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Article

Geochemical and microbiological indication of technogenic transformation of soils in the city of Balakovo (Saratov Oblast)

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Abstract. The soil-ecological studies (2023) conducted in the city of Balakovo, Saratov oblast allowed to detect two local technogenic geochemical anomalies with a high content of technophilic elements and major pollutants of soils (zinc, lead, copper and nickel). In terms of heterotrophic microorganisms enrichment, soils are characterized as highly rich (> 1×10^7 CFU/g), while in two sites of the industrial zone and in two plots of the recreational area as rich (1×10^7 CFU/g). The average number of cultivated aerobic heterotrophic microorganisms in urban soils is 2 times and in industrial 3 times lower than in natural soils. By micromycetes presence, urban soils range from very poor (< 2×10^6 CFU/g) to rich ($1–2 \times 10^7$ CFU/g). Zones of maximum technogenic soil transformation are typical of industrial areas and low-rise residential buildings with bad amenities of life.

Keywords: urban soils, heavy metals, bacteria, micromycetes

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Научная статья

Геохимическая и микробиологическая индикация техногенной трансформации почв города Балаково (Саратовская область)

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Аннотация. В результате почвенно-экологических исследований на территории города Балаково Саратовской области в 2023 г. выявлены две локальные техногенные геохимические аномалии. Установлено высокое содержание технофильных элементов и основные элементы-загрязнители почв – цинк, свинец, медь и никель. По уровню обогащенности гетеротрофными микроорганизмами почвы характеризуются как очень богатые (> 1×10^7 КОЕ/г почвы), на двух участках в промышленной зоне и на двух в рекреационной зоне – как богатые (1×10^7 КОЕ/г почвы). Среднее количество культивируемых аэробных гетеротрофных микроорганизмов в урбаноземах в 2 раза, в индустриоземах – в 3 раза ниже, чем в природных почвах. По уровню обогащенности микромицетами городские почвы варьируют от очень обедненных (< 2×10^6 КОЕ/г почвы) до богатых ($1–2 \times 10^7$ КОЕ/г почвы). Зоны максимальной техногенной трансформации почв характерны для промышленных районов и жилой малоэтажной застройки с низким уровнем благоустройства.

Ключевые слова: городские почвы, тяжелые металлы, бактерии, микромицеты

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Introduction

The impact of hazardous environmental pollutants on soils, as a depositing medium, is wide and diverse. Being ecotoxic, heavy metals (HM) are priority soil pollutants for control in large cities (Skugoreva et al., 2016). Intensity of xenobiotics contaminating the urban soils depends on the type of industrial enterprises. A wide variability of anthropogenic soil pollution makes it especially important to monitor the urban areas and to determine the degree of technogenic transformation of biogeocenoses not only based on geoindication, but also on bio indicators.

For the Saratov region, the problem of man-induced deterioration of soils next to industrial cities is relevant (Abrosimova and Makarova, 2018; Larionov, 2013; Larionov et al., 2020; Merkulova et al., 2015). Balakovo – an industrial city with the developed energy, mechanical engineering, chemical, metallurgical, transport, construction, food, and light industries is among the regional leaders in terms of the release of pollutants into the atmosphere. With a population of about 182 thousand people (data for 2022[1]), it is located on the left bank of the Saratov and Volgograd reservoirs. Pollutants enter soils mainly from air. For instance, annual dust emissions into the city air amounted to about 2.7 million tons/year in 2018–2022 according to the Saratov Center for Hydrometeorology and Environmental Monitoring[2].

Ecological and geochemical studies of soils in urban areas are of importance and aimed at diagnosing the ecological state of the human environment, identifying the foci of industry-related impacts, organizing the environmental monitoring and making the management decisions. Biomonitoring data serve as one of the sensitive indicators of the soil state. Soil is the main component of the terrestrial ecosystem, the functioning of which is largely ensured by soil microbiomes. Hence, the investigations of microbial communities are extremely topical (Pospelova et al., 2015; Wolińska et al., 2016). Studying the microbiocenoses provides the important information about the state of soils under industrial influence (Ananyeva et al., 2021; Stoma et al., 2020). Soil microbial communities respond to changes in the environment by modifying their structure and abundance. Many researchers note a high indicative ability of microorganisms (Abbasian et al., 2016; Adesina and Adelasoye, 2014; Alrumman et al., 2015). The indicators of the number of microorganisms of certain ecological and physiological groups are used in diagnostics of soil-biotic complexes transformation in conditions of urbopedogenesis (Stepanova et al., 2016; Zhuykova et al., 2016). Due to microbiological parameters, negative changes in soil can be detected even at the initial stage of technogenic impact (Korneykova et al., 2021; Sumampouw and Risjani, 2014).

The studies of the quality of the urbanized environment of Saratov oblast received the attention at the turn of the 1980–1990s. A geochemical anomaly with a high content of technophile elements (primarily Zn, Pb, Cu and Ni) was found in the city of Balakovo and its immediate vicinity[3]. Profound geochemical studies of soils were carried out in 1998 when creating the "Ecological Atlas of Balakovo". Polyelement anomalous technogenic geochemical fields located in the zone of industrial enterprises, a city dump, treatment facilities, residential buildings, and summer cottages (dachas) were mapped. Here, high concentrations of Pb, Zn, Ni, Cr and Cu were recorded (Makarov et al., 2002). In 2013, mapping of the ecological and geochemical state of soils in the impact zone of the Balakovo landfill was made; the ecologically hazardous areal contamination of soils with Ni, Zn and Cu was revealed (Eremin,

[1] Federal State Statistics Service. Web page. URL: rosstat.gov.ru (accesses: 12.02.2024).

