Sulphur dioxide content in soils in the zone of influence of Severonickel plant in Murmansk region of the Russian Federation

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Abstract. Anthropogenic air pollution attracts attention of scientists and the public around the world for many years. Traveling over vast distances, particles and aerosols pollute the environment many kilometers away from emission sources. Primary anthropogenic aerosols enter the air mainly with industrial emissions from factories. Secondly aerosols are formed in the atmosphere through various physical and chemical processes involving water vapor, organic compounds, etc. This group includes sulphur dioxide. The article discusses issues related to the pollution of the environment as a result of the activities of the copper-nickel plant Severonickel, located on the Kola Peninsula. In particular, the problem of accumulation of sulfur compounds in the soil, which occurs over decades at a different distance from the industrial factory. Sulphur dioxide is a toxic substance, at high concentrations in the air there is a harmful impact on living organisms, precipitation leads to acidification of the soil, disturbance of soil and vegetation cover, changes balance and destroy ecosystems. For this reason, it is important to monitor the condition of ecosystems that are under the influence of industrial plants. This issue is dedicated to the work of researchers and students of the Department of Environmental Management of the Faculty of Geography of Lomonosov Moscow State University, who for more than twenty years have been monitoring the state of ecosystems in the impact zone of Severonickel plant, including a number of studies devoted to pollution of the soil with sulfur compounds.

1. Introduction
Nowadays the Arctic region of Russia is involved in the process of economic development, which is not surprising. It has a significant resource base and a huge potential for the development of recreational, environmental and traditional nature use. Intensive impact of non-ferrous metals production on the landscape causes its significant anthropogenic transformation.

The research territory is located in the central part of the Murmansk region. One of its key features is that at the end of the XX - beginning of the XXI century it was an anthropogenic wasteland formed as a result of long-time influence of the Severonickel mining and metallurgical plant. Due to operation of this plant, sulfur compounds and metal-containing aerosols predominate in the structure of atmospheric emissions in the Murmansk region [1-2]. For forest-tundra and north taiga landscapes of the investigated territory the influence of factories of such level is most critical. Their assimilation potential and ability to self-recovery are extremely small, that is why the territory within a radius of several tens of kilometers around the plant is a impact area. There is no vegetation cover in some places, as well as the upper soil horizons and in deposit environment accumulate contaminants [3].
Maximum aerosol deposition of sulfur dioxide from smoke jet flares near the factory are most probable at low cloudiness, high air humidity, low wind speeds. The transition from the high-sulphur ores of the Talnakh deposit to the high-grade ores of the Zhdanovskoye deposit (located in the Murmansk region), which was completed in the late 1990s, has reduced SO2 emissions by several times (compared to the 1970s). In the last few years, this situation has been partially corrected thanks to the measures taken by Kola MMC to modernize production and reclamation of disfigurement of a landscape [4]. The need to assess these measures as key in the restoration of ecological well-being of the investigated territory is conditioned by the urgency of this study.

For many years, multiple researches devoted to the search for ways to rationalize environmental management in various regions of the North, including the Murmansk region, has been conducted by employees and students of the Faculty of Geography of Lomonosov Moscow State University. One of the priority tasks to assess the current level of pollution of the environment under the influence of Severonickel plant, to identify the contamination of the soil with sulfur dioxide in the zone of influence of the plant.

To achieve this goal, it was necessary to perform the following:

- To conduct a multiple environmental and geographical characteristics of the research territory, to identify its physical and geographical, and socio-economic characteristics;
- To study the peculiarities of the impact of Severonickel on the environment in different years of its operation;
- To conduct monitoring to assess the current level of accumulation of pollutants in various deposit environment, including sulfur dioxide in the soil, depending on the current situation, to correct the location of the previously established points and if necessary to lay a foundation for new monitoring points.

2. Materials and methods
Questions of optimization of natural resources use and the geoeconomic problems connected with various kinds of economic influence on environment are widely considered in a modern geographical science, much attention is given to consideration of different problems at regional level. Regional studies on the Kola Peninsula conducted by Russian and foreign scientists have also revealed a significant level of environmental impact from industry [5]. Among industrial factories, nonferrous metallurgy factories, one of which is Severonickel plant, are priority air pollutants.

For over twenty years, employees and students of the Department of Environmental Management have been observing the state of landscapes affected by the Severonickel plant, taking samples of water, snow, soil and vegetation cover and their subsequent analysis to identify the degree of pollution. The impact of the plant extends to the natural territorial complex of the tundra-north taiga landscape of the Monchetundra, swampy north taiga landscapes of the Priymandrovsky basement plain, complicated by tectonic-denudation massifs [6].

In 2017-2018 the research was held to identify the sulfur dioxide content in soils in the zone of influence of the plant. Within the framework of complex ecological and geochemical analysis the soil is the key deposit environment and the most important natural indicator [7]. It accumulates passively pollutants coming from the air. To determine the presence of sulfur compounds in the soil, the German method of chemical indication using sensitivity of sulfur compounds to butanol and potassium rhodanide has been applied.

