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Assessment of the impact of vehicle emissions on the geoecological state of soils and vegetation in the cities of the Irkutsk agglomeration

Svetlana A. Novikova

Irkutsk State Transport University, Irkutsk, Russian Federation
✉ eco-science@mail.ru

Abstract. The study examines the problem of the influence of vehicle emissions on the condition of soils and vegetation of roadside strips in the cities of the Irkutsk agglomeration. Sampling was carried out near intersections characterized by intense traffic flows. As a result of a mass (semi-quantitative) full spectral analysis of selected samples, the content of heavy metals in them was revealed to be higher than the maximum permissible and background concentrations. Calculations of the total pollution indicator were carried out, which made it possible to establish that the soils of roadside zones in urbanized areas of the agglomeration belong to the categories “dangerous” and “extremely dangerous”. Recommendations for improving the geoecological condition of soils and vegetation in urban areas are given.

Keywords: urbanized areas, vehicles, heavy metals, roadside areas, soil and vegetation

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Оценка влияния выбросов автомобильного транспорта на геоэкологическое состояние почв и растительности городов Иркутской агломерации

С.А. Новикова ✉

Иркутский государственный университет путей сообщения, Иркутск, Российская Федерация

✉eco-science@mail.ru

Аннотация. Рассмотрена проблема влияния выбросов автотранспортных средств на состояние почв и растительности придорожных полос городов Иркутской агломерации. Осуществлен отбор проб вблизи перекрестков, характеризующихся интенсивным движением автотранспортных потоков. В результате массового (полуколичественного) полного спектрального анализа отобранных проб выявлено содержание в них тяжелых металлов, превышающее значения предельно допустимой и фоновой концентраций. Проведены расчеты суммарного показателя загрязнения, позволившие установить, что почвы придорожных зон урбанизированных территорий агломерации относятся к категориям «опасная» и «чрезвычайно опасная». Даны рекомендации по улучшению геоэкологического состояния почв и растительности урбанизированных территорий.

Ключевые слова: урбанизированные территории, автотранспорт, тяжелые металлы, придорожные зоны, почва и растительность

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Introduction

Soil and vegetation are accumulators of harmful substances and, consequently, bioindicators of the quality of environmental components, in particular, the atmospheric air. The greatest danger is posed by heavy metals, as they are highly toxic and poorly removed from the environment. As is known, heavy metals are also part of car exhaust gases. In addition, they are emitted during various operations related to the operation of motor vehicles, such as tyres and brake pad wear, oil leakage, corrosion of batteries and other metal parts [1-2].

The increase in the number of motor vehicles leads to a deterioration of the urban environment. The impact of motorways is particularly intense in areas of low air exchange. About 20 % of particles are deposited in the roadside space, about 60 % of particles are deposited in the zone from 10 to 100 m, the remaining particles are usually carried by the wind over long distances. Areas located on leeward sides of the road are subject to the greatest accumulation of heavy metal particles [3].

The condition of urban green spaces directly affects the ecological functions they fulfil. Vegetation of urbanised areas is affected by a number of negative factors directly related to anthropogenic activity [4]. Plants absorb heavy metals not only by their roots from the soil, but also by their leaves from the atmosphere, sometimes up to half of the elements contained in these environments. According to literature data, heavy metals accumulate several times more in the needles and leaves of woody vegetation than in their trunk parts [5].

Thus, in the Irkutsk agglomeration the impact of motor transport emissions on the geoecological state of soil and vegetation of roadside areas was assessed [6-7]. In the cities of Irkutsk, Angarsk and Usolye-Sibirskoye, soil, leaves, needles, and grass were sampled at key sites – intersections characterised by increased intensity of motor traffic flows. Figure 1 presents a diagram of the number of vehicles recorded during the survey at the intersections during rush hours. As a result of the research, a database of indicators of heavy metal content in soils and vegetation of roadside strips of the agglomeration was formed and registered [8].

