Ecological and geochemical assessment of woody vegetation along the highways of Moscow

Kseniya Eremenko¹ and Valentina Zubkova

Russian University of State for Social, Department of Ecology and Ecosystems, Moscow, Russia

Abstract. The accumulation of heavy metals (HM) in the leaves of woody plants has been studied on busy municipal highways in North-Eastern (NEAD) and South-Western (SWAD) administrative districts of Moscow. Background contents and their exceeding values for Fe, Sr, Ba, Cr, Cu, Mn, Zn, Bi, Ni, Pb were determined. The study showed that among the dominant deciduous tree species, hanging birch, Norway maple, and small-leaved linden have a high ability to accumulate heavy metals, which are characterized by the accumulation of such elements as Zn, Mn, Sr. According to content of HM in the leaves for the studied territories, an acceptable category of pollution and a greater contribution of the technogenic component is observed in SWAD in comparison with NEAD.

1 Introduction

The development of industry and transport complex, providing the greatest negative impact on the urban environment, is often accompanied by pollution of atmospheric air and soil with various harmful substances, including heavy metals [1-3].

One of the main sources of technogenic load on green stands is atmospheric air pollution. Emissions of various harmful substances, such as oxides of nitrogen, sulfur, carbon, lead, cadmium, copper and others, can penetrate and accumulate in plant tissues, by causing metabolic disorders which leads to intoxication and destruction of plant cells [4].

The streets and highways which are characterized by high length and significance, are of the greatest interest. Due to their physiological and morphological properties, green stands have the ability to effectively absorb and neutralize significant amounts of harmful compounds that enter the environment and thereby contribute to maintaining ecological balance in the biosphere [5, 6].

In addition to pollution in urban conditions, an increase in air temperature, a decrease in soil moisture, also associated with anthropogenic influences, have a negative impact on the growth and development of plants.

According to the forecast of global climate change, the increase in temperature observed over the past 70 years, associated with the accumulation of carbon dioxide and other greenhouse gases in the atmosphere, will be accompanied by a series of abnormal

¹ Corresponding author: ksenia-land@mail.ru
meteorological phenomena, including an increase in the duration of dry periods, which is typical for Moscow in summer [7].

In recent years, biotechnological methods, including biotesting, have become widely used for environmental quality control. Biotesting is a way of indicating pollution by the accumulation of pollutants in biological objects. The leaves of trees can be used as indicators since their chemical composition can signal adverse changes occurring in the environment [8].

The use of biotechnological methods increases the reliability of environmental forecasts and is the scientific basis for the development of effective methods for improving the environment [9, 10].

The purpose of the research carried out in 2021-2022 was to assess the metal accumulation capacity of the leaves of the main types of woody plants used in the landscaping of Moscow.

2 Materials and methods

The research was conducted in 2021 during the growing season of plants. The objects of the study were green stands of the following dominant plant species: silver birch (Betula pendula), Norway maple (Acer platanoides), horse chestnut (Aesculus hippocastanum), small-leaved linden (Tilia cordata), green ash (Fraxinus pennsylvanica).

The trial sites were located in the North-Eastern and South-Western administrative districts of Moscow (NEAD and SWAD).

Leaf samples were taken in July, at the stage of full development of the leaf blade. The leaves were selected by an average sampling method in the lower part of the crown of trees, from the outside (along the circumference), by choosing from branches 1-2 years old, located at arm’s length.

Based on the data on the content of heavy metals for all the surveyed sites, the concentration coefficients were determined in relation to the threshold allowable concentration of ground vegetation and to the background content of HM in the leaves of woody plants of Moscow according to the formulas:

\[ C_{\text{conc}} = \frac{C_i}{K} \]

\[ K_k = \frac{C_i}{K_{\text{back}}} \]

where \( C_{\text{conc}} \) – concentration coefficients;

\( K \) – threshold allowable concentration in ground vegetation;

\( K_{\text{back}} \) – background content.

In our studies, the average content for each of heavy metals obtained by analyzing 37 plant species is taken as the background value. Due to the lack of data on threshold allowable concentration in ground vegetation of Ba and Bi, we have taken the average minimum content in plant leaves, based on the results of 2021 and 2022. (Table 1).

Table 1. Threshold allowable concentration of ground vegetation [11] and background content of HM in leaves of woody plants of Moscow.

