Distribution of Heavy Metals in Soil of Urban Ecosystems by the Example of the Oryol City

S Vorobyov \textsuperscript{a}, D Kozlov \textsuperscript{b}, T Poturaeva \textsuperscript{c}, I Chernyaeva \textsuperscript{d}

Oryol State University,
Komsomolskaya Street 95, Oryol, Russian Federation, 302026

E-mail: \textsuperscript{a} vorser323@rambler.ru, \textsuperscript{b} dimoktank@mail.ru, \textsuperscript{c} tanpo77@mail.ru, \textsuperscript{d} schunya87@yandex.ru

Abstract. The article deals with the impact of vehicle emissions on the distribution of heavy metals in the soils of urban ecotopes - land urban areas with similar parameters of the biosphere, the technosphere, demographic and urban development factors by the example of the Oryol city.

1. Introduction

Today, the problem of environmental protection is based on the concept of sustainable development, which is used throughout the world and serves as the basis for the development of environmental protection strategies for most countries in the world, including Russia [1, 2, 3]. At the same time, environmental problems are becoming increasingly important especially in urban areas. City - a specific human creation, adaptation for which is linked to human health problems [4]. The human as a biological species is adapted to life in other conditions. But since man is also a social being, its development by is associated with social needs [5]. Satisfaction of social needs and transformation of a environment by human is leads to a violation of the balance. Than greater the transformation of the environment that stronger the negative impact on the biosphere. The human is also a part of the biosphere that is way unbalance of the environment is effect on his health [6]. There is a paradox - a human created urbanized areas for maximum comfort, but pays for it with his health. In the Orel region of the Russian Federation the incidence of cardiovascular diseases of the urban population is 15% higher than of the rural population [7]. This fact is due by the high concentration of industry and vehicles in a limited area. Besides, in large cities 60-80% of atmospheric air pollution falls on motor vehicles [7]. One of the most dangerous types of pollutants in emissions of motor vehicles is a heavy metals. The number of motor vehicles is growing so rapidly that the reduction of emissions that achieved by the cleaners and high-quality fuel is offset by an increase in the number of cars [8]. Vehicles is very mobile, so it easily penetrates into the residential areas, while large industrial enterprises are located outside the city and are separated by sanitary protection zones [9]. Cities are now becoming the main systems for life, so it is important to study and forecast their effects on humans, their environment and the biosphere processes.
2. Results and discussions
As an example, we have analyzed the land territory Orel city as a typical regional center of Central Federal District of Russia. To detect anthropogenic impacts on urban ecosystems we have identified ecotopes - land urban areas with similar parameters of the biosphere, the technosphere (polluters), demographic and urban development factors. As these areas we have chosen the following areas: the area adjacent to the housing number 16 (Moskovskaya street 77) Oryol State University (area 1), the park near main building Oryol State University (Komsomolskaya street 95) (area 2), area adjacent to the Museum of Oryol writers (area 3). All of these areas are characterized by the similar buildings (five-storey buildings, the lack of high-rise buildings, flat terrain), the characteristics of human impact (prevalence of vehicle emissions from major highways), similar areas (about 4 ha), the same composition of green spaces, the same number of inhabitants. All of these areas are characterized by the same set of factors of anthropogenic impact and varying degrees of quantitative manifestation of these factors. As a control area that not feel the impact of these factors, we have chosen the area of Medvedevsky forest (area 4).

![Figure 1 – Location of Area 1](image1.png)

![Figure 2 – Location of Area 2](image2.png)
All ecotopes are differ by only in one indicator - traffic. To determine the number of vehicles for the subsequent calculation of emissions, at study sites were counted in the rush hour, within a year. Noted the number of cars in 30 minutes, followed by recalculation of 1 hour. Car traffic was divided into categories: passenger road transport; cargo, with a diesel engine; truck, with a carbureted engine; bus, diesel engine; with carburetor engine bus; trolley bus; minibuses. Separation was made to more accurately assess the environmental burden, as each of these categories is characterized by a specific set of emissions. Traffic is amounted 2067, 1528, 1231 cars in hour, for areas 1, 2 and 3 respectively.
Table 1 - Number of vehicles in the investigated areas, pcs / hour.

