Accumulation of heavy metals in soil and plants adjacent to municipal solid waste disposal facility

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Abstract. There are a number of environmental problems in the construction and disposal of solid waste landfills. One of the most important is the negative impact on the environment. The article includes the research findings related to content and accumulation of heavy metals such as zinc, lead, chrome and nickel in soil and plants on the territory adjacent to Shapsha Municipal Solid Waste Landfill, Shapsha settlement, Khanty-Mansiysk area, Khanty-Mansiysk Autonomous Okrug (Yugra), which is 28 km from Khanty-Mansiysk (Tyumen region, Russia). Intensity of heavy metal biological absorption was evaluated. The analysis of obtained results allowed to determine and roughly divide selected plants into two groups by their capability to accumulate heavy metals: accumulators (hyperaccumulators) that accumulate heavy metals both in case of their low and high soil content (Tussilago farfara L., Plantago major L.) and excluders that have limited input of metals to offshoots despite their high concentration in the environment (Tifolium hybridum L., Chamerion angustifolium L.). Identification of new plants prone to hyperaccumulation of heavy metals is important for efficient soil phytoremediation.

1. Introduction
Municipal solid wastes (MSW) are direct sources of accumulation of heavy metals in soils. They cause soil, ground, groundwater and air contamination and present hazardous ecotoxicological, bacteriological and helminthological pollution problems for surrounding and even remote areas and water zones. Therefore, MSW landfills may have a negative impact on remote areas [1]. An increase in municipal solid waste dumped in landfills that are in close vicinity to domestic buildings and facilities causes serious harm. As MSW landfills accumulate massive amounts of pollutants they always pose a major hazard as object of potential contamination. The rapid growth of municipal solid waste is one of the key environmental, economic and social problems at the federal, regional and municipal level. There is also an increase in heterogeneous waste, which leads to soil pollution by heavy metals being the most hazardous components of municipal solid waste [2]. Zinc, lead, chrome, nickel and their compounds pose a special hazard among heavy metals. Soil accumulates various pollutants. Plants accumulate heavy metals in tissues or on the surface of organs and provide intermediate storage for metals that ultimately pass from soil, water and air into human and animal bodies. Some plants serve as hyperaccumulators for heavy metals. What is more, there are plants that are capable of accumulating several heavy metals at once. Identification of new plants prone to hyperaccumulation is important for efficient soil phytoremediation [3, 4]. We examined accumulation of heavy metals at Shapsha Municipal Solid Waste Landfill, Shapsha settlement, Khanty-Mansiysk area, Khanty-Mansiysk Autonomous Okrug (Yugra), which is 28 km from Khanty-Mansiysk (Tyumen region, Russia).
region, Russia). The research objective: examine accumulation of heavy metals in soil and plants on the territory adjacent to Shapsha Municipal Solid Waste Landfill.

2. Materials and methods

2.1. Selection of sites
In order to identify the degree of heavy metal accumulation we selected observation sites at the distance of 10, 25, 50, 100 and 200 m from Shapsha Municipal Solid Waste Landfill. Coordinates of the landfill are 61°5.472' S, 69°27.989' V. The sites are square (20 x 20 m).

2.2. Sampling
Collection of soil samples and their preparation for quantitative chemical analysis were carried out in accordance with [5]. Each site had five samples collected.

2.3. Preparation of samples
We prepared samples using a microwave digestion system speedwave MWS-2 by PerkinElmer (USA). A weighed portion of soil (m = 4 g) was placed into a plastic tube to add HNO$_3$ and HCl at the ratio of 1:3. The tube was then placed into the microwave for digestion using the program recommended by the microwave manufacturer and the following heating cycle: temperature increase to 200°C in 5 minutes, standing at 200°C for 5 minutes, cooling to 45°C. The sample was transferred to a 15 ml test tube bringing the solution to the volume of 10 ml with deionized water. Afterwards we conducted the analysis.

For plant sample digestion and analysis we selected the most common (dominant) species of plants at each site: Plantago major L., Tifolium hybridum L., Chamerion angustifolium L., Tussilago farfara L. A weighed portion (m = 0.3 g) was placed into a tube to add H$_2$SO$_4$ and H$_2$O$_2$ at the ratio of 1:3. The next digestion steps followed the same order as outlined above.