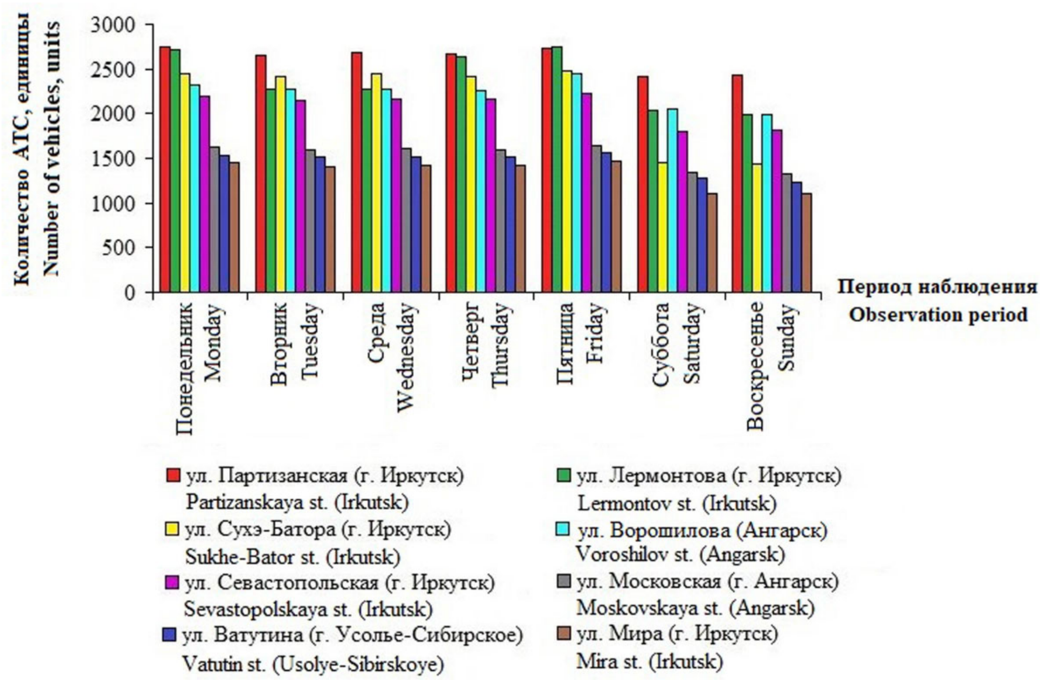

Figure 1. Dynamics of the number of motor vehicles, recorded at intersections during rush hours

Research methods

A total of 160 soil, grass, foliage, and needle samples were collected from the key sites as a result of sanitary and hygienic surveys – 40 samples for each medium. Soil and vegetation sampling was carried out using the "envelope" method. The essence of this method is the collection of five samples arranged in the form of a sealed envelope at the selected site (four points are located at the edges and one in the centre). Soil was sampled layer by layer from 0–5 and 5–20 cm depth. After point samples were taken, pooled samples were formed by combining and mixing them [9–10].

According[1] to the list of chemical indicators should include determination of the content of heavy metals: lead, cadmium, zinc, copper, nickel, arsenic, mercury as potentially hazardous chemicals for humans and the total indicator of soil contamination.

Mass (semi-quantitative) full spectral analysis was carried out in the laboratory of the Baikal branch “Sosnovgeologiya” of the Federal State Unitary Geological Enterprise (FSUGP) “Urangeo” (Irkutsk). The selected samples were dried at room temperature, weighed, then ground into powder to particle size of 75 μm and calcined in special installations at 400°C to avoid losses of volatile elements.

The applied “Methodology of mass (semi-quantitative) full spectral analysis”[2] allows to determine 50 chemical elements in selected samples: Si, Al, Mg, Ca, Fe, Na, K, Mn, Ni, Co, Ti, V, Cr, W, Mo, Zr, Hf, Nb, Ta, Cu, Pb, Zn, Sn, Sb, Tl, As, Ge, Bi, Cd, Ag, Be, Sc, Ga, Ce, La, Y, Yb, P, U, Th, Ba, Sr, Li, Rb, Cs, B, Te, In, Gd, Au. Each chemical element has a characteristic emission spectrum that is unique to it. The intensity of the emitted linear spectrum is a function of the content of the element under study in the sample. As a source of excitation of the characteristic spectrum a vertical electric arc between carbon electrodes is used, in one of which a powder of the investigated geological sample is placed. To separate in the spectrum the lines of elements differing in volatility and other physical and chemical constants, the phenomenon of fractional evaporation of elements of the analysed material is used – the method of current-time scanning method. A diffraction spectrograph DFS-8-1 was used for decomposition of radiation into a spectrum and its photographic registration.

