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Trace elements in soils of oases of Enderby Land (on an example of Vecherny oasis)

Tamara Kukharchyk[1*], Sergey Kakareka[1], Yury Giginyak[2]

[1]*Institute for Nature Management of the National Academy of Sciences of Belarus, Laboratory of Transboundary Pollution, Skoriny st. 10, Minsk, Belarus*
[2]*The Scientific and Practical Centre for Bioresources of the National Academy of Sciences of Belarus, Department of Monitoring and Cadastre of Fauna, Academicheskaya st. 27, Minsk, Belarus*

Abstract
The content of trace elements in the soils of the Vecherny Oasis (Enderby Land, East Antarctica), where the construction of the Belarusian Antarctic Station started in December 2015, is considered. The results of the research are based on data collected during four Belarusian Antarctic expeditions in the period from 2011 to 2017, and analytical testing of soil samples taken from impacted and non-impacted sites. A total of 22 soil samples were analyzed for the content of trace elements; to compare the levels of accumulation and possible migration pathways, 7 samples of bottom sediments were also analyzed. Determination of trace elements was carried out using the AAS method (Cd, Cr, Cu, Pb, Ni, Zn, Fe, Mn) and emission spectral analysis (about 40 elements). The average values and range of concentrations of trace elements in soils and bottom sediments of the oasis are presented. The possible dependence of the trace elements content on the location positions in the landscape and on the sources of impact is discussed. It is shown, that the variability of metals content in soil profile for background site is low. In comparison with other oases of Antarctica no hotspots have been revealed and no significant areas of soil contamination have been identified yet, which is largely due to the fragmentation of the soil cover and lack of significant sources of pollution.

Key words: trace element, heavy metals, human impact, soil pollution, Belarusian Antarctic Station

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Introduction

The content of trace elements in the soils of the Antarctic is one of the most important indicators of their state and environmental quality. Their accumulation and soil pollution connected with construction and operation of scientific stations, as well as actively developing touristic activities raise concern regarding the possible nega-

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*Corresponding author: T. Kukharchyk <tkukharchyk@gmail.com>
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tive impact on unique polar ecosystems (Chen et Blume 1995, Bargagli 2000, 2008; Tin et al. 2009, Braun et al. 2014, O'Neill et al. 2015, O'Neill 2017).

Soils of the Antarctic oases formed in extreme climatic conditions are characterized by slow soil-forming processes that caused their vulnerability to environmental change and anthropogenic impacts (Campbell et Claridge 1987, Ugolini et Bockheim 2008, O'Neill et al. 2015). As it was noted in (Bargagli 2000), the deposition of trace elements with long-range transport to the Antarctic is generally insignificant (with the exception of lead). The input of local sources is predominance for soil contamination in impact zones of scientific stations. Up to now, high levels of heavy metals were recorded at waste storage sites at McMurdo Station (Claridge et al. 1995), Scott Base (Sheppard et al. 2000), Casey station (Stark et al. 2008), around the Marambio station (Chaparro et al. 2007), at the former Vanda base (Webster et al. 2003), on the island of King George Fields Peninsula (Lu et al. 2012, Padeiro et al. 2014), on the Marina Point at the Argentine Islands (Parnikoza et al. 2016), etc. In a number of cases, a very significant chemical transformation of the original soils has been identified due to their contamination, as was the case in the vicinity of Trinity House and Nordenskjold Hut at Hope Bay (Antarctic Peninsula); this allowed to classify soils as technosols (Guerra et al. 2011). Regarding the soil pollution, the most evident cases are caused by anthropogenic loads connected with high density of stations functioning for a long time (Lu et al. 2012, Celis et al. 2015, Padeiro et al. 2016). The danger of soil contamination in the Antarctic oasis, even within the local areas, is associated with pollutants re-distribution and their entry into terrestrial water and coastal seas and their subsequent accumulation in sediments and biota (Santos et al. 2005, Kennicutt et al. 2010, Fryirs et al. 2015). In some cases, remediation of metal-contaminated soils has been needed (Snape et al. 2001, Taylor 2015).

Investigation of trace elements content in soils of Antarctic oases as well as main properties of soils and the structure of the soil cover are very different. According to (Bockheim 2015), more than 75% of the soil samples collected in the Antarctic come from the Transantarctic region of the Victoria Land and 16% - from the Antarctic Peninsula. According to (Szopinska et al. 2016), more than half of all studies related to the determination of pollutants in the environment until 2014 have been carried out in the Sea of Ross and South Shetland Islands. The share of East Antarctica accounts for about 18% of all studies. Recent publications on the soils of the oases of East Antarctica refer to the specific features of soil formation and the properties of soils in this region (Mergelov 2014, Mergelov et al. 2015, Dolgikh et al. 2015, Zazovskaya et al. 2016). As for the Enderby Land, the available data on soils are scarce and fragmentary (MacNamara 1969, Simonov 1971, Aleksandrov 1985, Dolgikh et al. 2015). Regarding the trace element content, data was not found.

