfy horizon with the content of humus 2-6%. The content of moving forms of nitrogen is low; that of phosphorus and potassium are average and high. The pH of water extract from the soil is 5.8-6.2 pH units.

The natural soil continuum in the largest part of the town territories was destructed and is preserved only in islets in town's wood meadows. Characteristic are the lack of genetic horizons and the presence of differently colored layers of different thickness of artificial origin [18].

Tyumen is a town in Russia, administrative center of Tyumen region and Tyumen district. It forms a town district Tyumen. It possesses the 18th place among Russia's town in terms of the population [19].

The objects of the research were soils of the town in inhabited and recreational areas, and sections of motorways. As control samples, the soil in the environmentally sound area (specially protected natural territory) were used.

Analyzing the results of the researches shown in Table 1, the low content of chlorides and sulfates in all researched territories can be mentioned: 0.62-0.81 mg/kg while the MPC is 360 mg/kg and 9.12-19.80 mg/kg while the MPC is 160 mg/kg respectively. The pH reaction of the soil solution was in the range 7.0-8.7 pH units – from neutral to strongly alkaline. For leached soils, the low mobility of heavy metals and micro-elements is characteristic due to soil swelling and low throughput capacity of water.

Table 1. Results of the Analysis of Soil Samples for Content of Chlorides and Sulfates, mg/kg.

Place of Collection of Soil Samples	pH	Indicators Determined	
		Concentration of Chlorides in the Soil, mg/kg	Concentration of Sulfates in the Soil, mg/kg
Inhabited Area	7.4 ± 0.2	0.73	14.04
Recreational Area	7.0 ± 0.2	0.81	19.80
Motorway Section	8.7 ± 0.2	0.62	9.12
MPC, mg/kg	Not rated	360	160

The content of heavy metals and benzapyrene in the soil is shown in Table 2. The assessment of the chemical contamination of the soil was carried out in accordance to SanPiN (Sanitary Regulations and Standards) 2.1.7.1287-03 "Sanitary and Epidemiological Requirements to the Quality of Soil" (Table 3) [20]. The contamination of the soil continuum in the researched territories was determined in relation to the values of maximum permissible concentration (MPC) of chemical substances in the soil and in comparison, to the background values which had been determined earlier [2]. The researches revealed an increased concentration of nickel at the motorway section; the content of the element was 5.43 mg/kg, while the MPC is 4.00 mg/kg. The concentration of total forms of arsenic, mercury, lead, benzapyrene and of moving forms of cadmium, copper and zinc in all analyzed samples of the soil did not exceed the set MPC standards. The distribution of heavy metals in soils was in the following descending order: lead > zinc > nickel > copper > cadmium > mercury > arsenic.

Table 2. Content of Heavy Metals and Benzapyrene in Soil, mg/kg.

Indicators Determined (Form)	Hazard Class	Inhabited Area	Recreational Area	Motorway Section	MPC/BACKG ROUND
Cadmium (moving)	1	0.068 ± 0.014	0.061 ± 0.013	0.081 ± 0.017	0.5/0.06
Arsenic (total)	1	<0.01	<0.01	<0.01	2.00/0.008
Mercury (total)	1	0.04 ± 0.01	0.04 ± 0.01	0.04 ± 0.01	2.10/0.02
Benzapyrene (total)	1	<0.005	<0.005	<0.005	0.02/0.002
Lead (total)	1	7.0 ± 1.75	8.0 ± 2.00	17.0 ± 4.25	32.00/16.0
Nickel (moving)	2	0.34 ± 0.071	0.40 ± 0.084	5.43 ± 1.14	4.00/0.40
Copper (moving)	2	0.38 ± 0.084	0.25 ± 0.055	0.62 ± 0.14	3.00/0.14
Zinc (moving)	1	5.46 ± 1.37	1.2 ± 0.3	11.42 ± 2.86	23.00/1.39

Largest values of contaminating substances were determined in the territories adjacent to motorways. In soils of the inhabited and recreational areas, no significant differences between the determined values; only in respect of zinc a tendency was observed of increased content of the element in the inhabited area, 5.46 mg/kg, while in recreational area the concentration was 1.20 mg/kg, and herewith no excess of the MPC, 23.0 mg/kg, was observed. In comparison to the regional background value of 1.39 mg/kg, it can be said that there is an increased anthropogenic impact.

According to SanPiN 2.1.7.1287-03, when assessing the level of chemical contamination, soils of all researched areas can be referred to the "clean" category in terms of content therein of cadmium, arsenic, lead and benzapyrene, from background values to MPC; they can be referred to the "acceptable" category in terms of the content therein of mercury and copper: the content in the soil exceeds the 2 background values, but not higher than that of MPC. In terms of content of zinc, soils of the recreational area can be referred to the "clean" category, and soils of the inhabited area and near

motorways can be referred to the “acceptable” category; the content of nickel at the motorway section was 5.43 mg/kg characterizes the “hazardous” territory; herewith the content of the element in inhabited and recreational areas is at the background level: the “clean” category.

Table 3. Assessment of the Level of Chemical Contamination of the Soil (SanPiN 2.1.7.1287-03).

Categories of Contamination	Content in the Soil (mg/kg)	
	I Hazard Class	II Hazard Class
Clean ^a	From background value to MPC	From background value to MPC
Acceptable	From double background value to MPC	From double background value to MPC
Hazardous	From MPC to Kmax	From MPC to Kmax

^a The contamination category refers to increased risk venues.