Quantitative chemical analysis of trace and heavy metals (Zn, Pb, Cr, Ni) accumulated in soil samples and in the whole phytomass was performed using the inductively coupled plasma method with the atomic emission spectrometer OPTIMA 7000 DV by PerkinElmer (USA). For calibration we used standard solutions by PerkinElmer (USA).

2.4. Biological absorption factor
In order to evaluate absorption efficiency of heavy metals we used the biological absorption factor ($K_{bp}$), which is the quotient obtained when trace element content in plant ash is divided by its content in the root layer. This research uses the simulation model with the biological absorption factor at its core $K_{bp}$ [1]:

$$K_{bp} = \frac{C_{j}^e}{C_{i}^p}$$

(1),

where $C_{j}^e$ is heavy metal content in the plant, mg/kg; $C_{i}^p$ is heavy metal content in soil, mg/kg [10, 11]. The factor value from 1 to 10 is indicative of intensive accumulation of the element by the plant, 0.1 to 1 points at medium accumulation, 0.01 to 0.1 — low accumulation, 0.001 to 0.01 — no biological accumulation of the element [6]. Statistic processing of experimental data was carried out with Statistica 6.0 software. We calculated arithmetic means (X), standard errors of the means (SD), and assessed significance of differences in the arithmetic means with the Student's t test.

3. Results and discussion

3.1. Heavy metal accumulation in soil
Having examined accumulation of heavy metals in soil at the Shapsha Municipal Solid Waste Landfill we identified the basic ones and arranged them in the following order according to their concentration
in soils of the examined sites: Zn > Pb > Cr > Ni. In the distance (10, 25, 50, 100, 200 m) we found an increased concentration of lead, which amounted to 48.21 (t=2.12) to 140.42 (t=1.87) mg/kg (200 to 10 m) with the maximum allowable concentration (MAC) of 32 mg/kg. We also found the excess of the MAC of zinc. Zinc concentration on sites varied from 55.54 (t=3.12) to 526.29 (t=2.14) mg/kg (200 to 10 m). The MAC was exceeded by 2-5 times. Total chrome content in soils exceeded the MAC by 2-10 times and fell within the limits of 5.80 (t=2.87) to 23.40 (t=3.69) mg/kg (200 to 10 m); the results are reliable at P<0.05. Unlike lead, zinc and chrome, nickel concentration in soil is significantly less. Its concentration in soils surrounding the landfill did not exceed the MAC (figure 1).

Figure 1. Accumulation of heavy metals in soils of the examined sites, mg/kg (X ± SD). Element concentration (y axis), distance from solid waste landfill to the sampling site (x-axis)

3.2. Heavy metal accumulation in plants

Heavy metals are accumulated in soils to be followed by plant accumulation. Many authors think that performing this protective function plants extract various chemical elements and accumulate them in their organs and tissues thus preventing contamination spread in the environment [7-9]. The obtained results let us identify specific plant properties relating to accumulation of heavy metals. We have concluded that selected dominant plant species show different absorption of heavy metals. The most common plant species were chosen for the analysis: Tussilago farfara L., Plantago major L., Tifolium hybridum L., Chamerion angustifolium L. The highest concentration of heavy metals was found in Tussilago farfara L.: Zn 68.59 (t=1.12) to 601.35 (t=2.41), Pb 53.53 (t=2.65) to 152.31 (t=3.22), Cr 21.63 (t=3.11) to 78.51 (t=4.22), Ni 8.61 (t=3.14) to 30.40 (t=2.19) mg/kg. The accumulative capability of Plantago major L. was found to be as high: Zn 61.77 (t=4.22) to 574.37 (t=3.17), Pb 50.49 (t=4.02) to 145.33 (t=2.12), Cr 18.09 (t=3.65) to 70.31 (t=3.46), Ni 6.39 (t=3.87) to 574.37 (t=2.14) mg/kg; the results are reliable at P<0.05. Tifolium hybridum L. and Chamerion angustifolium L. plants that grow in the distance from the waste collection and storage site showed lower concentration of heavy metals.

