Genesis and geochemistry of the soils of urban landscapes of the Black Sea coast of Russia

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Abstract.- In soils of Sochi (the Black Sea coast of Russia), in comparison with natural climatic soil types (burozems, zheltozems (acrisols)), the acid-alkali properties are transformed; in abrozems (technosols), an additional humus content is observed. The pH-water index shifted from 5,8 to 7,5 (average values for the genetic horizons of soils), the degree of saturation with alkali increased 1,3 times in the upper horizon (from 72,9 to 97,7 %) and 1,5 times (from 64,8 to 97,3 %) in the structural-metamorphic BM horizon (argic). Abrazems (technosols) are characterized by a decrease in the humus content relative to the background soils by about 2 times. Assessment of the content in soils of different landscapes of Sochi of a wide range of chemical elements (61) that are excessive and deficient concerning the background has shown the following. Soil contamination is mainly due to its enrichment with elements from mid-soil horizons and underlying parent rocks that can enter the upper soil horizons during excavation works and backfilling of construction sites and roads with local soil. The exception is Ca which enters the soil as a result of urban technogenesis. Pollutants, the contents of which must be controlled when monitoring urban soils, are: Ca, Cu, Ni, Mg, Mn, Cd, K and, additionally, in subordinate urban landscapes: Cs, Ga, Be, Rb, V, Fe, Li, Al, as well as 9 rare earth elements (REE): Dy, Tb, Sm, Ho, Eu, Gd, Sc, Y, Er. The total pollution index for the city's soils is not large; it is a value characteristic of the permissible level of pollution ($Zc > 16$) on slopes, a moderately hazardous pollution category ($Zc = 16 - 32$) on a flat surface adjacent to the slope and a dangerous pollution category ($Zc < 32$) in the coastal zone on the territory of sanatoriums.

Keywords: soil of subtropics of Russia; transformation in urban conditions; geochemical properties of soils.

Génesis y Geoquímica de Suelos de Paisajes Urbanísticos en la Costa Rusa del Mar Negro

Resumen.- Comparados con los suelos naturales zonales (tierras parda y amarilla), los suelos de la ciudad de Sochi situada en la costa Rusa del Mar Negro tienen propiedades ácidas alcalinas transformadas; se ve un contenido adicional de humus en los suelos del tipo abrozemo. El pH del agua cambia de 5,8 a 7,5 (valores medios para los horizontes genéticos de suelos); la saturación con álcalis en los horizontes superior y metamórfico estructural BM (árgico) aumentó por casi treinta (de 72,9 a 97,7 %) y cincuenta (de 64,8 a 97,3 %) por ciento. Los abrazemos tienen un contenido del humus dos veces más bajo en comparación con los suelos de fondo. La evaluación del contenido en suelos de diferentes paisajes de Sochi de una amplia gama de elementos químicos (61) que son excesivos y deficientes en relación con el fondo ha demostrado lo siguiente: La contaminación del suelo se debe principalmente a su enriquecimiento con elementos de los horizontes medios del suelo y rocas madre subyacentes que pueden ingresar a los horizontes superiores durante los trabajos de excavación y el relleno de sitios de construcción y carreteras con suelo local. La excepción es el Ca que entra el suelo por medio del tecnogénesis urbano. En el transcurso del monitoreo de suelos urbanos hay que controlar el contenido de Ca, Cu, Ni, Mg, Mn, Cd, K y también el contenido de Cs, Ga, Be, Rb, V, Fe, Li, Al y de nueve elementos de tierras raras (ETR) (Dy, Tb, Sm, Ho, Eu, Gd, Sc, Y, Er) en paisajes urbanos subordinados. El índice total de contaminación de los suelos en la ciudad no es alto y tiene un valor admisible ($Zc > 16$) en las pendientes, encaja en una categoría de peligro ligero ($Zc = 16 - 32$) en la superficie plana adyacente a la pendiente y en una categoría de peligro alto ($Zc < 32$) en la zona litoral del territorio de los sanatorios.

Palabras clave: suelos subtrópicos de Rusia; transformación en entorno urbano; propiedades geoquímicas de suelos.

