INTRODUCTION

The soil chemistry distinguishes heavy metals as a special group of elements because of their toxic effect exerted on plants upon their high concentrations. However, there is no common opinion on the hazard degree of any particular heavy metal in soils. Only three heavy metals, i.e., Pb, Cd, and Hg, were mentioned in the Global Monitoring Program adopted by the UNO in 1973 (cited after [15]). Later, in the report delivered by the Executive Director of the UN Environmental Program (UNEP), seven other heavy metals (Cu, Sn, V, Cr, Mo, Co, and Ni) and three metalloids (Sb, As, and Se) were added to the list of the most hazardous elements [32].

These recommendations still form the basis for monitoring heavy elements in soils. The Ministry of Natural Resources and Ecology of the Russian Federation controls the total content of nine heavy metals in soils [12]. For some metals (V, Mn, Pb), maximum permissible concentrations (MPC) were adopted; for others (Cd, Cu, Ni, and Zn), approximate permissible concentrations (APC) were introduced; and, for the third group of metals that are not described by any standards (Co, Cr), the soil’s contamination degree is estimated by the empiric criterion, i.e., a fourfold excess of the background values.

The Russian sanitary hygienic GOST 17.4.102–83 classifies As, Cd, Hg, Se, Pb, and Zn as highly hazardous elements, whereas Ni, Mo, Cu, and Sb as moderately hazardous ones [11]. This list of general toxicity is also applied for assessing the hazard of metals/metalloids in soils despite the fact that it ignores the interaction between the pollutants and soil components, which leads to misinterpretation of their toxicity. Later, special attention was paid to six heavy elements in soils, i.e., Ni, Cu, Zn, Cd, Pb, and As; and APC criteria were developed for them (cited after [1]).

In western countries worried about the environment condition, the development of standards is intensely promoted. The toxicity was assessed on the basis of the impact of heavy metals/metalloids on biological objects in soils and soil solutions. Dutch ecologists have generalized the research data on the toxicity of heavy metals/metalloids in soils.

The aim of this paper is to compare the Russian and the Dutch lists of hazardous metals/metalloids in soils and to attract attention to the most dangerous elements.

THE GROUP OF HEAVY METALS AND METALLOIDS

The metals with their atomic mass heavier than 50 are usually regarded as heavy metals [27]. However, the known lists of heavy metals are not precise. The number of heavy metals is not usually specified: the vague phrase “more than 40 chemical elements” is common [28]. Nevertheless, a list comprising 19 elements (Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, Mo, Cd, Sn, Sb, Te, W, Hg, Tl, Pb, and Bi) is often cited [28]. This list of metals does not contain Ba, lanthanides,
and actinides. Antimony included in this list is a metalloid, and soil scientists usually also add another metalloid, i.e., As [31]. In the later edition of textbook [29], only eleven elements are classified as the most typical contaminating heavy metals: Pb, Cd, Hg, Zn, Mo, Ni, Co, Sn, Ni, Cu, and V. It appears appropriate to add heavy metalloids (their former name was semimetals) to the group of heavy metals. Two of them, i.e., Sb and As, are included as hazardous metalloids on many lists of heavy elements. In this case, all the elements from V (atomic mass 50.9) to U (atomic mass 238) constitute the group of natural heavy metals and metalloids, except for halogens (the 17th group) and noble gases (the 18th group), which do not refer to heavy metals and metalloids (Fig. 1). The transuranium elements were artificially obtained; therefore, we don’t consider them. Thus, 57 elements form the group of heavy metals and metalloids.

Not all heavy elements entering soils as pollutants are similarly hazardous for plants, biota, and groundwater. At present, the general toxicological GOST operates in Russia, dividing heavy metals/metalloids into three classes by their hazard degree [11]. However, this versatile classification of elements does not take into account the specific features of the depositing environment; therefore, it appears to be more suitable for the air and water than for soils. Pollutants entering soil interact with its active phase (clay minerals, oxides and hydroxides of iron and manganese, and organic substance) and change their own activity either increasing or decreasing their hazard. Let us take Pb as an example. The high biological hazard of Pb is manifested in experiments with its salts. However, in soil, lead forms stable complex compounds with organic ligands, which become much less hazardous for living organisms than metal ions are [24]. In this case, the share of these complexes in the water extract can exceed 90% of the total lead content. As we show below, the lead hazard in soils is assessed now as low.

### ASSESSMENT OF HEAVY METALS AND METALLOIDS TOXICITY IN SOILS ACCORDING TO THE RUSSIAN AND DUTCH CRITERIA

Let us scrutinize the paper by Dutch ecologists [36] dealing with the standardization of the heavy metal/metalloid content in soils and sediments. The essence of this paper consists in the mathematical harmonization of a large number of experimental studies on the influence of heavy metals/metalloids on the biota and plants. The list of references includes 160 titles of publications. The maximum permissible addition (MPA) of the heavy metal/metalloid content in the soil is the key idea upon the standardization of the soil contamination. The MPA is calculated proceeding from the following condition:

\[
\text{MPA} = \frac{\text{NOEC}}{10},
\]

where the abbreviation NOEC stands for *no observed effect concentration*, i.e., the maximal concentration exerting no significant influence on the growth and reproduction of the test organisms. The Dutch ecologists took into account the influence of contaminated soils on soil fauna representatives (earthworms and arthropods), on the development of microbiological processes, and the response of plants. In addition, the biological effect of heavy elements passing into the solution (in laboratory experiments with suspensions) and into the ground and surface water (under natural conditions) was taken into consideration.

Let us analyze the MPA values; they permit us to rank a large set (17) of heavy metals/metalloids and to distinguish the most hazardous among them in the soils. Let us make several comparisons for this purpose. First, let us compare the set of elements toxicity according to the general toxicological criterion with the set of their toxicity in soil according to the MPA value and then the sequence of element toxicity according to their mobility to the same sequence according to the MPA values.

Comparison of the elements toxicity according to the general toxicological criterion to the sequence of the elements toxicity in the soil according to the MPA values.

The MPA values vary very widely, i.e., from 0.0061 mg/kg for a light metal Be (the most toxic element) to 253 mg/kg for Mo (the least toxic element). The wide range reflects the difference in the hazard degree of the elements in the soils. For subdividing the elements by their hazard on the MPA basis, we refer the elements with MPA < 1 mg/kg to the first class; the elements with 1 mg/kg < MPA < 10 mg/kg, to the second class; and those with MPA > 10 mg/kg, to the third class (Table 1). Above all, the absence of elements recognized as very hazardous in soils (beryllium and thallium) on the list of elements standardized in Russia stands out. At the same time, the hazard of Pb and Zn in the soils is not as high as in other media: they may be classified as the low dangerous third group.