The object of our investigation - oasis Vecherny, where the construction of the Belarussian Antarctic station started in 2015 after consideration and approval of Comprehensive Environmental Evaluation at XXXVIII ATCM in Sofia, Bulgaria. By now, the basic infrastructure has been created, including several residential and service models, diesel generators, *etc*. The station operates in seasonal mode (5-8 people); in the future it is planned to move to a year-round mode with a staff of about 12 people.

Between 1980 and 1991, the field base ‘Vechernyaya Mountain’ of the Soviet Antarctic Expedition (SAE) functioned here in the year-round mode, to provide operation of the airfield. To date, the remaining infrastructure of the field base has been partially dismantled. A few old facilities are used now, and a few of them are abandoned.

Objective of the research: to determine the content of trace elements in the soils of the Vecherny oasis and to reveal the features of their accumulation, taken into account the soil forming factors and human impact. The results of the work will be used as a starting point for the subsequent monitoring and impact assessment.

Material and Methods

The investigations were carried out in the Vecherny oasis located in the western part of Enderby Land at the Tala Hills (eastern part), in the coastal zone of the Alasheev Bay of the Cosmonauts Sea. There are a number of rocky ridges with a dominant height – Vechernyaya Mountain (272.0 m) and several lower ridges stretched almost parallel to the shore with a northwest – south-east orientation. The northeastern slopes of the ridges are steep and short, sometimes precipitous, and the southwestern ones are gentle. The ridges are separated by terraced valleys, the bottoms of which are occupied by glaciers and temporary watercourses. The eastern boundary of the region is the excurrent Hayes glacier. The nearest oasis Molodezhny is at a distance of 20 km. The area of the territory that is not covered by ice in the Vecherny oasis is about 6 km^2; for comparison, ice-free area in Molodezhny oasis - 10 km^2, Schirmacher oasis – 35 km^2, Vestfold oasis – 400 km^2, South Shetland islands – 500 km^2, McMurdo Dry Valleys - 6700 km^2 (Bockheim 2015).

Soil sampling was carried out by the participants of the 4th, 5th, 7th and 8th Belarusian Antarctic expeditions (BAE) in the period from 2011 to 2017 Yu. Giginyak, V. Myamin and A. Haidashou. In total, during the four expeditions, 15 points were laid in areas with loose sediments and 70 soil samples were taken. Soil sampling was collected at two background areas (remote from direct anthropogenic impact) and at three sites that were used before by SAE or are used now for the construction of Belarusian Antarctic station.

Location of soil sampling points is shown on Fig. 1.

The short description of investigated areas is given below.

Site I: the territory north of Lake Nizhnee, 0.7 km from the residential modules of Belarusian Antarctic station. It is separated by ridges from the sea, as well as from the former field base and Belarusian Antarctic station so it can be considered as a background one. Loose deluvial and fluvioglacial deposits cover several tens of square meters. Feathers of skuas are found on the surface. Vegetation is absent. A soil pit (point 3) with a depth of 55 cm was allocated.

Site II: the territory to the east of BAS at the distance 1 km; the area of moraine deposits location. Direct anthropogenic and ornithogenic impact are not present. Surface is a slightly inclined. Loose deposits were revealed at the area of a few tens of square meters. The vegetation is presented by mosses. Tree soil pits (points 50, 70 and 75) with a depth from 30 to 65 cm was allocated.

Site III: a territory formed by alluvial and fluvioglacial deposits of permanent streams near Lake Nizhneye. Impacted by the SAE field base in the 1980-1990th as well as by station construction site (with meltwater). The thickness of soil is up to 15-20 cm. Vegetation is absent.

Site IV: a gentle slope with depressions and temporary streams; buildings of the former field base are located here. Mainly short-profiled soils (up to 20 cm) on eluvial and deluvial deposits are presented. There are few cenoses with mosses and algae.

Site V: rocky wavy terrace with temporary streams; station construction areas; the soils are predominantly thin (up to 20 cm) on eluvial and deluvial deposits. One cenose with mosses is found.

In most cases, surface soil samples were collected from the entire soil profile (usually up to 15-20 cm). When the soil pits were excavated, samples have been taken by the horizons (for example, pit 3: 0-5, 5-10, 10-20, 20-30, 30-40, 40-50 and 50-55 cm; pit 50: 0-2, 2-10, 10-20, 20-30 cm).

