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ENVIRONMENTAL STATUS OF THE ARCTIC SOILS

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Abstract

The Arctic region is under an ever-increasing anthropogenic influence. The nature in the Arctic is extremely vulnerable to the effects of pollutants, which may eventually lead to certain irreversible ecological processes. Heavy metals occupy a special place among priority pollutants. Therefore, the aim of this study has been to assess the ecological status and the degree of contamination with heavy metals of the soils of Arctic and sub-Arctic areas.

Arctic soils were studied in the region of the White Sea and the Barents Sea during the Arctic Floating University, a research expedition held in July 2012 by M. Lomonosov Northern (Arctic) Federal University. During the expedition, samples were collected and the landscapes (topography, vegetation) were described. In order to assess the impact of environmental contamination, the total content of heavy metals in soils was evaluated by X-ray fluorescence analysis (XRF). The level of soil contamination was assessed according to the maximum permissible concentrations (MPC), temporary permissible concentrations (TPC), chemical substance factor (Kc) and the total pollution index (Zc).

Our analysis of the experimental data showed a wide-range change in the soil agrochemical parameters. It has been demonstrated that the investigated soils of the Arctic and sub-Arctic areas represent different soil properties, are affected by different climatic conditions and belong to different texture taxonomic classes, e.g. the grain-size distribution varies from sand to clay loam; the pH ranges from strongly acid to neutral and the content of organic substances can be very low to high.

According to the total pollution index, almost all the soils present an acceptable heavy metal contamination level. In most of the studied soils, the heavy metals in terms of amounts accumulated can be ordered as follows: Co > Pb > Cu > Zn > As > Ni > V > Mn.

Keywords: Arctic soils, agrochemical parameters, heavy metals.

INTRODUCTION

During the last decade, the ecological status of the Arctic and sub-Arctic areas has been given special attention due to their extremely vulnerabile environment, low resilience of the ecosystems as well as the important economic, social and environmental role that the Russian Arctic plays. The Arctic zone of Russia occupies more than a third of the country's territory and it is characterized by extreme climate conditions, diverse and significant reserves of natural resources and slow recovery of natural ecosystems (*Integrated scientific and educational expedition* 2012, *Strategic Action Program* 2009).

Environmental pollution is nowadays a global problem, to which heavy metals contribute most gravely, therefore their monitoring is obligatory in all environments.

The Arctic region is under an ever-increasing anthropogenic impact, including local industrial centers and changing ways of contaminant transport by air masses, flowing water and sedimentary material of the Arctic rivers. Emissions from the metallurgical and energy industries are almost invariably accompanied by the emission of acid-forming substances, which are transported over long distances and can contribute to acid leaching of labile elements of the constituent formations (especially aluminum, cadmium, zinc, etc.). The anthropogenic impact leads to the degradation of the Arctic soils due to the low mass and energy exchange as well as short food chains, contributing to a rapid transport of toxicants to final consumers. The Arctic environment is extremely vulnerable to the impact of pollutants, which may eventually lead to certain irreversible ecological processes (*Assessment of the Barents Hot Spot Report* 2013, Agbalyan 2011, Shevchenko et al 2003, *Heavy Metals in the Arctic*, 2002).

Therefore, assessment of the ecological status of the Arctic environment and protecting it from pollution becomes a priority goal, at least for the Arctic states.

MATERIAL AND METHODS

From June 1 to July 10, 2012, M. Lomonosov Northern (Arctic) Federal University co-organized a research expedition called Arctic Floating University. The other institutions involved were the Federal Northern Department of Hydrometeorology and Environmental Monitoring, Arctic and Antarctic Research Institute (AARI), and State Oceanographic Institute, Institute of Environmental Problems of the North, the Ural Branch of the Russian Academy of Science (IEPN UB RAS). The expedition received some financial support of the Russian Geographical Society. The research vessel called Professor Molchanov took the following route: Arkhangelsk – the White Sea – the Barents Sea – Novaya Zemlya – Franz Josef Land – Novaya Zemlya, Cape Zhelaniya – the Barents Sea along Novaya Zemlya – Kolguev Island – Sosnovets Island – the Solovetskie Islands – Arkhangelsk.