| Vehicle category | Area 1  | Area 2  | Area 3  |
|------------------|---------|---------|---------|
| Car              | 1560    | 1100    | 903     |
| Diesel truck     | 6       | 12      | 5       |
| Gasoline truck   | 48      | 24      | 7       |
| Diesel bus       | 3       | 2       | 12      |
| Gasoline bus     | 120     | 95      | 86      |
| Tolley bus       | 55      | 45      | 68      |
| Minibuses        | 275     | 250     | 205     |
| Total            | 2067    | 1528    | 1231    |

The main source of contamination at all study sites were selected vehicles, as it accounts for a significant portion of the emissions in the city of Oryol. To determine the amount of pollutants from vehicle emissions has been used a technique developed by A. Voeikov [10].

We obtained the following results on the emissions of vehicles on the study areas (Table 2):

Table 2 - Distribution of total and maximum single emission investigated areas

| Investigated area | Total emission, t/year | Maximum single ejection, g/s |
|-------------------|------------------------|------------------------------|
| Area 1            | 13454                  | 15.2789                      |
| Area 2            | 10274                  | 1.0471                       |
| Area 3            | 9338                   | 0.8971                       |

When studying the gross forms of heavy in urban and forest soils, we obtained the following results (Table 3).

Table 3 - Content of gross forms of heavy metals in soil (mg / kg)

| Investigated area | Lead, Pb | Zinc, Zn | Copper, Cu | Nickel, Ni |
|-------------------|----------|----------|------------|------------|
| Area 1            | 65.66    | 101.4    | 107.05     | 22.9       |
| Area 2            | 52.35    | 138.35   | 107.25     | 22.2       |
| Area 3            | 39       | 226.15   | 138.6      | 22.75      |
| Area 4 (control)  | 30.34    | 88.05    | 64.5       | 16.65      |
| MPC               | 130      | 220      | 132        | 80         |

From the data given in the table, it can be seen that the concentration of gross forms of heavy metals in the soil is no more than the MPC. The highest values of lead are noted in the soil of Area 1, the smallest - in the control section (Area 4). The difference between these data is 53.8%. The data obtained indicate a close direct relationship between the content of lead in the soil and the traffic ($r = 0.97$).

Gross zinc forms do not exceed the maximum permissible concentration values at most sites, except for the concentration at Area 3, where concentration more than MPC. The concentration of zinc in Area 3 is higher than in the remaining areas in 1.6–2.2 times and higher than in the control area in 2.6 times. The correlation coefficient $r = -0.74$, which indicates a rather high inverse relationship between the intensity of the traffic and the concentration of the gross forms of this heavy metal.

The highest values of copper concentration are recorded at Area 3 in 2.1 times higher than in the control area. The value of the correlation coefficient between the concentration of the total copper forms and the amount of electric transport (trolley bus) is high and is $r = 0.99$. 
The distribution of gross forms of nickel in soils of different areas differs uniformly. Its concentration in urban soils is higher than in forest soils, but does not exceed the MPC values. The biggest values in the Area 1.

Analysis of mobile forms of heavy metals in soil is also showed a different dependence of their concentration on the traffic (Table 4).

Table 4 - Content of mobile forms of heavy metals in soil (mg / kg)

| Investigated area | Lead, Pb | Zinc, Zn | Copper, Cu | Nickel, Ni |
|--------------------|----------|----------|-----------|------------|
| Area 1             | 48       | 22.39    | 0.34      | 3.35       |
| Area 2             | 2.83     | 28.07    | 0.24      | 3.55       |
| Area 3             | 10.16    | 19.16    | 1.72      | 3.45       |
| Area 4 (control)   | 2.8      | 8.13     | 0.14      | 2.64       |
| MPC                | 6        | 23       | 3         | 4          |

The biggest correlation dependence \((r = 0.99)\) is characteristic for a lead. For other elements, the correlation coefficient, respectively, is: \(Zn-r = 0.17; Cu-r = -0.73; Ni-r = -0.62\).