[2] Review of the state and pollution of the environment in the area of activity of the Saratov Center for Hydrometeorology and Environmental Monitoring - branch of the Federal State Budgetary Institution "Privolzhsk Department for Hydrometeorology and Environmental Monitoring " for 2022, 2023. Saratov Center for Hydrometeorology and Environmental Monitoring, Saratov, Russia, 80 p.

[3] Report on the project “Monitoring of the geological environment adjacent to the territory of the Balakovo NPP”, 1991. Saratov Center for Hydrometeorology and Environmental Monitoring, Institute of Geology of the Saratov State University, Russia, 704 p.

2016). The area around large enterprises in the southwestern part of the city (Heat Power Plant (HPP)-4, "Balakovorezinotekhnika", mineral fertilizer plant, "Khimvolokno" plant) should be considered as a historically formed technogenic geochemical anomaly.

All studies report about an increased (for Cr, Ni and Cu – high) local background content of HMs in soils of the large district Balakovsky that is associated with the soil-forming rocks and subregional pollution from the large industrial hub Balakovo. Emissions from the "Khimvolokno" plant (not operating now) contributed to high concentrations of Zn as well.

The content of HMs throughout the city of Balakovo has not been studied since 1998. Microbiological properties of urban soils, as well as their relation with geochemical indicators, were not investigated previously. The purpose of the study was to analyze the technogenic soil transformation in Balakovo using the geochemical and microbiological indication methods.

Material and methods

The territory of the city is conventionally divided into two parts by the dam of the Saratov Reservoir. The residential area is located on the banks of the reservoir to the east of the dam and the railway, while garden and summer cottages (dachas) - to the west. There three large residential districts: Ostrovnoy, Zakanalny and Tsentralny. Zakanalny and Tsentralny districts are separated by the Saratov water supply and irrigation canal. Industrial enterprises are mostly located to the south and southwest of the residential buildings.

The urban territory has a flat lowland relief of the above-the floodplain terraces of the Volga. Soil-forming rocks are late Pleistocene-Holocene sandy-clayey alluvial and estuary-marine formations. Because of the construction of the Saratov Reservoir and canals, as well as leaks from communications, groundwater lies at a depth of less than 5 m; most of the built-up area is flooded and locally swamped. The climate is continental. In the cold season, southern and southwestern winds prevail, whereas in summer - northern and northeastern ones.

In the immediate vicinity of the city, natural soils are represented by southern chernozems and dark chestnut soils developed on the Quaternary deposits of the above-the floodplain terraces of the Volga. Currently inundated by the reservoir, floodplain meadows are developed mainly in the floodplain. Natural landscapes adjacent to the city are forb-fescue-feather and fescue-feather grass steppes. Almost the entire land fund is used for agricultural purposes.

During our study, 50 soil samples, collected in the city of Balakovo at the end of August 2023, were examined (Fig. 1). All samples were analyzed in terms of geochemical indicators, 32 – by microbiological parameters. Sampling from the upper soil horizon (up to 5 cm) was made in accordance with GOST 17.4.4.02-2017[4] using the "envelope" method for sites of 5×5 m. Sampling sites were relatively evenly distributed throughout the residential built-up area (Table 1), locating within parks, courtyard green areas and front gardens at a distance from major highways and railways. Such an approach gives a general notion about the geochemical field of the urban area and enables to identify the sites for profound studies of the structure of possible pollution.

Background sampling sites are located to the southwest of anthropogenic zones: 20 km from the city and 14 km from the nearest rolled metal plant – the "Balakovo Metallurgical Plant".

Two selected background sites (analogous landscapes) on flat watersheds represent virgin steppe areas covered with natural fescue-feather grass vegetation. When studying the Balakovo testing ground (1998), this area was used as a local background since it was situated outside the established zones of snow and soil cover contamination. In our study, the reference value is taken as the arithmetic mean for the background sites.

For chemical studies, soil samples were dried at room temperature, quartered and grinded. Then, weighed samples of a fraction of less than 1 mm were prepared. The content of acid-soluble forms of Zn, Ni, Cr, Cu, Pb, Cd was examined in extracts with 1 M HNO_3 solution (RF Environmental Regulations 16.2.2: 2.3.71-2011[5]) using the method of atomic absorption spectrometry in the flame atomization mode on the spectrometer "Quantum-2AT" (limited company "KORTEK", Russia). The list of metals was compiled from the results of comprehensive soil-geochemical works conducted in the 1990s.

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[4] GOST 17.4.4.02-2017 Environmental Protection (Standards). Soils. Methods of sampling and preparing samples for chemical, bacteriological, and helminthological analysis (with Amendment).

[5] RF Environmental regulations 16.2.2:2.3.71-2011. Quantitative chemical analysis of soils. Methodology for measuring mass fractions of metals in sewage sludge, bottom sediments, and plant samples using spectral methods.

