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Research of the Arctic Soils Using an Artificial Neural Network

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ABSTRACT

Desert-Arctic soils – balasamy (W–C1), are found in the most northerly position in the Arctic. These soils are characterized by a light granulometric composition and are formed in the areas recently released from glaciers, and develop under a crust of blue-green algae. Arctic soils (AO-AY-BC–C) are common on loamy and gravelly–loamy soils (Severnaya Zemlya, Novaya Zemlya, Franz Josef Land, North of the Taimyr Peninsula). They are characterized by wedge-shaped horizons, and are formed in the form of polygons with a diameter of 0.5–1.0 m under moss-shrub vegetation. Carbonate pelozems (WSA–SSA) are found on deluvial deposits of carbonate rocks on loamy-gravelly soils. The vegetation cover is represented by lichens and rare specimens of flowering plants. In the Arctic tundra, on the most drained areas on loamy and gravelly-loamy soils, humified weak-clay (gley) soils (AO-A-CRMg-C(D)) are common. In terms of morphology and chemistry, these soils are similar to Arctic soils, but differ from them in the large development of wedge-shaped horizons. In this work, the composition of Arctic soils was studied using a neural network.

Keywords: pelozems, Arctic soils, composition.

INTRODUCTION

A large part of the coasts in the Arctic basin of Russia is formed in the area of permafrost (MMP). Depending on the degree of closure of the MMP, areas of continuous, discontinuous, and insular distribution are distinguished [Bailey, 2018; Boike, 2015; Atlas of the Arctic, 1985]. On the territory of Russia, most of the territories occupied by permafrost, up to 61.8%, are occupied by a continuous cryolithozone area, the borders of which cover most of the Arctic Islands and stretch almost continuously along the coast from the Kara sea to the Chukchi sea in the East, penetrating deep into the continent in Central Siberia and Yakutia. The island-type cryolithozone occupies 21.2% and extends from the Kola Peninsula to the coast of the Sea of Japan, Sakhalin and Kamchatka. The smallest area of 17% corresponds to the island-type cryolithozone [Polyakov, 2017].

The global area of permafrost distribution approximates 35 million km^2, which is 25% of the entire land area of the planet [Atlas of the Arctic, 1985]. Tundra soils occupy a significant share of the total area of Russia – 205975.3 thousand hectares or 12.6% [Schnuur, 2013].

In Eurasia, permafrost extends over 13 million km^2, extending from the circumpolar latitudes to 44° s [Boike, 2015]. In the Tibet-Himalayan high-altitude region, permafrost reaches 28° s. In North America, the permafrost area is almost half the above-mentioned value – 7.2 million km^2, the southern limits reach only 52–56° [Siewert, 2016]. Due to the spread of mountain terrain, permafrost islands penetrate to the South, for example, the high-altitude Tibetan-Himalayan permafrost island [Reza, 2016]; in Europe, the permafrost massifs are confined to the mountains of Scandinavia and Iceland, as well as the mountain systems including: the Alps, Pyrenees, Carpathians, and the Caucasus [Boike, 2015].

Varieties of soil determination

In Central Siberia and Western Yakutia, pale coarse humus soils with the profile AO-BPL–BC–C are found on plateaus and elevations overlain by siallite loam and gravelly–loam deposits under shrub tundra and forest tundra. They differ from typical pale yellow soils by a well-defined coarse humus color, AO and the absence of carbonates. In the same region, large areas are occupied by the plateaus composed of carbonate rocks. They can develop pale residual carbonate soils (AY-BPL–BCA–Cca) under shrub tundra and forest tundra. Their peculiarity is the increased content of humus and the presence of a carbonate horizon; carbonates are inherited from the underlying rock [Karelin, 2008]. In the tundra, forest-tundra, and North taiga zones, sand and loamy-gravelly rocks develop podburs (O-BHF-C) with a pronounced illuvial-humus-ferruginous horizon.

In the north of the ETR, a similar set of light substrates can be traced almost everywhere (Kola-Karelian moraine, alluvial, fluvio-glacial deposits, most marine and lacustrine-glacial rocks), but among the loamy rocks, the source of drift is replaced by the Western Fennoscandian and Eastern Ural-Novozemelsky [Goryachkin, 2008]. In the tundra zone of the Kola Peninsula, illuvial-humus subsurface (O-BH–(BF)–C) is common on sandy and boulder–sand deposits. The eastern territories of the Kola Peninsula are characterized by illuvial-ferruginous (O–BF–C) contours. Podzolized (O–BHFe–BHF–C) forests with pronounced signs of podzolization predominate in the forest tundra. Dry peat boars (TJ–BHF–C) are also found on the Kola Peninsula. Illuvial-ferruginous podzols (O–E–BF–C) are common on sand and sandy loam under sparse communities of pine forests in the European part of the territory,. In the Western part of the Russian Arctic (the Kola, Kanin, and Yamal peninsulas), gley podzols (O–Eg–BHFg–G–CG) are found on light rocks in depressions under tundra and forest-tundra vegetation.

In the Central part of the Russian Arctic, peat-humus cryosemes (Oh-CR-VS) are common on gravelly–loamy and loamy soils under tundra, forest–tundra and northern taiga vegetation. Surface-gley (O–G–BC–C) gleezems are common on stratified sediments with a material of lighter sosava at the surface, which is underlain by clays. Such soils are found on the territory of the Nenets Autonomous Okrug. Coarse–humus gleezems (Oao–G-CG) are found on the plains of Northern Siberia, on relatively drained surfaces in the typical tundra under moss-shrub vegetation. Peaty gleezems (O-AO-G-Cg) are most widely distributed in the Northern part of the Siberian plains under tundra vegetation, on loamy soils, including deposits of the ice complex with vein ice of various degrees of degradation. Pleasemy peaty humus forms a combination with a wide range of soils: podborany, yellow soils, cryosols, with peat or gleesome grubekompani. Peat-humus gleesems (Oh–G–(CRM)–CG) are common on plains and intermountain basins in tundra and forest tundra on medium-and heavy-loamy deposits. Pleasemy peaty humus forms complexes with soil stains and gleesome peat and mix with podborany, the cryosols and gleesome peat.