Photographic registration of spectra was carried out on spectral photoplates of 13×18 cm size. Each analysed sample was evaporated in an arc discharge once. After the end of imaging, the photoplate was developed, fixed and dried. Visual interpretation of the spectra of the analysed samples was carried out by the method of “line appearance-enhancement” in combination with the method of “line intensity comparison”.

The spectra of standard geological materials with known contents of the determined chemical elements were compared with the spectra of the analysed samples obtained under identical conditions. The detection limits of elements were estimated from artificial mixtures and samples with known contents of chemical elements.

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[1] SanPiN 2.1.3684-21. Sanitary and epidemiological requirements for the maintenance of urban and rural areas, water facilities, drinking water and drinking water supply, atmospheric air, soils, living quarters, operation of industrial and public premises, organization and implementation of health-preventive (preventive) measures.

[2] Methods of mass (semi-quantitative) full spectral analysis. Standard of enterprise of Sosnov production and geological association (PGO) (STP–PGO–009–84). Document dated 14.11.1984 № 251, Irkutsk, 1984. 35 p.

Results and discussion

Figures 2–5 present diagrams of some results of spectral analysis of heavy metals content in soils and roadside vegetation in comparison with normative – maximum permissible concentration (MPC) and background. As background concentrations of heavy metals content in soil were used recommended values of conditionally uncontaminated soil, typical for the territory of the region under consideration, allowing the most objective assessment of the degree of geochemical changes occurring under the influence of anthropogenic factor[3]. Since heavy metal MPCs for vegetation have not been developed, in this experiment the actual concentrations of heavy metals in leaves, needles and grass of roadside vegetation were compared with respect to the MPCs established for soil.

Thus, chromium concentrations in roadside soils exceed the MPC value in the samples taken: in Moskovskaya st. (Angarsk) – 3 times, Voroshilova st. (Angarsk) – 2.4 times, Partizanskaya st. (Irkutsk) – 2.3 times, Sukhbaatar st. (Irkutsk) – 1.5 times, Sevastopolskaya st. (Irkutsk) – 1.5 times. Partizanskaya st. (Irkutsk) – 2.3 times, Sukhbaatar st. (Irkutsk) – 1.5 times, Sevastopolskaya st. (Irkutsk) – 1.4 times, Lermontova st. (Irkutsk) – 1.3 times. Chromium concentrations in soil samples taken in Mira st. (Irkutsk) and Vatutina st. (Usolie-Sibirskoye) are within the MPC limits. Chromium concentrations in all soil samples exceed background values by 41-143 times. Chromium concentrations in all grass samples exceed background concentrations by 1.5-38.7 times. Chromium content in all foliage samples exceeds background in 1.5-11.2 times. Chromium content in conifers sampled on Lermontova st. exceeds background values 5.2 times, in Moskovskaya st. and Vatutina st. – 1.1 times (see Figure 2).

Lead concentration in roadside soil sampled in Sevastopolskaya street exceeds the MPC 1.1 times. Lead content in soil samples taken in Sukhbaatar and Mira streets is at the MPC limit. Lead concentrations in all soil samples exceed the background concentration by 15-44 times. Lead concentrations in almost all grass samples (except for samples from Moskovskaya street) exceed background concentrations by 1.2-6.2 times. The values of lead concentrations in the collected foliage samples in the following streets: Sevastopolskaya, Lermontova, Mira, Voroshilova, Moskovskaya, exceed the background concentration by 3.8; 2.9; 2.4; 1.9; 1.1 times, respectively. Lead content in the conifers sampled in Lermontova st. exceeds the background value 1.7 times, in other samples – values below background (see Figure 3).

[3] GOST 17.4.3.01–2017. Interstate Standard. Nature Protection. Soil. General requirements for sampling (implemented by Rosstandart Order from 01.06.2018 No. 302–st.).
GOST R 58588–2019. Selection and preparation of plant samples for isotopic analysis (implemented by the Order of the Federal Agency for Technical Regulation and Metrology from 09.10.2019 No. 928–st.).