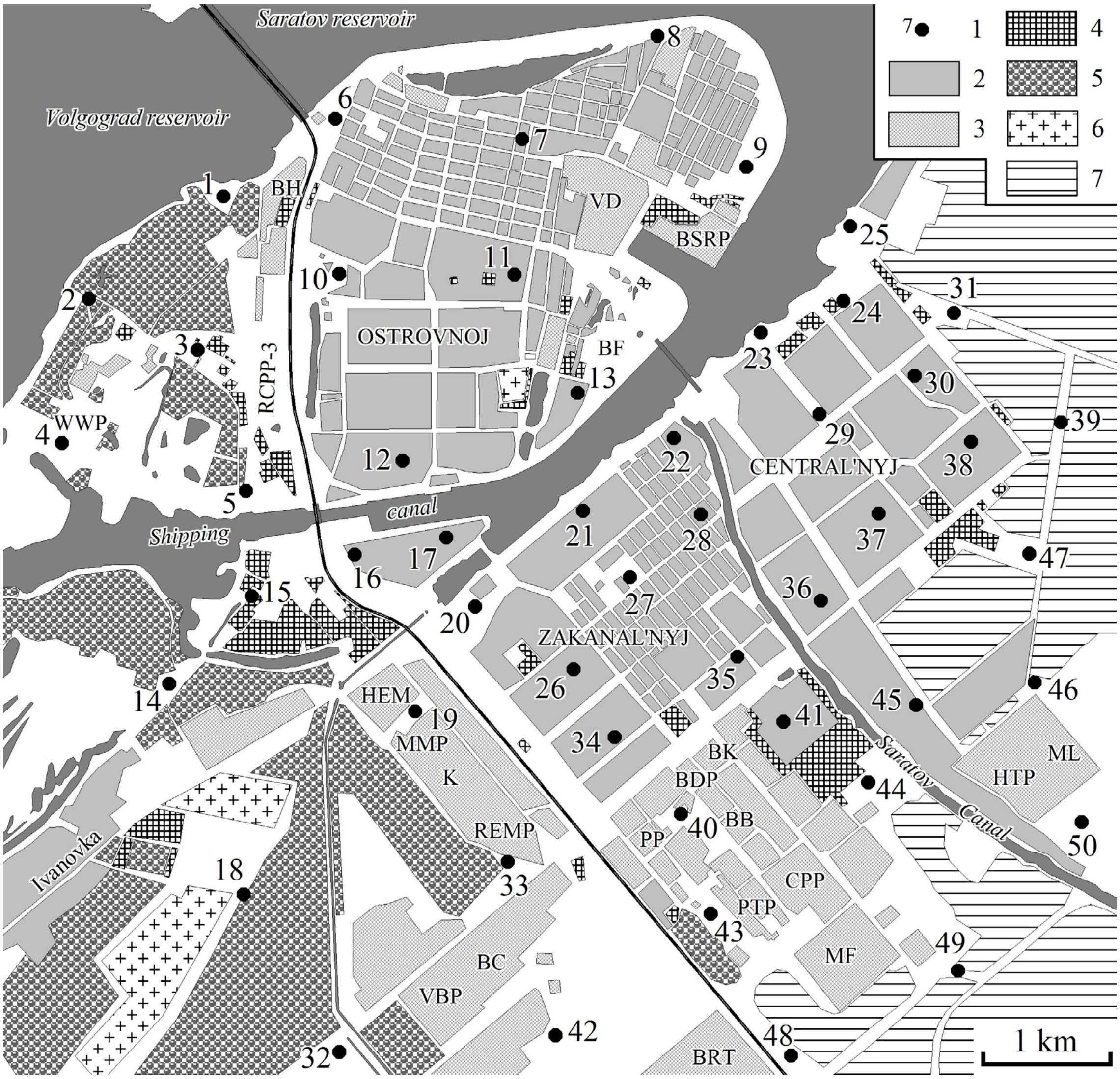

Fig. 1. Location of sampling sites. 1 – testing site and its number, 2 – residential buildings, 3 – industrial enterprises, 4 – garages and parking lots, 5 – dachas, 6 – cemeteries, 7 – agricultural lands.
Operating industrial enterprises: BC – "Balakovo-Centrolit" JSC, VBP – Wagon-Building Plant JSC, BRT – "Balakovorezinotekhnika", HTP – hydroturbine plant "Voith-Hydro" limited company, ML – "Molot" limited company, VD – "Volzhsky Diesel named after Maminykh", BSRP – "Balakovo Shipbuilding & Repair Plant" limited company, MF – furniture factory, HEM – "Hydroelektromontazh" JSC, BH – limited company "Balakovo Hydroelektromontazh" JSC, REMP – "Repair and Electromechanical Plant" limited company, K – "Kronverk" limited company, PTP – "PromTekhPlast" limited company, PP – "Poliprofil" limited company, BB – Balakovsky Brewery, BDP – Balakovsky Dairy Plant, BK – "Balakovokhleb", MMP – Modin Metal Plant, CPP – "Concrete Products Plant" limited company. Closed industrial enterprises: RCPP-3 – reinforced concrete products plant, WWP – woodworking plant, BF – brick factory.

Table 1. Brief characteristics of soil sampling sites.

