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Ecological and geochemical state of soils in the central part of the Curonian Spit Peninsula, Kaliningrad Region, Russian Federation

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Abstract. The research results presented in this article were obtained during the expedition to the Curonian Spit in the spring of 2024 as part of the final of the All-Russian Championship “Limitless Expeditions” of the All-Russian public and State Movement of Children and Youth

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“Movement of the First” in specially protected areas of the Russian Federation in 2023. A research group of students, who had previously successfully implemented the testing of techniques in the Stavropol Territory, conducted geoecological soil studies in the Curonian Spit National Park, laying a geochemical transect from the Curonian Lagoon to the Baltic Sea coast. The data obtained made it possible to clarify the current geoecological state of some types of soils common in the territory of the Curonian Spit National Park, as well as to identify criteria for the physico-chemical state of soils related to modern anthropogenic impact. In general, the values of the majority of the studied parameters indicate the ecological well-being of the research area, which confirms the effectiveness of the implemented measures aimed at its conservation.

Keywords: soil ecology, soil geochemistry, granulometric composition of soils, marine pulverization, specially protected natural areas, Baltic Sea, ecological status

Authors’ contribution. *Y.O. Lebedev* — methodology, analysis, verification of data, conducting research. *A.A. Karpichenka* — methodology. *A.A. Iurmanov* — conceptualization of research, definition of the research area. *N.S. Kokorina* — conceptualization of research, data administration. *M.N. Letz* — data administration, data verification. *V.L. Gaazov* — data administration, data verification. *A.Y. Lebedeva-Georgievskaya* — software, formal analysis. *K.V. Molodykh* — conducting research. *A.A. Rogachev* — conducting research. *M.R. Makhmudov* — conducting research and verifying data. *N.R. Sobolev* — conducting research. *A.G. Gigolov* — conducting research. *V.M. Nekrasov* — conducting research. *Z.A. Vasilenko* — conducting research. All authors have read and approved the final version of the manuscript.

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Эколого-геохимическое состояние почв центральной части полуострова Куршская коса, Калининградская область, Российская Федерация

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Аннотация. Представленные результаты исследований получены в период проведения экспедиции на Куршской косе весной 2024 г. в рамках финала Всероссийского чемпионата «Безграничные экспедиции» Общероссийского общественно-государственного движения детей и молодежи «Движение первых» на особо охраняемых территориях Российской Федерации за 2023 г. Исследовательская группа обучающихся, ранее успешно реализовавшая апробацию методик на территории Ставропольского края, провела геоэкологические почвенные исследования на территории Национального парка «Куршская коса», заложив геохимическую трансекту от Куршского залива до побережья Балтийского моря. Полученные данные позволили уточнить современное геоэкологическое состояние некоторых типов почв, распространенных на территории Национального парка «Куршская коса», а также выявить критерии физико-химического состояния почв, имеющих связь с современным антропогенным воздействием. В целом значения большинства исследованных параметров свидетельствуют об экологическом благополучии территории исследований, что подтверждает эффективность реализуемых мер, направленных на ее сохранение.

Ключевые слова: экология почв, геохимия почв, гранулометрический состав почв, морская импультверизация, особо охраняемые природные территории (ООПТ), Балтийское море, экологическое состояние

Вклад авторов. *Лебедев Я.О.* — методология, формальный анализ, верификация данных, проведение исследования. *Карпиченко А.А.* — методология. *Юрманов А.А.* — концептуализация исследования, определение области исследования. *Кокорина Н.С.* — концептуализация исследования, администрирование данных. *Леу М.Н.* — администрирование данных, верификация данных. *Гаазов В.Л.* — администрирование данных, верификация данных. *Лебедева-Георгиевская А.Я.* — программное обеспечение, формальный анализ. *Молодых К.В.* — проведение исследования. *Рогачев А.А.* — проведение исследования. *Махмудов М.Р.* — проведение исследования и верификация данных. *Соболев Н.Р.* — проведение исследования. *Гиголов А.Г.* — проведение исследования. *Некрасов В.М.* — проведение исследования. *Василенко З.А.* — проведение исследования. Все авторы ознакомлены с окончательной версией статьи и одобрили ее.

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Introduction

The Curonian Spit National Park is a peninsular natural and anthropogenic system of the southeastern Baltic Sea, located in Eastern Europe, and has the status of a specially protected natural area (SPNA) of federal significance and the only National Park in the Kaliningrad Region. The Curonian Spit is included in the list

of UNESCO World Heritage Sites and combines various landscapes and ecosystems [1].

The climate of the Curonian Spit is temperate, transitional from marine to continental, and is formed under the influence of air masses from the Baltic Sea and the mainland. Winters are mild, summers are moderately warm, and the weather is characterized by significant variability. The greatest amount of precipitation falls in the summer and autumn period. The Curonian Spit is characterized by constantly blowing winds, hurricanes occur several times a year. Stable ice cover is typical for the waters of the Curonian Lagoon; on the Baltic Sea coast, ice cover is short-lived or does not form at all.

The Curonian Spit has a moraine (glacial) origin and inclusions in the form of fragments of rocks of various genesis brought with the glacier. Traces of different geological epochs were brought by the glacier (for example, granites, gneisses, sandstones, as well as fossils of sponges and bryozoans of Cretaceous (K) age). The body of the spit consists of sand covered with a thin (several centimeters thick) vegetation layer, which has been forming for many decades. The spit is a narrow strip of land separating the Curonian Lagoon from the Baltic Sea. The length of the National Park is 98 km and the width is from 0.8 to 3.8 km [2]. Unique dune complexes are located on the territory of the Spit — a continuous strip of white sand dunes 0.3 — 1 km wide and up to 67 m high.

About 72% of the spit's territory is occupied by forests. Almost all forests are of artificial origin. The territory of the Curonian Spit National Park is characterized by a significant species richness of flora: 884 species, hybrids, varieties and forms of higher plants from 397 genera and 111 families are recorded on it. Gymnosperms are represented by 11 species (including 6 species of introduced plants); spore — 19; monocotyledons — 187; dicotyledons — 556. The adventitious component of the flora consists of 91 species (including 7 invasive ones). Plants rare in the Kaliningrad Region and listed in the regional Red Book and the lists of the Red Book of Russia (2005) are represented by 109 species [2]. The fauna includes 296 species of terrestrial vertebrates.

Pine forests make up more than half of the forest area of the Kurshka Spit, deciduous forests are represented by birch and alder trees with an admixture of aspen. There are also forests of oak, linden, hornbeam. Birch forests with an admixture of alder occupy the second place after pine forests, they often have a natural origin. Rare species of orchids can be seen in the meadows (palm trees): a real slipper, a dormouse. The vegetation of the Curonian Spit can be divided into three main groups: non-forest (meadow, marsh, dune), forest and synanthropic. Each of the groups represents an important landscape and biotopic significance for the ecosystem diversity of the territory of the Curonian Spit National Park [2].

The research results presented in this article were obtained during the expedition to the Curonian Spit in the spring of 2024 as part of the final of the All-Russian Championship "Limitless Expeditions" of the All-Russian public and State Move-

ment of Children and Youth “Movement of the First” in specially protected areas of the Russian Federation in 2023.

For our research, we selected an area developing under forest vegetation as the most stable ecosystem, the formation of which took a considerable time without or after human economic intervention. The purpose of this study was to clarify the current ecological and geochemical state of the soils of the natural and anthropogenic ecosystems of the Curonian Spit, which required solving a number of tasks, such as laying a soil transect (catena) through the body of the sand spit, followed by laboratory physico-chemical studies of soil samples and analysis of the results obtained. The study of physical properties involved determining the mechanical composition of soils to identify artifacts in the accumulation of multi-dimensional particles, while the study of the chemical composition of soils consisted in clarifying the concentration of toxic elements (heavy metals) in relation to their approximate permissible (APC) and maximum permissible concentrations (MPC) in soils.

Aims

The purpose of the research on the Curonian Spit is to assess the geocological state of the soil cover of the natural and anthropogenic territory.

The objectives of the study were defined as the selection of typical ecotopes, the formation of a soil catena, and the conduct of physico-chemical studies of the collected samples.

The results of the study should create an opportunity for monitoring and forecasting changes in the conditional reference territory in terms of the continuum-temporal transformation of the climate.

Methods

A research group of students, who had previously successfully implemented the testing of techniques in the Stavropol Territory, conducted geocological soil studies in the Curonian Spit National Park, laying a geochemical transect from the Curonian Lagoon to the Baltic Sea coast.