In the areas of vein ice development, peaty soils are found above the ice veins (T-S (ice)). They were studied by Höfle on the Fadeevskaya island. The soil profile is represented by dense moss sod with a thickness of 10-15 cm, which is covered with ice. Peat gleezems (T–G–CG) occur in relief depressions on poorly drained heavy loamy and loamy soils, including the soils with vein ice under the moss-sedge tundra. Hummocky peatlands are found in the lowlands of Northern Siberia.

Humus-carbonate soils (H–Cca–Mca) are common on the surface of limestone plateaus under forest-tundra and North-taiga vegetation in North-Western Yakutia. In the mountains and higher elevations on gravelly aluvia and diluvii dense rocks on the sea shingle spits are dominated by primitive gravelly soil (Petrosani typical O–M). They comprise sorted fine crushed stone with fine earth. On their surface, individual curtains of lichens, mosses, and flowering plants may occur. Locally, under clumps of vegetation the litter-tifany horizon may develop. Poorly developed carbonate soils (typical Carbo-petrozems, O–MSA) form on the eluvium and deluvium of carbonate rocks with very sparse vegetation. These soils are small crushed carbonate rocks with a dispersed peat horizon. Psammosere (W–S) occurs in soil sand areas with sparse lichen flora. Marching saline soils (S–Cs) are located on low-lying banks in the zones of littoral and wind-driven waters and are a black homogeneous clay mass that has the smell of hydrogen sulfide. Alluvial undeveloped soils (W–C) occur in floodplains and river deltas and represent an undeveloped humus horizon on alternating layers of pebbles and sand. In river valleys, they are combined with alluvial peat and peaty soils, in deltas – with marching saline soils. Alluvial peat and peaty soils (T–G–CG) are found in floodplains where a peat horizon of varying thickness lies on sand or pebbles [Jones, 2013; Karelin, 2008].

Soils, occupying the uppermost layers of the Earth's surface, affect the formation of the surface climate and the thermal regime of soils; this is especially strong in the conditions of the cryolithozone. The composition and structure of soils, the content of organic matter and moisture in them play an important role in the hydrothermal regime not only of the seasonally thawing and freezing soil itself, but also of the underlying frozen soils [Höfle, 2013]. Cryolithozone soils are characterized by a low potential for self-purification from pollutants [National Atlas of Soils of the Russian Federation, 2011]. If natural ecosystems are actively disturbed, transformations of the soil cover of these territories can lead to an increase in the number of positive feedbacks as well as significantly affect the changes in global biochemical cycles and climate trends. In Russia, huge areas of soil cover are negatively affected by the anthropogenic interference, which exceeds the number of implemented remediation measures. In 2000, the soil degradation in Russia was assessed as a widespread threat at the third Congress of the society of soil scientists at the Russian Academy of Sciences. Kashtanov quantified the following parameters: erosion and deflation (70 million ha), increased acidity (73 million ha), salinity of various degrees (40 million ha), waterlogging and waterlogging (26 million ha), littering with rocks (12 MLG ha) and shrubs and small woodlands (7 million ha), contamination with radionuclides (5 million ha), desertification (more than 1 million ha) (Fig. 1) [Hewitt, 2016].

The available data on the study of the background level of metals in soils under the influence of permafrost in the Lena river Delta and its watersheds in Northern Siberia (73.5–69.5°n) provide the information on the content of Fe, As, Mn, Zn, Ni, Cu, Pb, Cd, Co, and Hg in various soil types [Höfle, 2013]. The highest concentrations of Fe and Mn were observed in the soils with the highest MMP thickness and in buried soils formed during the Pleistocene in the ice complex, while the highest concentrations of Ni, Pb and Zn were found in the soils of the ice complex and the estuarine part of the Lena river Delta. The factors that determine the concentration of metals in the soils exposed to MMP include the content of organic matter, soil structure, temperature, and hydrological regime. At the border with permafrost, a geochemical barrier is formed in the gley layer, which contributes to the accumulation of heavy metals, limiting their penetration deep into the soil profile, which was observed for Zn and Ni in peat-gley soils and for Mn, Fe and As in the soil of the floodplain meadows [Höfle, 2013].

The high content of sulfur, carbon, and nitrogen oxides in the atmosphere of various regions of the planet causes increased acidity of precipitation, which in turn increases the acidity of soils [Hewitt, 2016].

Degraded soils can be dangerous, as their environmental protection functions are weakened, which may result in degradation of the Earth's surface as a whole and climate changes. Soil degradation causes considerable economic damage, undermining the ecological balance of natural ecosystems [Hewitt, 2016]. The analysis of the current state of soils in Russia indicates the need for a reasonable approach to the use of soil resources due to the exhaustion of soil buffer capacity.

Often, the definition of soil degradation or land cover degradation is considered purely anthropocentric, mainly considering the factors of economic well-being in human life. There is a soil definition of soil degradation, which states that "soil degradation is a change in the functioning of the soil

Table 1. Main impacts on ecosystems

Physical impact	Chemical influence	Biological effect
Mechanical disturbances	Chemical pollution	Organic pollution
Thermal pollution		
Changes in the hydrological and hydrogeological regime		
Radioactive contamination		
Qualitative and quantitative changes in biota and other ecosystem components		

Table 2. Main types of soil functions

Soil functions		
Environmental	Environmental regulators	Production facilities
The habitat of organisms	Absorption of atmospheric aerosols	Fertility (bio-productivity)
Connecting link of the biological and geological cycles	Regulation of the gas composition of atmospheric air	Of residential buildings, industrial and road facilities
	Filtration of natural and waste water	
	Protection of the lithosphere from erosion (denudation)	

system, and/or in the composition and structure of the solid phase, and/or the regulatory function of soils, resulting in a deviation from the environmental norm and deterioration of parameters important for the functioning of biota and humans" [Dungait, 2012]. It is necessary to take into account the system approach when studying the dynamics of development and evolution of the soil cover, as a complex structural formation consisting of many elements, the loss of even one of which can lead to the disappearance of the entire system.