Sample numbers	Characteristics of soils and substrates (after: Stroganova & Agarkova, 1992; Stroganova et al., 1997)	Location of sampling points
10, 16, 17, 38	Compacted Culturozems – loose fill material in landscaped blocks of modern development	Residential-transport zone with green plantings in multi-storey building areas
11, 12, 21, 22, 26, 30, 34, 35, 37	Urbanozems – anthropogenically deeply transformed soils, compacted, with abundant technogenic inclusions and physicochemical alterations, in old city districts	
7, 28	Culturozems of front gardens	Residential zone, front gardens and green areas in private housing sectors and cottage settlements
2, 41, 45	Urbanozems of low-rise building areas	
9	Urbanozem of a waterlogged area with moisture-loving vegetation	
14	Natural soils with household waste	
1, 8, 36, 43	Urbanozems – anthropogenically deeply transformed soils, compacted, with abundant technogenic inclusions, construction waste, and physicochemical alterations	Industrial zone with herbaceous and woody-shrub vegetation near operating and closed plants, garage complexes
15, 19, 33, 40, 42, 44	Technosols – substrates with abundant technogenic loose material, construction debris	
3, 5	Undisturbed soils, represented by compacted Southern Chernozem in natural condition	
13, 24, 29	Culturozems – recent fill material in landscaped parks	Recreational zone, areas in public gardens and parks
6, 20, 25	Compacted soils in old city parks	
23, 27	Urbanozems – anthropogenically deeply transformed soils, compacted, with physicochemical alterations, construction and household waste	
4, 18, 31, 39, 46, 47, 48, 49, 50	Undisturbed soils– Southern Chernozems and Dark Chestnut soils, littered in many areas, with abundant inclusions	Recreational zone, forest plantations on the city periphery
32	Urbanozem	

Table 2. Content of acid-soluble forms of HMs in soils of Balakovo city, mg/kg.

Sample number	Cu	Cr	Pb	Zn	Ni	Cd
1	5.19	0.19	8.68	13.65	6.63	0.05
2	6.66	0.22	21.54	34.25	8.11	0.09
3	9.97	0.51	12.53	33.34	15.4	0.17
4	7.22	0.43	4.67	15.19	13.57	0.08
5	3.97	0.22	3.21	9.92	6.0	0.04
6	5.83	0.23	8.0	21.07	7.52	0.11
7	6.28	0.21	15.32	29.91	6.86	0.09
8	7.29	0.25	23.57	26.18	8.86	0.08
9	7.57	0.33	27.99	20.55	13.03	0.1
10	6.45	0.23	12.59	29.07	8.47	0.07
11	5.43	0.27	9.68	25.72	8.67	0.25
12	4.29	0.19	6.93	30.45	6.15	0.13
13	4.84	0.2	5.13	16.81	7.38	0.11
14	12.82	0.18	9.09	45.32	12.52	0.26
15	4.75	0.16	13.14	20.57	5.15	0.14
16	7.11	0.32	14.84	44.83	9.47	0.17
17	7.19	0.21	13.76	77.08	5.7	0.17
18	6.48	0.24	5.61	27.12	7.68	0.1
19	14.78	0.31	85.51	77.98	4.86	0.21
20	6.06	0.21	7.03	20.62	7.78	0.13
21	6.0	0.19	8.73	46.12	7.61	0.11
22	6.39	0.26	85.59	174.36	6.13	0.27
23	3.97	0.14	4.43	15.43	3.87	0.05
24	5.26	0.2	4.31	18.85	7.99	0.13
25	4.08	0.18	5.22	13.18	5.97	0.05
26	7.04	0.21	9.3	48.51	7.29	0.15

Sample number	Cu	Cr	Pb	Zn	Ni	Cd
27	15.36	0.27	104.35	109.11	6.78	0.34
28	4.74	0.2	309.88	35.3	7.34	0.07
29	4.96	0.23	5.43	17.34	8.92	0.13
30	5.46	0.2	5.44	17.80	8.0	0.11
31	3.89	0.21	4.16	12.72	9.09	0.1
32	6.07	0.29	5.25	18.62	9.29	0.07
33	9.44	0.25	21.45	36.93	5.02	0.16
34	6.07	0.21	16.38	122.61	4.26	0.11
35	5.31	0.25	6.26	27.08	9.49	0.11
36	6.18	0.21	5.16	13.6	7.88	0.06
37	4.66	0.22	6.46	69.91	7.9	0.11
38	4.48	0.22	2.66	11.86	9.87	0.09
39	5.12	0.29	4.41	20.96	11.38	0.09
40	2.96	0.13	5.19	30.08	3.54	0.07
41	6.01	0.24	6.06	14.64	8.87	0.07
42	12.78	0.41	15.74	45.54	13.36	0.15
43	5.57	0.3	5.65	12.35	9.46	0.04
44	4.76	0.12	5.57	34.24	3.3	0.05
45	5.24	0.24	5.2	10.97	7.22	0.04
46	5.01	0.25	4.53	13.15	11.6	0.09
47	7.05	0.24	9.91	28.97	10.99	0.15
48	11.07	0.33	12.87	41.24	9.25	0.1
49	5.68	0.28	5.37	46.88	10.7	0.14
50	7.28	0.32	5.31	9.7	11.87	0.09
фон	6.42	0.36	7.09	15.09	10.67	0.16

Table 3. Concentration coefficients of chemical elements and total soil pollution of Balakovo city.