The impact on natural complexes during the research was limited to a point intervention with a violation of the soil and vegetation layer in the amount of 4 soil sections. At the end of the research, all completed soil sections were preserved (by backfilling) with the re-laying of the soil and vegetation layer. Soil ecological and geochemical studies without local disturbance of the soil and vegetation layer are not possible. The research area and the location of the soil sections are shown in a fragment of the Google Earth satellite image (Figure 1). The sequential laying of soil sections made it possible to cover the most typical biotopes in the research area and perform a geochemical transect across the Curonian Spit. It should be noted that no geochemically subordinate landscapes have been identified within the

framework of the transect, due to the rugged and slightly hilly terrain. Each soil section and the results of chemical studies related to it can be viewed from the perspective of automorphic (autonomous) landscape conditions.

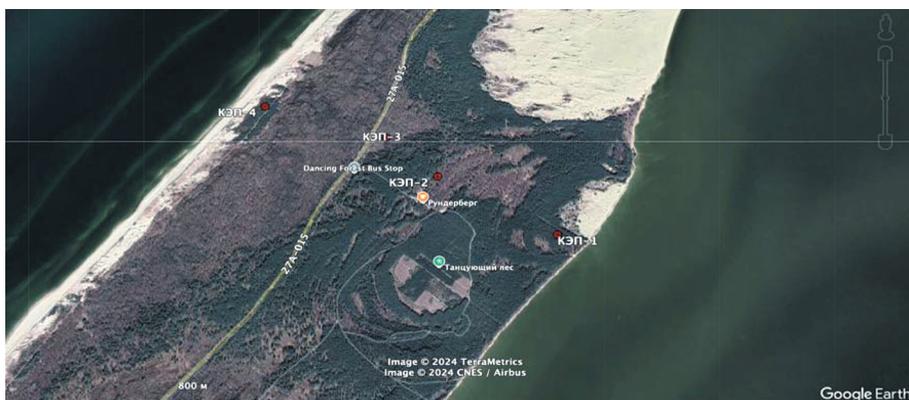


Figure 1. Research area and points of soil sections in NP “Curonian Spit”. Scale 1:20000

Source: compiled by Y.O. Lebedev based on Google Earth.

The research program included:

- field soil studies — laying of a soil catena (coordinates of the points are shown in Table 1);
- description of soil sections;
- fixation of the physical properties of the soil (temperature of soil horizons, native humidity, addition, etc.);
- sampling and subsequent sample preparation;
- study of physico-chemical parameters: granulometric (mechanical) composition, chemical composition of 27 elements.

Table 1. Coordinates of the points of the studied soil sections

| No. | The WGS-84 coordinate system | |
|------|------------------------------|-------------|
| | Latitude | Longitude |
| SE-1 | 55° 10.854' | 20° 52.185' |
| SE-2 | 55° 11.016' | 20° 51.664' |
| SE-3 | 55° 11.129' | 20° 51.432' |
| SE-4 | 55° 11.222' | 20° 50.875' |

Source: compiled by Y.O. Lebedev.

The sieve analysis of soil samples was carried out in accordance with the interstate standard GOST 12536-2014.¹ The fraction distribution schedules were executed in the Excel program.

¹ GOST 12536-2014. Soils. Methods of Laboratory Determination of Granulometric (Grain) and Microaggregate Composition. Moscow: Standartinform, 2016. (In Russ.)

The chemical analysis was carried out at the accredited research center IC MGULAB (certificate of accreditation RA.RU.21OM11 dated 11/25/2021). The samples were analyzed on the NPP-ISP instrument in accordance with GOST R 57165-2016 (ISO 11885:2007)² with a five-fold repetition of the definitions and automatic calculation of the confidence interval of the values based on the standard error of the average. The total content of the following elements was determined in the soil samples: Al, Ba, V, B, V, Fe, Cd, K, Ca, Co, Si, Li, Mg, Mn, Cu, Mo, Na, Ni, Pb, Se, Ag, S, Sr, Sb, Ti, P, Cr, Zn, followed by an analysis of the content of macrobiogenic elements (Ca, K, Mg, Na), heavy metals, as well as toxic elements. First of all, we were interested in geocological indicators related to the content (in gross form) of chemical elements in soils classified into groups 1, 2 and 3 of toxicological hazard (Zn, Pb, Cd, Cr, Cu, Ni, Co, Mn, As) according to hygienic standards³ for the subsequent assessment of the current geocological state of the soil cover within the framework of the established geochemical transect.

Results

The completed soil-geochemical catena stretches from the coast of the Curonian Lagoon to the coast of the Baltic Sea through biotopes typical of the area. As part of the study, we tried to establish soil sections in various biotopes in order to try to identify the specific features of the soil formation process for the territory. The sites where the soil sections were laid were located at a considerable distance from anthropogenic-disturbed territories: settlements, roads, ecological trails, thus they represented the background landscape conditions — as far as it is applicable to the natural-anthropogenic system of the Curonian Spit.

Point SE-1

The SE-1 point is located in the immediate vicinity of the coast of the Curonian Lagoon (about 40-50 m) in a pine forest (the pine forest biotope is the predominant type of forest on the Curonian Spit) with a thick grassy and moss-lichen overground. The total thickness of the soil section is 49 cm. The groundwater has not been opened. Soil: sod-slightly podzolic sandy. The morphological description of the soil section is given in Table 2.

² GOST R 57165-2016 (ISO 11885:2007). *Water. Determination of the Content of Elements by Inductively Coupled Plasma Atomic Emission Spectrometry*. Moscow: Standartinform, 2018. (In Russ.)

³ *Hygienic Standard 2.1.7.2511-09. Approximate Permissible Concentrations (APCs) of Chemicals in the Soil (for Sandy and Sandy Loam Soils)*. Moscow: Federal Centre for Hygiene and Epidemiology of Rospotrebnadzor, 2009 (In Russ.); Resolution No. 1 of the Chief State Sanitary Doctor of the Russian Federation dated January 23, 2006 “On the Introduction of Hygienic Standards GN 2.1.7.2041-06.” *KonturNormativ*. (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=9&documentId=299876&ysclid=mkpt70csy5181221664> (accessed: 12.12.2025); Letter of the Ministry of Natural Resources of the Russian Federation dated December 27, 1993 No. 04-25/61-5678 “On the Procedure for Determining the Amount of Damage Caused by Chemical Pollution of Land.” *KonturNormativ*. (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=8&documentId=6352&ysclid=mkptb5qce0581410956> (accessed: 12.12.2025).

Table 2. Morphological description of a section of turf slightly podzolic sandy soil, Point CAP-1

| General view of the biotope and section | Soil horizon | Description of the horizon |
|--|---|--|
|  | <p>Ad Depth: 0–5/6 cm Capacity: 5–6 cm t°C: 7.8°C Color:</p>  | <p>Color (by attachment / Munsell scale): grey-brown / 10YR 3/3 Humidity: humid Coloring: uniform Mechanical composition: moderate, sandy loam Density: loose Build: non-sticky, slightly plastic Inclusions: none Living phase: abundant grass roots, moss rhizoids $D = 1–2$ mm, frequent tree roots $D = 0.2–0.3$ cm Neoplasms: none Transition: noticeable in color Border: wavy</p> |
| | <p>A1/A2 Depth: 5/6–13/16 cm Capacity: 7–11 cm t°C: 7.5°C Color:</p>  | <p>Color (by attachment / Munsell scale): brown / 10YR 2/3 Humidity: humid Coloring: uniform Mechanical composition: sand Density: loose Build: non-sticky, non-plastic Inclusions: none Living phase: sparse tree roots $D = 0.2–0.8$ cm Neoplasms: none Transition: short Border: wavy</p> |
| | <p>B Depth: 13/16–38/41 cm Capacity: 22–28 cm t°C: 7.3°C Color:</p>  | <p>Color (by attachment / Munsell scale): light ochre / 5Y 5/4 Humidity: fresh Coloring: uniform Mechanical composition: sand Density: compacted Build: slightly sticky, slightly plastic Living phase: single small tree roots $D = 0.2–0.3$ cm Inclusions: none Transition: noticeable in color Border: wavy, drawn</p> |
| | <p>C Depth: 38/41–49 cm Visible capacity: 8–11 cm t°C: 7.4°C Color:</p>  | <p>Color (by attachment / Munsell scale): ochre / 7.5Y 5/3 Humidity: fresh Coloring: uniform Mechanical composition: sand Density: dense Build: slightly sticky, plastic Inclusions: none Live phase: missing Neoplasms: none</p> |

Source: the photo was taken by Y.O. Lebedev.