Physical degradation is determined when the power of organogenic and humus-accumulative horizons decreases, other genetic horizons and the entire profile are destroyed (mechanical degradation), as well as when the physical properties of a mechanically undisturbed profile change. The physical impact can come from human intervention, or as a result of natural factors such as changes in the climatic conditions, natural processes of weathering, erosion, abrasion, etc. The chemical degradation is recorded when the chemical properties of soils deteriorate, including depletion of nutrient reserves, salinization, and contamination with toxic chemical elements and compounds. The biological degradation occurs when the number of species diversity decreases, the optimal ratio of different types of microorganisms is violated, the soil is contaminated with pathogenic microorganisms, and the sanitary and epidemiological indicators deteriorate. It is important to note that if any type of degradation occurs, the biological degradation will also be activated, since all violations in the system are first reacted by living organisms.

The natural conditions of the island Samoilovsky

At the Stolb meteorological station (Central part of the Lena river Delta), a slight increase in average annual and average summer (June-August) air temperatures was observed in the period 1981–2006. However, for the period 2006–2016, there is a negative trend in both average annual and average summer air temperatures. At the Ust-Olenek station, there is a negative temperature trend, in the period 1999–2008. The air temperature indicators in the summer period grow in a negative direction. Therefore, it is difficult to judge the unambiguous dynamics of widespread climate warming in the Arctic over the past decades. The summer air temperatures that have a greater impact on the frozen ground regime, have exhibited negative trends in recent decades [Carvalhais, 2014].

The dynamics of soil cover temperatures has been recorded since 2002, and since 2005, the temperature of permafrost rocks is measured at different depths (Fig. 1).

During the period of observations of temperature, indicators revealed:

- the greatest depth of thawing is reached in late August-early September;
- the greatest depth of thawing for the period from 2002 to 2011 ranges from to 55;
- air temperature is not the direct cause of thawing maxima;
- there is no unambiguous relationship between average annual and average summer air temperatures and soil temperatures at different horizons;
- in addition to air temperature, the depth of thawing and soil temperature are also affected by the height of snow cover and cloud cover [Carvalhais, 2014].

The Lena river Delta (Fig. 4) is the largest Northern Delta in the world, which is located in the Arctic zone and has an area of about 29,630 km^2. Due to such a huge area and location, it has a significant impact on the water regime of the Arctic Ocean, since a large amount of fresh water flows from the Delta to the least salty ocean of our planet [Carvalhais, 2014]. The density of the river network in the western part of the Delta is 0.13 km/km^2; the eastern part is 0.34 km/km^2; the entire Delta is 0.24 km/km^2. There are 235 Islands in the western part

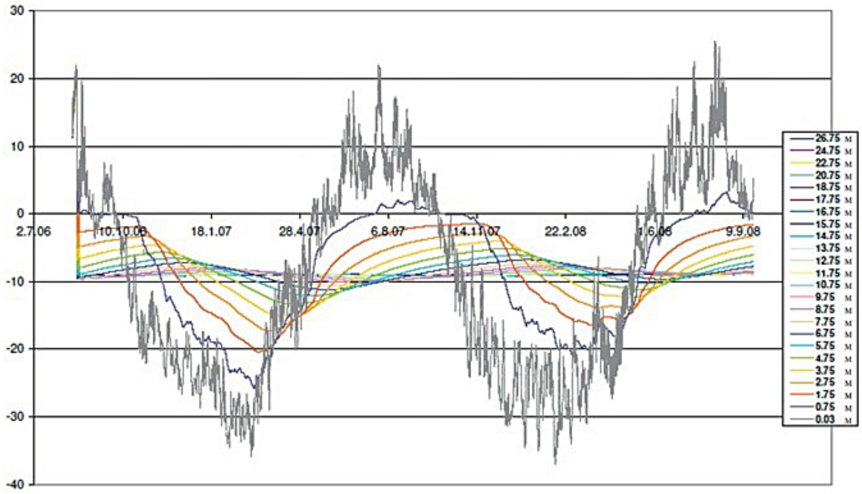

Figure 1. The temperature of the soil in the hole Samoilovsky

of the Delta and 764 in the eastern part. The western and north-western coasts of the Delta are more affected by sea water, while the north-eastern and eastern coasts are affected by the river flow. Greater salinity of water in the surface layer is observed in the western and north-western parts: 10–14 and 8–10%, respectively, than in the eastern sections [Carvalhais, 2014].

According to the classification of B. D. Zaykov (1946), the Lena river belongs to the group with the predominance of the spring flood of the East Siberian type. The water regime is characterized by a high coefficient of regulation, the value of which is equal to the share of runoff for the period when the daily values of runoff are lesser than the annual average (basic runoff), which varies in the range of 0.25–0.5 [Geography of Siberia at the beginning of the XXI century, 2015]. During the period of ice formation, due to the narrowing of the riverbed and a drop in its capacity, a sharp increase (0.5–1 m) in the water level occurs, which is a consequence of flooding of the floodplain areas. When the spring-summer flood subsides, there are fluctuations in the level with the beginning of rain floods, which are observed throughout the summer. The annual amplitude of fluctuations