During the expedition, samples were collected in accordance with GOST 17-4-4-02-84, in order to study the ecological status of soils at the 12 landing stations.

For each sampling point, the taxa of the soil-ecological classification (Map of soil-ecological zoning, 1997) are provided and the taxonomic position is identified according to the WRB (*World Reference Base for Soil Resources* 2014). The landscape description (topography, vegetation) is also provided.

The following characteristics were examined: texture by means of elutriation (Vashenko, Lange et al. 1982); pH of an aqueous extract of soil (GOST 26423-85) and organic matter content (GOST 26213-91). The agrochemical properties were studied in the Laboratory of Biogeochemical Research of the Institute of Natural Sciences and Technologies (NArFU). In order assess the impact of environmental contamination in the surface layer (0-10 cm), the total content of heavy metals in soils was evaluated by means of X-ray fluorescence analysis (XRF), in accordance with method M049-P/04. This part of the research was performed with the equipment of the Arctic Centre for Shared Use of Research Equipment (NArFU) and with financial support of the Ministry of Education and Science of the Russian Federation (unique works identifier RFMEFI59414X0004).

The level of soil contamination was assessed by the factor of the maximum permissible concentrations (MPC) and temporary permissible concentrations (TPC) excess, according to MU 2.1.7.730-99 and GN 2.1.7.2511-09, using the scales of environmental regulation.

In the assessment of biogeochemical changes due to the anthropogenic impacts, the following system of coefficients was used:

– *chemical substance factor* (referred to as Кc in formulas) – the factor is determined through the ratio between the actual content of a substance

(C) in mg kg^{-1} of soil and the regional background index (Co) : $K_c = \frac{C}{C_0}$;

– *total pollution index* equals the total amount of concentration factors of pollutants and is estimated as follows: $Z_c = \sum \frac{K_c}{n-1}$, where n – is the number of the analyzed pollutants (Pilugina et al. 2007).

RESULTS AND DISCUSSION

The voyage route stretched over two geographical zones (the Arctic and Boreal). The Arctic Zone extends to Novaya Zemlya, the neighbouring islands and Franz Josef Land; the sub-Arctic Zone – to the south from Novaya Zemlya, to the entrance of the White Sea (Kolguev, Kanin Nos Cape). The White Sea islands belong to the Northern Taiga Subzone.

Soils of Novaya Zemlya, the neighbouring islands and Franz Josef Land present the Cryosols Haplic. Being formed in a harsh environment, they are characterized by the poor development of soil processes and the soil profile, as well as the poor vegetation cover of mosses and lichens. The soils develop on rubble and rocky moraines and rocks; they are mostly sandy loam. The soil cover is represented by a mosaic of soil spots. According to our data (Table 1), these soils are sandy and loamy, with the pH reaction close to neutral (pH 4.80-6.88) and with a high organic matter content (6%).

On Kolguev Island, the soil type is identified as Podzols Entic. Such soil develops on well-drained, sandy-loam-rubble sediments and rocks with the

Table 1

Agrochemical properties of the Arctic soils

Location	pH	Texture	Organic matter (%)
Cryosols Haplic			
Golfstream island	6.88±0.34*	sandy loam	na**
Cape Zhelaniya	6.62±0.33	heavy loam	6.03±0.30
Russian Harbour, Novaya Zemlya	4.80±0.24	heavy loam	na
Tihaya Bay, Franz Josef Land	6.77±0.34	light loam	6.05±0.30
Podzols Entic			
Kolguev Island (1)	5.56±0.28	sandy loam	1.12±0.06
Kolguev Island (2)	6.11±0.31	light loam	3.03±0.15
Podzols Gleyic			
Kanin Nos Cape	5.18±0.26	sand	4.00±0.20
Fluvisols Dystric			
Zimnegorsky Cape	5.77±0.29	heavy loam	na
Podzols Haplic			
Solovetskie Islands	4.73±0.24	sand	na
Letnyaya Zolotitsa	4.47±0.22	sandy loam	8.90±0.45
Histosols Fibric Soil			
Sosnovets Island	3.86±0.19	na	na

Treatment: * – standard errors
** na – not available

low-density texture. The examined soil has coarse texture and more acidic pH reaction in comparison with the Cryosols Haplic (pH 5.56-6.11).