The soil is sandy, up to a depth of 20 cm, humus illuviation is noted, plant roots are found up to a depth of 40 cm. Slight podzolization to a depth of 13–16 cm was noted. The moisture content of the profile corresponds to atmospheric moisture and the washing regime of the soil. The density of horizons increases with depth, corresponding to the natural gravitational compaction. Sieve analysis of the samples from the SE-1 soil section revealed no differences in the distribution of fractions of the horizons studied (Figure 2).

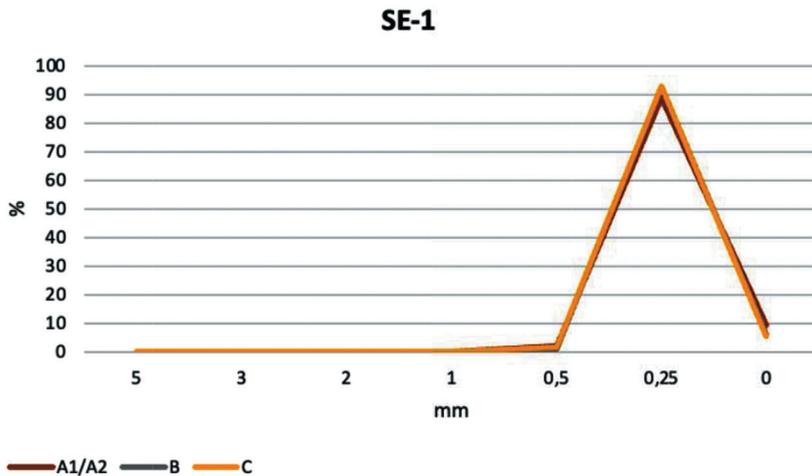


Figure 2. Graph of the distribution of fractions of slightly podzolic sandy soil, point SE-1

Source: compiled by A.Y. Lebedeva-Georgievskaya.

It can be seen from the graph that the distribution of solid phase fractions in all the studied soil (organo-mineral and mineral) horizons is almost identical, which may indicate a natural and gradual accumulation of the solid phase of the soil during its formation. Over 90% of the samples from the three horizons studied are from the 0.25 mm fraction, which is medium sand.

Thus, the fraction prevailing in the studied horizons and the content of clay and dusty particles make it possible to classify this soil according to its granulometric (mechanical) composition as sandy sand [3].

Analysis of the chemical composition results indicates a free migration of macrobiogenic elements down the soil profile with a low concentration of Ca, Mg and Na in the mineral horizons (Figure 3). In the A1/A2 horizon, the gross content of Mg and K decreases, while in the remaining horizons the value for K remains in the range of 2900–3000 mg/kg.

Analysis of the results of the determination of the content of heavy metals and toxic chemical elements revealed a slight excess of MPC (maximum permissible concentration) and APC (approximate permissible concentration) for Sg (6.8 ± 1.4 mg/kg) and As (2.3 ± 1.2 mg/kg) in the organogenic horizon of Ad and for Cr (6.5 ± 1.4 mg/kg) in the mineral horizon of C (> 2.0 and > 6.0 mg/kg for

As and Cr, respectively).⁴ Free (gravitational) migration was noted for a number of metals studied (Ni, Co, Mn, As), while accumulation in mineral horizons was observed for Zn, Pb, Cr, and Cu, which may indicate the presence of a geochemical barrier of a physicochemical type. The distribution of the concentration of the studied elements over the horizons is shown below (Figure 4). Here and further, the MPC values are given for the elements in accordance with regulatory documents.^{5,6}

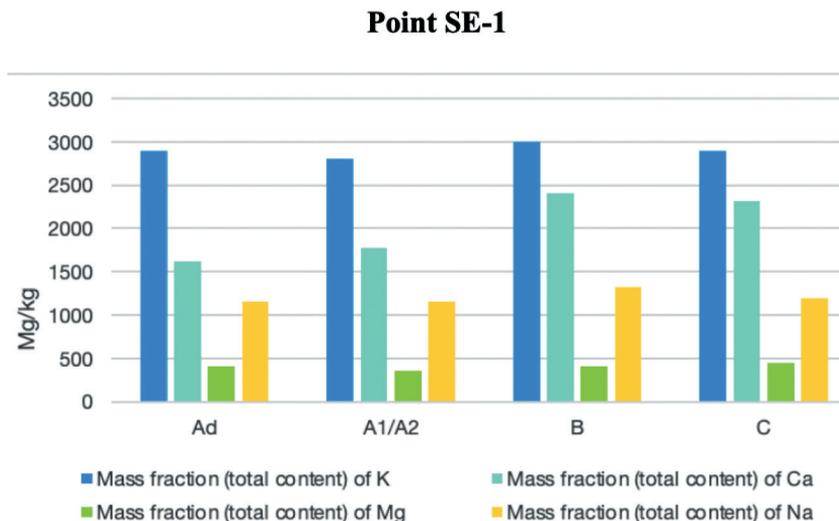


Figure 3. Graph of the distribution of macrobiogenic elements in the horizons of turf slightly podzolic sandy soil, point SE-1

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

A consistent decrease in the gross Mn content from the organogenic to the mineral horizon was noted. The ecological and geochemical state of the slightly podzolic sandy sod soil (SE-1 point) can be assessed as favorable with minor single Cr and As exceedances in the Ad and C horizons.

⁴ Hygienic Standard 2.1.7.2511-09 “Approximate Permissible Concentrations (APCs) of Chemicals in the Soil” (for Sandy and Sandy Loam Soils). Moscow : Federal Center for Hygiene and Epidemiology of Rospotrebnadzor; 2009. (In Russ.); Resolution № 1 of the Chief State Sanitary Doctor of the Russian Federation dated January 23, 2006 “On the Introduction of Hygienic Standards GN 2.1.7.2041-06.” *KonturNormativ* (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=9&documentId=299876&ysclid=mkpt70csy5181221664> (accessed: 12.12.2025).

⁵ Hygienic Standard 2.1.7.2511-09. *Approximate Permissible Concentrations (APCs) of Chemicals in the Soil (for Sandy and Sandy Loam Soils)*. Moscow : Federal Center for Hygiene and Epidemiology of Rospotrebnadzor; 2009 (In Russ.).

⁶ Resolution No. 1 of the Chief State Sanitary Doctor of the Russian Federation dated January 23, 2006 “On the Introduction of Hygienic Standards GN 2.1.7.2041-06.” *KonturNormativ*. (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=9&documentId=299876&ysclid=mkpt70csy5181221664> (accessed: 12.12.2025).

Point SE-1

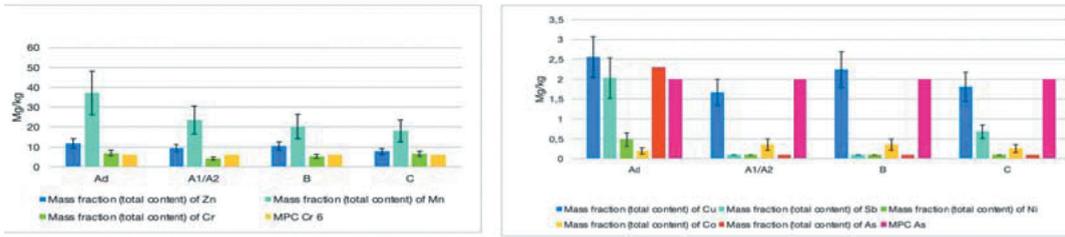


Figure 4. Distribution of the content of elements of toxic metals in the horizons of turf slightly podzolic sandy soil, point SE-1

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

Point SE-2

The SE-2 point is located on the border of a pine forest that turns into a mixed forest (birch, aspen, spruce) with a predominance of birch. The total capacity of the soil section is 63 cm. The groundwater was opened at a depth of 60 cm. Soil: peaty-gley slightly saline sandy. The morphological description of the soil section is given in Table 3.