K_{max} – the maximum value of the permissible level of content of an element by one of four nuisance values.

Due to the fact that the MPC values for oil products in soils are not developed, when determining the level of contamination of soils, the value of 1.0 g/kg was used in accordance to the Methodology for Determination of the Harm to Environment in Cases of Accidents on Main Oil Pipelines (1995) [15]: the content of oil in soils within the limit of 1 g/kg is assessed as acceptable, that of 1-2 g/kg as low, 2-3 as average, 3-5 as high, and over 5 as extremely high.

The maximum value of oil products content in soils of researched areas (Figure 1) is determined at the motorway section and was 280.9 mg/kg, which corresponds to the “acceptable” level.

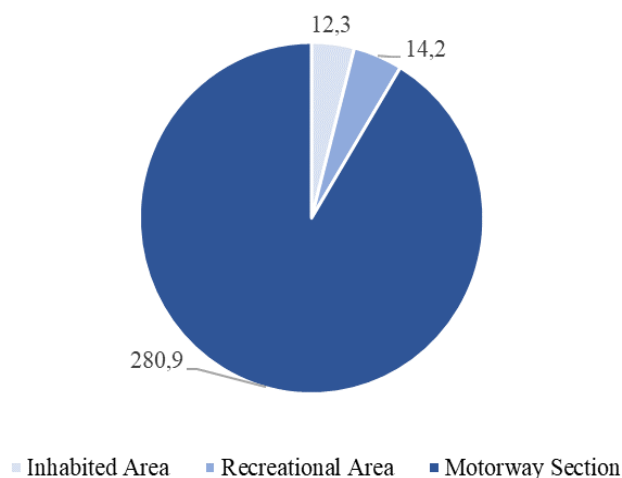


Figure 1. Oil Products Content in the Soil, mg/kg.

According to the grading developed by Yu Pikovsky [16], the content of oil products in the researched samples equal to 280.9 mg/kg corresponds to the level of 100 – 500 mg/kg, which may be considered as high: oil products in such quantities are actively utilized by microorganisms, washed out by rain flows and snow melts without human interference.

According to the V. S. Khomich rate scale [17], the following can be determined: content of oil products less than 5 mg/kg is the natural background; 5 – 50 mg/kg is the regional background, is formed under the influence of regional contamination and was detected in the inhabited area and the recreational area: 12.3 – 14.2 mg/kg respectively; 50 – 250 mg/kg are slightly contaminated soils, most frequently found; 250 – 1000 mg/kg are medium contaminated soils, such territories were found at the motorway section (280.9 mg/kg).

The soil toxicity was determined using the biotesting method; invertebrates were used in the experiment because they quickly adapt to laboratory conditions and are sensitive to toxic substances. The results of the experiments carried out with daphnids (Table 4) showed a 100% survival rate of *Daphnia magna Straus* in the samples of water extracts from the soil samples. Soil samples had no expressed acute toxicity.

Table 4. Results of Biotesting of *Daphnia magna Straus*.

Test Object	Toxicity Indicator	Measurement Units	Results of the Analysis	Inaccuracy	Reciprocal Dilution	Assessment of the Tested Sample
Inhabited Area						
<i>Daphnia magna Straus</i>	NDR 10-48 ^a HDR 50-48 ^b	%	100	10	No dilution	No acute toxic effect
Recreational Area						
<i>Daphnia magna Straus</i>	NDR 10-48 ^a HDR 50-48 ^b	%	100	10	No dilution	No acute toxic effect
Motorway Section						
<i>Daphnia magna Straus</i>	NDR 10-48 ^a HDR 50-48 ^b	%	100	10	No dilution	No acute toxic effect

^a NDR 10-48 – Non-Hazardous Dilution Rate (NDR) of the researched water resulting in death of not more than 10% of test objects after 48-hour exposure.

^b HDR 50-48 – Average Hazardous Dilution Rate (HDR) of the researched water resulting in death of 50% and more of test objects after 48-hour exposure.

4. Conclusions

The researched soils have pH rate from neutral to strongly alkaline. The maximum pH level was observed in the area with the strongest technogenic impact which contributes to depositing of contaminants in the top soil level.

Priority contaminating substances are compounds of nickel and zinc. The highest level of accumulation of chemical elements were observed in the soils of the motorway section and certain territories of the inhabited area. Qualitative and quantitative characteristics of soil contamination by heavy metals depend on their types, granulometric texture and formation maturity. The highest level of contamination of the town's soils by total forms was observed in respect of lead, that is connected with the type of underlying soils. Soils contain moving forms of copper and zinc.

The content of oil products in the territory of the inhabited area and the recreational area is insignificant, it corresponds to the natural and regional background and is 12.3-14.2 mg/kg. Increased concentrations of oil products up to 280.9 mg/kg were observed in soils adjacent to motorways, the territory may be characterized as "medium contaminated soils".

Main indicators of the physical and chemical state of the transformed soils: active acidity, share of oil products and accumulation of heavy metals combined with biological diagnostics can serve as early diagnostic indicators allowing to assess the degradation processes in urban landscapes at initial stages.

Research of the content of heavy metals and ecotoxins in the soil continuum of the residential landscape of the town of Tyumen allows to give preliminary recommendations for the preservation and improvement of their quality: there is a need for organization of monitoring of the state of the soil continuum as the baseline component of ecosystems in the town.

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