On the Effect of Green Spaces on the Natural Risks Associated with Air Quality Decrease of the Urban Environment

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Abstract. Despite the high interest to the study of the effect of green spaces on the processes of substance migration in the system “lithosphere – biostrome – atmosphere”, the negative aspects of these interactions are not considered. A scheme of the circulation of heavy metals in this system is proposed; dependences for calculating the density of heavy metal flows between components are obtained. Methods are proposed and experimental studies of the dynamics of Fe, Cu, Pb, Zn concentration in each component of the system are carried out. A correlation between the processes of plant growing and the concentration of heavy metals in air was established. The flows of Fe, Cu, Pb, Zn in the system “lithosphere – biostrome – atmosphere” are calculated, graphic representations of their balance are proposed. The diagram analysis which made it possible to establish the fact of the influence of green spaces on their migration at a selected point was carried out.

1. Introduction
The modern city is located at the intersection of all the main geo-shells: the lithosphere, hydrosphere, biostrom and atmosphere. The lithosphere significantly slows down the intensity of the migration of substances, turning into a natural collector of pollutants produced by the technosphere of the urban environment [6].

Plants, during their growing season, are able to absorb the cycles of matter in the “lithosphere – biostrome – atmosphere” system, in particular, heavy metals that are formed during the operation of industrial facilities and vehicles [11]. In Q. Fan studies, the ability of plants to transfer Cd and Pb in soil from bound forms to mobile forms is noted, which contributes to an increase in the intensity of migration of these elements to the soil surface and into the atmosphere [4]. The ability of plants to absorb heavy metals and subsequently give them to the atmosphere and hydrosphere is also noted [2]. Such processes worsen the quality of the air environment, forming a negative impact on the human body, but they are poorly reflected in modern studies.
2. Relevance of the research
The dust effect on the body is determined by the morphological and chemical composition, concentration dynamics [7]. The values of these properties are determined by the soil type, the intensity of anthropogenic activity [5].
As a result of anthropogenic processes (operation of industrial facilities, maintenance of vehicles), heavy metals which can be adsorbed on dust particles are released into the air [8-10]. Once in the human body, they reduce the reproductive and adaptive abilities of the body [3]. Epigenetic changes caused by heavy metals are inherited [1].
The soil absorbs heavy metals from air, accumulating them in bound forms. A group of researchers at Nanjing University found that heavy metals pass from bound forms to free ones as a result of biochemical processes in the root system of plants [4]. Then they can migrate to the soil surface and get into the atmosphere. The theory of substance transfer in the system “lithosphere – biostrome – atmosphere” under the influence of plants is not well developed; the migration processes of heavy metals in the soil surface are not taken into account when planning landscaping of urban settlements.

3. Research objective and methods
The effect study of green spaces on the migration of heavy metals in the system “lithosphere – biostrome – atmosphere” is a timely and urgent task. We conducted such studies on the territory of the city Orel which is one of the administrative centres of the Central Federal District of the Russian Federation. The selected point is located close to the railway and industrial facilities; therefore, the concentration of heavy metals in the soil is quite high.

4. Theoretical part
The theoretical and experimental studies are based on a process diagram of heavy metal diffusion transfer in the system “lithosphere – biostrome – atmosphere”, presented in Figure 1.

Figure 1. Heavy metal transport scheme in the system «lithosphere - biostrome – atmosphere» in the selected area.

Flow \( j_1 \) characterizes the vertical movement of heavy metals under the influence of their concentration gradient over the thickness of the soil. In the cold season the lithosphere accumulates and retains heavy metals, the flow \( j_1 \) will be directed from the soil surface deep onto the soil.
According to Q. Fan’s concept, during the warm season this flow can be directed from the soil depth to the soil surface. The calculated dependence for flow $j_1$:

$$j_1 = \frac{c_1 - c_2}{\tau \cdot S_s} \quad (1)$$

where: $c_1$, $c_2$ – high metal concentration in the lithosphere and in the plant; $S_s$ – horizontal projection square of the considered site; $\tau$ – time of the research.

Flow $j_2$ saturates plants with heavy metals through their root system by molecular diffusion (2):

$$j_2 = \frac{c_2 - c_3}{\tau \cdot S_r} \quad (2)$$

where: $c_1$, $c_2$ – high metal concentration in the lithosphere and in the plant; $S_r$ – square of plant root system; $\tau$ – time of the research.

Flows $j_3$ and $j_4$ form a circulation of heavy metals between the lithosphere and atmosphere. The concentration of heavy metals in the air is determined by the resulting flow ($j_{res}$):

$$j_{res} = j_4 - j_3 = \frac{c_2 - c_4}{\tau \cdot S_s} + 1,204 \frac{293 \nu}{293 + t_{air}} \quad (3)$$

where: $\nu$ – air speed due to wind, m/s; $t_{air}$ – air temperature, °C.