The graph (Figure 5) shows that the distribution of solid phase fractions in the studied soil horizons is different. While the fractional distribution in the organo-mineral A1/A2 and mineral horizons turned out to be completely identical, a diverse fractional composition is observed in the organogenic horizon, which may indicate an unnatural accumulation of the solid phase of the soil during its formation and a connection with past anthropogenic activity. In the organo-mineral and mineral horizons, 90% of the samples are from the 0.25 mm fraction of medium sand. In the organogenic horizon of Ad, the distribution is different — 40% of the sample belongs to fractions of 0.25 and 0.5 mm — medium and coarse sand, respectively. In general, according to the fractions (medium sand) prevailing in the studied horizons and the content of clay and powdery particles, this soil was classified by us as sandy sand according to its granulometric (mechanical) composition [3].

An analysis of the results of the chemical composition determination indicates the migration of macrobiogenic elements down the soil profile with a peak increase in Ca concentration (4100 ± 1200 mg/kg) in the organogenic horizon of Ad (Figure 6) and a subsequent decrease to the mineral horizons. The increased calcium content may be due to biological uptake and deciduous fall of trees growing in the area of the SE-2 point. A low K content (<1800 mg/kg) was noted, and the Mg content of the Bg mineral horizon decreased.

The soil is sandy with a powerful detached organogenic horizon Ad (16–18 cm), humus illuviation (along the roots) is noted to a depth of 22–25 cm, plant roots are found throughout the depth of the profile. Weak podzolization was noted at a depth

of 18–25 cm. The humidity of the profile corresponds to atmospheric moisture, the washing regime of the soil and the proximity of groundwater. The density of horizons increases slightly with depth, corresponding to natural gravitational compaction. The sieve analysis of the samples of the SE-2 soil section made it possible to clarify the features of the distribution of fractions of the studied horizons (Figure 5).

Table 3. Morphological description of the section of peat-gley slightly saline soil, Point SE-2

| General view of the biotope and section | Soil horizon | Description of the horizon |
|---|---|---|
|  | Ad Depth: 0–16 cm Capacity: 16 cm t°C: 7.5°C Color:  | Color (by attachment / Munsell scale): brown / 7.5YR 3/4 Humidity: humid Coloring: uniform Mechanical composition: bleached mule Density: loose Build: non-sticky, plastic Inclusions: none Living phase: thin, abundant grass roots D < 1 mm, frequent tree roots D = 1–1.5 cm Neoplasms: none Transition: clear Border: slightly wavy |
|  | A1/A2 Depth: 16–22/25 cm Capacity: 6–9 cm t°C: 6.7°C Color:  | Color (by attachment / Munsell scale): light brown / 7.5YR 4/4 Humidity: humid Coloring: uniform Mechanical composition: sand Density: loose Build: slightly sticky, plastic Inclusions: none Living phase: sparse tree roots D = 2–2.5 cm Neoplasms: none Transition: gradual Border: uneven |
|  | Bg Depth: 25–63 cm Visible capacity: 38 cm t°C: 6.8°C Color:  | Color (by attachment / Munsell scale): light brown / 7.5YR 4/6 Humidity: humid Coloring: heterogeneous, with spots of neoplasms Mechanical composition: sand Density: compacted Build: sticky, plastic Inclusions: none The living phase: single tree roots Neoplasms: rare spots of calcification, ochreous spots and blemishes |

Source: the photo was taken by Y.O. Lebedev.

The analysis of the results of the determination of the heavy metal content revealed some features of the studied soil. Thus, the organogenic horizon of Ad has the highest concentrations (among the examined samples) for Zn, Cu, and Ni.

For Cr chromium, a slight excess (> 6.0 mg/kg) of MPC and APC⁷ of 7.0 ± 1.4 mg/kg was noted in the A1/A2 organo-mineral horizon, as well as the highest concentrations (among the examined samples) for Mn (65.0 ± 20.0 mg/kg). The content of the remaining heavy metals correlates with their content in the horizons of other surveyed soils. The content of Ni, Cu, and Pb is gradually decreasing towards the mineral horizons, but it is many times higher than the content of other heavy metals in the organogenic horizon (which may indicate the presence of a source of anthropogenic pollution). Peak concentrations for Zn, Pb, Cd, Cu, Ni, and Mn were noted in the organogenic horizon of Ad. The distribution and concentration of individual heavy metals may be a confirmation of the assumption about the anthropogenic nature of soil cover disturbances. The distribution of the concentration of the studied elements over the horizons is shown below (Figure 7).

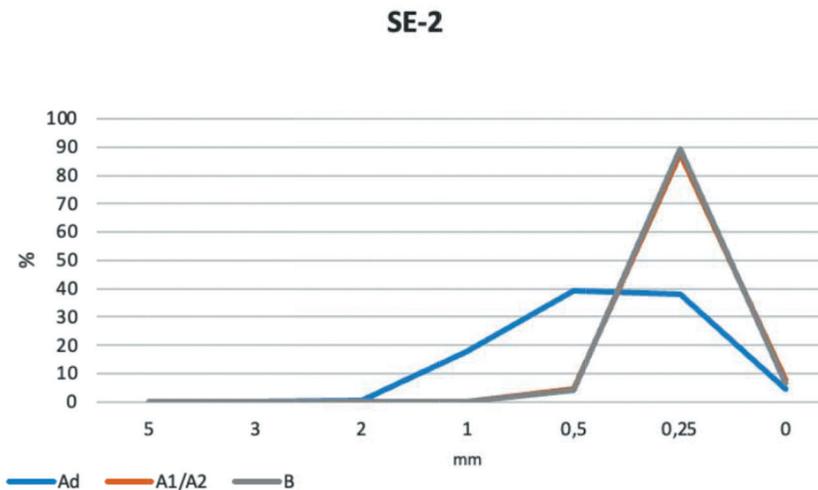


Figure 5. Graph of the distribution of fractions of peat-gley slightly saline sandy soil, point SE-2

Source: compiled by A.Y. Lebedeva-Georgievskaya.

Despite the established insignificant single excess for Cr in the A1/A2 horizon, the ecological and geochemical state of the peaty-gley slightly saline sandy soil (point SE-2) can be assessed as favorable.

⁷ Hygienic Standard 2.1.7.2511-09. Approximate Permissible Concentrations (APCs) of Chemicals in the Soil (for Sandy and Sandy Loam Soils). Moscow : Federal Center for Hygiene and Epidemiology of Rospotrebnadzor; 2009 (In Russ.); Resolution No. 1 of the Chief State Sanitary Doctor of the Russian Federation dated January 23, 2006 “On the Introduction of Hygienic Standards GN 2.1.7.2041-06.” *KonturNormativ*. (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=9&documentId=299876&ysclid=mkpt70csy5181221664> (accessed: 12.12.2025).

Point SE-2

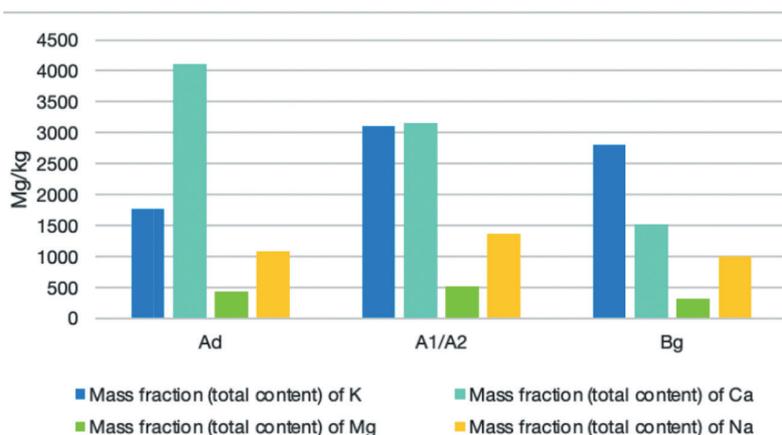


Figure 6. Graph of the distribution of macrobiogenic elements in the horizons of peat-gley slightly saline sandy soil, point SE-2

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

Point SE-2

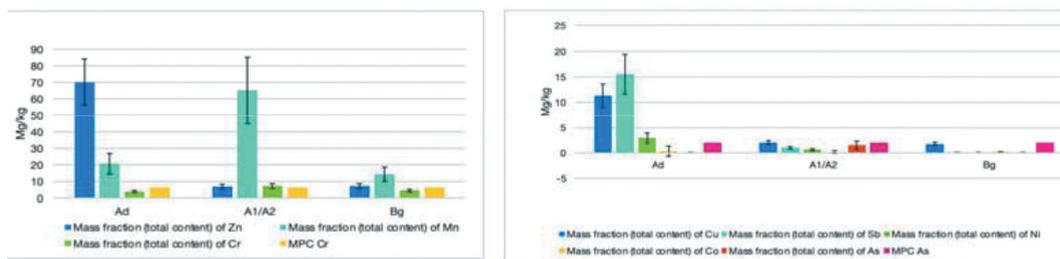


Figure 7. Distribution of the content of elements of toxic metals in the horizons of turf slightly podzolic sandy soil, point SE-2

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

Point SE-3

The SE-3 point is located in the central part of the spit in a mixed forest (pine, alder, birch) with a predominance of pine. The total thickness of the soil section is 59 cm. The groundwater has not been opened. Soil: sod-podzolic sandy. The morphological description of the soil section is given in Table 4.