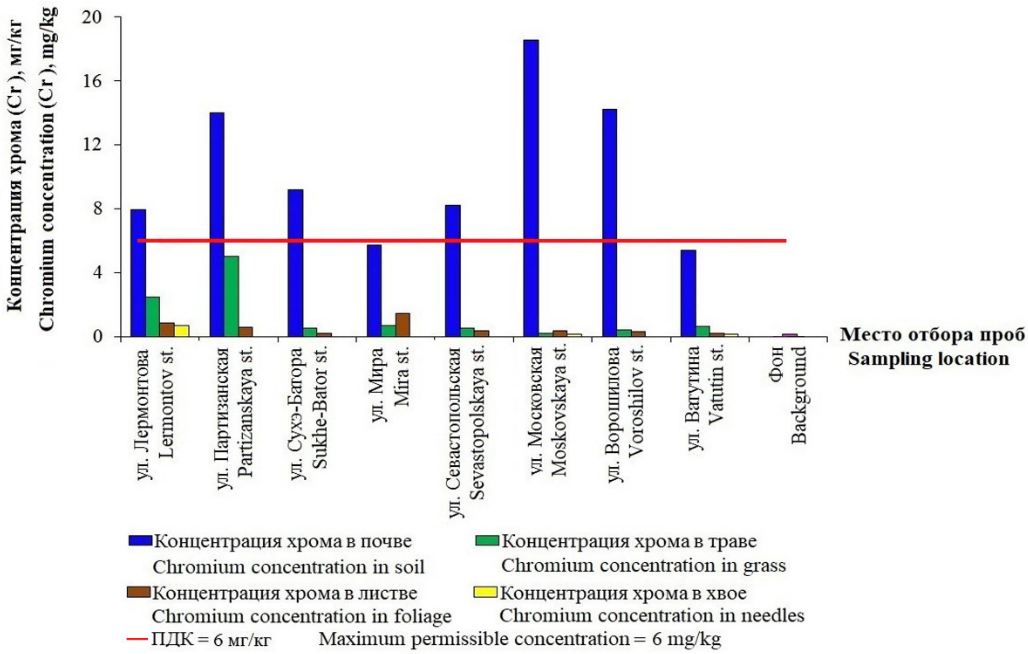

Figure 2. Chromium concentration in selected samples

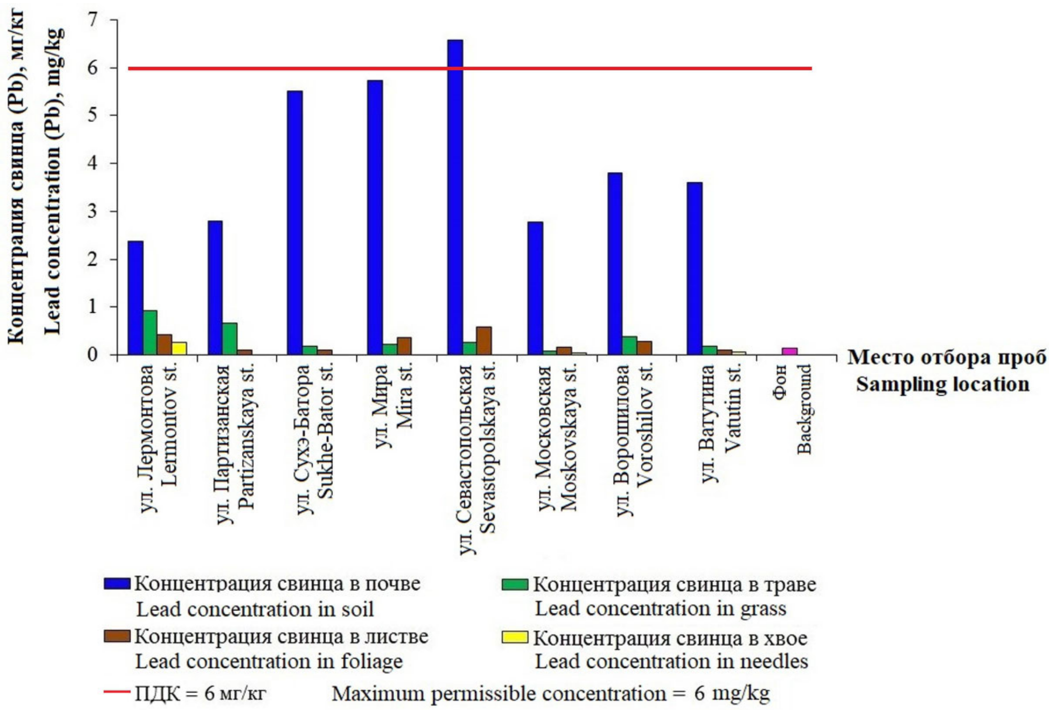

Figure 3. Lead concentration in selected samples

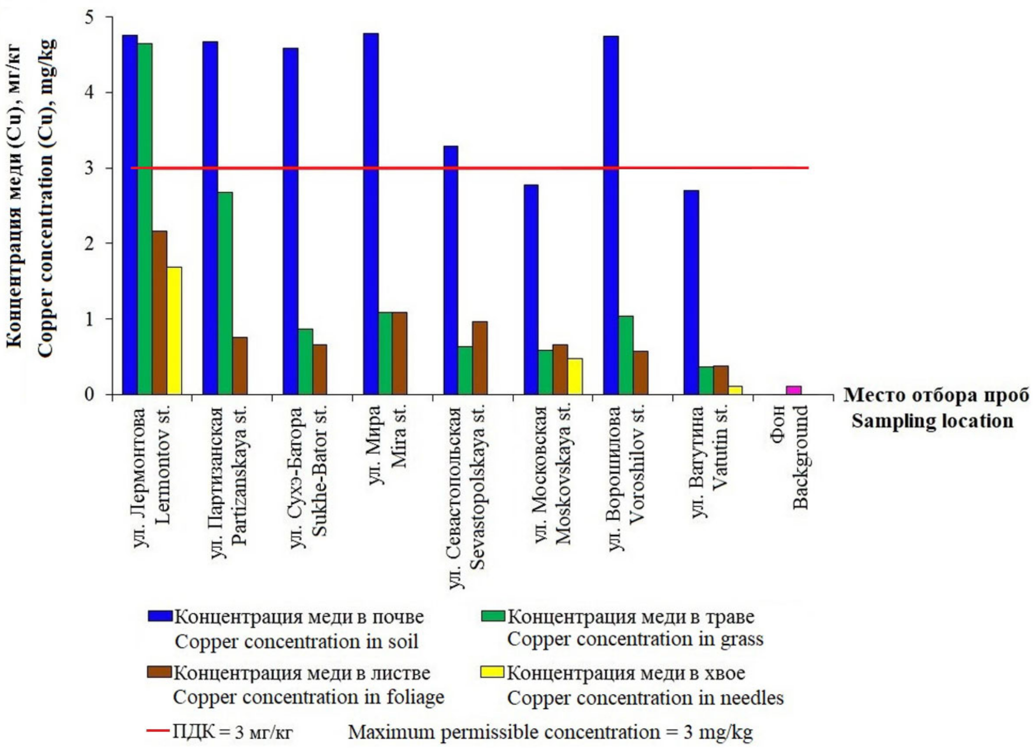

Figure 4. Copper concentration in selected samples

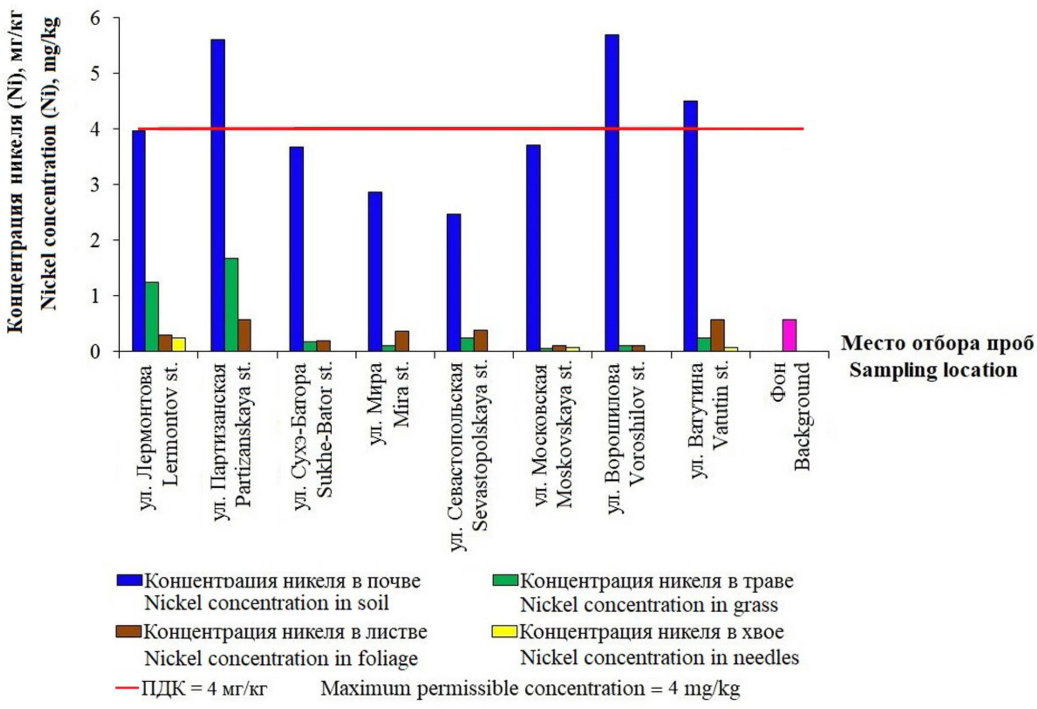

Figure 5. Nickel concentration in selected samples

Copper content in roadside soils sampled in Lermontova, Mira, Partizanskaya streets exceeds MPC 1.6 times, in Sukhbaatar Street – 1.5 times, Voroshilova street – 1.6 times, Sevastopolskaya street – 1.1 times. Concentrations of copper in soil samples in Moskovskaya and Vatutina streets are at the limit of MPC. Copper concentrations in all soil samples exceed background concentrations by 25–44 times. Copper concentrations in grass sampled on Lermontov street exceed the MPC value 1.6 times; in grass sampled in Partizanskaya street – concentrations are close to the MPC value. In all grass samples copper concentrations exceed the background concentration by 5.3-42.2 times. Copper content in all foliage samples exceeds the