More to the south, at Cape Kanin Nos, the soil type is identified as Podzols Gleyic. The vegetation cover is represented by sedge-grass associations and tree species. The characteristic morphological feature of this subtype is the presence of a gley horizon and signs of a subtle form of podzolization. According to their texture, the soils are mostly acidic sands (pH 5.18) with a low organic matter content (1-3%).

The soils of the Solovetskie Islands and Letnyaya Zolotitsa are identified as Podzols Haplic. The vegetation is represented by tree-forest formation. The soils are acidic sands with an even higher pH reaction (pH 4.73), but also with a high content of organic matter (8.9%).

Fluvisols Dystric was identified at Cape Zimnegorsky. This heavy loam soil is found on a floodplain; the pH reaction is close to neutral (pH 5.77). The vegetation is represented mainly by grasses and sedges.

The soils of the island of Sosnovets belong to the type of Histosols Fibrics. The soils of this type are formed under specific conditions characterized by excessive moisture, with hydrophilous vegetation that develops nearly without any dissolved oxygen in the water, a low content of nutrients in the substrate and acidic reaction (pH 3.86). The vegetation is represented mainly by cloudberries, mosses and lichens. In the boreal climate conditions, plant remains are exposed to incomplete decomposition.

Our analysis of the experimental data concerning the total content of heavy metals allowed us to estimate the extent of soil contamination in the Arctic and sub-Arctic areas of the Arkhangelsk region.

The comparative analysis of the total content of heavy metals in the soils of the Arctic and sub-Arctic areas (Table 2) showed absence of Pb, Mn or V contamination. However, in the soils of Sosnovets Island the maximum allowable concentration (MAC) of Pb is exceeded 3.4 times, which corresponds to a low level of contamination. In the soils of Cape Zhelaniya, the total content of V is 1.1 MAC, which also corresponds to a low level of contamination. There is no evidence of the exceeded MAC for Mn.

Soils in this area are slightly contaminated with Zn. In the Cryosols Haplic and in the Fluvisols Dystric of Cape Zimnegorsky, the tentative permissible concentration (TPC) of Zn was detected to be exceeded, with the maximum of 2.3 TPC. In addition, 58.3% of the collected soil samples are slightly contaminated with Cu, 66.7% – with Ni, 91.7% – with As. The maximum concentrations of these metals were 1.8 TPC (Sosnovets Island), 3.1 TPC (Kuzov Island) and 4.8 TPC (Cape Zimnegorsky), respectively. However, in the soils of Sosnovets Island, the TPC for Zn was exceeded 9.9 times and the TPC for As – 13.5 times, which corresponds to an average level of contamination.

An exceeded MAC for Co was detected in the soil samples from Cape Kanin Nos and Sosnovets Island: 1.9 and 1.2 times, respectively. In the soil