A comparative analysis of the data in Tables 3 and 4 showed that the pattern of the distribution of gross and mobile forms of heavy metals over the areas is basically identical. The difference is that the highest concentration of mobile forms is observed for a lead. Gross forms do not exceed MPC, but the content of mobile lead is above the MPC at all areas, respectively, at 8; 3.6 and 1.7 times. Mobile forms of Cu do not exceed the values of MPC, but in area 3 the concentration of this heavy metal is higher than on a other areas in at 5.1 to 7.2 times. For mobile forms of Cu, a rather high inverse dependence on the total number of vehicles, but if we consider separately the trolleybus transport in the investigated areas and its influence on the concentration of the this metal, the correlation coefficient is positive and high \((r = 0.98)\). This close connection, as well as the fact that most quantity trolley buses on area 3, makes it possible to assume that in this area the soil complexes, while still coping with the Cu flow, are able to accumulate this heavy metal (the values of the mobile form concentration are not exceed the MPC), but gradually, with increasing traffic, lose their effectiveness. Probably, the presence in the soil of an organic substance capable to fix a this metal to a stationary state is decreased. Over time and with increasing levels of pollution, this process is accelerated more and more. Therefore, in areas 1 and 2, the values of the concentration of mobile forms do not differ much from each other. It can be assumed that organic soil complexes actively absorb this element, and at Area 3 the concentrations differ sharply from the other.

The mobile forms of Zn is exceed the MPC values only at Area 2. The concentration values on the other investigated areas do not differ much between themselves and, although they do not exceed the MPC, but approach this mark.

The mobile forms of Ni do not exceed the MPC and differ in the relative uniformity of the distribution. The highest concentrations are in the area 2. Nickel is characterized by a low correlation coefficient of concentration and traffic \((r = -0.62)\), and a negative sign indicates an inverse relationship between Ni concentrations and traffic.

The revealed dependencies between the content of gross and mobile forms of heavy metals are determined by the mobility of these elements in the soil. Data on the mobility of heavy metals, the ratio of the concentration of the mobile element to its gross content are given in Table 5.
Table 5 - Values of the mobility of heavy metals

| Investigated area | Lead, Pb | Zinc, Zn | Copper, Cu | Nickel, Ni |
|-------------------|----------|----------|------------|------------|
| Area 1            | 0.73     | 0.22     | 0.003      | 0.150      |
| Area 2            | 0.42     | 0.20     | 0.002      | 0.16       |
| Area 3            | 0.26     | 0.08     | 0.012      | 0.16       |
| Area 4 (control)  | 0.09     | 0.09     | 0.002      | 0.15       |

Analysis of the data in the table showed that the coefficient of mobility of all elements, more in urban soil than in the control. We can see the highest values the coefficient of mobility and the ratio to the control soil are characteristic for a Pb. The maximum value of the coefficient of mobility is in Area 1, in the soil of which more than 70% of lead is in mobile form, while in control soil it is only 9%. The lowest values of the coefficient of mobility are characteristic for the Area 3, where the share of trolleybus transport is high. The values of the coefficient of mobility on the investigated areas are very different from each other - the difference between the maximum and minimum values for urban areas is almost 3 times (Figure 5).

![Figure 5 - The values of the coefficient of mobility of Pb](image)

The increase in the mobility of lead under the influence of traffic is particularly noticeable if we compare these indicators with forest soil in which the coefficient of mobility decreases, compared to the soil of Area 1 in 8 times.

The dynamics of distribution of the coefficient of mobility of zinc is similar to the previous one, but the values of the coefficient of mobility are smaller. The coefficient of correlation of the values of the coefficient of mobility of Zn and the total amount of vehicle in the investigated areas is $r = 0.85$, which allows to talk about a rather high degree of influence of vehicles.

Higher values of the coefficient of mobility in urban soils in comparison with forest soil testify to the effect of transport on the increase in the soil of mobile forms of zinc (Figure 6).

