Investigation of the influence of distribution of heavy metals from construction waste disposal on plant associations of adjacent ecosystems

N V Dinkelaker¹, E A Ovsyuk¹, N A Sinelnikova¹, I A Muraviev¹, N F J Dinkelaker² and T S Semenova¹

¹ ITMO University, 9, Lomonosova st., St. Petersburg, 191002, Russia
² St. Petersburg forest engineering University. S. M. Kirova, 5, Institutskii per., St. Petersburg, 194028, Russia

E–mail: nvdinkelaker@mail.ru

Abstract. The question of influence of distribution of pollution of soils by heavy metals from the landfill on the soil–plant complex of natural ecosystems in the zone of influence of object is investigated. The presence of increased bioaccumulation of heavy metals of certain specialized ecological groups of plants – submerged macrophytes and weed–ruderal plants was revealed. Specificity of accumulation of heavy metals is not a property of plant life forms. However, within plants of one life form there are species with an increased ability to selective accumulation of individual heavy metals, which is especially pronounced in mosses. The results obtained can be used to improve the efficiency of bioengineering protection of the natural environment through environmental planning of landscapes in the areas contaminated with heavy metals around landfills and other industrial facilities.

1. Introduction

Against the background of the acute problem of disposal of construction waste in modern Russia and the prevalence of such type of disposal as landfill disposal, the issues of environmental safety of such facilities for adjacent ecosystems and their components, including humans, are of particular importance. Construction waste landfills are characterized by soil contamination of adjacent territories with heavy metals. These pollutants in concentrations higher than natural are toxic to all groups of living organisms. They cause stress reactions both at the level of ecosystems and communities of living organisms, and at the organizational level. Long–term exposure to high concentrations of HM can lead to irreversible changes in ecosystems (change of communities, decrease in the number and production of organisms, extinction of species). The increase in the area of landfills in Russia inevitably leads to an increase in the area of various ecosystems located in the zone of soil and surface water pollution by heavy metals. The main danger for animals and humans in the spread of heavy metals in soils around landfills is the inclusion of these toxicants in the food chains of local ecosystems in the zone of pollution and their transition...
through food chains to larger ecosystems, located outside the territory of the direct impact of the landfill. Such areas often contain both valuable natural ecosystems and residential areas.

The first and main barrier for inclusion of HM in food chains of local ecosystems is the possibility of their accumulation in plant biomass. Plants are able to extract metals from the soil from sedentary forms [1]. At the same time, with the help of physiological barriers, they can limit the transition of xenobiotics from the root system to the aboveground part [2]. It is known that the ability to accumulate HM varies in different species of plants. However, the relationship of ecological and systematic characteristics of plants with the ability to accumulate heavy metals from soils is not currently established due to the small number of data, which makes it difficult to develop and apply environmentally effective methods of reclamation of contaminated areas around landfills of construction waste.

2. Materials and methods

This study is aimed at studying the differences in the ability to bioaccumulate HM in different ecological groups and life forms of wild species of higher plants.

The research was carried out in 2017–2019 in the territories adjacent to the construction waste landfill "North Samara" (61 hectares), located in Vsevolozhsk district of the Leningrad region. This landfill is active and has existed since 1974. The amount of waste disposed from 1974 to 2016 was 22,354,000 m³ and 4,350,000 m³ in a compacted state [3]. To date, it is almost completely filled and in the coming years is subject to reclamation. The facility is surrounded by natural ecosystems.

We conducted field studies in June – July 2017 and 2018, during which samples of soils and major plant species (135 species in total) were selected from different biotopes in the impact zone of the landfill. The study of HM content in soils and leaves of plants was carried out by x-ray fluorescence method [4] using the spectrometer "SPECTROSCAN Max – G" after grinding using a disk eraser and drying the material to an air-dry state.

3. Results and discussions

In the zone of impact of the landfill there are moist pine–green moss, pine trees mixed with birch, meadow areas, grasslands, wet floodplain meadows. The territories remote from the landfill for more than 1.5 km are mainly represented by old–aged and middle–aged pine forests, blueberry–grass, as well as orchards. 137 species of higher plants from different ecological groups and having different life forms were studied.