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1. Introduction

The increase of urban areas causes a growing interest of international soil science in the genesis of urban soils. The change in the global ecological potential of soils is due to an increase in the technogenic load on the topsoil. Areas with natural and arable land with actively functioning soil are being reduced. Prediction of changes in the ecological functions of the urban topsoil in order to find new ways to preserve these functions is the most important problem of modern soil science. It is possible to solve it only with a comprehensive study of the transformation of all the properties of urban soils that are formed in different natural and technogenic conditions.

In recent decades, the nomenclature and classification of urban soils, reflecting their transformation processes with increasing urbanization, have been widely discussed [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. The processes of reducing the content of humus, total concentrations of N, and the microbial activity of urban soils have been studied [11]. The geochemical features of the soils of the urban landscapes, the spectra of chemical elements whose contents in soils significantly exceed the background indicators have also been in the focus of research. It has been established that the content of heavy metals positively correlates with clay and silt particles [12], is connected with the texture of the soil, the content of organic matter in it [13] and the time of technogenic load on the soil [14, 15]. For various environmental conditions, differing in the degree and nature of anthropogenic impact, a similar composition of pollutants has been established: Cd, Cr, Ni, Zn, Cu, Pb, As, Fe, V [16, 17, 18, 19, 20, 21, 22, 23]. Concentrations of these elements in soils of different types of land use in cities vary within 2–4 orders of magnitude [24, 25, 26]. The degree of variation in the concentration of elements decreases in the following row: Zn> Cr> Ni> Pb> Cu> As> Cd> Hg (Li, 2018). Quite often, the integrated potential environmental risks (PER) of contaminated soils vary from low [27], elevated [26, 28], significant and very high levels [13, 29, 25]. In a number of cases, geochemical anomalies take place in urban conditions, caused not by technogenesis, but by the natural factors of the composition of regional parent rocks [30, 31] or by location near active volcanoes [32]. The alkalization of soils takes place everywhere due to the intake of metal salts occurring as a result of urban technogenesis and having, as is known, an alkaline reaction [33, 34, 35].

With extensive data on the transformation of soils in urban areas, an objective assessment of their changes with an increasing technogenic load in specific regional conditions is important.

Soils of Sochi, located on the Black Sea coast of Russia in the subtropical climate zone, have developed on rocks that are very rich in chemical elements (black tar shales, dark blue mudstones, siltstones). In Sochi during the Olympic construction in 2014, additional elements from the fragmented local rocks used for backfilling of roads and construction sites were involved in the migration processes. A study of soils in the zone of such an active impact can help to identify new theoretical aspects of the geochemistry of technogenesis. In addition, international scientific publications lack information on the spread and behavior of chemical elements in the urban soils of the subtropical zone of Russia.

Studying the soil genesis of Sochi, identifying geochemical indicators of their transformation processes in typical urban landscapes is the main research objective.

2. Material and Methods

2.1. *Objects*

Soils of Sochi were studied in the water divide – slope – coastline system of two ecological and geochemical profiles (Figure 1). The latter are located in the Khostinsky district of the city between the lower reaches of the Sochi and Bzugu rivers, along the banks of the Gnilushka stream flowing between them. All of these streams flow into the Black Sea. The first (conditionally background) profile is located on the territory of the Sochi Arboretum Park, the second is located in the zone of active urban technogenesis adjacent to the park from the southeast. The anthropogenic factor, both of the studied region and the whole territory of the city, is mainly due to the typical urban infrastructure, conveyor lines, thermal power plants, household waste, etc. For Sochi, which has historically developed as a resort city [36], industrial facilities are not typical. The terrain is low-mountain of erosion-denudation type, near the coastal zone characterized by a wide spread of the processes of hill-creeping, planar erosion and slow movement of the weathering crust. The upper points of the profiles are located at an altitude of approximately 120 m, the lower points - at a height of 10 m above sea level.