Samples of bottom sediments from permanent lakes as well as from temporary lakes, which are fed mainly by snowmelt, were selected for a preliminary assessment of the possible migration of trace elements.

The general characteristics of soil sampling sites are given in Table 1.

Samples of soils and bottom sediments were collected in plastic containers and stored in a cold place until delivery to Belarus.

Sample preparation of soils was carried out in a chemical analytical laboratory at the Institute of Nature Management (Minsk) according to ISO 11464. Samples of soils and bottom sediments were dried and sieved through 1 mm sieve. For chemical analyses a fraction of less than 1 mm was used.

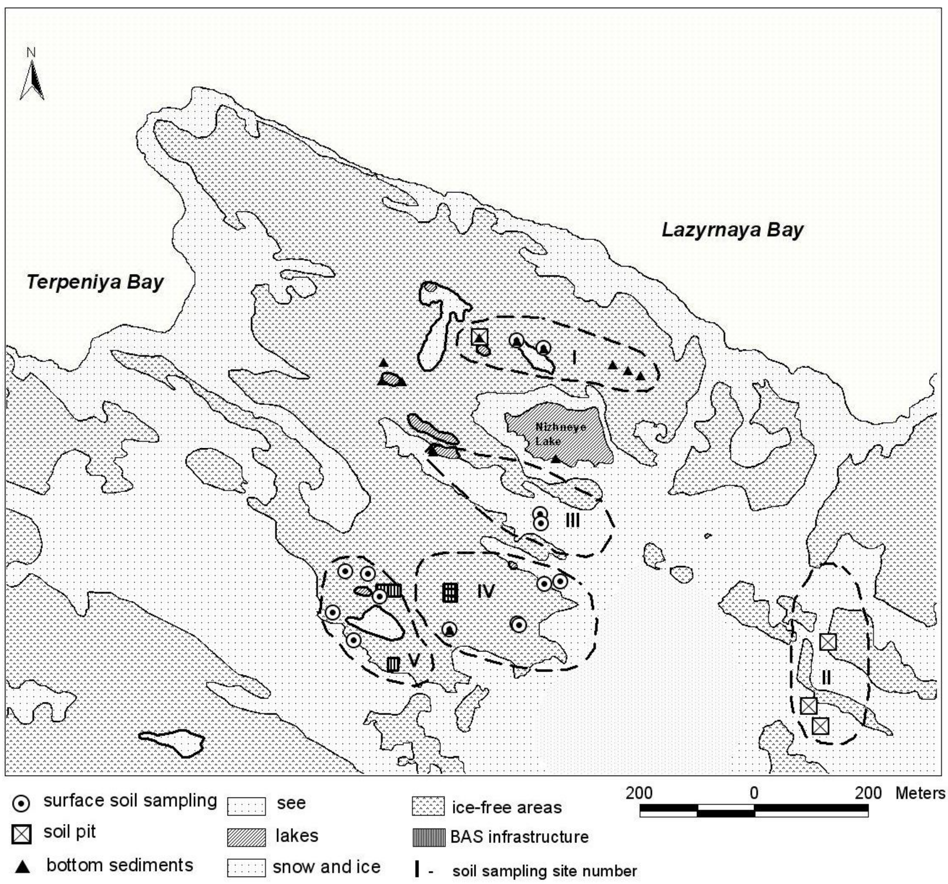

Fig. 1. Location of soil sampling points at Vecherny oasis.

Investigated site (amount of soil sampling points)	Type of samples, depth	Altitude (m)	pH_{KCl}	Humus (%)	The share of fraction <1 mm (%)	Possible sources of pollutants
Site I (3)	Soil pits: samples by horizons. Surface, 0-15	43-47	4.0-5.7	2.4-4.3	15-64	Background area to the north from station; separated from the BAS by a ridge
Site II (3)	Soil pits: samples by horizons.	95	6.4	0.16	67	Background area to the east from station (about 1km)
Site III (2)	Surface, 0-20	42-43	5.0-5.4	-	15-97	Area of the past activities of the field base in 1980-1990th; melt water from Sites IV and V
Site IV (5)	Surface, 0-20	70-84	5.2-5.6	0.16	31-71	Area of the past activity of the field base in 1980-1990th; residential buildings; melt water from Sites V
Site V (5)	Surface, 0-15	77-95	4.5-5.6	0.09-2.24	77-95	Current activity (Belarusian Antarctic station construction and operation); fuel storage area

Table 1. General characteristic of soil samples collection sites at Vecherny oasis.