The soil is sandy with a low-power detached organogenic horizon Ad, humus illumination is noted up to a depth of 8-9 cm, and up to 49 cm along the roots of plants. The roots of the plants are found throughout the depth of the profile. There is a slight podzolization at a depth of 9-14 cm. The moisture content of the profile corresponds to atmospheric moisture and the washing regime of the soil. The density of horizons increases with depth, which corresponds to the natural gravitational

compaction. The sieve analysis of the samples of the SE-3 soil section made it possible to clarify the features of the distribution of fractions of the studied horizons (Figure 8).

Table 4. Morphological description of the section of sod-podzolic sandy soil, Point SE-3

| General view of the biotope and section | Soil horizon | Description of the horizon |
|--|--|--|
|  | <p>Ad Depth: 0–5/7 cm Capacity: 5–7 cm t°C: 6.2°C Color:</p>  | <p>Color (by attachment / Munsell scale): dark brown / 10YR 2/2 Humidity: humid Coloring: uniform Mechanical composition: moderated Density: loose Build: sticky, slightly plastic Inclusions: none Living phase: frequent grass roots, moss rhizoids $D = 1–2$ mm, frequent tree roots $D = 0.2–0.3$ cm Neoplasms: none Transition: clear in color and mechanical composition Border: slightly wavy</p> |
| | <p>A2 Depth: 5/7–10/14 cm Capacity: 3–9 cm t°C: 6.1°C Color:</p>  | <p>Color (by attachment / Munsell scale): gray-brown / 10YR 3/2 Humidity: fresh Coloring: uniform Mechanical composition: sandy loam Density: compacted Build: slightly sticky, slightly plastic Inclusions: none Living phase: frequent grass roots $D = 1–2$ mm, tree roots $D = 0.3–0.6$ cm Neoplasms: none Transition: clear Border: slightly wavy</p> |
| | <p>B Depth: 10/14–51/53 cm Capacity: 37–43 cm t°C: 6.1°C Color:</p>  | <p>Color (by attachment / Munsell scale): ochre-gray / 10YR 5/2 Humidity: fresh Coloring: uniform Mechanical composition: sand Density: compacted Build: slightly sticky, non-plastic Inclusions: none Living phase: frequent small tree roots $D = 0.3–0.8$ cm Neoplasms: none Transition: noticeable in color and density Border: slightly wavy</p> |
| | <p>C Depth: 51/53–59 cm Visible capacity: 6–8 cm t°C: 6.2°C Color:</p>  | <p>Color (by attachment / Munsell scale): ochre-brown / 10YR 4/3 Humidity: fresh Coloring: uniform Mechanical composition: sand Density: dense Build: slightly sticky, plastic Inclusions: none Live phase: missing Neoplasms: none</p> |

Source: the photo was taken by Y.O. Lebedev.

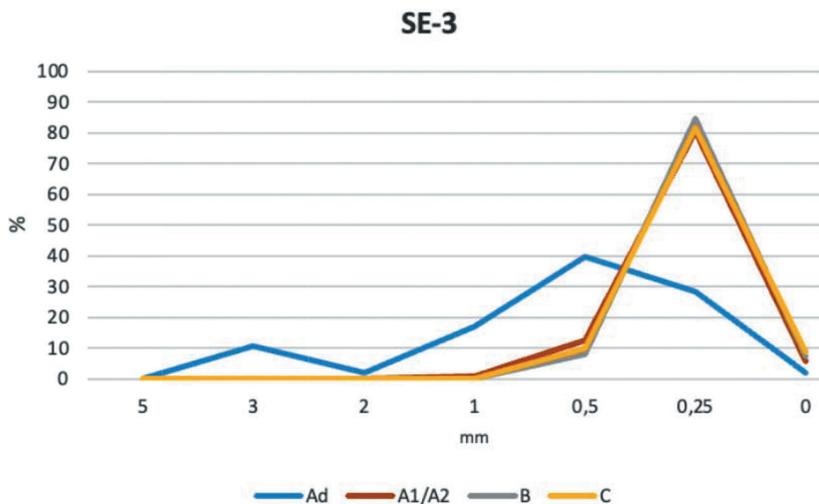


Figure 8. Graph of the distribution of fractions of sod-podzolic sandy soil, point SE-3

Source: compiled by A.Y. Lebedeva-Georgievskaya.

The graph shows that the distribution of solid phase fractions in the studied soil horizons is different. While the fractional distribution turned out to be completely identical in the organo-mineral A1/A2, B, and mineral horizons C, the organogenic horizon Ad has a much more diverse fractional composition, which may indicate an unnatural accumulation of the solid phase of the soil during its formation and a connection with anthropogenic activity. In the organo-mineral and mineral horizons, 90% of the samples are from the 0.25 mm fraction of medium sand. In the organogenic horizon, the distribution is different — 40% of the sample belongs to fractions of 0.25 and 0.5 mm — medium and coarse sand, respectively.

The organogenic horizon of Ad is dominated by fractions of medium and coarse sand. In general, according to the fractions (medium sand) prevailing in the studied horizons and the content of clayey, dusty particles, this soil was classified by us as sandy sand according to its granulometric (mechanical) composition [3].

The chemical composition of the soil is similar to slightly podzolic peaty-gleamy sandy soil (CAP point-2), which indicates disturbances in the migration of macrobiogenic elements down the soil profile with a peak increase in Ca concentration in the organogenic horizon of Ad (Figure 6) and a subsequent decrease to the mineral horizons. A low K content (> 2000 mg/kg) was noted, and the Mg content of the Bg mineral horizon decreased.

Analysis of the results of chemical composition determination indicates the features of migration of macrobiogenic elements down the soil profile: a peak increase in Ca concentration (3230 ± 970 mg/kg) in the organogenic horizon of Ad (Figure 9) and subsequent sequential accumulation to the mineral horizons. The increased calcium content is most likely due to biological absorption, as well as the effect of deciduous and deciduous tree species growing in the area of the CAP-3 point. The content of K and Mg peaks in the organo-mineral horizon A1/A2 and decreases towards the mineral horizon C.

Point SE-3

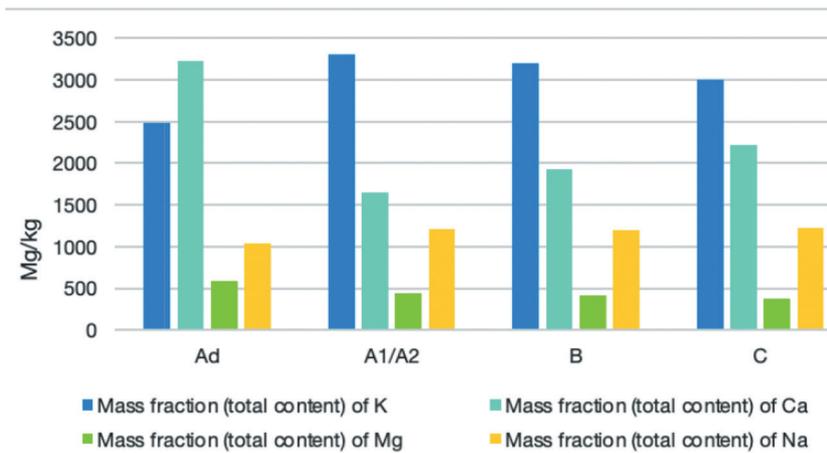


Figure 9. Graph of the distribution of macrobiogenic elements in the horizons of sod-podzolic sandy soil, point SE-3

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

Analysis of the results of the determination of the heavy metal content revealed for As (2.7 ± 1.3 mg/kg, the highest of the recorded exceedances) in the organogenic horizon of Ad and for Cr (6.9 ± 1.4 mg/kg) in the mineral horizon of B, a slight excess of MPC and APC (> 2.0 mg/kg and > 6.0 mg/kg, respectively). For a number of metals studied (Zn = 48.0 ± 9.6 , Pb = 13.3 ± 3.3 , Cu = 13.6 ± 2.7 , Mn = 34.0 ± 10.0 mg/kg), a significant peak in concentration in the organogenic horizon of Ad was noted, which may indicate the presence of a source of anthropogenic pollution. Free (gravitational) migration is characteristic of Zn, Pb, Cd, Cu, Ni, Mn (except for the A1/A2 elluvial horizon for Mn), and is evenly distributed over the horizons of Co. There are no geochemical barriers. The distribution of the concentration of the studied elements over the horizons is shown below (Figure 10).

