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Bioaccumulation of Heavy Metals with Environmental Objects and Assessment of Health Risks (the Former Mining Enterprise Khingansky GOK as an Example)

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Abstract—Bioaccumulation of heavy metals with environmental objects has been studied. High concentrations of toxic heavy metals have been found in the recycling wastes of tin ore. The heavy metals migration to the environmental objects (snow, anthropogenic soils, water, and sediments) has been revealed. Finally, the metals are accumulated in living organisms, including agricultural production grown in suburban areas located near the tailings.

Industrial pollution of agricultural ecosphere contributes to the related diseases, including those of respiratory, nervous, and digestive systems.

Keywords: bioaccumulation, heavy metal, environmental hazard, human health risk, tailing

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INTRODUCTION

Intense extraction of mineral ores in Jewish Autonomous Oblast as stressed upon the ecological situation near the mining enterprises. The tailings containing toxic materials (copper, zinc, lead, cadmium, mercury, etc) are among negative environmental factors. Estimation of its impact on the biosphere components (including living organisms) is a topical issue. This study aimed to investigate heavy metals accumulation with environmental objects and to elucidate the associated human health risks. In view of that, the study was divided into the following tasks:

(1) to analyze and generalize the related published data;

(2) to elucidate the effect of tailing as a pollution source;

(3) to investigate bioaccumulation of heavy metals with anthropogenic soils, waters, sediments, and living organisms and to elucidate the human health risks;

(4) to propose means to reduce the negative environmental effects of the tailings.

The study was based on the earlier doctrines of Vernandskii [1] and Kolesnikov and Motorina [2]. Various geobotanical, forestry, geomorphological, physico-chemical, and biological methods were applied to collect, model, and process the data.

RESULTS AND DISCUSSION

The analysis of earlier published data [3–14] revealed that bioaccumulation of heavy metals with environmental objects has been scarcely studied so far.

Wastes of the former Khingansky GOK tailing contain cassiterite (SnO_2), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), arsenopyrite (FeAsS), pyrite (FeS), and halenite (PbS). The non-metallic components include quartz, peach, and fluorite. The wastes show up high content of toxic elements: Cu, Zn, Sn, Pb, and As; Cd and Mo are found in somewhat lower concentration. The heavy metals can migrate from the

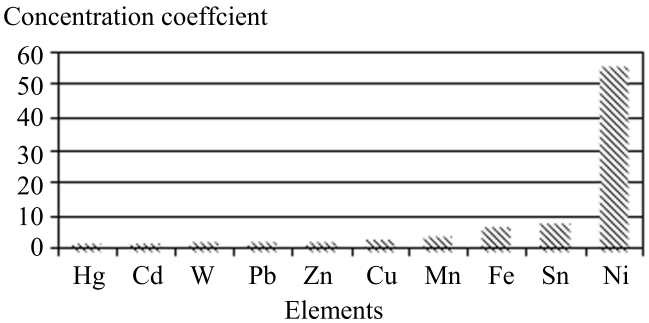

Fig. 1. Concentration coefficients of elements in the liquid phase of snow.

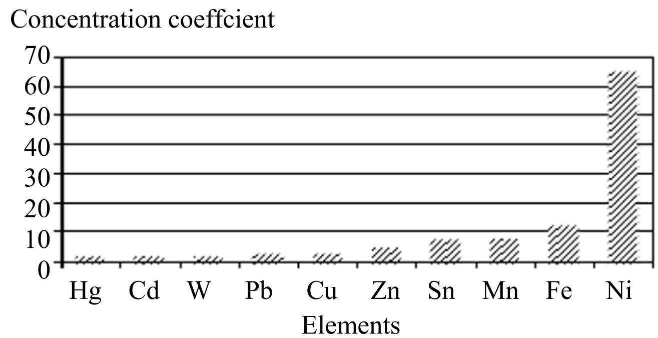

Fig. 2. Concentration coefficients of elements in the suspended phase of snow

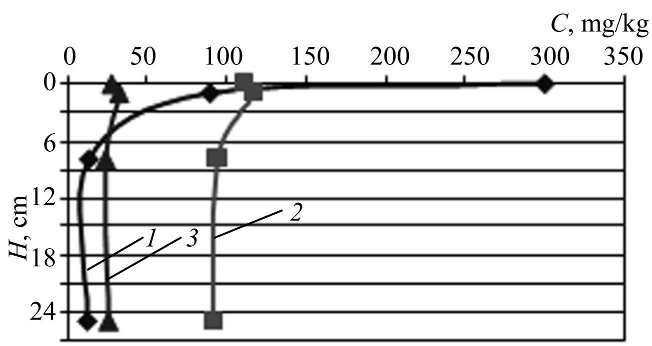

Fig. 3. Technogenic-accumulative distribution of heavy metals in the soil profile within the studied tailing: (*1*) Ni, (*2*) Zn, and (*3*) Cu.