Table 2

Total content of heavy metals (mg kg^{-1}) in the Arctic soils

Location	Chemical element							
	Pb	Zn	Cu	Ni	Co	Mn	V	As
Golfstream island	25.0±1,2*	64.9±3.2	34.7±1.7	31.7±1.6	12.9±0.6	355.9±17.8	100.7±5.0	6.0±0.3
Cape Zhelaniya	25.0±1,2	94.0±4.7	51.0±2.6	51.0±2.6	17.0±0.9	443.8±22.2	162.0±8.1	6.0±0.3
Russian Harbour, Novaya Zemlya	30.0±1,5	69.0±3.5	41.2±2.1	40.0±2.0	17.6±0.9	679.2±34.9	139.9±7.0	7.2±0.4
Tihaya Bay, Franz Josef Land	25.0±1,2	77.0±3.9	41.0±2.1	42.0±2.1	27.0±1.4	363.2±18.2	122.0±6.1	6.0±0.3
Kolguev Island (1)	25.0±1,2	22.1±1.1	20.0±1.0	11.5±0.6	21.6±1.1	377.1±18.9	27.5±1.4	6.0±0.3
Kolguev Island (2)	20.0±1,0	53.0±2.7	26.0±1.3	25.0±1.2	17.0±0.9	558.7±27.9	65.8±3.3	4.8±0.2
Kanin Nos Cape	30.0±1,5	12.0±0.6	24.0±1.2	12.4±0.6	92.8±4.6	833.4±41.7	18.4±0.9	7.2±0.4
Zimnegorsky Cape	40.0±2,0	127.6±6.4	44.0±2.2	39.2±2.0	23.2±1.2	891.0±44.6	105.6±5.3	9.6±0.5
Solovetskie Islands	30.0±1,5	12.0±0.6	24.0±1.2	12.5±0.6	26.9±1.3	181.8±9.1	12.0±0.6	7.6±0.4
Letnyaya Zolotitsa	32.5±1,6	13.6±0.7	26.0±1.3	13.6±0.7	41.9±2.1	217.5±10.9	13.9±0.7	7.8±0.4
Kuzov Island	25.0±1,2	94.0±4.7	58.0±2.9	62.0±3.1	10.0±0.5	1454.5±72.7	40.0±2.0	6.0±0.3
Sosnovets Island	108.6±5,4	544.8±27.2	90.0±4.5	49.5±2.5	59.4±3.0	373.2±18.7	45.0±2.3	27.0±1.4
MPC (M.U. 2.1.7.730-99)	32.00	87.00	53.00	85.00	50.00	1500	150.0	2.000
Clark in soil**	10.00	50.00	20.00	40.00	8.000	850.0	100.0	5.000
TPC (ГН 2.1.7.2511-09)	32.00	55.00	33.00	20.00	na	na	na	2.000

Treatment: * – standard errors
** according to Vinogradov (Alexeenko 2000)
*** na – not available

samples collected at the other points, the MAC for this metal was not exceeded.

For a more complete assessment of the environmental status of the soils, the chemical substance factor (Kc) and the total pollution index (Zc) were calculated (Table 3).

Table 3

Chemical substance factor (K_c) and total pollution index (Z_c)

Location	Chemical substance factor (K_c)								Z_c
	Pb	Zn	Cu	Ni	Co	Mn	V	As	
Golfstream island	2.5	1.3	1.7	0.8	1.6	0.4	1.0	1.2	2.1
Cape Zhelaniya	2.5	1.9	2.6	1.3	2.1	0.5	1.6	1.2	2.2
Russian Harbour. Novaya Zemlya	3.0	1.4	2.1	1.0	2.2	0.8	1.4	1.4	2.3
Tihaya Bay. Franz Josef Land	2.5	1.5	2.1	1.1	3.4	0.4	1.2	1.2	2.3
Kolguev Island (1)	2.5	0.4	1.0	0.3	2.7	0.4	0.3	1.2	3.7
Kolguev Island (2)	2.0	1.1	1.3	0.6	2.1	0.7	0.7	1.0	2.2
Kanin Nos Cape	3.0	0.2	1.2	0.3	11.6	1.0	0.2	1.4	5.7
Zimnegorsky Cape	4.0	2.6	2.2	1.0	2.9	1.0	1.1	1.9	2.9
Solovetskie Islands	3.0	0.2	1.2	0.3	3.4	0.2	0.1	1.5	3.0
Letnyaya Zolotitsa	3.3	0.2	1.3	0.3	5.2	0.3	0.1	1.6	3.8
Kuzov Island	2.5	1.9	2.9	1.6	1.3	1.7	0.4	1.2	2.2
Sosnovets Island	10.9	10.9	4.5	1.2	7.4	0.4	0.5	5.4	8.1

Soils of the sub-Arctic and Arctic zones are affected by human activities, which leads to the accumulation of heavy metals. This is proven by the chemical substance factors, the values of which (for most metals) are higher than 1. In general, the heavy metals can be ranked as follows in terms of amounts accumulated in the soils: Co > Pb > Cu > Zn > As > Ni > V > Mn.