<table>
<thead>
<tr>
<th>HM</th>
<th>Average value</th>
<th>Threshold allowable concentration in ground vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>158.97</td>
<td>200.0</td>
</tr>
<tr>
<td>Sr</td>
<td>13.29</td>
<td>35.0</td>
</tr>
<tr>
<td>Ba</td>
<td>5.97</td>
<td>3.42</td>
</tr>
<tr>
<td>Cr</td>
<td>0.53</td>
<td>1.8</td>
</tr>
<tr>
<td>Cu</td>
<td>4.21</td>
<td>8.0</td>
</tr>
</tbody>
</table>
meteorological phenomena, including an increase in the duration of dry periods, which is typical for Moscow in summer [7].

In recent years, biotechnological methods, including biotesting, have become widely used for environmental quality control. Biotesting is a way of indicating pollution by the accumulation of pollutants in biological objects. The leaves of trees can be used as indicators since their chemical composition can signal adverse changes occurring in the environment [8].

The use of biotechnological methods increases the reliability of environmental forecasts and is the scientific basis for the development of effective methods for improving the environment [9, 10].

The purpose of the research carried out in 2021-2022 was to assess the metal accumulation capacity of the leaves of the main types of woody plants used in the landscaping of Moscow.

2 Materials and methods

The research was conducted in 2021 during the growing season of plants. The objects of the study were green stands of the following dominant plant species: silver birch (Betula pendula), Norway maple (Acer platanoides), horse chestnut (Aesculus hippocastanum), small-leaved linden (Tilia cordata), green ash (Fraxinus pennsylvanica).

The trial sites were located in the North-Eastern and South-Western administrative districts of Moscow (NEAD and SWAD).

Leaf samples were taken in July, at the stage of full development of the leaf blade. The leaves were selected by an average sampling method in the lower part of the crown of trees, from the outside (along the circumference), by choosing from branches 1-2 years old, located at arm’s length.

Based on the data on the content of heavy metals for all the surveyed sites, the concentration coefficients were determined in relation to the threshold allowable concentration of ground vegetation and to the background content of HM in the leaves of woody plants of Moscow according to the formulas:

\[ C_{\text{conc}} = \frac{C_i}{K} \]
\[ K_{\text{back}} = \frac{C_i}{K_{\text{back}}} \]

where \( C_{\text{conc}} \) – concentration coefficients; \( K \) – threshold allowable concentration in ground vegetation; \( K_{\text{back}} \) – background content.

In our studies, the average content for each of heavy metals obtained by analyzing 37 plant species is taken as the background value. Due to the lack of data on threshold allowable concentration in ground vegetation of Ba and Bi, we have taken the average minimum content in plant leaves, based on the results of 2021 and 2022. (Table 1).

<table>
<thead>
<tr>
<th>HM</th>
<th>Average value</th>
<th>Threshold allowable concentration in ground vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>158.97</td>
<td>200.0</td>
</tr>
<tr>
<td>Sr</td>
<td>13.29</td>
<td>35.0</td>
</tr>
<tr>
<td>Ba</td>
<td>5.97</td>
<td>3.42</td>
</tr>
<tr>
<td>Cr</td>
<td>0.53</td>
<td>1.8</td>
</tr>
<tr>
<td>Cu</td>
<td>4.21</td>
<td>8.0</td>
</tr>
<tr>
<td>Mn</td>
<td>17.32</td>
<td>205.0</td>
</tr>
<tr>
<td>Zn</td>
<td>21.69</td>
<td>30.0</td>
</tr>
<tr>
<td>Bi</td>
<td>0.31</td>
<td>0.05</td>
</tr>
<tr>
<td>Ni</td>
<td>0.52</td>
<td>2.0</td>
</tr>
<tr>
<td>Pb</td>
<td>0.45</td>
<td>1.25</td>
</tr>
</tbody>
</table>

3 Results

The results of the studies show that the maximum excess of background values in the NEAD and the SEAD for manganese and zinc was noted in the leaves of silver birch. In both districts, the leaves of horse chestnut accumulated the maximum amount of iron. Small-leaved linden was characterized by a maximum content of strontium. A high content of copper in the leaves of green ash was found in NEAD, and barium in SWAD was also found in it (Figure 1).

![Fig. 1. Excess of the background content of HM in leaves of trees.](image)

In relation to threshold allowable concentration of ground vegetation, maximum zinc concentration coefficient was also noted in silver birch, the content of barium in NEAD — in horse chestnut, in SWAD — green ash. In both districts, the maximum excess of threshold allowable concentration iron was found in horse chestnut (Figure 2).
4 Discussion

Chemical elements selectively accumulating in various green stands can be represented by accumulation series.