Point SE-3

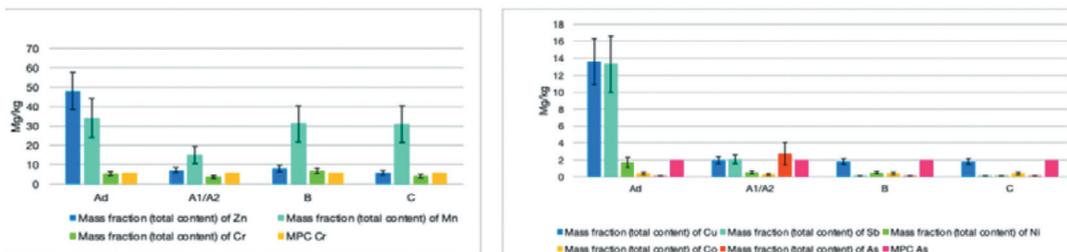


Figure 10. Distribution of the content of elements of toxic metals in the horizons of sod-podzolic sandy soil, point SE-3

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

The ecological and geochemical state of the sod-podzolic sandy soil (point SE-3) can be assessed as favorable with minor single exceedances in As and Cr in the horizons of Ad and B.

Point SE-4

The SE-4 point is located on the shore of the Baltic Sea behind the avenue in a mixed forest (birch, aspen, spruce) with a predominance of birch. The total thickness of the soil section was 49 cm. The groundwater was opened at a depth of 49 cm. The section is represented by slightly podzolic sandy soil. The morphological description of the soil section is given in Table 5.

Table 5. Morphological description of a section of slightly podzolic sandy soil, Point SE-4

| General view of the biotope and section | Soil horizon | Description of the horizon |
|--|---|--|
|  | Ad Depth: 0–4 cm Capacity: 4 cm t°C: 4.9°C Color:  | Color (by attachment / Munsell scale): dark brown / 10YR 2/1 Humidity: humid Coloring: uniform Mechanical composition: sandy loam Density: loose Build: slightly sticky, plastic Inclusions: none Living phase: thin abundant grass roots and moss rhizoids $D = 0.1$ cm Neoplasms: none Transition: noticeable in color and me- chanical composition Border: slightly wavy |
| | A1/A2 Depth: 4–18 cm Capacity: 14 cm t°C: 4.8°C Color:  | Color (by attachment / Munsell scale): brown / 10YR 3/1 Humidity: humid Coloring: uniform Mechanical composition: sand Density: loose Build: slightly sticky, non-plastic Inclusions: none Living phase: frequent grass roots $D = 1–2$ mm, frequent tree roots $D = 0.3–2.0$ cm Neoplasms: none Transition: clear Border: slightly wavy |
| | B Depth: 18–40 cm Capacity: 22 cm t°C: 5.0°C Color:  | Color (by attachment / Munsell scale): ochre-brown / 2.5Y 5/4 Humidity: humid Coloring: uniform Mechanical composition: sand Density: loose Build: slightly sticky, non-plastic Inclusions: none Living phase: sparse tree roots $D = 0.1–0.6$ cm Neoplasms: none Transition: clear Border: slightly wavy |

Table 5, ending

| General view of the biotope and section | Soil horizon | Description of the horizon |
|---|--|---|
| | C Depth: 40–49 cm Visible capacity: 9 cm t°C: 5.0°C Color:  | Color (by attachment / Munsell scale): light brown / 2.5Y 4/4 Humidity: humid Coloring: heterogeneous Mechanical composition: sand Density: loose Build: slightly sticky, non-plastic Inclusions: none Living phase: single small tree roots D = 0.2–0.5 cm Neoplasms: single bluish-ochreous spots and patches |

Source: the photo was taken by Y.O. Lebedev.

The soil is sandy with a low-power organogenic horizon, humus illumination is noted up to a depth of 18–19 cm, and up to 28 cm along plant roots. The roots of plants can be found up to a depth of 38 cm. Weak podzolization was noted at a depth of 15–18 cm. The moisture content of the profile corresponds to atmospheric moisture and the washing regime of the soil. The depth density of horizons does not change, and natural gravitational compaction is poorly developed. The sieve analysis of the samples of the SE-4 soil section made it possible to clarify the features of the distribution of fractions of the studied horizons (Figure 11).

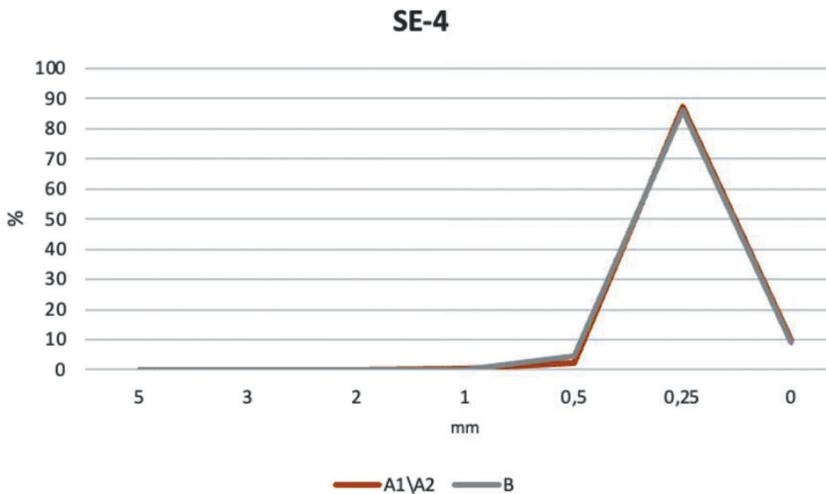


Figure 11. Graph of the distribution of fractions of slightly podzolic sandy soil, point SE-4

Source: compiled by A.Y. Lebedeva-Georgievskaya.

It can be seen from the graph that the distribution of solid phase fractions in all the studied soil (organo-mineral and mineral) horizons is identical, which may indicate a natural and gradual accumulation of the solid phase of the soil during its

formation in the immediate vicinity of the avandune. More than 80% of the samples from the three horizons studied are in the 0.25 mm fraction, which is medium sand.

The fraction prevailing in the studied horizons and the content of clay and dusty particles make it possible to classify this soil according to its granulometric (mechanical) composition as sandy sand [3].

The analysis of the chemical composition results indicates the free migration of macrobiogenic elements (K, Ca, Mg) down the soil profile. For Na, an increase in the concentration to the mineral horizons was noted (Figure 12).

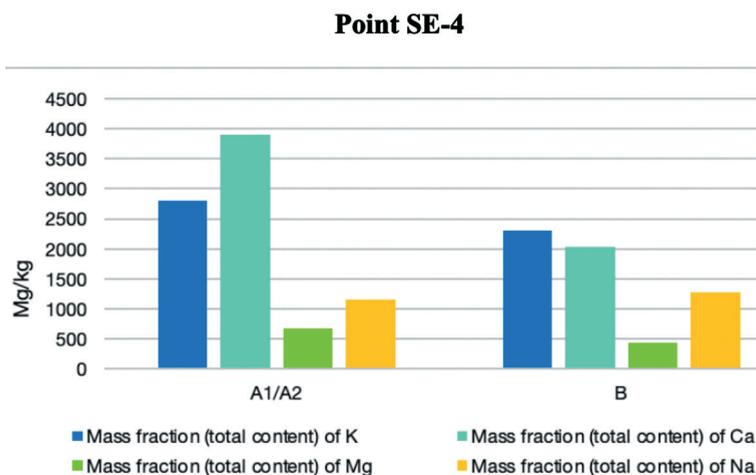


Figure 12. Graph of the distribution of macrobiogenic elements in horizons of slightly podzolic sandy soil, point SE-4

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

Analysis of the results of the determination of the heavy metal content revealed a slight excess of the maximum permissible concentration (> 6.0 mg/kg) for Cr in the A1/A2 organo-mineral horizon⁸. At the same time, this value is the highest among all tested soil horizons (7.4 ± 1.5 mg/kg). For Pb (2.25 ± 0.56 mg/kg) and Mn (81.0 ± 24.0 mg/kg), a peak concentration was observed in the A1/A2 organo-mineral horizon, for Cu (3.44 ± 0.69 mg/kg), in horizon B. Free (gravitational) migration is characteristic of Zn, Cr, Pb, Co, as well as Cd and Mn, are evenly distributed over the horizons of As. An increase in the concentration to the mineral horizon was noted for Cu and Ni, which may indicate the presence of a physico-chemical barrier of the redox type. The distribution of the concentration of the studied elements over the horizons is shown below (Figure 13).