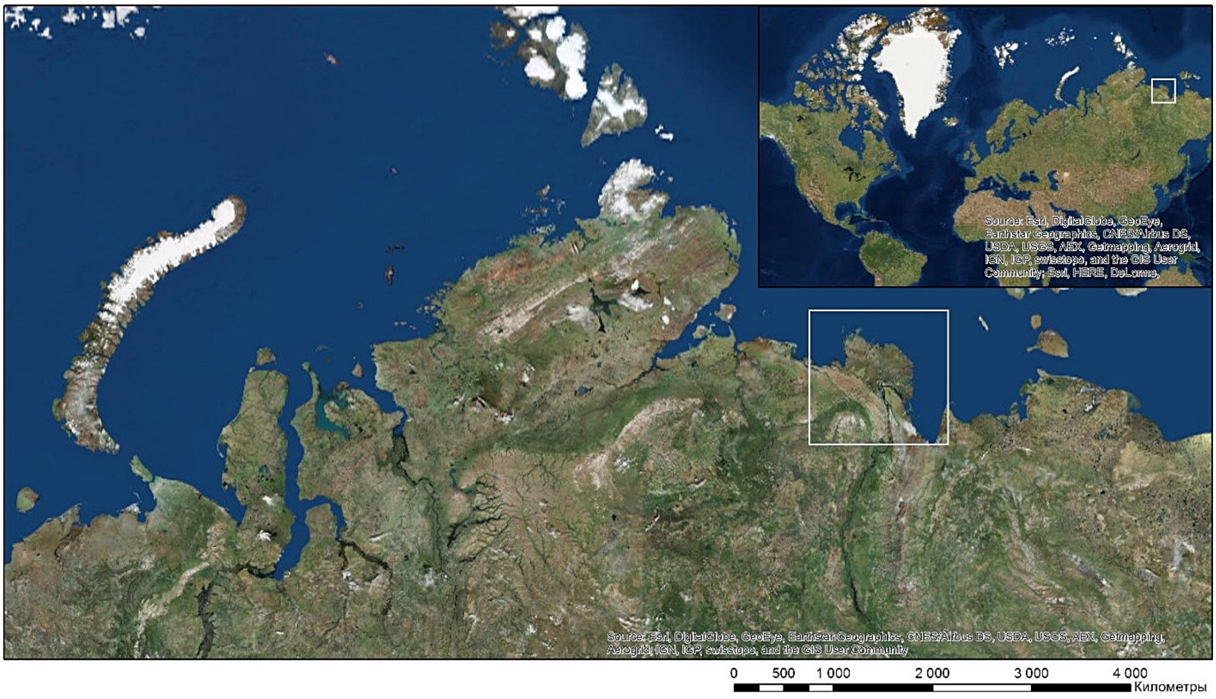

Figure 2. Lena River Delta, Siberia

in the river level is about 7–8 m, with maximum marks in the lower reaches up to 28 m. The greatest runoff occurs in spring, summer and autumn, whereas in winter the river flow is minimal.

The water temperature depends on the climatic conditions, power sources, the direction and speed of the river flow, as well as the depth of the stream. Some local factors also have an impact, namely: ground water, permafrost, ice in reservoirs, watercourses and soils, karst phenomena. The annual course of the water temperatures generally follows the course of the atmospheric temperature. There is a tendency to increase the water temperature over the past 40 years [Geography of Siberia at the beginning of the XXI century, 2015].

The granulometric composition of sediments, consisting of 7 fractions (dust, silt, clay, sand, gravel, pebbles, boulders), varies depending on the conditions of particle formation and the transport capacity of the river flow. Sediment runoff also increases in the spring and summer period, when active flushing of particles from the slope areas adjacent to water bodies occurs. Alluvial processes play an important role in the evolution of the soils of the first terrace and floodplain of the Samoilovsky island, as they constantly carry out alluvial deposition of fresh material, forming the stratification of soil horizons and soil-forming rocks. During high water, the Delta accumulates tree trunks and small tree and plant detritus [Carvalhais, 2014].

The Lena river, like most Siberian rivers, belongs to the bicarbonate class of waters. During the minimum (winter) runoff, the mineralization in the lower reaches is < 50 mg/l, and during the maximum (summer-autumn), it reaches 50–100 mg/l.

The diversity of the geomorphological structure, the abundance of water bodies, the ubiquity of permafrost, and a number of cryogenic processes determine the variability of the landscapes of the study area. Harsh climatic conditions have predetermined the spread of tundra landscapes in this area.

The western part of the Samoilovsky island is located on the territory of a river floodplain, the eastern part belongs to the first above-floodplain terrace, the characteristic landscape of which is represented by polygonal tundra. It combines elevated ridges bordering waterlogged depressions with many thermokarst, old-age and sinkhole lakes. Basically, the lakes have a tetragonal shape. Dry tundra is common on rising polygonal ridges, while the central depressions of polygons, territories located along channels, streams, and other negative landforms are characterized by wet tundra [Boike, 2013]. The diversity of landscape and soil cover is caused by specific forms of meso-and microrelief formed in the presence of permafrost, crack formation, solifluction, swelling, and thermokarst [Shoba, 2010].

On the Samoilovsky island, 12 sections were analyzed in different terrain positions: the soils at points C1, C2, C3, C4 are located in the western part of the island and are subject to seasonal flooding; C5, C6, C7, C8, C9.1, C9.2 are located in the northern and eastern parts of the island, which are outside the flood zone; C11 and C12 are located in the center of the island on the border with the non-flooded part (Fig. 3).

The soils of the Samoilovsky island develop under the influence of soil-alluvial processes of soil formation and a combination of zonal processes such as peat formation, gluing and cryogenesis. Soil diversity is represented by barrels (bioorganic and singletone), which includes 5 departments (organic-accumulative, lifehouse, peat, gley). Table 3 shows the data on the soil horizons for the samples taken on the Samoilovsky island in August 2016.

Assessment of the content of heavy metals in the soil

Soils are an important component of ecosystems and have the ability to buffer and immobilize substances of natural and anthropogenic origin. Projected climate changes, together with other anthropogenic impacts, may affect the biogeochemical processes that increase leaching and migration of trace elements in the permafrost-affected soils. This is especially important, as the Arctic ecosystems are considered very sensitive to the climate change, as well as to chemical pollution.