This method allows to visually estimate the amount of sulfur in the upper soil horizon in plantionths of a fraction (ppm). Small amounts of soil from the upper horizon were selected for analysis. The selected soil was cleaned from inclusions and placed in a test tube. Then the sample was filled with a solution of potassium rhodium, after which a small amount of butanol was added to the test tube. The sample was then thoroughly mixed. After a while, the upper part of the solution was painted red. In terms of colour saturation the conclusion was made about the presence of sulphur...
compounds (saturated red is a high indicator). The color in the test tube was compared with the color on a scale specially developed in the spectrophotometric laboratory of MSU.

Measurements of sulfur content were carried out along the routes in the Priymandrovskaya basement plain and the Monche-Tundra mountain ranges: a) in different directions from the Severonickel plant in the north-south and west-east directions by pre-determined points selected depending on the distance from the plant in accordance with the current directive document (EP - 52.44.2-94), according to which samples were taken on the main wind rhumb at distances of 1, 2, 5, 10, 15, 20, 30 and 40 km from the site [8], as well as taking into account the windrose, relief, vegetation cover in various natural territorial complex; b) on the slopes of Monchetundra mountain in the northwest and southeast expositions at a certain distance (every hundred steps), and also considering the steepness of slopes, type of relief and deposits, soil and vegetation conditions.

At each point a detailed description was carried out, containing a brief physical and geographical description of the area, noted features of nature use, visual degradation of the natural and territorial complex as a result of anthropogenic activity (changes in landscapes, disturbance of phytocoenosis, soil, etc.) Descriptions were carried out at sites 50x50 m. The results of measuring of sulfur content in soils were used to create a corresponding map. For this purpose the whole range of the obtained values was divided into five levels, then the sampling points were mapped in accordance with the obtained gradation.

3. Results and discussions

The study area is located beyond the Arctic Circle, which causes a small amount of solar radiation. The sum of active temperatures is also small - 300-1000°C [6]. This determines the general slowdown of the biogeochemical cycle in landscapes, which contributes to the accumulation of anthropogenic pollutants in them. Differences in climatic features of different parts of the Kola Peninsula and different conditions of atmospheric circulation allow us to identify several zones that differ in atmospheric pollution potential. The area around the Severonickel plant is characterized by high atmospheric pollution potential with weak air transport in most directions and moderate air transport in the south-west - north-east direction [9].

The accumulation of aerotechnogenic pollutants in the natural landscapes of the territory is also strongly influenced by geomorphological factors: the Severonickel plant is located in geologic low and is surrounded by the mountains of Monchetundra, Sopchuaivench, Nyuduaivench, Pozuaivench with an average height of 700-800 meters. This location enhances the effect of local accumulation of heavy metals, sulphur oxides and other pollutants.

The outskirts of Monchegorsk and the town-forming factory "Severonickel", located a few kilometers south of the town, are characterized by the prevalence of weak winds (up to 5 m/s). In winter, the area has also increased the frequency of surface inversions, which creates conditions for stagnation of industrial emissions. According to the classification of the Main Geophysical Observatory named after A. I. Voeikov, there is an increase in the frequency of surface inversions during the winter period, which creates conditions for stagnation of industrial emissions. According to the classification of the Main Geophysical Observatory named after A. I. Voeikov, in terms of climatic conditions of impurities dispersion in the atmosphere the territory of Monchegorsk belongs to the zone with moderate pollution potential [10].

In the course of research it was found that the research territory located in the northern taiga subzone is characterized by a mosaic soils both natural and anthropogenic. Within a radius of 5 km from the planr, depending on the nature of atmospheric transport and relief, the soil and vegetation cover is characterized by mosaic, caused by the close direct impact of the plant. In the zone of anthropogenic wasteland the soil is strongly degraded, the horizon B appears on the surface. Further up to approximately 10-15 km to the south from the plant the soil, even in the plain, has a shorter profile than similar areas of landscapes not influenced by the plant. The characteristic soil profile is a weakly humulated forest litter (A0), under which lie podzol horizon (A2). Illuvial horizons (B, B2, BC) of ochre color lie below.
During field works, sulphur content in the upper soil layer was conducted. The results of this study are shown on the map (figure 1). The studies carried out revealed the distribution of sulfur concentration in the soil on the slopes of Monchettehundra. The maximum concentration of sulfur is observed on the windward slope (about 7 ppm) at an altitude of about 400 m, which declines above (at the top - 5 ppm, on the windward slope - 4.5 ppm) (figure 2).

![Figure 1](image1.png)

**Figure 1.** Sampling points of the topsoil horizon for field determination of sulfur content in soil and value of sulfur content indicator (ppm) on different routes.

