Migration of heavy metal in the soil-plant system in the territory adjacent to the MSW landfill

N Milyutina¹, N Osmolovskaya¹ and N Politaeva²

¹Saint Petersburg State University, Universitetskaya amb., 7/9, Saint Petersburg 199034, Russia
²Peter the Great Saint Petersburg Polytechnical University, Politekhnicheskaya str., 29, Saint Petersburg 195251, Russia

E-mail: milyutina_no@mail.ru

Abstract. The results of analysis of the efficiency of extraction of heavy metals (HM) from contaminated soils by plant roots naturally growing in the area between the existing and closed MSW landfills are presented. The parcelling of HM between the roots and above-ground parts of the wormwood Artemísia absínthium L. and stinging nettle Urtica urens L. was analyzed. The migration coefficients of HM between the organs of the studied plants were calculated. Maximum concentration of HM in the leaves of plants was found.

1. Introduction

Solid waste located at the landfill interacts with air and precipitation. The landfill functions as a “bioreactor”, in which biogeochemical processes proceed intensively. The destruction of organic is carried out under the influence of a complex of physical, chemical and microbial reactions in the body of the landfill, which result in the release of biogas, leachate and heat, the formation of solids, migration of elements [1-4]. Despite the protective measures at municipal solid waste (MSW) landfills, a common problem is the spread of polluting elements to large areas [5, 6]. In this regard, it is necessary to monitor natural environments and objects around landfills. An important monitoring object is the soil around the body of the landfill and the assessment of their contamination with heavy metals (HM). Soils perform environmental functions to preserve habitats and species diversity of biota, ensure the existence of biogeocenoses and the biosphere as a whole [7]. It should be borne in mind that as a result of a complex of biogeochemical processes occurring in the «rhizosphere – roots – above-ground parts of plants» system, HM are extracted from the soil and bound in the root system of plants, after which metals are transferred from roots to shoots and accumulated in above-ground ones plant organs [8]. The aim of this study was to assess the degree of extraction of heavy metals by plants from contaminated soils and analysis of their migration in plant organs.

2. Materials and methods

The object of the study is a MSW landfill, located in the Tambov region in Russia. The MSW landfill has been operating since 2007. On the south side of the landfill there is a closed MSW landfill (100 m). Arable lands are located on the western, northern, and eastern sides (Fig. 1).

At this object, an assessment of the degree of HM contamination soils around the existing landfill was made. Soil samples were taken at 30x30 m sites using the envelope method. The dried and ground samples were mineralized by microwave analysis in a mixture of concentrated nitric, hydrofluoric and
hydrochloric acids in a volume ratio of HNO$_3$: HF: HCl = 5: 4: 1, after which the resulting solution was filtered and analyzed for a total content of HM (Cu, Ni, Pb, Zn).

To analyze the migration of HM in the soil-plant system, plant samples (wormwood Artemisia absinthium L. and stinging nettle Urtica urens L.), naturally growing in this area, were taken at sites where the soils were taken. Analysis of plant samples was carried out separately: samples of roots, stems and leaves of plants. Dried and crushed samples of plant organs were subjected to ashing with a mixture of concentrated nitric and perchloric acids in a volume ratio of HNO$_3$: HClO$_4$ = 4: 1 at 160 °C, after which the resulting solution was filtered and analyzed for a total content of HM (Cu, Ni, Pb, Zn).

The total content of heavy metals in the samples was determined by the inductively coupled plasma method on an ICPE-9000 optical emission spectrometer (Shimadzu, Japan).

3. Results and discussion
As a result of the study, soil pollution was detected at sites №№ 1, 2 and 3 (Fig. 2), which corresponds to the area between the existing and closed MSW landfills. The total cuprum content in this area was higher than the admissible concentration limit (ACL) for soils [9] by 1.5–4.7 times, lead content by 1.8–4.4 times, zinc content by 3.1–7.8 times. The total nickel content at sites №№ 1, 2 and 3 is higher than at sampling sites №№ 4-8, but does not exceed the ACL for soils. The total content of the studied metals in the soil from the western, northern, and eastern sides does not exceed the ACL for soils.

Considering the climatic, geographic and geological conditions of the territory, as well as the operating technology of the existing landfill, it was found that soil contamination is due to the impact of the closed MSW landfill.
The total content of the studied metals in the roots and leaves of nettle and wormwood is shown in Figures 3 and 4. The lead content in the graphs is not displayed, because it turned out to be basically below the detection limit, i.e. 1 mg / kg, which is consistent with the idea of low bioavailability of this metal [10]. Analyzing the obtained data, it can be noted that there is a positive correlation between the elevated levels of Cu, Ni, and Zn concentrations in soils adjacent to the MSW landfill and the levels of the corresponding HM in plant organs growing in this territory.

**Figure 2.** Content of HM in soil around the existing landfill.

**Figure 3.** Content of HM in roots and leaves of wormwood.
Analyzing the parcelling of HM in the organs of wormwood, a tendency for the maximum concentration of HM in leaves is observed, which is a good indicator for using this plant as a local phytoremediator. This consistent pattern of a greater accumulation of metals in the leaves as compared to the roots was revealed irrespective of the sampling site and, therefore, irrespective of the contamination of the soil. In stinging nettles, the maximum accumulation of HM in leaves is observed in the contaminated area (sampling sites №№ 1, 2, and 3) for all metals – Cu, Ni, and Zn, whereas this consistent pattern is observed only for Cu and Ni at sampling sites №№ 4–8 located on uncontaminated soils. For Zn at these sites is characterized by the maximum accumulation in nettle roots, which is probably due to the fact that zinc is a trace element for plants and on uncontaminated soils is more in demand in nettles at the root level. It should be noted that in uncontaminated territory, the concentration of HM in the roots and leaves of nettle is close in value. Minimum concentrations of determined HM were established in plant stems, which is explained by the transit function of this plant organ [11].

