Geoelectrical Survey of Active Layer Depth in Urban and Mature Environments of Yamal Region

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Abstract. Active layer thickness and the depth of the permafrost are the basic features of the soil cover of the Arctic region. Urban ecosystems are characterized by disjunctive character of soil cover. Identification of separate soil bodies within the urban ecosystems, their spatial limitation and vertical stratification should be performed for adequate ecological assessment of urban territories. Methods of field electrophysics, which do not lead to any mechanical disturbances of soil cover, should be preferably used for both urban and natural environments. Studied soil profiles revealed significant differences in profile distribution of electrical resistivity values and active layer depths. Predominance of sand fraction in soil of Salekhard site (Spodic Cryosol) determines higher rates of thawing process compared to soil from natural site (Aquiturbic Cryosol), where clay is predominant fraction. Both soil profiles and their electrical resistivity curves are significantly affected by natural cryoturbation processes. However, vertical profile of electrical resistivity value in urban soil is more complicated and has a number of fluctuations due to higher rates of ground mixing, mechanical pressure and high amount of artefacts.

1 Introduction

Active layer thickness and the depth of the permafrost are the basic features of soil cover of the Arctic region and could be assessed by different direct or indirect methods. Excavation of the soil profile and soil mass drilling are classic methods. They have the aim of morphological fixation of the permafrost and active layer border. It is also possible to perform an immersion of a sharpened steel bar into the ground until the frozen ground is encountered. This method has essential disadvantages – exchange of local soil stratification and penetration of air and water from the upper solum to the bottom one. Nowadays, direct-current resistivity (DC resistivity) methods should be used for the identification of permafrost depth and soil profile heterogeneity.

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Geophysical approaches was previously used by authors for permafrost-affected soils examination [1-4]. Vertical sounding by electrical resistance allows determining the permafrost depth without any mechanical disturbances of the soil-permafrost layer [2]. This seems to be especially important in the terms of permanent monitoring plots, where soils are usually affected by the mechanical immersion of a steel bar. This may lead to a reassessment of permafrost degradation. In addition, the convenience of applying this methodology for studying the salinity of soils and moisture in various media was shown [6].

Soil electrical resistivity is a function of a number of soil properties, including soil chemical composition, the nature of the solid constituents, porosity, pore size distribution, connectivity, water content and [5-7].

Urban ecosystems are characterized by disjunctive character of soil cover [8]. In this regard, the issues of identifying individual soil organs in urban ecosystems, their spatial limitation and vertical stratification are sharply increasing for the purpose of an adequate environmental assessment. Field investigations of urban soils are complicated due to overloading of urban ecosystems with various types of land management, protection regimes and of communications tunneled in urban grounds [9]. Therefore, application of traditional disturbance methods (e.g. digging of soil pits leading to disturbances in soil cover) is significantly limited. On the other hand, application of field electrophysical methods, which do not lead to any mechanical disturbances of soil cover, seems to be preferable [10-14]. Current ecological management of urban territories requires an operative assessment of ground conditions [15-17].

This research was aimed at the application of the vertical sounding by electrical resistance to the soil profiles from both urban and natural environments of Yamal region and at the revelation of the characteristic features of active depths in various characteristics of substrate and rate of anthropogenic forcing.

2 Materials and methods

Soils of urban and natural areas of Yamal region were investigated in order to assess the active layer thickness and permafrost depth with special reference to geoengineering properties of the soil-ground strata [19-22]. Considered sites are located in southern Yamal both in urban and natural environments (Fig.1).

Schlumberger geometry is commonly used to perform the vertical sounding by electrical resistance (Fig.2). The Schlumberger array consists of four collinear electrodes. The inner two electrodes (MN) are the potential electrodes whereas the two outer (AB) electrodes are current electrodes. The potential electrodes are installed at the center of the electrode array with a small separation. The current electrodes were more separated during the survey while the potential electrodes remained in the same position until the observed voltage became too small for measurements. The advantages of this method is that small amount of electrodes need to be moved in order to perform each sounding and the cable length for the potential electrodes is shorter. In comparison with Wenner array, Schlumberger soundings generally have better resolution, greater probing depth, and less time-consuming field deployment [18].

Permafrost significantly complicates profile distribution of electrical resistivity values, because unfrozen soil characterized by R_a values are about 10-799 Ohm*m and frozen layers characterized by R_a values are thousands Ohm*m.