Determination of Cd, Cr, Cu, Pb, Ni, Zn and Mn was performed by atomic absorption spectrometric (AAS) method according to ISO 11047. A flame atomic absorption spectrometer (Saturn-3) was used. The concentration of elements was detected in an aqua regia extract of the sample prepared in accordance with ISO 11466. HCl and HNO_3 in proportion 3:1 was used for acid digestion of sample. Stock solution of all elements has been prepared using the state standard sample (SSS): SSS070-12-93; SSS7874-2000; SSS7873-2000; SSS7836-2000; SSS7837-2000.

Before conducting of each series of experiments, at least five calibration solutions has been prepared covering the concentration range of the element being determined. Calibration lines for each element was created. A blank sample was used as a zero. The accuracy of digestion and analytical procedures was verified for each batch of samples through analysis of reagent blanks and determination of elemental concentrations in Standard Reference Material (Lead-zinc Concentrate 680-75; Bismut copper concentrate 616-75). The detection limit for Cd was 0.007 mg/l, Pb - 0.05, Cu - 0.004, Ni - 0.02, Zn - 0.004, Cr -0.005 and Mn - 0.004 mg/l. Quality control was evaluated by duplicate analysis. The relative standard deviations for all measured metal concentrations were lower than 25%.

Determination of Co, V, Ti, Mo, Zr, Nb, Ge, La, Y, Yb, Ga, Bi, Sc, Sn, Li, B, Ba, W, As, Sb, Hf, Ta, Ag, U, Th, Be, Sr and In was carried out by emission spectral analysis. For spectral emission analysis, samples have been ground and homogenized. Internal standards were used for spectral lines identification. Quantitative assessment of the element content has been done with the usage of calibration graphs. Standard Reference Material (Shale and Basalt) with fixed content of trace elements were used for analytical procedures. The relative standard deviations for trace element content were lower than 20%.

Determination of trace elements was done in the laboratory of the Institute for Nature Management and in the laboratory of State Enterprise 'Research and Production Center for Geology'. To check the procedure accuracy, inter-laboratory measures were undertaken.

Trace element concentrations are expressed in mg /kg dry weight.

Statistical methods for analysis of trace element content in soil was applied to calculate average content and standard error.

In the total of 22 soil samples and 7 bottom sediments were analyzed.

Content of major elements, humus, pH as well as the share of fraction of less than 1 mm have been also determined.

Results

According to the results, the following mean concentrations of trace elements were obtained, mg/kg: Cd – 0.75, Pb – 9.9, Cu – 19.2, Zn – 42.9, Ni – 9.6, Cr – 21.9, Fe – 9754, Mn – 114.5, Co – 23.7, V – 60, Ti – 1430, Mo – 0.8, Zr – 15, Nb – 1.1, Ge – 1.7, Y – 12, Yb – 3.5, Ga – 10.9, Sn – 2.8, P – 545, Li – 3.3, B – 5.2 (*see* Table 2). Content of La, Bi, Sc and Ba was detected in less than 50% of samples; for these element mean values were not estimated. Content of W, As, Sb, Hf, Ta, Ag, U, Th, Be, Sr and In was below the detection limit in all samples.

Comparison with Upper Continental Crust (UCC) given in (Rudnick et Gao 2003) has shown, that content of most elements (including Pb, Cu, Zn) in soil of oasis Vecherny is comparable with UCC. Content of Cd, Ni, Cr and V is more corresponded with their content in podzolic soil according to (Kabata-Pendias et Pendias 2001). Concentrations of Mn, Zr, Nb, Sc, Ba and Li in soils of oasis Vecherny are significant less than in the UCC.

In bottom sediments mean content of trace elements was as follow: Cd – 1.2, Pb – 18.2, Cu – 43.0, Zn – 83.4, Ni – 20.0, Cr – 23.3, Fe – 10013, Mn – 164.0, Co – 12.0, V – 33.0, Ti – 430, Mo – 1.3, Zr – 15.0, Nb – 1.5, Ge – 1.5, Y – 23.0, Yb – 2.8, Bi – 1.3, Ga – 6.0, Sc – 5.0, Sn – 3.0, B – 17.0. Content of W, As, Sb, Hf, Ta, Ag, U, Th, Be, Sr and In was below the detection limit. Mean concentrations were not estimated for La, Ba and Li as their concentration was detected in less than 50% of samples.

For analysis all samples of soil were separated for two parts represented background sites and sites with possibility anthropogenic impact. The main parameters of trace elements content (which is belong to heavy metals) for these cases are presented in the Table 3.