⁸ Resolution No. 1 of the Chief State Sanitary Doctor of the Russian Federation dated January 23, 2006 “On the Introduction of Hygienic Standards GN 2.1.7.2041-06.” *KonturNormativ*. (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=9&documentId=299876&ysclid=m-kpt70csy5181221664> (accessed: 12.12.2025).

Point SE-4

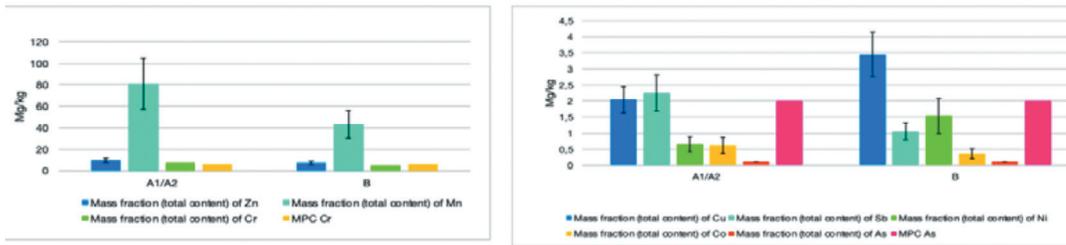


Figure 13. Distribution of the content of elements of individual metals in horizons of slightly podzolic sandy soil, point SE-4

Source: compiled by Y.O. Lebedev, A.A. Karpichenka, A.A. Iurmanov, N.S. Kokorina, M.N. Letz, V.L. Gaazov, A.Y. Lebedeva-Georgievskaya, K.V. Molodykh, A.A. Rogachev, M.R. Makhmudov, N.R. Sobolev, A.G. Gigolov, V.M. Nekrasov, Z.A. Vasilenko.

Despite the established insignificant single excess for Cr in the A1/A2 horizon, the ecological and geochemical state of the slightly podzolic sandy soil (point SE-4) can be assessed as favorable.

The presented analysis of the results of physico-chemical studies of soil samples suggests the presence of features of the distribution of sand fractions in slightly podzolic peat-gley sandy and sod-podzolic sandy soils (points CAP-2 and CAP-3, respectively), which may be associated with economic activity here in the past or with the active aggregation of particles with a high content Ca and Mg (coagulating cations). The excess of MPC and ODC for As was found in 2 samples — in sod-podzolic sandy soil (point CAP-3) and in sod-slightly podzolic sandy soil (point CAP-1) and the excess of MPC for Cr in 5 samples — in all studied soils (points CAP-1 — CAP-4). The reasons for the identified physico-chemical features will be discussed below.

The soil sections of the embedded catena were located in biotopes typical of the territory of the Curonian Spit [4, 5] at a distance from each other and allowed us to assess the features of the chemical composition of soils, the influence of plant communities on it, past anthropogenic activity and the pulverization of marine aerosols, and geochemical features and the nature of soil moisture contributed to the formation of physico-chemical barriers (point CAP-1) [6].

The soil sections uncovered and described in the course of the research correspond to the types of soils common in the territory of the Curonian Spit, which are formed on aeolian (wind) sediments under various conditions of water regime and humus accumulation [7]. At the SE-4 point, partially flooded and watered horizons B and C are watered by capillary rise of atmospheric moisture (as well as, possibly, water from the marine area located at the same height as the SE-4 point behind the avenue at 30 meters) with salts dissolved from the soil, so, during sample preparation, bringing It took a considerable amount of time to achieve a constant mass of the selected samples, due to the fact that salt dissolved in water actively retained

moisture in contact with the solid phase of the soil⁹. The close occurrence of groundwater in general, as well as the presence of slightly salted groundwater (as a result of pulverization and subsequent migration of thalassophilic elements with marine aerosols), may be a geochemical bioinhibitor for the development of the root system of woody vegetation in depth, rather than so much the light (weakly cohesive, cohesive sand) granulometric composition of soils (on the contrary, contributing to development of the root system of plants) and exacerbate the consequences of destructive winds for the ecosystem [8]. In addition, the detected salinization of groundwater and mineral horizons of soils cannot be the result of agricultural activities, as evidenced by the data from the lake water study. Chaika and the waters of the Curonian Lagoon for the content of dissolved salts using the EcoLabox express laboratory, — average hardness was noted for water samples, nitrate content less than 1 mg/l, nitrite content less than 0.05 mg/l, ammonium content less than 0.2 mg/l, phosphates were not detected [4; 5]. The soil horizons of the SE-4 point are characterized (except those described above) by a high content of Na, Mg, P, Mn, as well as Fe, Li, Ti, and Cr, compared with the other horizons of the studied soils.

The sand fractions prevailing in the granulometric composition of soils of Aeolian origin [9] correspond to their genesis, while the organogenic horizons of soil sections located in the central part of the catena bear traces of anthropogenic transformation (turbation) [10]. The distribution of sand fractions at the point of CAP-2 and CAP-3 may indicate its anthropogenic disturbance, as indicated by a significant content of coarse sand fractions and a small amount of gravel in the organogenic horizon, which is inconsistent with the fractional distribution in the organogenic horizons of other studied soil sections. At the same time, no economic activity is currently being conducted in these territories, the road infrastructure is located at a considerable distance, as a result of which it can be assumed that the soil cover was disrupted or the Aeolian transfer of individual sand fractions to these areas in the past. The introduction of fractions of 0.5–3 mm in size may presumably be related to the organization of the road network in the central part of the Curonian Spit in the past, as it corresponds to the range of fractions of the previous and current state standards for construction sand.¹⁰ No special mineralogical study has been conducted to confirm or refute this assumption.

Our analysis of the gross content of macrobiogenic elements (Ca, K, Mg, Na), heavy metals and toxic elements classified into groups 1, 2 and 3 of toxicological

⁹ *National parks of Russia: A Handbook*. Moscow: The Biodiversity Conservation Center Publishing House; 1996.

¹⁰ *GOST 8736-93. Sand for Construction Work. Technical Specifications*. Moscow: Srandartinform; 2005. (In Russ.); *GOST 8736-2014. Sand for Construction Work. Technical Specifications*. Moscow: Srandartinform; 2019. (In Russ.).

hazard (Zn, Pb, Cd, Cr, Cu, Ni, Co, Mn, As)¹¹ showed that certain geochemical features of the studied soils may be related to atmospheric circulation and proximity to the Baltic Sea. In particular, it was noted that the Na content increases in organo-mineral and mineral horizons of soil sections facing the Curonian Lagoon (SE-1, SE-2), while in soil sections facing the Baltic Sea (SE-4, SE-3), on the contrary, — the Na content increases towards the mineral horizons.

Possible pulverization of Ca, Mg (as well as Sr, P and a number of other elements) with marine aerosols was noted, resulting in a gradual decrease in the Ca content in organo-mineral horizons (on average 2,449 mg/kg), Mg — in organogenic soil horizons (on average 450 mg/kg) — when moving from the Baltic Sea coast to the Curonian Lagoon. However, no such pattern was found for K and Na.

In the samples of their 2 surveyed horizons, an excess of MPC and APC in As (max = 2.7 ± 1.2 mg/kg) was found. The excess of As content noted in soil horizons can be explained by the processes of pulverization with marine aerosols, which is a typical method of its transport [11].

In the samples of their 5 surveyed horizons, an excess of the MPC in Cr (max = 7.4 ± 1.4 mg/kg) was found. In some cases, its increased concentration in the soil horizons of the sandy soils prevailing here may be associated with geochemical barriers (redox conditions) [6]. The presence of chromium in all the soils studied by us, which are sandy in their granulometric composition, regardless of their anthropogenic disturbance, indicates the peculiarities of the mineralogical composition of the sands themselves, which is consistent with the literature data [12].