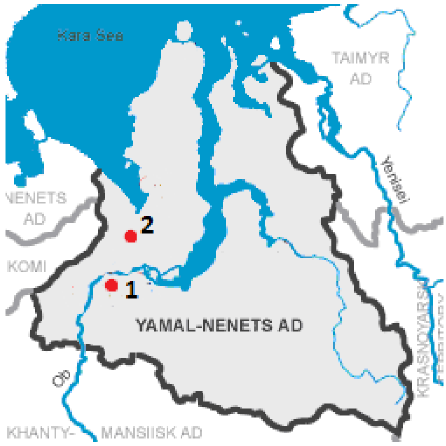

Fig 1. Study sites. 1 - Salekhard site (Podsolic Cryosol, urban environment), 2 – the Polar Urals (Aquiturbic Cryosol, natural environment)

The relationship between values of electrical resistivity in soils and predominance of certain category of soil water was shown in this source [6]. The ER of the soil profiles could be estimated from the vertical electrical sounding (VERS) measurements, which provides data about the changes in the electrical resistivity throughout the profile from the soil surface without pits excavation or drilling. Authors performed the resistivity measurements using four-electrode (AB + MN) arrays of the AMNB configuration with use of the Schlumberger geometry.

A VERS was used to examine the upper 0-to-3 m thick layer in detail. The distance between the A and B electrodes ranged from 10 to 300 cm while the distance between the M and N electrodes was constantly equal to 10 cm. Electrodes were situated on the soil surface with depth of penetration into the soil for about 0.5 cm. The geometric factor (K) was initially calculated for all the electrode spacing using the formula $K = \pi (L2/2b - b/2)$, for Schlumberger array with $MN = 2b$ and $1/2AB = L$. The obtained values were subsequently multiplied with the resistance values to obtain the apparent resistivity. The modeling of the VERS measurements at two stations was used to derive the geoelectrical sections for the various profiles. These modeling revealed that there were mostly two or three geologic layers beneath each VERS station.

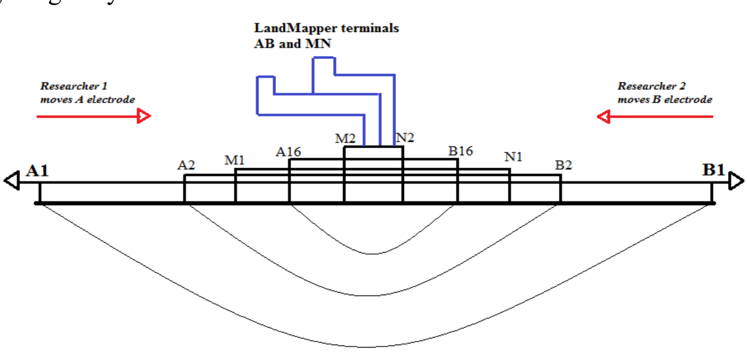

Fig 2. Schematic representation of Schlumberger geometry and with using of LandMapper device.

Soil diagnostics were performed according to World Reference Base for Soil resources (FAO, 2014).

3 Results

The main soil characteristics from studied sites are represented in Table 1. The predominance of sand fraction in soil of Salekhard (urban environments) and clay fraction in soil of the Polar Urals (natural environments) should be noticed.

Table 1. The main soil characteristics of studied soil profiles.

Soil ID	Depth, cm	TOC, %	pH in water	Particle size distribution, %		
				Clay	Silt	Sand
Salekhard, Spodic Cryosol						
Sal1	0-3	3,27	4,82	-	-	-
Sal2	3-20	2,93	4,79	15	25	60
Sal3	20-45	1,57	5,54	14	25	61
Sal4	45-90	1,26	6,21	7	20	73
Sal5	90-147	0,82	6,31	10	20	70
The Polar Urals, Aquiturbic Cryosol						
PU1	0-5	6,89	6,34	-	-	-
PU2	5-23	2,38	6,52	34	25	41
PU3	23-56	1,53	6,42	45	20	35
PU4	56-76	2,23	6,23	54	20	26
PU5	76-83	1,23	6,42	64	15	21
PU6	83-95	0,53	6,32	70	16	14

Results of the vertical distribution of electrical resistivity values within studied soil profiles are presented in Fig.3, 4.