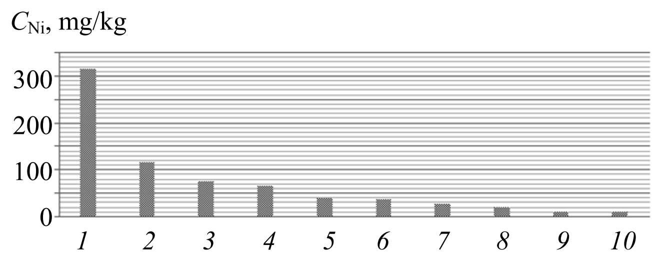

Fig. 4. Distribution of plants in the area of the studied tailing according to Ni content: (*1*) *Rubus sachalinensis*, (*2*) *Artemísia vulgaris*, (*3*) *Polytrichum commune*, (*4*) *Sorbaria sorbifolia*, (*5*) *Larix gmelinii*, (*6*) *Alnus hirsuta*, (*7*) *Tanacetum boreale*, (*8*) *Usnea*, (*9*) *Lycopodium clavatum*, and (*10*) *Ledum palustre*.

wastes to snow, artificial soils, plants, and finally to other living organisms (including humans), the bioaccumulation resulting in various pollution effects.

Following the GOST 17.4.1.02-83, the soil-accumulated elements are divided into three classes of hazard: class 1 (As, Cd, Hg, Se, Cu, Pb, and Zn); class 2 (B, Co, Ni, Mo, Sb, and Cr); and class 3 (Ba, V, W, Mn, and Sr).

During a winter season, the snow accumulates 900 kg of soluble inorganic compounds and 98 tons of dispersed compounds from the tailing. The content of Ni, Zn, Cu, Pb, and Mn in snow exceeded the MPC by 1.9–5.5 times (Figs. 1 and 2).

Accumulation of heavy metals in the surface layer of anthropogenic soils (Fig. 3) was dependent on the organic matter content; increasing of the latter reduced mobility of Cu, Zn, and Pb. The highest concentration of Ni, Zn, and other metals were found at 100 to 1000 m from the tailing, being decreased at farther distance. The overall soil pollution with Cu, Pb, Zn, and other elements in the built-up area was higher than the permitted level.

In the soil, the sulfide compounds are oxidized with oxygen and the atmospheric precipitates; highly concentrated solution is thus formed in the soil micropores and then comes into the plants root system [5, 14]. As a result, the plants growing in the tailing region accumulate various toxic heavy metals: Zn (187 mg/kg), Cu (32 mg/kg), and Pb (28 mg/kg). The strongest accumulation of the heavy metals with plants was observed both near the tailing area (up to 14 km) as well as near Khingan river. The heavy metals were majorly accumulated in the plants roots and leaves. Our studies demonstrated that the vegetation state was a universal integral indicator of the ecosystems (natural as well as anthropogenic) state [1–6, 9, 12]. Accumulation of the heavy metals with the overground parts of the plants was significantly enhanced. For example, grass at the polluted area (near the tailing) contained 38% more of copper than the reference sample. Mossy and lichen plants revealed the strongest accumulation of the heavy metals.

The vegetation of the studied region accumulated 3–4 to 28 times more of the heavy metals as compared with the background level typical of the region (Fig. 4).

Using the geomicrobiological method to estimate the pollution level, we demonstrated the low biogenic value of the soil in the tailing-affected area. In particular, the number of saprophytes was of 4.7–7.5 million per 1 g of the substrates, such soil is normally classified as poor [7]; the bacterial complex was suppressed. The microbiological parameters of the soil concluded about significant structural and functional violations of the microbial biocenosis in the tailing-affected area.

Statistical processing of the biological tests (plants growth at the sampled substrates and seeding watering with the ground water) revealed that the germinative energy affected by the tailing was of 9% with respect to the reference.

The technogenic factors are known to affect the living organisms via the cellular mechanism. In view of this, cytology and cytogenetic testing systems were extremely valuable. In particular, express testing of the environment state using the Pollen sterility and the Growth tests [15, 16] revealed the pollen sterility of the selected plants of up to 20–28% at the polluted areas (the reference level being of 0.3–0.5 %). The conclusions were as follows:

(1) The pollen sterility of the plants was increased in response to the technogenic factor;

(2) The plants reaction revealed a threshold character, similar to the reports [14, 16];

(3) Enhancing the technogenic factor was reflected in the changes of morphology characteristics of the plants.

Ecological situation near the tailing of former Khingansky GOK was classified as critical basing on the set of physico-chemical and biological methods.

Furthermore, our study revealed accumulation of the heavy metals in the agricultural production grown near the tailing (1.5–3.5 km). Therefore, there is a certain human health risk in the region. For instance, content of zinc in potato tops was of 110 mg/kg, and that in the tubers was of 19 mg/kg. The heavy metals content in tomato was also significant (48 mg/kg of Zn and 21.3 mg/kg of Cu).

As a result, the environment-related diseases can appear among the human population inhabiting the tailing-affected area. Our analysis showed that the highest hazard coefficients (HQ > 1) were those of suspended compounds (HQ = 49.5), copper (HQ = 23.5), manganese (HQ = 4.9), and sulfur dioxide (HQ = 1.7). Cumulative hazard index was the highest for the compounds affecting the respiratory system (HI = 98) and the nervous system (HI = 4.96).

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