Sample number	K_c						Z_c
	Cu	Cr	Pb	Zn	Ni	Cd	
1	0.81	0.53	1.22	0.9	0.62	0.31	< 16
2	1.04	0.61	3.04	2.27	0.76	0.56	< 16
3	1.55	1.42	1.77	2.21	1.44	1.06	< 16
4	1.12	1.19	0.66	1.01	1.27	0.5	< 16
5	0.62	0.61	0.45	0.66	0.56	0.25	< 16
6	0.91	0.64	1.13	1.4	0.7	0.69	< 16
7	0.98	0.58	2.16	1.98	0.64	0.56	< 16
8	1.14	0.69	3.32	1.73	0.83	0.5	< 16
9	1.18	0.92	3.95	1.36	1.22	0.63	< 16
10	1.0	0.64	1.78	1.93	0.79	0.44	< 16
11	0.85	0.75	1.37	1.7	0.81	1.56	< 16
12	0.67	0.53	0.98	2.02	0.58	0.81	< 16
13	0.75	0.56	0.72	1.11	0.69	0.69	< 16
14	2.0	0.5	1.28	3.0	1.17	1.63	< 16
15	0.74	0.44	1.85	1.36	0.48	0.88	< 16
16	1.11	0.89	2.09	2.97	0.89	1.06	< 16
17	1.12	0.58	1.94	5.11	0.53	1.06	< 16
18	1.01	0.67	0.79	1.8	0.72	0.63	< 16
19	2.3	0.86	12.06	5.17	0.46	1.31	17.84
20	0.94	0.58	0.99	1.37	0.73	0.81	< 16
21	0.93	0.53	1.23	3.06	0.71	0.69	< 16
22	1.0	0.72	12.07	11.55	0.57	1.69	23.31
23	0.62	0.39	0.62	1.02	0.36	0.31	< 16
24	0.82	0.56	0.61	1.25	0.75	0.81	< 16
25	0.64	0.5	0.74	0.87	0.56	0.31	< 16

Sample number	K_c						Z_c
	Cu	Cr	Pb	Zn	Ni	Cd	
26	1.1	0.58	1.31	3.21	0.68	0.94	< 16
27	2.39	0.75	14.72	7.23	0.64	2.13	23.47
28	0.74	0.56	43.71	2.34	0.69	0.44	45.05
29	0.77	0.64	0.77	1.15	0.84	0.81	< 16
30	0.85	0.56	0.77	1.18	0.75	0.69	< 16
31	0.61	0.58	0.59	0.84	0.85	0.63	< 16
32	0.95	0.81	0.74	1.23	0.87	0.44	< 16
33	1.47	0.69	3.03	2.45	0.47	1.0	< 16
34	0.95	0.58	2.31	8.13	0.4	0.69	< 16
35	0.83	0.69	0.88	1.79	0.89	0.69	< 16
36	0.96	0.58	0.73	0.9	0.74	0.38	< 16
37	0.73	0.61	0.91	4.63	0.74	0.69	< 16
38	0.7	0.61	0.38	0.79	0.93	0.56	< 16
39	0.8	0.81	0.62	1.39	1.07	0.56	< 16
40	0.46	0.36	0.73	1.99	0.33	0.44	< 16
41	0.94	0.67	0.85	0.97	0.83	0.44	< 16
42	1.99	1.14	2.22	3.02	1.25	0.94	< 16
43	0.87	0.83	0.8	0.82	0.89	0.25	< 16
44	0.74	0.33	0.79	2.27	0.31	0.31	< 16
45	0.82	0.67	0.73	0.73	0.68	0.25	< 16
46	0.78	0.69	0.64	0.87	1.09	0.56	< 16
47	1.1	0.67	1.4	1.92	1.03	0.94	< 16
48	1.72	0.92	1.82	2.73	0.87	0.63	< 16
49	0.88	0.78	0.76	3.11	1.0	0.88	< 16
50	1.13	0.89	0.75	0.64	1.11	0.56	< 16