![Figure 4. Content of HM in roots and leaves of nettle.](image)

To assess the degree of metal extraction from the soil by plant roots efficiency of their migration into the above-ground part of plants, the migration coefficients of metals in the soil – root and root – leaf systems were calculated. The coefficients were determined as the ratio of the content of the element in the root to the content of the element in the soil and the ratio of the content of the element in the leaves to the content of the element in the root, respectively (in mg/kg dry matter). Migration coefficients of cuprum, nickel and zinc were calculated for plant samples taken between the existing and closed landfills, i.e. from sites №№ 1, 2 and 3, where soil contamination was detected.

The efficiency of metal extraction and transfer, measured in the soil-root system, varies both among individual metals and depending on the sampling site. In wormwood, the cuprum migration coefficient in the soil-root system varies from 0.09 to 0.22, the nickel migration coefficient from 0.18 to 0.26, the zinc migration coefficient from 0.11 to 0.23. For nettle, the ranges are higher: the cuprum migration coefficient varies from 0.11 to 0.30, the nickel migration coefficient from 0.11 to 0.35, the zinc migration coefficient from 0.12 to 0.32. Such heterogeneity of descriptors is obviously associated with the different sorption capacity of the roots of the studied plants with respect to their absorption of different metals, as well as with high differences in the concentration of metals in soils in the contaminated area. The migration coefficients of metals in the root-leaf system are higher than the
coefficients of extraction of elements from the soil on which these plants were taken. In wormwood, the copper migration coefficient in the root-leaf system varies from 1.25 to 1.75, the nickel migration coefficient from 1.41 to 2.14, the zinc migration coefficient from 2.19 to 3.02. For nettles, the copper migration coefficient varies from 0.83 to 2.35, the nickel migration coefficient from 0.53 to 2.77, the zinc migration coefficient from 1.16 to 1.58. As follows from the data obtained, in general, migration of HM between plant organs in wormwood is less variable and higher than in nettle, which makes wormwood more suitable as a natural phytoremediator in this area. Moreover, the biomass of the above-ground parts of the plant in wormwood is higher, which also positively affects the efficiency of extracting HM from the soil. In this regard, the authors recommend the use of wormwood Artemisia absinthium L. for the purpose of phytoremediation cleaning of soils [12] from polluting metals, thus creating a kind of barrier for the movement of HM in the direction from the closed MSW landfill, thereby reducing the concentration of HM in the flow of pollutants from a closed MSW landfill.

4. Conclusion
1. A positive correlation between the elevated levels of Cu, Ni, and Zn concentrations in soils and the levels of the corresponding HM in plant organs (using the example of wormwood Artemisia absinthium L. and stinging nettles Urtica urens L.) growing on them was established.
2. For wormwood, the consistent pattern of maximum concentration of the studied heavy metals in plant leaves was found. For nettles, this consistent pattern differs depending on the metal and the degree of contamination of the soil on which the samples were taken.
3. The degree of extraction of HM from soil by plants naturally growing in this territory was analyzed, and the migration coefficients of elements between plant organs in the root-leaf system were established.
4. It is proposed to use the wormwood Artemisia absinthium L., which naturally grows at the border of existing and closed landfills, for phytoremediation purposes, thereby reducing the concentration of heavy metals in the flow of pollutants from the closed MSW landfill.

References
[1] Gourc J P, Staub M J, Conte M 2010 Waste Management 30 p 1556
[2] Yao J, Kong Q, Qiu, Z, Chen L, Shen D 2019 Chemical Engineering Journal 375 p 122060
[3] Chen W, Zhang A, Jiang G, Li Q 2019 Waste Management 85 p 283
[4] He R, Shen D, Wang, J, He Y, Zhu Y 2005 Process Biochemistry 40 p 3660
[5] Essien J, Inam, E, Ikpe D, Udofia G, Benson N 2019 Nanotechnology, Monitoring and Management 11 100215
[6] Cambier P, Michaud A, Paradelo R, Germain M et al. 2019 Monitoring and modelling Science of the Total Environment 651 p 2961
[7] Fajardo C, Costa G, Nande M, Botías P, Garcia-Cantalejo J, Martin M 2019 Applied Soil Ecology 135 p 56
[8] Kabata-Pendias A, Pendias H 2001 Trace elements in soils and plants (CRC Press, Boca Raton)
[9] 2006 GN 2.1.7.2041-06 Admissible concentration limit of chemicals in the soil (Moscow: Federal Center for Hygiene and Epidemiology of Rospotrebnadzor)
[10] Cristaldi A, Conti G, Jho E, Zuccarello P et al. 2017 A brief review Environmental Technology and Innovation 8 p 309
[11] Verloo M, Cottenie A, Landschoot G 1982 Analytical and biological criteria with regard to soil pollution (Landwirts-chaftliche Forschung: Kongressband) p 394
[12] Kurilenko V, Osmolovskaya N 2018 Phytoremediation method for cleaning soils contaminated with heavy metals Patent RU 2665073 C1