5. Discussion of the research results of heavy metal transfer processes in the system “lithosphere – biostrome – atmosphere”

5.1. The results of experimental studies

To calculate the flows $j_1 \div j_4$ at a selected point, the concentration values of heavy metals ($c_{hm}$, mg/kg) in the soil, air and plants throughout 2019 were experimentally determined. Soil and air samples were taken every month. Soil samples were taken from depths of 25; 75; 150 mm; air samples were taken at a height of 1.0 m from the earth surface. Plant samples were taken from March to November. The $c_{hm}$ values in plants were determined by atomic absorption spectrometry; the $c_{hm}$ values in soil and air samples – by methods approved in the Russian Federation.

According to the obtained results (fig. 2), in the cold season heavy metals are concentrated in the depths of the soil. The value of the concentration gradient across the thickness of the soil is: $\text{grad } c_{hm} = 12 \div 30 \, \text{g/m}^4$.

During the plant growing heavy metals migrate to the soil surface, increasing the $c_{hm}$ value in the upper zone by 25–70% relative to the January minimum. The greatest increase in $c_{hm}$ was detected for Cu and Zn. Heavy metals actively accumulate in plant organs throughout the growing season. This process is most expressed from March to June. The concentration of Fe, Cu, Zn in plant organs at the end of the growing season is much higher than that of Pb.

The minimum $c_{hm}$ in the air is observed at the beginning of the year, after which it rises, reaching maximum values from June till September. The decrease in $c_{hm}$ in the air in the autumn months is associated with intense precipitation. Abnormally high $c_{hm}$ in March and October are associated with wind-laid processes.

In the obtained data there is a correlation between the periods of increased plant growth and the dynamics of $c_{hm}$ in the air. It proves the influence of green spaces on the processes of heavy metal transfer in the system “lithosphere – biostrome – atmosphere”.
Figure 2. The concentration of heavy metals in the depth of the soil (a - in January; b - in July; c - in October).

5.2. The results of theoretical studies
Based on the experimental data, flows $j_1$ – $j_4$ were calculated, their graphical representations (Figures 3) which illustrate the effect of green spaces on the heavy metal transfer in the system “lithosphere – biostrome – atmosphere” were obtained.

As can be seen, the values of flows $j_1$ ÷ $j_4$ differ by several orders. The weakest is the flow $j_1 = 6 \cdot 10^{-4} ÷ 4 \cdot 10^{-3}$ mg/(day·m²). However, due to the large contact area between the atmosphere and the lithosphere, it has a significant effect on $c_{hm}$ in the air. In the cold season it is directed deep into the soil (on the diagram $j_1$). A decrease in the heavy metal concentration in the upper layers of the soil intensifies the flow $j_4$ directed from the atmosphere to the soil. The similar process forms a negative zone on the balance diagrams.

During the plant growing season the flow $j_2$ forms in the soil but the flow $j_1$ changes its direction (on the diagram $j_1^+$). Heavy metal accumulation in the upper layers of the soil causes an increase in $j_3$ and a decrease in $j_4$; as a result $c_{hm}$ in the air increases. This process forms a positive zone on the flow diagrams. At the end of the plant growing period the direction of the flows changes again; it contributes to the accumulation of heavy metals in the deep layers of the soil and the reduction of $c_{hm}$ in the air. A negative zone of flows is formed on the diagram.

6. Conclusions
The acceleration of the migration processes of heavy metals in the system “lithosphere – biostrome – atmosphere” under the influence of green spaces was found. In the cold season the concentration of heavy metals at a depth of 1.1 – 1.3 times higher than in the upper layers. During the plant growing period there is an active migration of heavy metals to the soil surface; as a result, $c_{hm}$ in the upper layers increases by 1.2 – 1.7 times by mid-autumn.

A correlation between the course of heavy metal concentration in the air and the activity of plant growth, in which $c_{hm}$ in the air increases in proportion to the increase of $c_{hm}$ in the upper layers of the soil, was found.
Figure 3. The balance of the flows of heavy metals in the cycle of heavy metals in the system of geoshells "lithosphere - biostrome - atmosphere" (a – iron, b – copper, c – lead, d – zinc).

The obtained results made it possible to determine the tasks of further studies of the processes of heavy metal transfer in the system "lithosphere – biostrome – atmosphere". Among them is the establishment of the manifestation degree of the plant influence in the territories where soil is less saturated with heavy metals. It is also necessary to select crops that are least conductive to the transition of heavy metals from bound forms to mobile ones. The results of these studies will enhance the recommendations for planning green spaces of the urban environment.

7. References
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