As can be seen from the above, we observed varying accumulative capability for heavy metals in the examined species where increased concentrations are caused by increased man-made load. This regularity was found at all observed sites, which is in line with the data provided by other researchers [10, 11]. According to many researchers, plants extract and concentrate various chemical elements in their organs and tissues, performing a protective function, thereby preventing the spread of pollutants in the environment [12-14]. In numerous experiments it has been established that almost all plants are able to protect themselves, to varying degrees, from the harmful effects of elevated concentrations of heavy metals in soil and water. Different mechanisms for such protection are described by different
authors [15, 16]. Concentration of heavy metals in soil and plants decreases as the distance from the landfill increases, thus 10 > 25 > 50 > 100 > 200. *Tussilago farfara* L., *Plantago major* L. plants act as hyperaccumulators (non-excluders). Hyperaccumulation is one of the strategies of plant resistance to metals related to the ability to accumulate them in tissues. Hyperaccumulation was found for Zn, Pb, Cr and Ni.

### 3.3. Biological absorption factor

In order to evaluate the intensity of plant heavy metal absorption from soil we calculated the biological absorption factor (*K*bp) (table 1), which is the ratio between metal content in the plant to its overall content in soil. Heavy metals are transferred from soil into plants as a result of biological absorption of elements by the biomass. The more *K*bp exceeds 1, the higher the risk of pollution is.

**Table 1.** Accumulation of heavy metals in *Tussilago farfara* L., *Plantago major* L., *Tifolium hybridum* L., *Chamerion angustifolium* L. plants at the examined sites, mg/kg dry weight, (X ± SD)

| L, m | Cr     | *K*bp | Pb     | *K*bp | Ni     | *K*bp | Zn     | *K*bp |
|------|--------|-------|--------|-------|-------|-------|--------|-------|
|      |        |       |        |       |       |       |        |       |
| 200  | 15.63±0.16 | 1.2   | 32.53±0.12 | 0.7  | 6.61±0.13 | 1.1   | 68.59±0.12 | 1.2  |
| 100  | 42.57±0.21 | 1.2   | 72.42±0.14 | 1.1  | 12.55±0.12 | 1.2   | 136.36±0.13 | 1.3  |
| 50   | 56.39±0.13 | 1.3   | 91.45±0.14 | 1.1  | 18.36±0.12 | 1.2   | 288.68±0.14 | 1.3  |
| 25   | 68.66±0.13 | 1.3   | 123.37±0.13 | 1.1  | 25.59±0.13 | 1.2   | 389.37±0.14 | 1.3  |
| 10   | 88.51±0.13 | 1.4   | 162.31±0.14 | 1.2  | 30.40±0.12 | 1.3   | 661.35±0.13 | 1.3  |
|      |        |       |        |       |       |       |        |       |
| 200  | 13.09±0.22 | 1.0   | 50.49±0.13 | 1.0  | 6.39±0.24 | 1.1   | 61.77±0.23 | 1.1  |
| 100  | 34.59±0.21 | 1.0   | 70.42±0.13 | 1.0  | 11.66±0.13 | 1.1   | 128.12±0.25 | 1.2  |
| 50   | 48.65±0.19 | 1.1   | 79.22±0.21 | 1.1  | 16.59±0.14 | 1.1   | 255.37±0.13 | 1.2  |
| 25   | 59.66±0.17 | 1.1   | 125.44±0.12 | 1.0  | 22.56±0.12 | 1.1   | 355.40±0.14 | 1.2  |
| 10   | 85.31±0.13 | 1.3   | 155.33±0.15 | 1.0  | 27.42±0.13 | 1.2   | 624.37±0.13 | 1.2  |
|      |        |       |        |       |       |       |        |       |
| 200  | 8.34±0.13 | 1.0   | 24.37±0.13 | 1.0  | 6.35±0.13 | 1.0   | 25.54±0.23 | 1.0  |
| 100  | 19.59±0.12 | 1.0   | 41.25±0.14 | 1.0  | 6.62±0.12 | 1.0   | 59.44±0.12 | 1.0  |
| 50   | 31.48±0.13 | 0.7   | 61.67±0.26 | 0.8  | 11.54±0.11 | 0.8   | 125.91±0.20 | 0.6  |
| 25   | 36.48±0.12 | 0.7   | 89.31±0.15 | 0.8  | 16.58±0.12 | 0.8   | 223.53±0.15 | 0.7  |
| 10   | 46.47±0.15 | 0.7   | 121.48±0.13 | 0.9  | 19.52±0.11 | 0.8   | 345.34±0.24 | 0.7  |
|      |        |       |        |       |       |       |        |       |
| 200  | 6.32±0.12 | 2.0   | 17.63±0.13 | 1.4  | 2.31±0.11 | 0.4   | 17.41±0.11 | 0.3  |
| 100  | 17.29±0.11 | 0.5   | 32.46±0.16 | 0.5  | 4.70±0.16 | 0.4   | 55.47±0.12 | 0.5  |
| 50   | 17.54±0.12 | 0.4   | 52.25±0.13 | 0.6  | 9.43±0.13 | 0.6   | 109.44±0.12 | 0.5  |
| 25   | 30.48±0.13 | 1.0   | 74.52±0.13 | 0.7  | 13.66±0.12 | 0.7   | 190.09±0.20 | 0.6  |
| 10   | 39.27±0.15 | 0.6   | 114.71±0.16 | 0.8  | 17.39±0.10 | 0.7   | 298.25±0.11 | 0.6  |