![Figure 2](image2.png)

**Figure 2.** Upper soil horizon sampling points for field determination of soil sulphur content and sulphur content index (ppm) value on the route Monchetundra mountain.

The highest sulphur concentrations in the soil were recorded in 1 km from the industrial site in the lower part of the basin, on the lower parts of the slopes facing the plant. High concentrations are also found within a radius of up to 15 km south of the industrial site. Similar measurements were made southward to Kandalaksha along the Murmansk-St. Petersburg highway. It was noted that to the south
from the industrial site of the plant the increase of sulfur concentration in soils can be traced to the distance of more than 80 km.

4. Discussions

Zone separation of anthropogenic degradation of natural and territorial complexes as a result of antropogenic emissions of the plant was visualised clearly during the field work. The most striking negative changes in natural territorial complex can be traced to the south of the plant. Within a radius of more than 40 km from the mining and smelting plant ellipsoidal zones of natural landscape changes can be traced, stretched submeridionally in the direction of prevailing winds. In the immediate vicinity of the plant in the northern taiga zone, currently there is an anthropogenic wasteland zone, where the vegetation is completely destroyed (replacing the northern taiga), soils are highly degraded (Horizon B in some areas comes to the surface), and differences in elevation zones on the nearby slopes are erased. As we move away from the plant, tree species appear - first small willows and birches without moss-shrub cover, further from the plant the ground vegetation cover gradually closes, but there are no plant species sensitive to pollution (blueberries, lichens, sphagnum mosses). Only at the distance of 10-15 km to the south from the plant coniferous species appear, and species common for the northern taiga in the ground cover.

It is already possible to observe the appearance of Northern taiga in some places in the 5 km zone from the plant, but visually even at a distance of 15-20 km needles necrosis, chlorosis and leaf necrosis can be seen. The sublatitudinal transport of sulphur dioxide emissions is weaker [11]. For example, on the northern slope of Nyduaivench mountain, 2.5 km from plant to the east, the pollution is not visualised, only pollution according to field measurements of sulfur content in the soil (2.3 ppm) can be traced. Lichens grow on the slope and there are pine undergrowth. Further on the mountain slope there is a highly degraded forest tundra zone with pine needles necrosis, top-dry trees which is typical sign of sulfur dioxide influence on vegetation [12], total projective cover is less than 30 %, soil horizon B comes to the surface, lichens and mosses remain at the height of about 400-450 m. There is no visual influence of the plant at the very top - in phytocoenosis of mountain tundras there are mosses, lichens. On the downwind slope anthropogenic influence is visualized at the level of 300-400 m — strip of top-dry woods and deprimate flora is observed. These data are also confirmed by field measurements of sulphur content in the upper soil horizon (4.5 ppm).

5. Conclusion

As part of this work, multiple ecological, geographical and ecological and geochemical research of the area affected by the Severonickel plant was held. In order to assess the current level of pollutants accumulation, the location of the previously established points was adjusted and new monitoring points were established.

As a result of field studies, the impact of the plant's emissions in both submeridional and sublatitudinal transportation was identified, special attention paid to the study of sulfur dioxide content in soils in the area of the plant influence.

Study of sulfur dioxide content in soils was carried out as part of a multiple study of the plant's impact on the environment. According to the data of snow cover samples analysis, and also the analysis of moss sphagnum (using brioindikation method) on the maintenance of heavy metals it is possible conclude that and at the present stage of operation of industrial complex for the investigated territory dynamics of decreasing pollution, there is a process of restoration of the destroyed landscapes. During the period of the most strong impact when destroyed ecosystem territory reached a record 400 thousand hectares, 15 thousand hectares of which were anthropogenic wasteland, now the impact areas are present only within a radius of 5 km.

According to the data of snow cover testing, the most contaminated points are located within a radius of 2.5-3, as well as 8-10 km to the south of the plant, according to brioindication - the southern border of pollution is located approximately 25 km southly from the plant. Contamination with sulphur dioxide in soils, as in the depot environment, is traced much further. Points with sulphur
concentrations of more than 5 ppm are found both in the immediate vicinity of the plant (northern slopes of the Monchettehundra massif, Nyduaivench and Sopchuaviench mountains) and at a distance of almost 50 km to the south. However, in comparison with similar researches which were held by employees of department in 1980th [4; 6], level of pollution by sulphur compounds has considerably decreased. Nevertheless, despite a significant reduction in emissions "supply" of pollutants accumulated in natural territorial complex including sulfur compounds, inhibit the natural self-recovery of ecosystems - even at visual well-being the accumulated pollutants damage the soil for a long time.

Acknowledgement
This study was carried out with the financial support of the RFBR project "Detection and mapping of potential nature management during prospective economic development of the Russian Arctic zone" N 18-05-00335 and within the framework of the state assignment "Sustainable development of territorial nature management systems".

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