background value by 3.5-19.6 times. Lead content in conifers sampled in Lermontova st. exceeds the background value 15.3 times, in Moskovskaya st. – 4.4 times, in Vatutina st. – concentration values are at the background level (see Figure 4).

The nickel content of roadside soils selected in the streets of Partizanskaya and Voroshilov exceeds the established sanitary standard by 1.4 times; in Vatutina street – 1.1 times. Concentrations of nickel in soil samples taken on the streets of Lermontov, Sukhe-Bator, Moscow are on the border of the MPC. Nickel concentrations in all soil samples are 4 to 10 times higher than background concentrations. The nickel content in all roadside grass, foliage and needle samples does not exceed MPC, but the nickel concentration in grass taken on the Partizanskaya st. and Lermontov st, exceed the background in 3 and 2.2 times, respectively. In samples of grass selected in Vatutin street, the nickel concentration is at the ambient level, in the remaining specimens – below the ambient value (see Figure 5).

Thus, heavy metal concentrations are correlated with traffic density (see Figure 1), which explains their origin in automobile exhaust.

The assessment of the level of chemical contamination of soils as an indicator of adverse health effects is carried out, including by indicators developed in conjunction with geochemical and hygienic studies of the environment of urban areas with active sources of pollution. The indicators are as follows:

– *the chemical concentration coefficient*, which is determined by the ratio of the actual pollutant content in the soil (C_i) in mg/kg soil to regional background ($C_{фон i}$);

– *total pollution index* (Z_c).

To assess the cumulative effect of the 6 major pollutants (Ni, Co, Cr, Cu, Pb, Zn) the total soil pollution index of the study area, calculated by the formula[4]:

$$Z_c = \sum_{i=1}^{N} \left(\frac{C_i}{С_{фон i}} \right) - (n-1),$$

where Z_c – total soil contamination index;

[4] Resolution of the Chief Medical Officer RF from 28.01.2021 No. 2 “On the approval of health regulations and standards SanPiN 1.2.3685–21 ‘Hygiene standards and safety and (or) human environmental conditions’”.