A comparative analysis of the data obtained showed that in comparison with the content of elements in the soils of O. Samoilovsky in the Delta of the Lena river below. Table 3 and Table 4 show the data on the content of acid-soluble and mobile forms of heavy metals in the soils of Samoilovsky island.

The content of heavy metals in mobile forms is an order of magnitude lesser than their acid-soluble forms, which means that the compounds available to plants are significantly lesser than their actual content in the soil. On the other hand, this indicates the absence of technogenic soil contamination, since the main amount of HM is strongly associated with soil particles and is in a form that is difficult to access for microorganisms and plants.

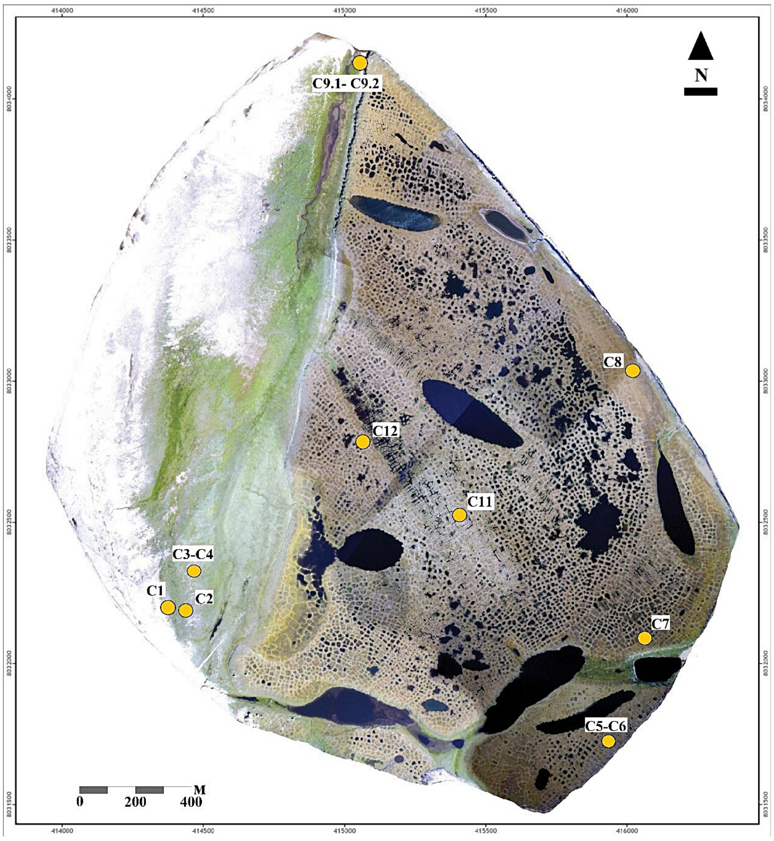

Figure 3. Soil sections on Samoilovsky island

Table 3. The content of acid-soluble forms (gross content) of heavy metals in the soils of Samoilovsky island

Sample	Acid-soluble forms						
	As	Cd	Co	Cu	Ni	Pb	Zn
C1(0-4)	<0.1	<0.002	0.965±0.009	2.12±0.02	1.88±0.018	1.94±0.018	6.02±0.057
C1(4-13)	<0.1	<0.002	1.12±0.01	2.61±0.025	2.11±0.02	2.21±0.021	6.22±0.059
C1(13-27)	<0.1	<0.002	1.58±0.015	3.11±0.03	3.01±0.028	2.8±0.027	8.63±0.082
C1(27-30)	<0.1	<0.002	0.895±0.009	2.33±0.022	1.67±0.016	1.77±0.017	4.73±0.045
C1(30-51)	<0.1	<0.002	1.45±0.014	2.73±0.026	2.71±0.026	2.64±0.025	8.27±0.078
C3(17-23)	<0.1	<0.002	1.99±0.019	3.24±0.031	3.42±0.032	2.69±0.025	4.29±0.041
C4(0-12)	<0.1	<0.002	1.81±0.017	4.07±0.039	3.47±0.033	3.21±0.03	9.87±0.094
C4(12-29)	<0.1	<0.002	0.968±0.009	1.92±0.018	1.75±0.017	1.97±0.019	5.05±0.05
C4(29-43)	<0.1	<0.002	0.793±0.008	1.28±0.012	1.46±0.014	1.65±0.016	7.96±0.076
C5(20-39)	<0.1	<0.002	2.83±0.027	6.42±0.061	5.75±0.055	3.85±0.036	16.4±0.156
C6(15-39)	<0.1	<0.002	2.56±0.024	7.33±0.07	5.92±0.056	5.04±0.048	19.9±0.189
C6(39-45)	<0.1	<0.002	2.05±0.019	5.62±0.053	5.02±0.048	3.53±0.033	17.2±0.163
C7(9-23)	<0.1	<0.002	2.12±0.02	4.22±0.04	3.88±0.037	3.46±0.033	9.75±0.092
C8(16-30)	<0.1	<0.002	0.731±0.007	0.98±0.009	1.13±0.01	1.46±0.014	3.24±0.031
C9.1(13-34)	<0.1	<0.002	1.68±0.016	3.75±0.036	3.55±0.034	2.79±0.026	9.56±0.091
C9.1(34-38)	<0.1	<0.002	0.796±0.008	1.77±0.017	1.62±0.015	2.01±0.019	6.1±0.058
C9.1(38-46)	<0.1	<0.002	0.664±0.006	2.48±0.024	2.2±0.02	2.04±0.019	6.87±0.065
C9.2(10-18)	<0.1	<0.002	1.24±0.012	2.15±0.02	2.47±0.023	2.47±0.023	7.74±0.073
C11(8-15)	<0.1	<0.002	3.01±0.029	4.69±0.045	4.89±0.046	3.46±0.033	14.6±0.139
C12(6-17)	<0.1	<0.002	3.92±0.037	6.84±0.065	5.69±0.054	5.01±0.047	15.2±0.144
MPC	2		5	55	85	32	100
UEC, mg/kg	2	0.5		33	20	32	35