The study of soil pollution by heavy metals shows a mosaic distribution of pollutants within areas not related to distance from the landfill in the zone of influence. Excess of the content of heavy metals in the soil in the zone of influence of the landfill (800 m) relative to the maximum permissible concentrations (MPC) established by hygienic standards (GN 2.1.7.2041–06) was observed for arsenic (7 times on average) and zinc (3.5 times on average). At the same time, soil pollution is mosaic and in some points there were significant (up to 100 times) exceedances of MPC. Statistical single–factor analysis of ANOVA with a significance level of p=0.1 showed that almost all metals have no significant relationship between their concentration in the soil and the type of ecosystem. At the same time, it is shown that strontium accumulation in soils significantly differs among local ecosystems: moist pine forests, grassland swamp (average 99 mg/kg); ridge, quarry, old forest, stream (average 151 mg/kg); gardens (average 196 mg/kg). The principal component method showed that strontium and zinc make the main contribution to the difference between the spectrums of heavy metals from different ecosystems of the polygon zone of influence.

All studied plant species showed increased relative to the background (for the region) values of zinc and strontium. To analyze HM accumulation in different plant species, the following parameters were used: local ecosystem; plant life form (according to Serebryakov [5]), ecological group. The ratio of HM in plants from different local ecosystems showed high variability, significant links between the
accumulation of HM and the type of habitat has not been established. The study of the relationship of the accumulation of individual HM with such parameters as belonging to an ecological group and the life form of plants. For this purpose, series of groups of each trait were constructed in order of decreasing the average content of each studied heavy metal in plants of each group and life form (table 1).

Table 1. Series of groups in order of decreasing metal concentration

| Metal | Environmental group | Form |
|-------|---------------------|------|
| Sr    | Submerged macrophytes>ruderal > > forest=meadow=coastal–aquatic | aquatic grasses=terrestrial grasses>woody=mosses>shrubby |
| Pb    | submerged=weed>forest=coastal–water>meadow | mosses>aquatic grasses>woody>terrestrial grasses>shrubby |
| As    | forest>weed=submerged > meadow>coastal–water | mosses>terrestrial grasses>aquatic grasses>woody>shrubby |
| Zn    | weeds> > submerged>forest>meadow>coastal–water | woody> > terrestrial grasses>mosses>aquatic grasses> > shrubby |
| Ni    | weeds>submerged>forest>meadow>coastal–water | aquatic grasses>woody>terrestrial grasses>mosses>shrubby |
| Fe³⁺  | Submerged> > coastal–water>forest=weed=meadow | aquatic grasses> > mosses> > terrestrial grasses>woody>shrubby |
| Mn²⁺  | submerged> > coastal–aquatic> > forest=meadow> > weed | aquatic grasses> > woody>shrub>terrestrial grasses>mosses |
| Cr    | submerged>forest=coastal = water = weed=meadow | shrub>aquatic grasses>mosses>woody= terrestrial grasses |
| Ti⁴⁺  | submerged>forest=weed>coastal–water=meadow | |

Analysis of bioaccumulation of heavy metals in plants of different ecological groups showed species–specific accumulation of these toxicants in different species. Nevertheless, the general regularities of significantly increased content of heavy metals in groups of aquatic submerged and weeds were revealed in comparison with the rest of the studied groups.

Strontium accumulation is significantly higher (on average 2 times) in groups of submerged aquatic plants and plants of weed associations. At the same time, the average strontium content in forest, meadow and coastal water plants is generally lower and does not differ between groups. Increased average zinc content is observed in plants of ruderal associations. It is in this group that almost all the high rates of zinc accumulation are observed (sagebrush (1091 mg / kg), wormwood (792 mg / kg), pink hybrid clover (643 mg / kg), bird Highlander (320 mg / kg)). The group of submerged plants on a par with weed plants has
twice-increased accumulation of titanium, iron, chromium, strontium, lead and manganese in comparison with other groups.

Analysis of the accumulation of heavy metals in plants of different life forms shows the highest accumulation of zinc in woody species. Mosses accumulate arsenic, lead and titanium more strongly, and water grasses – strontium, nickel, iron, manganese.

The intensity of biological accumulation was estimated using the biological accumulation coefficient (BAC) [6]:

\[ \text{BAC} = \frac{C_p}{C_n} \]

where \( C_n \) is the gross content of the element in the soil, \( C_p \) is the concentration of the element in the plant.