Thus, the excess of the gross content in individual horizons of As and Cr soils that we have established is of natural origin and is not related to anthropogenic pollution. Based on the conducted research, the ecological and geochemical state of the soils of the Curonian Spit within the framework of the established catena can be assessed as favorable with minor single exceedances of MPC and APC for Sg and As related to the natural features of geology and the coastal position.

The data obtained made it possible to clarify the current geocological state of some types of soils common in the territory of the Curonian Spit National Park, as well as to identify criteria for the physico-chemical state of soils related to modern anthropogenic impact.

¹¹ *Hygienic Standard 2.1.7.2511-09. Approximate Permissible Concentrations (APCs) of Chemicals in the Soil (for Sandy and Sandy Loam Soils)*. Moscow : Federal Center for Hygiene and Epidemiology of Rospotrebnadzor, 2009 (In Russ.); Resolution No. 1 of the Chief State Sanitary Doctor of the Russian Federation dated January 23, 2006 “On the Introduction of Hygienic Standards GN 2.1.7.2041-06.” *KonturNormativ*. (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=9&documentId=299876&ysclid=mkpt70csy5181221664> (accessed: 12.12.2025); Letter of the Ministry of Natural Resources of the Russian Federation dated December 27, 1993 No. 04-25/61-5678 “On the Procedure for Determining the Amount of Damage Caused by Chemical Pollution of Land.” *KonturNormativ*. (In Russ.). Available from: <https://normativ.kontur.ru/document?moduleId=8&documentId=6352&ysclid=mkptb5qce0581410956> (accessed: 12.12.2025).

Conclusion

The conducted study of the ecological and geochemical state of soils in the central part of the Curonian Spit peninsula made it possible to update data on physico-chemical characteristics, including the values of the content of a wide range of toxicological elements. It was found that in 2 soil horizons examined, the As content exceeds the APC; the maximum As content was 2.7 ± 1.3 mg/kg (A1/A2 horizon, SE-3). For 5 of the surveyed soil horizons, the MPC for Cr was found to be exceeded; the maximum content of Cr was 7.4 ± 1.5 mg/kg (A1/A2 horizon, SE-4).

A study of the granulometric composition of soils has shown that the organogenic soil horizons at the points of SE-2 and SE-3 have signs of anthropogenic interference in the past (presumably in connection with the construction of the road), while the rest of the soils developed naturally.

Clarifying the reasons for the increased content of Cr (7.4 ± 1.5 mg/kg) at the SE-4 point does not allow us to conclude about anthropogenic pollution for a number of reasons. Thus, the increased content of Hc is explained by the geological features of the territory and the presence of geochemical barriers: oxidative conditions contribute to an increased content of Hc, while in reducing conditions its content decreases due to active migration.

The increased As content in organogenic and organo-mineral horizons is explained by its active pulverization from the waters of the Baltic Sea (and also, possibly, from the waters of the Curonian Lagoon). At the same time, the SE-4 point is protected by an avandune, which prevents its accumulation. At the same time, it is not possible to exclude anthropogenic impact, since its high content is noted in the disturbed horizons of the SE-2 and SE-3 points. In addition, a number of the studied heavy metals (Zn, Pb, Cu, Ni) have a significant peak concentration in the organogenic horizons of these points, which may also indicate the presence of a modern source of anthropogenic pollution.

The ecological and geochemical state of the surveyed soils: turf slightly podzolic sandy soil (point CAP-1 and CAP-4), slightly podzolic peaty-gleamy sandy soil (point CAP-2) and sod-podzolic sandy soil (point CAP-3), can be assessed as generally favorable with minor isolated exceedances of the MPC and ODC values for Sg and As, respectively.

The conducted research can become the basis for the organization of geochemical monitoring of soils in the natural and anthropogenic territory of the Curonian Spit National Park. The research can be scaled up by increasing the number of research points, laying additional transverse and longitudinal catenae. In general, the values of the majority of the studied parameters indicate the ecological well-being of the research area, which confirms the effectiveness of the implemented measures aimed at its conservation.

References

- [1] Lange EK, Yezhova EE, Bagirov NE, Volodina AA, Gerb MA, Polunina JYu, Sharton AY. Characterization of the state of biota based on the monitoring results of the coastal zone of the Curonian Lagoon within the Curonian Spit National Park in 2021. In: Zhukovskaya IP, editor. *Problems of Studying and Protecting the Natural and Cultural Heritage of the Curonian Spit National Park: A Collection of Scientific Articles*. Issue 18. Kaliningrad: Polygraphic Center of the BFU named after I. Kant; 2023. (In Russ.)
- [2] Rylkov OV, Zhukovskaya IP. Especially valuable natural and cultural sites of the Curonian Spit National Park. In: Zhukovskaya IP, editor. *Problems of Studying and Protecting the Natural and Cultural Heritage of the Curonian Spit National Park: A Collection of Scientific Articles*. Issue 17. Kaliningrad: Publishing House of the BFU named after I. Kant; 2021. (In Russ.)
- [3] Kachynski NA. Mechanical and Microaggregate Composition of the Soil, Methods of Its Study. Moscow: USSR Academy of Sciences; 1958. (In Russ.)
- [4] Bibko AP, Krivovyaz EV, Khrulev TS, Filippenko DP. A research expedition in the Curonian Spit National Park in 2023. Kaliningrad region. In: *Collection of Abstracts of Scientific Research Papers of Participants of the All-Russian Championship "Limitless Expeditions" in 2023 and 2024*. Moscow: ANO «Centre for Expeditionary Assistance»; 2024. p. 56–59. (In Russ.)
- [5] Dotkaev VV, Derevyanchenko YA, Kuzina EV, Baranovskaya AV, Kolesnikov EA, Kasimova DM, Yarovenko PV, Kudryashova YV, Balagurova AD, Bakanova AV, et al. The results of a scientific research expedition in the Curonian Spit National Park of the Kaliningrad region. Kaliningrad region. In: *Collection of Abstracts of Scientific Research Papers of Participants of the All-Russian Championship "Limitless Expeditions" in 2023 and 2024*. Moscow: ANO «Centre for Expeditionary Assistance»; 2024. p. 54–56. (In Russ.)
- [6] Glazovskaya MA. Geochemical barriers in plains soils, their typology, characteristics and environmental importance. *Lomonosov Geography Journal*. 2012;(1):8–14. (In Russ.) EDN: OWYGNF
- [7] Naydenov AS, Vasilko VP, Terekhova SS. *Soil moisture (principles and ways of regulation of water regime of soil)*. Krasnodar : KubGAU; 2020. (In Russ.)
- [8] Komarova IA. The effectiveness of measures to eliminate the consequences of the massive wind in the Curonian Spit National Park (Kaliningrad Region). *Plant Protection News*. 2007;(4):54–56. (In Russ.) EDN: JIVYYM
- [9] Osintseva NV, Schmidt IV, Gorbunova TA, Lauer T, Schneider B, Tinapp C, Stoible H. Subaerial deposits of chernoozerye low ridge (Irtysh valley): granulometric texture, genesis, rate of sedimentation. *Geomorfologiya*. 2022;53(2):51–60. (In Russ.). <https://doi.org/10.31857/S0435428122020080> EDN: EHGE CZ
- [10] Panin AM, Muralev SG. Investigation of the importance of the granulometric composition of soils and soil-forming rocks in carrying out land assessment work. *Vestnik of Lobachevsky University of Nizhni Novgorod*. 2010;(4):109–114. (In Russ.) EDN: MWCFFB
- [11] Breuninger ES, Tolu J, Aemisegger F, Thurnherr I, Bouchet S, Mestrot A, Ossola R, McNeill K, Tukhmetova D, Vogl J, Meermann B, Sonke JE, Winkel LHE. Marine and terrestrial contributions to atmospheric deposition fluxes of methylated arsenic species. *Nature Communications*. 2024;15(1):9623. <https://doi.org/10.1038/s41467-024-53974-z> EDN: INIQL
- [12] Kharin GS, Zhukovskaya IP, Icatchenko SM, Eroshenko DV. Ore sands in Curonian Spit sediments (Baltic Sea). *Okeanologiya*. 2021;61(1):132–140. EDN: KOYYAK

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