C_i –actual concentration of the *i*-th element in the soil;
$C_{фонi}$ –background concentration of the *i*-th element in the soil;
N – amount of pollutants;
n – number of substances to be determined.
There are several categories of soil contamination depending on the size of Z_c:
– 0 – pure;
– less than 16 – permissible;
– 16–32 – moderately dangerous;
– 32–128 – dangerous;
– more than 128 – extremely dangerous.
The results of the calculations are presented in the table.

Soil pollution category

Sampling location	Value Z_c	Soil pollution category
Lermontov St	107.6	Dangerous
Partizanskaya St	161.0	Extremely dangerous
Sukhe-Bator St	133.8	Extremely dangerous
Mira St	114.8	Dangerous
Sevastopolskaya St	118.7	Dangerous
Moskovskaya St	170.7	Extremely dangerous
Voroshilov St	166.6	Extremely dangerous
Vatutin St	77.2	Dangerous

Conclusion

The results of the analyses show that the roadside zones of the key sections of the Irkutsk agglomeration under consideration are contaminated with heavy metals, including motor vehicle exhaust gases. Thus, as a result of the mass (semi-quantitative) spectral analysis, exceedances of concentrations of the following elements were found: Cr, Cu, Ni, Pb, Co, Zn, Mo:

– exceedances were detected in soil samples *MPC*: chromium (1.3–3.1 times), copper (1.1–1.6 times), nickel (1.1–1.4 times);

– *ambient concentrations* were exceeded in soil samples: chromium (41.5–142.8 times), copper (24.6–43.5 times), lead (15.8–43.8 times), nickel (4.3–10.0 times), cobalt in (3.9–8.2), zinc (3.2–8.3 times), molybdenum (1.9–3.3 times);

– Copper *MPC* is exceeded in grass samples (1.6 times);

– *ambient concentrations* were exceeded: copper (in grass samples – 3.4–42.2 times, leaves – 3.5–19.6 times, needles – 4.4–15.3 times), chromium (in grass samples – 1.5–38.7 times, leaves – 1.5-11.2 times, needles – 1.1–5.2 times), nickel (in grass samples – 2.2–2.9 times), lead (in grass samples – 1.2–6.2 times, leaves – 1.1–3.8 times, needles – 1.7 times), cobalt (in grass samples – 1.5–3.0 times), zinc (in grass samples – 1.1–2.0 times), molybdenum (in grass samples – 1.2 times; leaves – 1.3 times);

Calculations have shown that the soils of roadside areas of the Irkutsk agglomeration cities belong to the categories "dangerous" and "extremely dangerous" (the value of the total soil pollution index is in the range of 77.2–170.7), which indicates a significant pollution of roadside areas by heavy metals, which are mainly included in the exhaust gases of motor transport (see Table). Statistical processing allowed to draw conclusions about the degree of homogeneity and correctness of data obtained because of mass (semi-quantitative) full spectral analysis of selected soil and vegetation samples.

Soil particles with pollutants contained in it can be lifted by wind into the atmospheric air and, therefore, worsen its quality. To improve the condition of roadside soils, sanitation of urbanized areas should be provided.

As can be seen from the results of the survey, leaves and grass of roadside areas contain heavy metals in quite high concentrations. According to the normative act[5] burning of tree and shrub leaves on the territory of residential areas is prohibited. Collected leaves of trees and shrubs are subject to removal to waste disposal, neutralization, or recycling facilities. However, in the settlements of the Irkutsk agglomeration, cases of grass burning are often revealed[6], which, in addition to the threat of spontaneous combustion of adjacent territories, may be a cause contributing to the deterioration of the environmental situation.

Thus, in order to prevent the deterioration of the environmental situation by the introduction of heavy metals and other toxic components into the atmosphere, It is necessary to regularly monitor the territory of the cities of the Irkutsk metropolitan area with the help of unmanned aerial vehicles, especially during the fire season, and to bring perpetrators to justice. Cases of burning dry roadside vegetation should be reported to the Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters (Ministry of Emergency Situations of Russia).

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Bio note:

Svetlana A. Novikova, Senior Lecturer, Department of Technosphere Safety, Irkutsk State Transport University, 15 Chernyshevsky St, Irkutsk, 664074, Russian Federation. ORCID: 0000-0003-2534-3379. eLIBRARY SPIN-code: 8593-1545. E-mail: eco-science@mail.ru