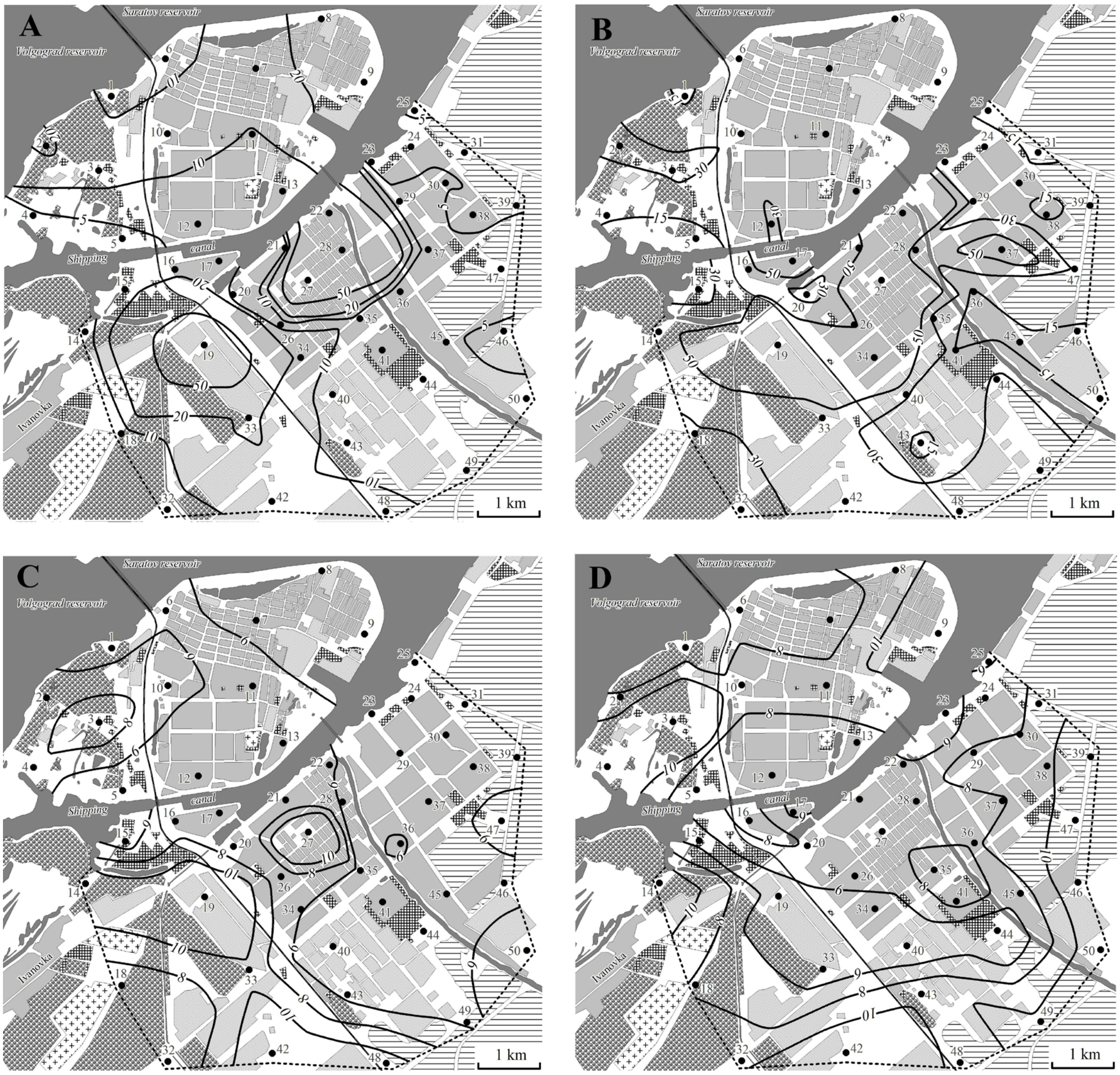

Fig. 2. Content of acid-soluble forms of HMs in soils, mg/kg. **A** – lead, **B** – zinc, **C** – copper, **D** – nickel (other designations as in Fig. 1).

In order to assess the man-made geochemical transformation of soils, the concentration coefficients of chemical elements were calculated:

$$K_c = C_i / C_b,$$

where C_i is the content of the i-th element in the sample, C_b is its background content.

For integral evaluation of polymetallic pollution, we used the indicator of total contamination:

$$Z_c = \sum(K_{ci} + ... + K_{cn}) – (n – 1),$$

where K_{ci} – the concentration coefficient of the i-th element, n is the number of elements with $K_c > 1$.

Chemical pollution categories were identified in accordance with Sanitary Rules & Regulations 1.2.3685-21[6] by Z_c values: < 16 – permissible, 16–32 – moderately hazardous, 32–128 – hazardous, > 128 – extremely hazardous.

[6] SanPiN 1.2.3685-21. Hygienic standards and requirements for ensuring safety and (or) harmlessness of environmental factors for humans (Section IV. Soil of populated areas and agricultural lands).

The number of microorganisms in soil was determined with the use of the limiting dilution method by inoculating soil suspensions on agar nutrient media with further counting the grown colonies after 3–7 days of cultivation at a temperature of 28–30 °C. The total number of cultivated heterotrophic microorganisms (TNHM) on GRM agar was estimated (State Scientific Center for Applied Microbiology and Biotechnology, Obolensk, Russia) (Netrusov et al., 2005). Sabouraud medium was employed to define the quantity of microscopic fungi. GRM-agar inoculation was performed in three replicates from dilutions of 10^{-6}, 10^{-7}, on Sabouraud medium – 10^{-3}. The data on microorganisms abundance were recalculated for air-dried samples.

The experimental data were tested for normalcy of distribution based on the Kolmogorov – Smirnov criterion. In comparison of mean values, we used the Fisher test and the least significant difference indicator ($p \leq 0.05$) of the one-way analysis of variance (ANOVA). The correlation analysis of the relationships between the microbiological and geochemical properties of soils was made using the Pearson coefficient (r). In data processing and analysis, we applied STATISTICA 13.0 package (TIBCO Software Inc. 2017, Statsoft Russia). Maps were created in MapInfo Pro 11.0 (Pitney Bowes Software Inc., 2011, USA).

Results and discussion

The results of metal content determination in the city of Balakovo are presented in Table 2, calculations of concentration coefficients and total pollution indices in Table3, and concentrations of HMs in soil in Fig. 2.

The Cd content was within the background level in 84% of samples, and only in 8 it was higher. The value of K_c > 1.5 was recorded for soils of four test sites, removed from each other (11, 14, 22, 27). No clear patterns of Cd areal distribution were found.

Since the background level of Cr was high, in samples (94%) of urban soils its content was lower and only in three samples (sites 3, 4, 42) higher by 1.5 times. No patterns of spatial distribution were found.

The content of Ni lower the background level was revealed in 40 samples (80%) and higher in 10 (20%, all up to 1.5 background). Increased concentrations of Ni in natural soils were recorded in the eastern and south-eastern outskirts of the city, as well as in the west of its island part. Here, the increased content of Ni is, probably, characteristic of natural soils. Dispersion of this element is noted with culture soils creation and physicochemical impacts in residential and industrial areas. In some samples, the increased level of Ni is associated with industrial impact. Thus, the maximum content was found at sites nos. 4 (K_c = 1.27), where previously a wood processing plant was located; 14 (K_c = 1.17) next to it an oil depot, and 42 (K_c = 1.25), including the area between HPP-4, a road and a railway.