Table 4. The content of mobile forms (gross content) of heavy metals in the soils of Samoilovsky island

Sample	Mobile forms						
	As	Cd	Co	Cu	Ni	Pb	Zn
C1(0-4)	<0.1	<0.002	<0.002	1.8±0.017	0.415±0.004	0.373±0.004	1.64±0.016
C1(4-13)	<0.1	<0.002	<0.002	2.05±0.019	0.516±0.005	0.412±0.004	1.39±0.013
C1(13-27)	<0.1	<0.002	<0.002	1.68±0.015	0.538±0.005	0.409±0.004	1.23±0.012
C1(27-30)	<0.1	<0.002	<0.002	1.5±0.0142	0.419±0.004	0.361±0.003	1.17±0.011
C1(30-51)	<0.1	<0.002	<0.002	1.96±0.018	0.488±0.005	0.534±0.005	1.39±0.013
C3(17-23)	<0.1	<0.002	0.368±0.003	0.222±0.002	0.558±0.005	0.239±0.002	1.07±0.01
C4(0-12)	<0.1	<0.002	3.69±0.035	0.26±0.002	0.51±0.005	0.491±0.005	1.14±0.01
C4(12-29)	<0.1	<0.002	0.116±0.001	0.068±0.001	2.48±0.024	0.203±0.002	0.47±0.004
C4(29-43)	<0.1	<0.002	<0.002	0.062±0.001	0.151±0.001	0.177±0.002	0.491±0.005
C5(20-39)	<0.1	<0.002	0.859±0.008	2±0.019	1.33±0.013	0.732±0.007	2.01±0.019
C6(15-39)	<0.1	<0.002	0.4±0.004	0.23±0.002	0.824±0.008	0.671±0.006	2.56±0.024
C6(39-45)	<0.1	<0.002	0.828±0.008	2.56±0.024	1.37±0.013	1.2±0.011	1.36±0.013
C7(9-23)	<0.1	<0.002	0.313±0.003	0.114±0.001	5.15±0.049	0.404±0.004	1±0.009
C8(16-30)	<0.1	<0.002	0.063±0.0006	1.56±0.012	0.364±0.003	0.203±0.002	1.15±0.01
C9.1(13-34)	<0.1	<0.002	<0.002	0.245±0.002	0.641±0.006	0.36±0.003	0.794±0.008
C9.1(34-38)	<0.1	<0.002	<0.002	2.16±0.02	0.624±0.006	0.351±0.003	1.17±0.011
C9.1(38-46)	<0.1	<0.002	0.121±0.001	0.177±0.002	0.283±0.003	0.317±0.003	0.557±0.005
C9.2(10-18)	<0.1	<0.002	3.08±0.023	2.39±0.023	0.377±0.004	0.343±0.003	1.49±0.014
C11(8-15)	<0.1	<0.002	0.551±0.005	1.73±0.016	9.08±0.086*	0.39±0.004	2.88±0.027
C12(6-17)	<0.1	<0.002	<0.002	0.443±0.004	8.4±0.08*	0.647±0.006	1.75±0.017
MPC, mg/kg			5	3	4	6	23
UEC, mg/kg	2	0.5		33	20	32	35

In excess of the limit values for mobile forms of heavy metals

The highest gross content of acid-soluble and mobile forms of TM is observed in zinc. Zinc is one of the vital elements for plant development and is actively involved in many biochemical cycles. Its content varies in the range of 63 mg/kg in gray forest soils, 46–55 mg/kg in chernozems, and 16–19 mg/kg in peat soils for the Russian plain [Ivanov, 1996]. In the soil cover of Samoilovsky, there is a clear shortage of Zn available for plants, the content of its acid-soluble forms varies within the background values, the maximum of its gross content is fixed in the striated stratozem (17.2–19.9 mg/kg). Peat is an active sorbent of trace elements, which is why the content of HM is increased in torn horizons and profiles of peat soils.

Copper is second in the proportion of concentrations in soil samples. Cu is also a vital element for plants, but at the same time it is quite toxic in excess. Clark copper 53 mg/kg, the available concentrations of the element in the soils of the island are much lower and keep within the background concentrations. Co is a microelement that is actively involved in N_2 fixation. It is well sorbed by iron and manganese oxides, as well as clay minerals, so often even with a small contamination, the soil may experience a deficiency of this element. Clark Co is 29 mg/kg, and soil samples show a deficiency of mobile forms of Co. Pb has a Clark of 13 mg/kg. In the soil, it is quickly inactivated, sorbed (hydro) by iron oxides and loses its toxicity. Lead sorption by humic acids is credited to its fixation in humus-accumulative horizons. The lead content in soil samples of the island is quite small, the maximum concentration noted in stratagema peated and Stroganova amounts to 5.04 and 5.01 mg/kg respectively. The Ni content in soil samples is also small, but there is an increased content of mobile forms of this element in comparison with acid-soluble ones in samples C11 (gray-humus) and C12 (stratosem gray-humus). This may be due to a combination of conditions of increased organic matter content and excessive moisture, in which Ni compounds are transformed and mobile forms of