![Figure 6 - The values of the mobility coefficient Zn.](image)
The values of the coefficient of mobility of copper are as follows. The greatest value is accounted for by Area 3 (where concentration of copper more than MPC) and differs from the values in the remaining areas by almost 4 times. The values of the mobility coefficient for the soils of the remaining areas do not differ much from each other, which indicates that this metal is in a relatively fixed state. The correlation coefficient of the total amount of vehicles and the coefficient of mobility of Cu is $r = -0.71$, the inverse relationship is high. But if we consider separately the category of trolleybus and its influence on the coefficient of mobility of Cu, then the correlation coefficient is $r = 0.98$, which indicates a very high degree of influence. The dynamics of the distribution of mobility coefficients completely coincides with the dynamics of the distribution of mobile forms of Cu (Figure 7).

![Figure 7 - The values of the coefficient of mobility of Cu](image1)

In comparison with forest soil, the mobility of copper in area 3 is increased by a control in 6 times. In other areas the coefficient of mobility does not differ from the value in control area. The values of the coefficient of mobility for nickel are characterized by a slight difference not only in the soils of experimental areas, but also on the value of the coefficient of mobility in the control area (Figure 8).

![Figure 8 - The values of the coefficient of mobility of Ni.](image2)

These data indicate that the influence of vehicles on the mobility of this metal is minimal, which is confirmed by a negative value of the correlation coefficient ($r = -0.64$).

3. Conclusions
The distribution of heavy metals in the soil is affected by traffic. In all three areas the values of mobile Pb more than MPC (from 2 to 10 times) do not exceed the gross forms, but more clearly show the dependence of concentration on traffic. Movable forms of Cu do not exceed MPC, gross forms is exceed MPC in Area 3. This is due to the fact that there are more trolleybuses in this area compared to other areas. Rubbing of the contact wires is a source of Cu. The mobile forms of Zn is exceed the MPC values at all areas, although the values of the gross forms is exceed the MAC values only in Area.
3. The mobile and gross forms of Ni do not exceed the MPC and differ in the uniformity of the distribution. Thus, the distribution of heavy metal in urban ecotopes is affected by motor vehicles, except of Ni.

References

[1] Ilyichev V. About the dynamic formation of the urban livelihood system compatible with the biosphere. V. Ilyichev, S. Emelyanov, V. Kolchunov, N. Bakaeva. Applied mechanics and materials. V. 725-726, 2015, p. 1224-1230.

[2] Ciegis R. The Concept of Sustainable Development and its Use for Sustainability Scenarios. Inzinerine Ekonomika-Engineering Economics. The Economic Conditions Of Enterprise Functioning. 2009. p. 28-37.

[3] Kates R. Environment: Science and Policy for Sustainable Development, Robert W. Kates, Thomas M. Parris, and Anthony A. Leiserowitz, 2005. 47, 3, p. 8–21.

[4] Stephen Appiah Takyi; Andrew D. Seidel Adaptive management in sustainable park planning and management: case study of the city of Vancouver Parks. Jurnal of Urban Ecology. Volume 3, Issue 1 January 2017.

[5] Gabriella Hancz, János Bíró The potential role of urban green infrastructure in sustainable municipal water supply management in a Hungarian town. Jornal of International Scientific Publications: Ecology&Safety. V. 10. 2016. p. 409-417.

[6] Peter M. Groffman. Moving Towards a New Urban Systems Science. Ecosystems January 2017, Volume 20, Issue 1, pp 38–43.

[7] Vorobev S. Using bioindication methods for assessing the environmental quality of urban settlements from the perspective of the concept of biosphere compatibility on an example of the Oryol city. Vorobev S, Kozlov D. Lambert academic publishing: Saarbruken, Deutschland, 2014. p. 54.

[8] John Pastor. Ecosystem Ecology and Evolutionary Biology, a New Frontier for Experiments and Models. Ecosystems. March 2017, Volume 20, Issue 2, pp 245–252.

[9] Vorobev S. Application Biosphere Compatibility Concept To Evaluate The Quality Of Urban Environment By Bioindication Methods. Volume 50, 2017, Pages 1-8.

[10] Vorobev S. The influence of meteorological factors on the pollution emission by vehicles in the city Orel // S. Vorobev, D. Kozlov - VI International scientific conference «21 century: fundamental science and technology» (North Charleston, SC, USA, 20-21 Aprylr 2015) Charleston, SC, USA: Science Book Publishing House, 2015. 11-14 p.