E	Soil			Bottom sediments			Mean A	Mean B
	Range	Mean ±st.error	Oc (%)	Range	Mean ±st.error	Oc (%)		
Cd[1]	nd-2.09	0.75±0.18	86	0.14-2.42	1.2±0.32	100	0.09±0.01	0.37
Pb	nd-22.8	9.9±2.1	86	nd-36.3	18.2±4.5	86	17.0±0.5	22
Cu	9.0-30.2	19.2±1.1	100	12.4-78.5	43.0±9.7	100	28±4.0	13
Zn	10.2-172.9	42.9±8.6	100	13.1-162.8	83.4±19.7	100	67±6	45
Ni	0.52-30.7	9.6±2.5	100	2.0-37.5	20.0±5.8	100	47±11	13
Cr	4.2-57.9	21.9±4.5	100	5.2-43.5	23.3±6.0	100	92±17	47
Mn	56.7-160	114±18	100	98.4-214	164±12	100	774±116	270
Co[2]	10.0-70.0	23.7±4.7	100	7.0-20.0	12.0±3.9	100	17.3±0.6	5.5
V	30.0-70.0	60.0±3.3	100	20.0-50.0	33.0±8.8	100	97±11	67
Ti	200-3000	1430±230	100	300-500	430±67	100	3900±585	2600
Mo	0.5-1.0	0.8±0.07	100	0.5-3.0	1.3±0.8	100	1.1±0.3	1.3
Zr	5.0-30.0	15.0±2.7	100	5.0-30.0	15.0±7.6	100	197±28	160[4]
Nb	nd-3.0	1.1±0.2	67	nd-3.0	1.5±0.9	67	12±1	-
Ge	0.5-3.0	1.7±0.3	100	0.5-3.0	1.5±0.8	100	1.4±0.1	-
La	nd-30.0	-	27	nd-30.0	-	33	31±3	37.4[4]
Y	nd-30.0	12.0±2.4	80	10.0-30.0	23.0±6.7	100	21±2	-
Yb	1.0-7.0	3.5±0.7	100	0.5-7.0	2.8±2.1	100	1.96±0.4	4.0[4]
Bi	nd-0.5	-	27	nd-2.0	1.3±0.7	67	0.16±0.06	-
Ga	7.0-30.0	10.9±1.4	100	3.0-10.0	6.0±2.1	100	17.5±0.7	-
Sc	nd-10.0	-	47	5.0	5.0±0	100	14.0±0.9	5
Sn	<1-5.0	2.8±0.4	93	1.0-7.0	3.0±2.0	100	2.1±0.5	-
Ba	nd-50.0	-	7	nd-200	-	33	628±83	330
Li	nd-5.0	3.3±0.6	67	nd	-	0	24±5	22
B	1.5-10.0	5.2±0.9	100	10.0-30.0	17.0±6.7	100	17±8	22

Table 2. Trace elements content in soil of oasis Vecherny, mg/kg.
Notes: E – Elements, Oc – Occurrence, Mean A – Mean content in upper continental crust (Rudnick et Gao 2003)[3], Mean B – Mean content in podzols soil (Kabata-Pendias et Pendias 2001) [1] – elements from Cd to Mn have been determined by AAS; [2] – elements from Co to B - by emission spectral analysis; [3] – average content ± standard deviation; [4] – average content in soil (Kabata-Pendias 2010).

The results shown that more significant variability of heavy metals content especially Cd, Pb, Zn and Cr is characteristic for the areas where human activity has been done in the past and/or are continued now. The mean content for the background area is estimated as follows: Cd - 0.12 mg/kg, Pb - 4.6, Cu - 22.1, Zn - 23.0, Ni - 14.1 and Cr - 10.2 mg/kg. The mean content of Cd in soil of impacted sites approximately 10 times more in comparison with the background area, Pb - 3.3, Zn - 2.6 and Cr - 3.2 times. Close data has been received regarding Ni and Cu.

Site	Par.	Cd	Pb	Cu	Zn	Ni	Cr
Non impacted site (I-II)	Range	nd -0.22	nd-15.0	9.0-30.0	10.3-40.0	1.2-50.0	4.6-20.0
	Mean ± STD	0.12±0.09	4.6±1.2	22.1±2.1	23.0±2.7	14.1±6.2	10.2±1.7
Impacted sites (III-V)	Range	0.15-2.09	nd -22.8	10.6-30.2	10.2-172.9	0.5-30.7	4.2-57.9
	Mean ± STD	1.19±0.24	15.0±2.8	19.0±1.3	59.7±12.6	14.7±3.1	32.3±6.2

Table 3. Mean content of heavy metals by sampling sites. *Notes*: Par. – parameter, STD – standard error.