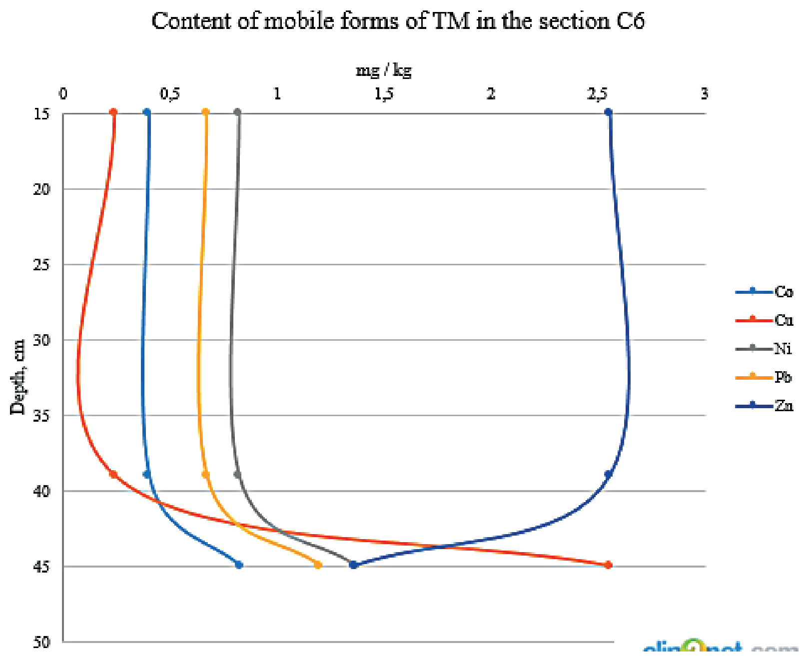

Figure 4. Content of mobile forms of HM in section C6 the

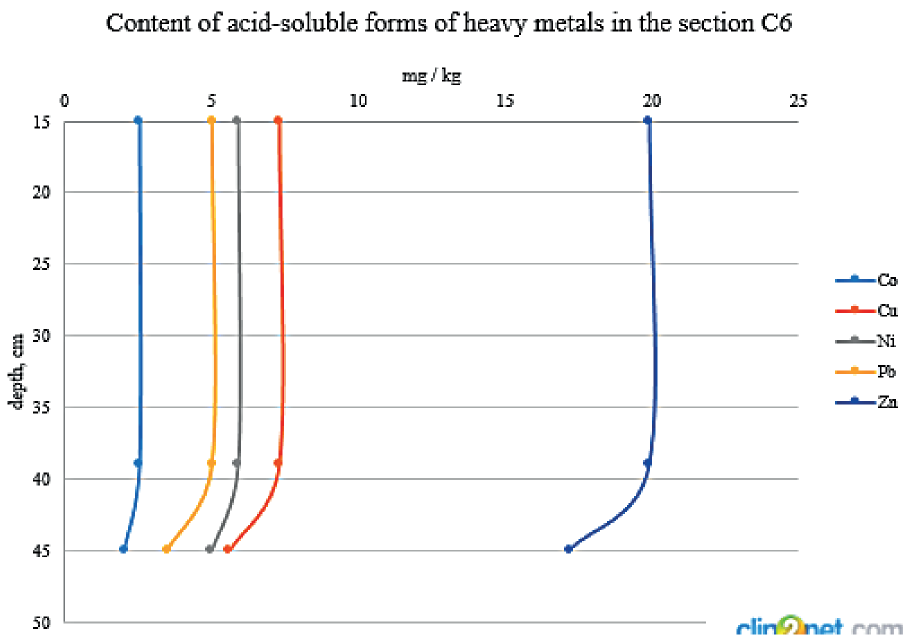

Figure 5. The content of the acid forms of TM in the context of S6 (stratagem)

metal, soluble in water, exchange in water, and amorphous Fe compounds [Plekhanova, 2007]. Under these conditions, the potential danger posed by this element increases.

The concentrations of Cd and As are extremely low and range below 0.002 mg/kg and 0.1, respectively, and none of the samples showed an excess of these concentrations.

The highest concentrations of heavy metals, both mobile and acid-soluble forms, are confined to the horizons with a high content of organic matter and a less alkaline / more acidic reaction of the medium. This is due to the fact that humic acids sorb most of the presented metal, and under conditions of lower pH values, the solubility of compounds of these elements increases.

Among all the soil diversity, the lowest concentrations of heavy metals are observed in the soil samples of stratozems, or rather in the horizons of mineral resources of light granulometric composition.

The highest concentrations of HM are found in the following soil samples:

- gray-humus soil: Ni>Zn>Cu>Co>Pb>Cd (mobile forms) and Zn>Cu>Ni>Pb>Co>Cd (acid-soluble forms);
- stratozem of the gray humus Ni>Zn>Pb>Co, Cd (mobile forms) and Zn>Cu>Ni>Pb>Co>Cd (acid-soluble forms)
- peat-gleezem: Zn>Cu>Ni>Co>Pb>Cd for mobile and acid-soluble forms;
- the torn-off stratozem (Fig. 4)

In Figure 4 the concentrations of mobile forms of Co, Cu, Ni, and Pb decrease significantly down the profile, in contrast to Zn, where the opposite situation is observed. For 4 out of 5 of these elements, there is a clear accumulation in the permafrost horizon, which may be due to the adsorption of elements by humic acids and their further migration to the underlying layers.

The horizons of this profile are characterized by humus content for the horizon RY (15–39) 7% and TE-7.4%, and also have pH 4.48 and 5.24, respectively.

Figure 5 shows the total content of acid-soluble forms of TM in the C6 profile. The concentrations of acid-soluble forms are an order of magnitude higher than mobile ones, and the situation of concentration

Table 5. Granulometric composition of soils on the island Samoilovsky

Soil sample	depth, cm	sand	clay	dust
C1	0-4	85.225	12.575	2.2
C1	4-13	86.325	13.275	0.4
C1	13-27	78.85	19.05	2.1
C1	27-30	88.675	9.75	1.575
C1	30-51	90.55	8.05	1.4
C2	0-17	76.53	12.34	11.13
C2	17-79	84.3	7.6	8.1
C4	12-29	91.95	7.85	0.2
C4	29-43	96.4	3.025	0.575
C5	0-20	71	1.03	27.97
C5	20-39	69.8	12.49	17.71
C6	0-15	58	41.67	0.33
C6	15-39	65.86	32.34	1.8
C6	39-35	43.75	54.3	1.95
C7	0-23	57.75	40.65	1.6
C9.1	0-3	79	14.87	6.13
C9.1	3-13	83	15.15	1.85
C9.1	13-34	71.98	20.5	7.52
C9.1	34-38	72.84	12.74	14.42
C9.1	38-46	61.83	32.76	5.41
C12	0-6	51.6	45.73	2.67
C12	6-17	61.7	37	1.3
C12	17-31	48.05	49.95	2

