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Toxic metals in soils of the Russian North

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ABSTRACT

Results of soil cover studies in different regions of the Russian North from the Kola Peninsula in the West and the Chuckchi Peninsula in the East are presented. Toxic metal distribution in soils (podzols, cryosols, histosols of different types) of both impact (technogenically disturbed) and background regions were studied. HCl and ammonium acetate (A/A) buffers were used as the extraction agent followed by atomic absorption spectrometry. More than 100 field sites were studied. It was demonstrated that microelement soil content is closely connected with that of parent rocks which differ in different regions. Noticeable increase of heavy metals (Cu, Ni, Co, Pb, Zn etc.) in the upper soil horizons is marked near large industrial sites (up to 20 km from the source of pollution) sometimes exceeding background for more than 10–100 times. Each region and soil type has its own background concentration level. That is why no general superregional background concentration patterns may be revealed based on numerous soil sampling in different regions of the discussed territory.
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1. Introduction

Ecological problems of the Russian North nowadays attract heightened attention regarding the importance of this region for preserving global ecological balance and its rich mineral and hydrocarbon resources. The Russian North which includes unique natural ecosystems, is highly unstable to anthropogenic impact. Recent investigations showed that alongside with radio nuclides and organic chlorine compounds toxic metals belong to priority contaminants dangerous for Arctic ecosystems (AMAP, 1998; Evseev et al., 2000; Kozlov and Barcan, 2000; Volosov et al., 2009; Walker et al., 2003 etc.). Russian North ecosystems experience increasing anthropogenic impact connected with long range metal air transportation and local industry (Ruhling et al., 1987; Steinnes, 1984; Walker et al., 2003). Their main sources are copper–nickel plants at the Kola Peninsula (Murmansk region) and in Norilsk (Middle Siberia). For example by the end of the 20th c. and at the beginning of the 21st c. annual emissions of metallurgical plants in Murmansk region reached 3000 t for Ni, 2000 t for Cu and 100 t for Co (AMAP, 1998; Evdokimova and Mozgova, 1993; Evseev and Krasovskaya, 2010). Mining industry, energy production, transport, housing and communal services as sources of toxic metal emissions were of minor importance. Pollution monitoring system development needs data for background concentrations of toxic metals in different environment media, including soils. Studies of soil characteristics influenced by airborne pollutants in the discussed region are not so numerous as in more southern regions of Russia and refer mainly to the Kola Peninsula and Norilsk area (AMAP, 1998; Evdokimova and Mozgova, 1993; Koptsik et al., 2003; Steinnes, 1984). Background concentration comparison was not discussed.

It is known that different airborne pollutants fall with time and are fixed in upper horizons of Arctic soils (AMAP, 1998; Ruhling et al., 1987; Steinnes, 1984). In northern regions fixation rate for toxic metals depends on soil mechanical composition, humus content, thickness of peat layer, and moss–lichen vegetation cover development. The studied toxic metal-pollutants are relatively mobile in acid environment. This promotes their slow redistribution both in soil profiles and landscape-geochemical systems. As a result complicated model of toxic metal distribution in upper organic soil horizons is formed: heightened concentrations are found only in case of long-term impact of their considerable amounts.

Toxic metal concentrations in parent rocks stipulate initial concentration level in soil profile. Arctic soil cover has a slow evolution rate, low intensity and capacity of biogeochemical cycle, and experiences permafrost influence (Evseev, 1982). Intensive anthropogenic impact causes considerable changes in soils, their degradation and development of strongly eroded soils (Evdokimova and Mozgova, 1993; Evseev and Krasovskaya, 2010; Evseev et al., 2000; Gordeev et al., 2001).

2. Study area and methods

We studied microelements and macroelements in soils both in impact regions and at background territories. Impact regions were formed near large sources of pollutant emissions. The investigations were supported by the Moscow State University, the Hydro-Meteorological and Environment Monitoring Service and Russian Scientific Foundation

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Fig. 1. Sampling fields. 1—Monchegorsk, 2—Vorkuta, 3—Norilsk, 4—Pevek; a—Lapland Nature Reserve, b—Bol'shezemel'skaya Tundra, c—Amderma, d—Taimyr Nature Reserve, e—Beringia nature park.