Similar trends were noted for Cu. Its content below the background level was observed in 32 (64%) and above – in 18 soil samples (36%). Cu concentrations exceeding 1.5 background values are typical for the southwestern part of the city with energy and mechanical engineering industrial enterprises. Important that in two samples (sites nos. 14 (K_c = 2) and 42 (K_c = 1.99)) with the highest Ni, the content

Table 4. Correlation between geochemical and microbiological indicators of soils. * – significant level r at p = 0.05; C – metal concentration; TNHM – total number of heterotrophic microorganisms.

Indicators	C_{Ni}	C_{Pb}	C_{Zn}	C_{Cu}	C_{Cr}	C_{Cd}	TNHM	Micromycete number
C_{Ni}	1	−0.128	−0.258	0.274*	0.740*	0.089	0.117	−0.070
C_{Pb}		1	0.327*	0.193	0.001	0.203	−0.025	0.206
C_{Zn}			1	0.399*	0.055	0.640*	−0.068	0.060
C_{Cu}				1	0.506*	0.635*	−0.119	−0.200
C_{Cr}					1	0.208	−0.114	−0.063
C_{Cd}						1	−0.086	−0.187

of Cu was also the greatest. In sites nos. 19 (K_c = 2.3) and 27 (K_c = 2.39), the operating and closed construction-installation workshops with the construction-household waste are located.

Concentrations of Pb in soil samples varied in a wide range: from 2.66 to 309.88 mg/kg. The background level was exceeded in 24 samples (48%), decreased in 26 ones (52%). In the Zakanalnaya part of the city with a predominance of private housing and a relatively low level of improvement, the most contrasting anomaly existed in three sites: nos. 22 (K_c = 12.07), 27 (K_c = 14.72) and 28 (K_c = 43.71). Lead pollution in this city area was obviously "inherited", being formed under the influence of vehicle emissions. The second anomaly of Pb was recorded in a vast industrial zone with machine-building and construction enterprises, i.e. in sites nos. 19 (K_c = 12.06) and 33 (K_c = 3.03). The increased Pb content (sites nos. 8 (K_c = 3.32) and 9 (K_c = 3.95)) in the east of the island part of the city is explained by industrial impact. Agricultural lands and forest plantations on the outskirts of the city, as well as the areas of the new development with spread culture soils are distinguished by the least pollution.

The range of Zn concentrations in urban soils is significant: from 9.7 to 174.36 mg / kg. Its content is above the background in 39 (78%) and below – in 11 samples (22%). The most contrasting anomaly extends from the industrial zone in the west of the city to the northeast through the residential area of old medium- and low-rise buildings. The maximum content of Zn is noted in the residential zone (K_c = 7.23–11.55). In a large city area, its content is twice as much as the background indicator: sites nos. 17 (K_c = 5.11), 19 (K_c = 5.17), 22 (K_c = 11.55), 27 (K_c = 7.23) and 34 (K_c = 8.13). As compared to the citywide background, the lowest concentrations of Zn were common for the island part.

Our data on HMs concentrations correspond to the results obtained in the 1980s – 1990s. In the city, a geochemical anomaly with a high content of technophile elements is still present. The priority pollutants for lithogeochemical monitoring are Zn, Pb, Cu and Ni.

The correlation analysis (Table 4) has revealed the relationship between the certain pairs of HMs; a strong direct correlation in Ni–Cr (r = 0.74; p = 0.05), an average correlation (r values ± 0.3–0.69) in Cd–Zn, Cd–Cu, Cr–Cu, Zn–Cu, Pb–Zn, and a reliable weak one in Ni–Cu.

By concentrations of Z_c, 46 test sampling sites (92%) fall in the category of allowable chemical pollution (Table 3). Moderately hazardous pollution was detected in sites nos. 19 (association $Pb_{12.06}$–$Zn_{5.17}$–$Cu_{2.3}$–$Cd_{1.31}$) and 27 ($Pb_{14.72}$–$Zn_{7.23}$–$Cu_{2.39}$–$Cd_{2.13}$), while a strong soil contamination in site 28 ($Pb_{43.71}$–$Zn_{2.34}$). Spatially, the polymetallic contamination forms two local technogenic geochemical anomalies:

1) in the industrial zone (site no. 19);

2) in the city center with its private residential buildings distinguished by a low level of amenities (sites nos. 2, 27, 28).

Despite the strong influence of seasonal factors, the total number of heterotrophic microorganisms is a reliable indicator of the ecological state of urban soils (Sumampouw and Risjani, 2014).

In terms of heterotrophic microorganisms enrichment by the scale of D.G. Zvyagintsev (1978), soils of Balakovo were characterized as very rich (> 1×10^7 CFU/g), and in some sites (nos. 20, 33, 36 and 48) as rich (1×10^7 CFU/g) (Table 5). The number of cultivated aerobic heterotrophic microorganisms (≈ 10^{10}) was maximal in samples from sites nos. 5, 47 (natural soils) and 41 (culture soil). Their average number declined as follows: natural soils → culture soils → urban soils (2.5×10^8, 1.9×10^8 and 1.2×10^8 CFU/g, respectively). In industrial soils, the average number of cultivated aerobic heterotrophic microorganisms was 3 times lower than in natural soils, amounting to 8.3×10^7 CFU/g. TCHM turned out to be the lowest (1×10^7 CFU/g) in sites nos. 33 and 36 of the industrial zone, nos. 20 and 48 of the recreational zone. It may indicate a possible inhibitory effect of pollutants.