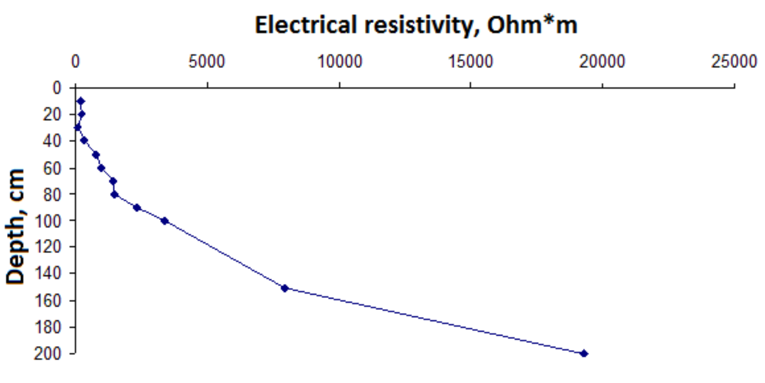

Fig.3. Profile distribution of electrical resistivity values within Spodic Cryosol (Salekhard site).

Values of electrical resistivity in studied Spodic Cryosol is gradually increasing within the soil layer from several hundreds of Ohm*m to almost 8000 Ohm*m. This could be explained by a decrease in soil temperature and gravity water with increasing depth. The active layer depth was identified as equal to 150 cm. Higher values of active layer depths and higher rates of permafrost thawing compared to natural soil profile at this site are caused by predominance of sand fraction (Table 1).

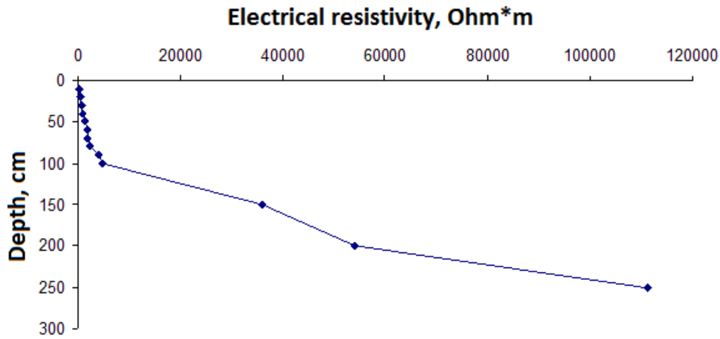

Fig. 4. Trace elements content in urban soils of Yamal region and Murmansk.

Values of electrical resistivity in studied Aquiturbic Cryosol are gradually increasing within the soil layer from several hundreds of Ohm*m to almost 5000 Ohm*m. It could be explained by decreasing of soil temperature and gravitational water with a depth as well as in urban soil. The active layer depth was identified as equal to 97 cm. Lower values of active layer depths and lower rates of permafrost thawing at this site could be explained by predominance of clay fraction in studied soil (Table 1).

Although cryoturbation processes significantly affect both soil profiles and their electrical resistivity curves, data analysis revealed that vertical profile of electrical resistivity value in urban soil is more complicated and has a number of fluctuations due to higher rates of ground mixing, mechanical pressure and high amount of artefacts. Obtained data coincided with soil-profile morphology data of active layer – permafrost border depth. The main trend of increasing R_a values within the permafrost strata observed in both soil profiles could be explained by morphology of permafrost. Usually it becomes more homogeneous, and the number of cracks decreases with increasing depth. This fact explains the lower amount of water, iron oxides, dissolved organic matter accumulated in lower parts of permafrost layer compared to the gleyic-permafrost geochemical border [2]. In the aggregate with the geoelectrical surveys the investigation of the hydrophysical properties of the soil should be made as a part urban development [23, 24]. These measures [25, 26] are important during the various types of engineering works, including the flood protection measures [27].

4 Summary

Studied soil profiles in urban and natural environments revealed significant differences in profile distribution of electrical resistivity values and active layer depths. Predominance of sand fraction in soil of Salekhard (Podsolic Cryosol) determines higher rates of thawing process compared to soil from natural site (Aquiturbic Cryosol), where clay is the predominant fraction. These differences, which caused by predominant texture class of the soil, should be used for geoengineering purposes, while the data about the active layer depths in permafrost-affected landscapes and its dynamics should be significantly broadened. Cryoturbation processes lead to the cryogenic mass transfer, homogenization of soil mass and to the complication of profile distribution of electrical resistivity values. However, these processes could be overlapped by anthropogenic extra-mixing of soil mass leading to appearance of more fluctuations in profile distribution of electrical resistivity values.

5 Acknowledgments

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