The value of biological accumulation was determined by the gradation of A I Perelman [7]:

- Group I – "Vigorously accumulated" (CBN 10–100)
- Group II – "Highly accumulated" (CBN 1–10)
- Group III – "Weak accumulation or medium capture" (CBN 0.1–1.0)
- Group IV – "Weak capture" (CBN 0.01–0.1)
- Group V – "Very weak capture" (CBN 0.001–0.01)

Category III was further divided into two subcategories: III b (above-average accumulation) – 0.1 to 0.5 and Iii (increased accumulation) – 0.5 to 1.0. As the gross content of the element in the soil, the average values of concentrations from the growing places of the studied plants were taken. Table 2 presents the results of the study of the distribution of ecological groups and plant life forms to the groups identified by bioaccumulation of heavy metals.

| Environment group | Sr, mg/kg | Pb, mg/kg | As, mg/kg | Zn, mg/kg | Ni, mg/kg | Fe2O3, % | Cr, mg/kg | TiO2, % |
|-------------------|----------|-----------|-----------|-----------|-----------|----------|-----------|----------|
| Forest vegetation | IIIa     | IIIb      | IIIb      | II        | IIIb      | IV       | II        | IIIb     |
| Medow plants      | IIIb     | IIIb      | IIIb      | IIIa      | IIIb      | V        | II        | IIIb     |
| Submersed plants  | IIIa     | IIIb      | IIIb      | II        | II        | II        | IIIa      | IIIa     |
| Helophytes        | IIIa     | IIIb      | IIIb      | IIIa      | IIIb      | IV        | II        | IIIb     |
| Ruderel plants    | IIIa     | IIIb      | IIIb      | III        | IIIb      | IV        | IIIa      | IIIb     |
| Water grasses     | IIIa     | IIIb      | IIIb      | II        | IIIb      | V        | II        | IIIb     |
| Wood              | IIIa     | IIIb      | IIIb      | II        | IIIb      | IV        | IIIa      | IIIb     |
| Shrubby           | IIIa     | IIIb      | II        | IIIb      | IIIb      | V        | IIIa      | IIIb     |
| Ground grasses    | IIIa     | IIIb      | IIIb      | III        | IIIb      | V        | II        | IIIb     |
| Mosses            | IIIb     | IIIb      | IIIb      | IIIa      | IIIb      | IV        | IIIa      | IIIb     |

The value of biological accumulation in the majority of studied plants of different ecological groups and life forms belongs to groups IIIa and IIIb. However, when considering the characteristics of the accumulation of individual heavy metals, the following features can be noted:

- submerged plants are the strongest bioaccumulators of heavy metals,
– among heavy metals, the greatest bioaccumulation in plants of various ecological groups and forms is manifested in zinc and chromium;
– very low bioaccumulation capacity in plants was observed in vanadium and copper.

Differences in the ability to accumulate heavy metals in different plant life forms are not expressed, and to a greater extent determined by the specifics of the species. The analysis showed relatively low average bioaccumulation of the studied heavy metals except zinc and chromium in mosses. However, species-specific increased accumulation of individual metals in certain species was noted: Polytrichum commune – on the accumulation of zinc (II category, CBN = 1.4), Dicranum polysetum Sw. ex Mlchx. and Pleurozium schreberi (Brid.) Mitt – on the accumulation of strontium – it has a weak accumulation of all studied metals, except strontium. None of the 16 species of mosses studied have any special abilities to accumulate heavy metals and their biological storage capacity is estimated on average as "weak accumulation or average capture" and below.

4. Conclusion
The obtained results indicate the existence of a relationship between the belonging of plants to an ecological group or life form and the ability to accumulate heavy metals in some of the most specialized ecological groups of plants–in submerged macrophytes and ruderal vegetation. At the same time, it was found that within the ecological groups of plants that do not have on average a pronounced increased or decreased ability to accumulate, there are species that have specificity in relation to the accumulation of a certain heavy metal. This feature is most pronounced in mosses. The results obtained testify to the ecochemical aspect of the importance of preserving the species diversity of plant ecosystems under the influence of industrial facilities, in particular, landfills. Also, reasonable use of the differences in accumulative capabilities of individual ecological groups of plants and the properties of certain plant species can improve the efficiency of protective zones around landfills and other industrial enterprises.

References
[1] Vorobyeva L A 1998 Chemical analysis of soils (Moscow: MSU)
[2] Kabata-Pendias A, Pendias H 2001 Trace elements in soils and plants (London: CRC Press)
[3] Materials of public hearings on the project Reconstruction of solid waste landfill "North Samara" 2016 (St. Petersburg)
[4] Federal Register 1.31.2018.32143 Determination of elements and element oxides in soil and sediment samples
[5] Serebryakov I G 1962 Ecological morphology of plants (Moscow)
[6] Popova L F, Nakvasina E N 2014 Normalization of urban soil quality and organization of soil–chemical monitoring (Arkhangelsk)
[7] Perelman A I, Kasimov N S 1999 Geochemistry of landscape (Moscow: MSU)