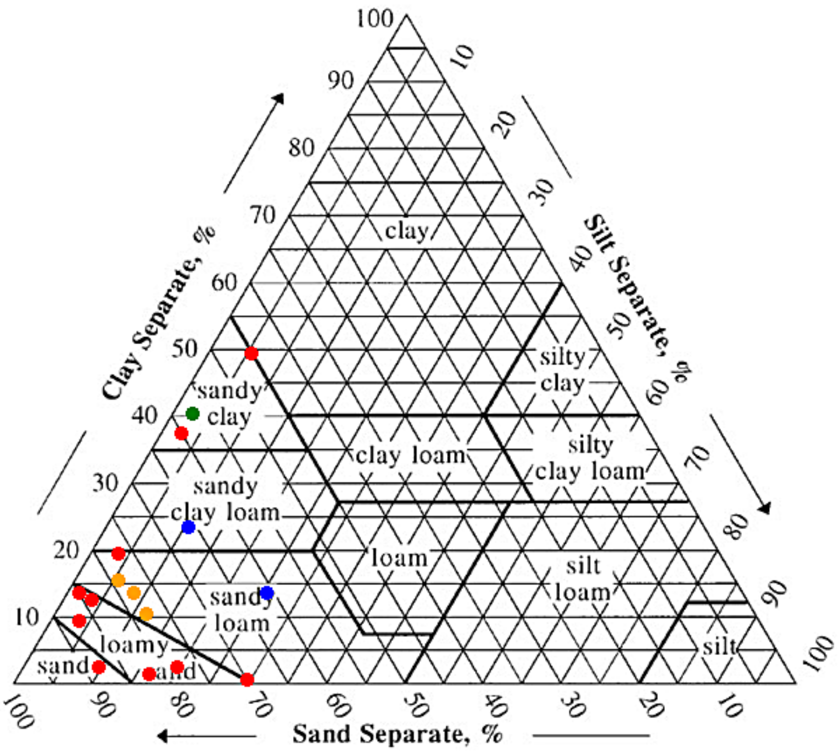

Figure 6. Ferre Triangle, granulometric composition of Samoilovsky island soil; – gley; – stratagem; – gray humus; – peat

distribution down the profile changes. All five elements reduce their content in the underlying layer.

The studied area is largely remote from the centers of industrial activity, which is why the anthropogenic load is extremely low, and the soils here are unpolluted. There are also no natural sources that precede the abnormal content of HM in soils. The diversity of soil and geochemical conditions within the island determines the differences in the levels of HM concentrations in the soils. The analysis of the presented data showed that the mobility of trace elements is influenced by hydrothermal conditions, soil acidity, and the content of organic matter in soil horizons.

Determination of soil fractions was carried out using the Kaczynski method. The soil analysis data are shown in Table 5.

The analysis data is shown in Figure 6, where the Ferre triangle is represented. All soil samples were classified into 5 types of granulometric composition: sand, loamy sand, sanded loam, sanded clay loam and sanded clay.

Among other fractions, sand prevails, which is the result of its deposition by the river flow in the zones of influence of alluvial processes. the current carries alluvium consisting of large quartz particles. To a greater extent, the sand fraction is represented in the stratozems located within the river floodplain. The soils located on the Holocene terrace are characterized by a heavier granulometric composition. The departments of gley and peat soils are represented by sandy loam, sandy clay loam and sandy clay.

CONCLUSIONS

The highest microbiological activity is found in the soils where the processes of peat formation and peat accumulation occur, located on more drained territories with increasing water content and stagnation of moisture, in which microbiological activity decreases. Conversely, the lowest indicators are noted in stratozems, where seasonal flooding by river waters, erosion of humus-accumulative horizons and redeposited material occur annually, which in most cases adversely affects the activity of the microbiota. Consequently, the activity of soil CO_2 emission is directly affected by orographic features of the area, hydrological and climatic indicators at the initial site. The highest content of organic carbon is confined to the organogenic horizons, while the mineral horizons of alluvial alluvium contain much less carbon.

Several groups of natural processes influence the formation and development of soils in the Lena river Delta. The close location of the MMP has an impact in the form of the development of cryogenic processes. Rocks also act as a geochemical barrier, where organic matter and organo-mineral compounds accumulate. Accumulation of TM at the border with MMP is noted. The features of the TM distribution in the profile directly depend on the nature of the humus distribution, as well as the acidity of the soil. Among the natural factors, it is necessary to identify the climatic, geomorphological, geological, as well as biological and hydrological factors. Due to the fact that there has not been an unambiguous trend of increasing air temperatures in the island and its surroundings over the past decades, at the moment it is difficult to discuss the immediate risks of climate change and, as a result, an increase in CO_2 emissions at the initial site.

The diversity of soil and geochemical conditions within the island determines differences in the levels of HM concentrations in the soils. The study area is largely remote from the centers of industrial activity, which is why the anthropogenic load is extremely low, and the soils are not contaminated with heavy metals. There are also no natural sources that precede the abnormal content of HM in soils. The highest gross content of acid-soluble and mobile forms of TM is observed in zinc. The excess of MPC says only the mobile forms of Ni in the samples soil and stratagem. This may be due to a combination of conditions involving high organic matter content and excessive moisture, in which Ni compounds are transformed and mobile forms of this trace element increase. When predicting an increase in the anthropogenic load and the constant introduction of pollutants into the soil cover of this region, it is necessary to note the possible accumulation of pollutants in the soil profile on the border with permafrost, in such soils as gleezems, peat, with poor drainage in conditions of constant accumulation of organic matter and a heavier grunulometric composition, and accumulation in humus-accumulative soil horizons is also possible.

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