The biological absorption factor for *Tussilago farfara* L. is approximately the same at all sites (*K*bp = 1.20); however, it is significantly bigger for Cr, Ni and Zn (1.3 to 1.4), which points at increased contamination. Biogeochemical activity of this species is most prominent for Cr at the distance of 10 m from the landfill because of the element's activity. At all sites, *Tussilago farfara* L. accumulates the largest amount of heavy metals. The biological absorption factor (*K*bp) is ≥ 1. The concentration of pollutants in the overall biomass of *Tussilago farfara* L. and *Plantago major* L. is in direct relationship to the man-made load with the highest content found at the distance of 10 to 20 m from the landfill. Pollutants may be accumulated by plants because of carbon emissions caused by waste burning at MSW landfills.
The analysis of obtained results let us roughly divide selected plants into two groups by their capability to accumulate heavy metals: accumulators that mostly accumulate metals in their overground organs both in case of their low and high soil content \((Tussilago farfara \text{ L.}, \text{ Plantago major \text{ L.}}) \ (K^i_{bp} \geq 1)\) and excluders that have limited input of metals to offshoots despite their high concentration in the environment \((Tifolium hybridum \text{ L.}, \text{ Chamerion angustifolium \text{ L.}}) \ (K^i_{bp} < 1)\). According to the biological absorption factor in \(Tifolium hybridum \text{ L.} \) and \(Chamerion angustifolium \text{ L.}, \) zinc, lead, chrome and nickel fit into the low absorption group \((K^i_{bp} = 0.3 \text{ to } 0.9)\). It is possible that accumulation of metals in these plants follows the barrier model (table 1).

The research findings show that different plant species vary in their capability to accumulate heavy metals. In the context of increased technogenic pollution this can be widely used to establish the environmental balance in populated localities.

4. Conclusion
Analysis of the obtained data allowed to arrange heavy metals in the order of concentration decrease in soils adjacent to Shapsha Municipal Solid Waste Landfill: \(\text{Zn} > \text{Pb} > \text{Cr} > \text{Ni}\). Intensity of heavy metal biological absorption was evaluated. The analysis of obtained results allows to roughly divide selected plants into two groups by their capability to accumulate heavy metals: accumulators that mostly accumulate metals in their overground organs both in case of their low and high soil content \((Tussilago farfara \text{ L.}, \text{ Plantago major \text{ L.}}) \ (K^i_{bp} \geq 1)\) and excluders that have limited input of metals to offshoots despite their high concentration in the environment \((Tifolium hybridum \text{ L.}, \text{ Chamerion angustifolium \text{ L.}}) \ (K^i_{bp} < 1)\). According to the biological absorption factor in \(Tifolium hybridum \text{ L.} \) and \(Chamerion angustifolium \text{ L.}, \) zinc, lead, chrome and nickel fit into the low absorption group \((K^i_{bp} = 0.3 \text{ to } 0.9)\). Accumulation of these metals in such plants follows the barrier model. We observed varying accumulative capability for heavy metals in the examined plants with the increased concentrations caused by an increase in the man-made load. Concentration of heavy metals in soil and plants decreases as the distance from the landfill increases, thus 10 > 25 > 50 > 100 > 200. The identified plants-accumulators plants may be used for phytoremediation, which is a modern technology for contaminated soil cleanup with green plants.

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