and lasted for more than a decade beginning from the end of the 20th c. Pb, Ni, Co, Cu, and Zn were in the focus of our attention. Other metals studied included: Cd, Cr, Hg, Fe, Mn and Sn. Sampling fields comprising several sampling sites each were randomly located from the Kola Peninsula in the West to the Chuckchi Peninsula in the East (Fig. 1). Impact zone formed by non-ferrous metallurgical plant “Severonickel” in Monchegorsk and background territory in the Lapland Biosphere Nature Reserve situated 20 km to the south-west from the source of pollution were studied at the Kola. Vorkuta (coal mining), Timano-Pechora (hydrocarbons extraction) impact zones and Amderma and Bol'shezemel'skaya Tundra background territories situated more than 100 km from pollution sources were studied at the North-East of the European part of Russia. Norilsk impact zone formed by non-ferrous metallurgical plant and coal mining and Taimyr Nature Reserve area more than 300 km to the north-east from pollution source as a background territory were studied at the North of Middle Siberia. Pevek region (complex anthropogenic impact) and remote territories of “Beringia” nature park more than 200 km to the west from the source of pollution were studied at the North of the Far East. Soils from more than 100 soil sampling fields were collected presenting different types of podzols (WRB-PZ), histosols (WRB-HS), and cryosols (WRB-CR). Sampling depths varied from 10–15 up to 100 sm depending on soil profile depth. Soil horizons and parent rock were sampled. Plants sampling at the same sampling fields included mosses (*Sphagnum* sp.), lichens (*Cladonia* sp., *Cetraria* sp.) following AMAP sampling methods (AMAP, 1998). These plant species are used to monitor airborne pollutant long-range transport (AMAP, 1998; Evseev and Krasovskaya, 1996).

Typical soil types were studied: illuvial-humic (PZeb) and illuvial ferrous podzols (PZrs), tundra cryosols of different types (Crhi,CRgl), and tundra histosols (HS).

Table 1
Toxic metal concentrations in a podzolic soil, transect Monchegorsk–Olenegorsk, Murmansk region, (mg/kg).

Horizon	Pb		Ni		Co		Cu		Zn	
	HCl	A/A*	HCl	A/A	HCl	A/A	HCl	A/A	HCl	A/A
A_0	12.8	2.3	80.1	18.6	1.7	1.4	119.9	8.8	28.3	12.0
A_2	2.4	0.5	3.3	1.8	0.9	–	9.6	3.1	5.6	3.8
B	6.2	0.2	28.5	1.3	6.9	–	32.8	2.8	26.5	2.6
BC	5.7	0.8	25.9	0.8	6.2	–	38.1	14.5	5.0	5.7
C	3.2	0.3	10.3	0.4	3.4	–	23.1	3.2	9.1	1.9

* Ammonium acetate buffer.

HCl (1:10) and ammonium acetate (CH_3COONH_4, A/A) buffers were used as the extraction agent. 5 g of dry soil sample was mixed with 50 ml HCl and 25 ml A/A and left for 24 h. The atomic absorption spectrometry AAS (Perkin Elmer, Hitachi instruments) followed. A/A extraction corresponds to metal uptake by plants from soil solutions. HCl extraction gives results close to bulk metal concentrations.

3. Results and discussion

The received results were used for Arctic pollution monitoring purposes by Hydro-Meteorological and Environment Monitoring Service of Russia. Results of separate soil studies presented in Tables 1–6 demonstrate typical processes of metal accumulation in impact and background regions. Extremely high concentrations of Cu, Ni, Co, Pb, and Zn were found in illuvial-ferrous soils close to the territory of non-ferrous metallurgical plant “Severonickel”. The highest bulk concentrations were found in the upper eroded soil horizon at the industrial site for Cu, Ni (≥10,000 mg/kg) and Co (≥800 mg/kg). These exceed background for more than 50 times. High concentrations are typical for mobile forms of metals as well. Heightened concentrations of toxic metals were found in the upper organogenic horizon of podzolic soils (Table 1). Similar results were received by other researches (Evdokimova and Mozgova, 1993; Koptsik et al., 2003) and are presented in AMAP report (AMAP, 1998).

Table 2
Metal concentrations in a podzolic soil in Lapland Biosphere Nature Reserve, (mg/kg).

Horizon	Depth	Metals								
	Sm	Cr	V	Ni	Co	Cu	Zn	Pb	Sn	Mo
A_0	0–2	20.0	10.0	60.0	5.0	30.0	50.0	4.0	0.3	0.8
A_2	2–8	30.0	20.0	5.0	3.0	3.0	5.0	1.5	0.3	0.8
B	8–18	20.0	20.0	6.0	3.0	6.0	6.0	1.0	0.3	–
BC	18–22	20.0	15.0	6.0	3.0	6.0	6.0	0.8	0.2	–
C	22–23	30.0	20.0	8.0	3.0	8.0	6.0	1.0	0.3	0.5

Table 3
Mobile metal concentrations in tundra gley soil near Amderma (mg/kg).

Horizon	Depth, sm	Ni	Cd	Cu	Zn	Pb
A_0–A_1	3–8	2.6	0.6	4.4	5.1	4.4
B_1	8–15	1.2	0.5	4.4	2.2	3.4
Cg	30–40	2.5	0.5	4.3	2.5	3.6

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