It should be stressed that the highest content of zinc (172.9 mg/kg), chromium - 57.9, lead - 22.8, cadmium - 2.09 mg/kg was revealed in the soil near the temporary watercourse (Sample 1, Site III). It means that migration of contaminants with melt-water is possible. The detected concentrations within Site III are similar to the levels in the lakes bottom sediments, which may confirm a redistribution of pollutants and their accumulation in lakes.

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Compared with the mean concentration values for the soils of the Vecherny oasis, concentration in lakes sediments is 2.3 times higher for nickel, 2.1 times –for copper, 2 –for zinc, 1.9 –for lead, and 1.6 –for cadmium (Fig. 2).

The distribution of heavy metals through the soil profile (Table 4) is considered on an example of a soil pit (3) which was dug outside the impact zone (on Site I).

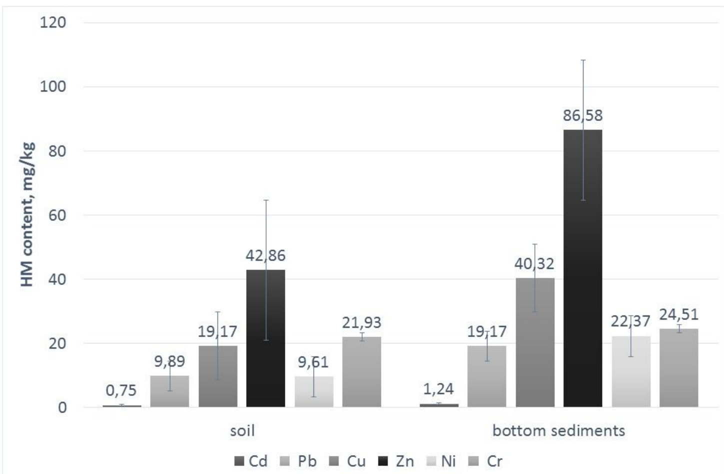

Fig. 2. Comparison of mean heavy metals content in soils and bottom sediments of Vecherny oasis (error bars are shown).

Sampling depths, cm	The share of fraction <1 mm, %	Loss on ignition, %	Cd	Pb	Cu	Zn	Ni	Cr
0-5	64.5	1.7	<	<1	15.3	18.6	1.9	6.9
5-10	73.6	1.8	<	3.2	17.6	18.2	2.2	7.6
10-20	67.1	1.4	<	2.0	19.6	17.3	2.2	6.4
20-30	76.1	1.8	0.16	4.3	24.3	22.0	2.7	7.2
30-40	76.6	1.4	0.11	3.5	29.6	22.7	2.7	7.6
40-50	62.3	1.2	0.21	2.2	19.9	17.8	2.2	6.6
50-55	60.1	1.3	0.22	2.2	13.7	15.7	1.8	6.0

Table 4. Distribution of heavy metals by soil profile (pit 3, Site I), mg/kg[1].
[1] the relative standard deviations for all measured metal concentrations were lower than 25%.

According to the obtained results, the cadmium content is below the detection limit up to the depth of 20 cm; deeper it ranges from 0.11 to 0.22 mg/kg. The lead content in the surface horizon is less than 1 mg/kg, it increases with the depth; the maximum values (4.3 mg/kg) are confined to the horizon of 20-30 cm. The minimum values of copper (13.7 mg/kg), zinc (15.7), nickel (1.8) and chromium (6.0 mg/kg) were detected at the depth 50-55 cm; maximum values (29.6 mg/kg copper, 22.7 mg/kg zinc, 2.7 mg/kg nickel and 7.6 mg/kg chromium) - at the depth 30-40 cm. In general, the variability of heavy metals content is low; elevated concentration of heavy metals on the depths 20-40 cm may results of the processes of metal redistribution with fine soil particles (< 1 mm). The maximum share of this fraction (76.1-76.6%) was found here (in the surface horizon its share is 64.5%, at a depth of 50-55 cm – 60.1%). Loss on ignition varies insignificantly between soil samples: from 1.8% in the surface horizon, to 1.2% in the underlying horizon. This means that the influence of organic matter to the heavy metals distribution in soil profile is probably not important. According to (Zvěřina et al. 2012), the key role in maximum concentrations of Cr, Cu, Ni and Zn fixed at depths of 2 to 20 cm in soil of the coastal zone of James Ross Island belong to increased content of clay minerals and iron oxyhydroxides in this horizon that have a high sorption capacity and can accumulate heavy metals.