In this study, no reliable correlations between the content of heavy metals and the number of heterotrophic microorganisms in soil microbiocenoses of the city were established. In general, this microbiological indicator in urban soils did not differ significantly from that in the background soils located outside the city that characterizes the environmental situation as favorable (with the exception of several sites). It is known that the microbial complex response to soil pollution with heavy metals is the greatest immediately after their introduction, however later it gradually weakens due to the action of protective mechanisms in bacteria. Our studies of urban soils are evidence of microbiocenoses resistance to anthropogenic impact and their high adaptive potential.

V.A. Terekhova (2007) has proved the possibility and necessity of using indicators of the number and species composition of micromycetes in indication and diagnostics of soil pollution. Often, anthropogenic impacts can be responsible for a decline in species richness and diversity of micromycetes in soil

Table 5. Results of the assessment of microbiological indicators in soils of Balakovo city.

Soils	Sample number	Total number of heterotrophic microorganisms, lg CFU/g	Micromycete number, lg CFU/g
Urbanozems	1	8.2	6.2
	8	8.6	5
	11	8.2	6
	21	8.4	6
	26	9	6.2
	32	8	6
	35	7.6	5.6
	36	7	6.3
	37	8.3	7
	43	7.5	7
Technosols	19	7.6	5
	33	7	7
	40	8	6.2
	42	8	7
	44	9	7
Culturozems	9	9	5.8
	10	8.8	5.6
	13	8	5.5
	14	9	6
	20	7	6.7
	24	7.9	5.9
	25	7.5	7
	28	8.2	7.3
	29	7.3	6.2
	41	10	6
Undisturbed soils	4	8.7	6
	5	10	5.8
	18	8.3	6.1
	31	8.3	6
	39	8.7	7
	47	9.5	5.5
	48	7	6.3
	49	7.3	7
	50	7.5	5.9

that is considered a dangerous trend (Marfenina, 2005). It is shown that in the heavily polluted soils containing the Zn+Pb+Cd complex, sometimes only a few species with a high frequency of occurrence are preserved or atypical species emerge. Because of HMs influence, fungi species (*Penicillium funiculosum*, *Penicillium purpurogenum*, *Penicillium lilacinum*, *Aspergillus terreus*), resistant to high metal concentrations, appear in microbial cenoses (Berseneva and Salovarova, 2011). With further transition from the zone of resistance to repression, the complete suppression of the growth and development of micromycetes may occur. There are the data on stimulating the development of soil phytopathogenic micromycetes dominated by *Verticillium tenerum*, *Fusarium solani* under conditions of anthropogenic pollution with Cd and Cu compounds (Rudakov and Rudakov, 2009).

In soils of Balakovo, the level of micromycetes enrichment varied greatly (Table 5): from very poor (< 2×10^6 CFU/g) to rich ($1–2\times10^7$ CFU/g). Any relationship between this microbiological indicator and the level of soil contamination with heavy metals was not found. The maximum number of micromycetes (≈ 10^7) was observed both in industrial and urban soils in the south of the studied area (e.g., in samples from sites nos. 33, 42, 43 and 44) and in culture soils of the north-eastern part (nos. 25 and 28). In the island part of the city, they were not as abundant. The average number of micromycetes in natural, culture, urban and industrial soils was similar (≈ $1–2\times10^6$ CFU/g). The micromycetes content in the background and mentioned above soils did not differ.

Conclusions

The geochemical analysis of the urban territory of Balakovo, made it possible to detect major pollutants of soils (Zn, Pb, Cu and Ni) that is consistent with the results of the studies conducted in the late XX century. The sites of maximum technogenic soil transformation caused by polymetallic contamination have been identified near large enterprises in the southwestern part of the city and the low-rise residential development with a low level of amenities. Particularly noteworthy is the influence of the quality of improvement and measures on the creation of the comfortable urban environment. In contrast to the old low-rise development with detected lithogeochemical anomalies, culture soils of squares and parks in modern microdistricts, are in a satisfactory condition.

The quantitative composition of microbiocenoses of Balakovo and background soils differ insignificantly. We have established a decreasing trend in the content of heterotrophic microorganisms: natural soils → culture soils → urban soils → industrial soils. In culture, urban and industrial soils, the average number of cultivated aerobic heterotrophic microorganisms is 1.3, 2 and 3 times lower than in natural soils.

The data obtained from the geochemical and microbiological studies were used for preparation of the cartographic material clearly reflecting the problem sites in various city areas. The implemented zoning can serve as a basis of soil monitoring for environmental and sanitary-hygienic purposes.

Our findings give a comprehensive notion about the distribution of hazardous ecotoxicants in the urban sites (exposed to various technogenic loads), as well as their effect on soil microbiocenoses that should be considered when designing and creating the comfortable human environments. To reduce HM concentrations in soil, it is necessary to modernize the industrial enterprises and provide the expanded sanitary protection zones around them. The territory reclamation of the closed and partially dismantled enterprises (with lots accumulated wastes) calls for a particular attention.

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