In accumulation series of heavy metals of the studied tree species, the largest share is accounted for such elements as zinc and manganese which are biogens at low concentrations. At the same time, as a rule, zinc predominates in total content of HM in NEAD, and manganese — in SWAD. However, the share of strontium in leaves of some trees increases sharply. The predominant element among all studied plants is iron (Table 2).

Table 2. HM accumulation series in the leaves of trees in NEAD and SWAD of Moscow.

<table>
<thead>
<tr>
<th>Plant species</th>
<th>District</th>
<th>Accumulation series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betula pendula</td>
<td>NEAD</td>
<td>$Fe_{n_{100}}^{n_{10}} Zn_{n_{10}}^{n_{10}} Mn_{n_{10}}^{n_{10}} Sr_{n_{10}}^{n_{10}} Cu_{n_{10}}^{n_{10}} Ba_{n_{10}}^{n_{10}} Cr_{n_{10}}^{n_{10}} Pb_{n_{10}}^{n_{10}} Ni_{n_{10}}^{n_{10}} Bi_{n_{10}}^{n_{10}}$</td>
</tr>
<tr>
<td></td>
<td>SWAD</td>
<td>$Fe_{n_{100}}^{n_{10}} Mn_{n_{10}}^{n_{10}} Zn_{n_{10}}^{n_{10}} Sr_{n_{10}}^{n_{10}} Cu_{n_{10}}^{n_{10}} Ba_{n_{10}}^{n_{10}} Cr_{n_{10}}^{n_{10}} Pb_{n_{10}}^{n_{10}} Ni_{n_{10}}^{n_{10}} Bi_{n_{10}}^{n_{10}}$</td>
</tr>
<tr>
<td>Acer platanoides</td>
<td>NEAD</td>
<td>$Fe_{n_{100}}^{n_{10}} Zn_{n_{10}}^{n_{10}} Mn_{n_{10}}^{n_{10}} Ba_{n_{10}}^{n_{10}} Cu_{n_{10}}^{n_{10}} Cr_{n_{10}}^{n_{10}} Pb_{n_{10}}^{n_{10}} Ni_{n_{10}}^{n_{10}} Bi_{n_{10}}^{n_{10}}$</td>
</tr>
<tr>
<td></td>
<td>SWAD</td>
<td>$Fe_{n_{100}}^{n_{10}} Mn_{n_{10}}^{n_{10}} Zn_{n_{10}}^{n_{10}} Sr_{n_{10}}^{n_{10}} Cu_{n_{10}}^{n_{10}} Ba_{n_{10}}^{n_{10}} Cr_{n_{10}}^{n_{10}} Ni_{n_{10}}^{n_{10}} Bi_{n_{10}}^{n_{10}} Pb_{n_{10}}^{n_{10}}$</td>
</tr>
</tbody>
</table>
Chemical elements selectively accumulating in various green stands can be represented by processes occurring in plants. According to the obtained results, woody plants have the ability to accumulate heavy metals selectively which depends on genetic factors that determine the elemental composition of plants. The environmental factor, which manifests itself when environmental conditions change, is a priority as well. In our work, it is evidenced by changes in the share of certain elements in the total content of metals in the plants of NEAD and SWAD.

5 Conclusion

Currently, fragmentary data on the content of HM in the leaves of woody plants are presented in the literature. Many of them were carried out in regions that differ sharply in climatic conditions and the direction of economic activity compared to Moscow [12, 13]. In this connection, significant variability in the content of particular elements was noted, while most studies confirm the bioindicative capabilities of such species as Betula pendula, Acer platanoides, and Tilia cordata.

According to the obtained results, woody plants have the ability to accumulate heavy metals selectively which depends on genetic factors that determine the elemental composition of plants. The environmental factor, which manifests itself when environmental conditions change, is a priority as well. In our work, it is evidenced by changes in the share of certain elements in the total content of metals in the plants of NEAD and SWAD.

### References

2. O.E. Tokar, Samara J. Sci. 9(3), 142-147 (2020)
5. L.V. Kopylova, Samara J. Sci. 7(4(25)), 57-63 (2018)
7. L. M. Akimov, Arid Ecosys. 4(89), 3-12 (2021)
11. V. V. Dobrovolskii, Fundamentals of biogeochemistry (HSE, Moscow, 1998)