Based on these coefficients, the total pollution index for Zc (Table 3) was calculated. It is widely used as an integral indicator reflecting the overall contribution of TM to soil contamination. According to this index, all the soils studied within this research area have an acceptable heavy metal contamination level, of which we take their total content (Zc < 16).

No significant impact of the agrochemical properties to the total content of heavy metals was identified (Table 4), although a link was found (determination coefficient $R^2 > 0.5$) between zinc and cobalt and the pH of the soil solution (Figure 1).

Table 4

Relationship between the content of heavy metals and agrochemical properties of the Arctic soils

Metal	pH		Organic matter	
	equation	determination coefficient R^2	equation	determination coefficient R^2
Pb	$0.0008x^2 – 0.1334x + 8.7855$	0.4878	$0.0333x^2 – 1.3987x+18.12$	0.3934
Zn	$-0.0004x^2 + 0.182x+4.8595$	0.5669	$0.0019x^2–0.1794x+7.2263$	0.2345
Cu	$-0.0014x^2 +0.136x+2.8338$	0.4587	$-0.0143x^2+1.1208x-14.52$	0.3934
Ni	$-0.0026x^2+0.171x+3.3226$	0.2102	$0.0013x^2–0.0349 + 4.5442$	0.087
Co	$0.001x^2 – 0.128x +8.0337$	0.5494	$-0.0036x^2+0.4094x–2.616$	0.4669
Mn	$-0.0006x^2 +0.0091x +3.4055$	0.1463	$0.0005x^2–0.0416x+15.814$	0.4684
V	$0.0005x^2 + 0.0255x +4.3771$	0.3869	$0.0005x^2–0.0803 + 6.2782$	0.2056
As	$0.0141x^2 – 0.5668x+8.8722$	0.5072	$0.5773x^2–5.8281x+ 18.12$	0.3934

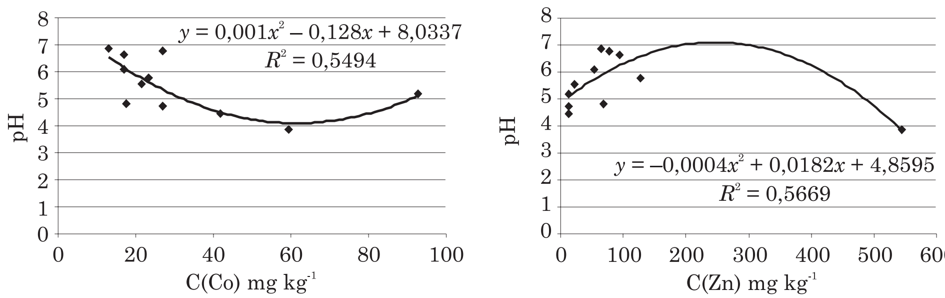

Fig. 1. Relationship between the concentration of cobalt and zinc and pH

CONCLUSIONS

1. The analyzed soils of Arctic and sub-Arctic areas were characterized by different soil and climatic conditions, and their taxonomic position is different as well. The agrochemical properties of the surface layer (0-10 cm) of these soils vary considerably: texture - from sand to heavy clay loam, pH - from highly acid to neutral, organic matter content - from very low to high

2. According to the total pollution index, all the soils of the study area have permissible levels of heavy metal pollution. The heavy metal accumulation order in the most of the studied soils was: Co > Pb > Cu > Zn > As > Ni > V > Mn.

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