Discussion

Variability of trace elements content in the soils of the Vecherny oasis can be caused by both natural and anthropogenic factors. It can be assumed that one of the most important natural factors determining the initial concentrations of trace elements is the composition and properties of parent rocks, as shown by the example of other stations (Crockett 1998, Malandrino et al. 2009, Kostova et al. 2015, Vlček et al. 2017, Smykla et al. 2018, Sheppard et al. 2000). According to the data (Myasnikov 2011, Karataev et Garetsky 2011), metamorphic rocks of the Archaean and Proterozoic ages are represented in the Vecherny oasis: plagiogneisses, enderbite-charnockites, charnockite gneisses and augen-gneisses; for granitoids of the charnockite stratum, signs of an increased content of Fe, Ti, Cu, and Zn elements have been revealed. The different intensity of the processes of physical and chemical weathering of local rocks, as well as the introduction of moraine deposits create the prerequisites for initial differences in soils.

Preliminary data on the grain size distribution and mineralogical features of soils of the Vecherny oasis have shown that soils are represented mainly by sand of different fractions (Kukharchyk et Kakareka 2016). The primary minerals, first of all quartz and feldspar are dominated in the soil samples. It has been established, that when the fraction size is decreased, the share of quartz is increased (reaching 80% for the fraction 0.16 mm). With increasing fraction size, the share of granite, feldspar and diorite is increased (up to 71% in the 2.5 mm fraction). The semi-crocked and angular-rounded form of quartz and granite grains and other minerals indicates the influence of water flows on the soil-forming process as a result of seasonal snowmelt.

The chemical properties of soils, including the content of trace elements, are influenced as well by other natural factors that determine the intensity of physical and chemical weathering. The soils of the Vescherny oasis, like many other oases, have a low organic matter content and exchange bases (Kukharchyk et Kakareka 2016). They are fragmentary and differ in properties even within small investigated areas. For example, the share of fine fraction (less than 1 mm) in Site III varies from 15 to 97%, in Site I - from 15 to 64%, in Site IV - from 31 to 71%. The pH value in soil samples collected at Site III varies from 4.6 to 5.6, and the humus content is from 0.09 to 2.24%. It is corresponding with the results given in (Campbell et Claridge 1987), was shown that the properties of soils differ significantly even within an oasis, depending on the location in the relief, the exposure of slopes, remoteness from the shoreline, moisture, vegetation, distance from penguin nesting grounds and other factors.

The cases of elevated concentrations of heavy metals in the soils and bottom sediments of the Vecherny oasis may be considered as a results of chemical elements migration with water flows. Since the water flows pass through the territory where the SAE field base facilities were formerly located, as well as the Belarusian Antarctic station fuel storage site, it is possible to assume an anthropogenic contribution to the increased concentrations of heavy metals. In the future, this factor should be given special attention, since a lot of watercourses are appeared in summer, which is caused by significant differences in the altitude between investigated areas: from 42 m to 95 m.

It should be stressed that the identification of natural and anthropogenic factors of accumulation of heavy metals in the soils of Antarctica is a complex process, which require conduction of detailed studies and the collection of data for poorly investigated areas. First of all, it is necessary to establish background concentrations for different soil parameters, taking into account the parent rocks and their location in the relief. The importance of the initial environmental conditions which determine the heterogeneity of metals distribution and their migration is indicated in some papers (Gasparon et Matschullat 2006, Bargagli 2008). Available data shows significant variability in the content of trace elements in natural undisturbed and unexposed Antarctic soils (Santos et al. 2005, Padeiro et al. 2014, De Lima Neto et al. 2017, Smykla et al. 2018) - *see* the Appendix. Not considering in detail the differences in the properties of the Antarctic soils, we should mention only some of the contrasting values which are known now: for example, non-humus and organic (ornithogenic) soils, acid and alkaline, dry and waterlogged, *etc.* In other words, according to the range of these indicators only, one can judge the diversity of natural factors and their combinations, characteristic of the oases of Antarctica.

As it was shown above and in Appendix, the contaminated soils have a very clear connection with sources of pollutants, most often waste and / or fuel spills (Amaro et al. 2015, Parnikoza et al. 2016, De Lima Neto et al. 2017). Recorded extremely high metal concentrations in soils at fire sites, reaching several grams per kilogram of soil according to the data (Guerra et al. 2011, Guerra et al. 2013), refer to exceptional cases; probably the sources of pollution were the burning station's debris. Among the list of pollution sources, paints from old painted surfaces of abandoned buildings (Pertierra et al. 2013) as well as field seasonal bases (De Lima Neto et al. 2017) are indicated. As a secondary source of soil contamination penguins are considered, as far as soil contamination at penguins nesting areas was detected (Celis et al. 2015, Vlček et al. 2017, Cipro et al. 2018).

Generally, in comparison with the soils of most studied regions of Antarctica (Antarctic Peninsula, Fields Peninsula, Ross Islands, King George, McMurdo Dry Valleys), the soils of the Vecherny oasis has a relatively low trace elements content.

Conclusion

New data on the content of trace elements in soils and bottom sediments of the Vecherny oasis are summarized. It is shown that variability of content values can be caused by both natural and anthropogenic factors. Among the most important natural factors determining the initial concentrations of trace elements is the composition and properties of parent rocks.

The cases of elevated concentrations of Cd, Pb and Zn in soils and Cd, Cu, Ni, Pb and Zn in the bottom sediments of the Vecherny oasis confirm, on the one hand, the migration and redistribution of chemicals with melt water flows, and, on the other, the influence of previous human activities related to the functioning of the field base in the 1980-1990's (possibility of current human activity influence is not excluded). In comparison with other oases of Antarctica, no hotspots have been revealed and no significant areas of soil contamination have been identified yet, which is largely due to the fragmentation of the soil cover and lack of significant sources of pollution.

Assessment of the trace element accumulation in soil is complicated because of only the preliminary data has been received for this region. It is necessary to continue research in this oasis with an emphasis on clarification of background values of trace elements, considering the fragmentation of soils, slow pedogenesis as well as the subsequent evaluation of their accumulation due to the functioning of Belarusian Antarctic station.

To estimate the level of pollution and its danger, threshold values (Maximum Permissible Levels) elaborated in Belarus or in other countries can hardly been directly applied for the Antarctic soils taking into account their specific properties as well as Antarctic biota high vulnerability and sensitivity. Establishing of critical loads and thresholds values for the Antarctic soils is a one of the task for future investigation involving full-scale study of soil-biota relationships, mapping and modeling ([1] - ATCM XL IP005, 2017). Regulation of anthropogenic loads will help to prevent irreversible changes in unique polar ecosystems within stations location.

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Appendix:
Content of heavy metals is soils of different Antarctic stations (survey of published data).

Location	**Cd**	**Cr**	**Cu**	**Mn**	**Ni**	**Pb**	**V**	**Zn**	**Reference**
Background territories									
Robert Island, South Shetland Islands	<0.2	52	47.8	453	40.4	7.3	109	43.9	De Lima Neto et al. 2017
The Collins Glacier, Fildes Peninsula, King George Island	0.2	28-31	49-70	-	12-18	5-7		56-87	Padeiro et al. 2014
Ferraz station, King George Island	-	40	44	442	5.1	12	91	52	Santos et al. 2005
Edmonson Point, Victoria Land	0.21	7.8	3.9	380	33.6	1.7	11.2	42.9	Smykla et al. 2018
Terra Nova Bay, Victoria Land	0.4	54	25	-	19	19		-	Malandrino et al.2009
The Hurd Peninsula of the Livingstone Island	-	36	-	1100	14	-	190	110	Culicov et al. 2017
Impact areas									
Robert Island, South Shetland Islands, near wastes	<0.2	72	107	545	37.9	102	122	148	De Lima Neto et al. 2017
Hope Bay, Antarctic peninsula, after the fire at British station	50	-	2100	-	-	19380	-	5200	Guerra et al. 2011
Fildes Bay, near fuel tanks	0.5	-	30	-	-	-	-	154	Amaro et al. 2015
Ferraz station, after fire, alarming levels	-	1600	34000	6800	15.9	13700	250	42200	Guerra et al. 2013

McMurdo station, Gray soil	0.13	172	39	-	98	5.8	-	115	Crockett 1998
O'Higgins Base	4.3	65	422	405	28	282	-	485	Celic et al. 2015
Fildes Peninsula, King George Island	0.04-0.34	17.1-64.9	51.1-176.5	449-1400	7.2-25.0	2.8-60.5		41.6-80.6	Lu et al. 2012
Fildes Peninsula, King George Island	0.2-1.2	15-263	56-179	-	12-141	3-418		68-949	Padeiro et al. 2014
The Bulgarian Antarctic Base, Livingston Island	3.7-4.7	42.9-59.5	50-50.8	-	32.5-33.6	8.3-44	91-224	86.8-199.7	Kostova et al. 2015
Marina Point near Diesel station, Galindez Island of the Argentine Islands	20.9	-	1856	77.1	12.2	741	-	667	Parnikoza et al. 2016
Chilean Bernardo o΄Higgins, Antarctic Peninsula	-	5	201	-	4	21	39	771	Vlček et al. 2017