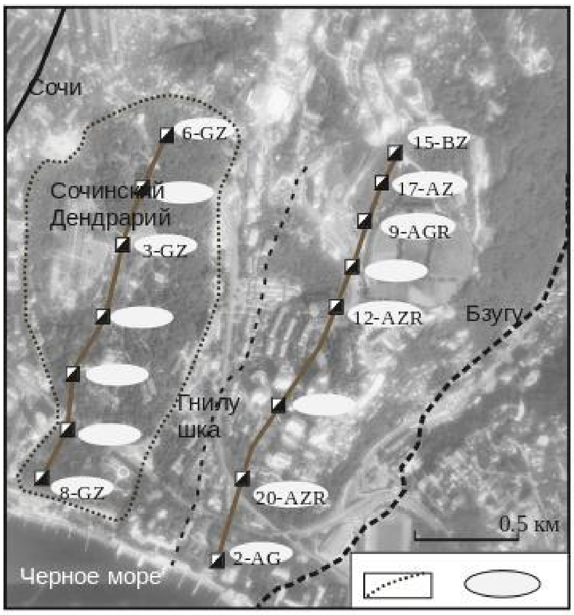

Figure 1: Schematic map of soil sampling in Sochi. 1 - border of the Sochi Arboretum; 2 - sampling points, numbers of sampling points. Latin letters used for soil indices: GZ – yellow soil. BZ – burozem (brown soil). AZR – reclaimed technosol (abrazem). AGR– agro-abrazem. AZ– technosol (abrazem). AG– agrozem

One of the most challenging tasks in characterizing the geochemical properties of soils in urban landscapes is the selection of similar sites not affected by anthropogenic impact for assessing the natural geochemical background (background soil-geochemical parameters), a comparison with which reveals the technogenic geochemical anomalies that are not related to the natural composition of rocks and soils.

By the conditions and type of soil formation, the soils of the Arboretum park are closest to the studied urban soils (transformed zheltozems and burozems (Acrisols)). However, although to a much lesser extent, this area is also experiencing anthropogenic urban pressure. Therefore, at a considerable distance from the city on the territory of the Caucasian State Reserve upstream the Achipse river (the right tributary of the Mzymta river, 40 km northeast of the lower point of the technogenic profile), close in genesis natural soils (lithosolic burozems (acrisols)) were studied, which, like urban soils, are characterized by zonal soil formation.

The parent rocks selected for the comparison are similar. On the territory of the Arboretum park and in the urban area of active technogenesis, the parent rocks are represented by Oligocene clays with interlayers of siltstones and sandstones; upstream the Achipse river, the parent rocks are mainly terrigenous (clastic) rocks represented by Jurassic mudstones, with interbeds of siltstones and sandstones.

2.2. *Methods*

Soil diagnostics was carried out in accordance with the Russian Soil Classification, 2008 [37], at the first mention of the name of the soil, its name is given in accordance with the World Reference Base for Soil Resources, WRB. The following indicators were evaluated in the soils: humus - according to Tyurin in the modification of Central Research Institute of Agrochemical Services for Agriculture (GOST 26213-91) with the selection of plant residues during sample preparation by further oxidation of the organic substance with a solution of potassium dichromate in sulfuric acid and the subsequent determination of trivalent chromium, equivalent to the content of organic matter, using a photoelectric colorimeter; water and salt pH (1 mEq/L KCl) extracts (soil-solution ratio = 1:2,5) potentiometrically (GOST 26423-85, GOST 26483-85, respectively); hydrolytic acidity according to the Kappen method in the modification of Central Research Institute of Agrochemical Services for Agriculture titrometrically (extract of 1 mEq/L CH_3COONa, in the soil: solution ratio of 1:2,5, GOST 26212-91); the content of exchange forms of calcium and magnesium trilonometrically with the extraction of 1 mEq/L NaCl (GOST 26487-85).

The gross contents of 61 chemical elements in soils were determined by quantitative methods - mass spectrometric and atomic emission analyzes with inductively coupled plasma (ICP-MS and ICP-AES) according to the certified method of Scientific Council on Analytical Research Methods No.499-AES/MS "Determination of the elemental composition of rocks, soils, and bottom sediments by inductively coupled plasma atomic emission and inductively coupled plasma mass spectral methods". Equipment used: inductively coupled plasma mass spectrometer Elan-6100 (Perkin Elmer, USA); inductively coupled plasma atomic emission spectrometer Optima-4300 DV (PerkinElmer, USA).

The procedure for decomposition of samples in an open system using HF, HNO_3, HCl and $HClO_4$ was applied. The decomposition stage of each sample was controlled using stable isotopes. The correctness of the analysis was confirmed by the use of standard samples. The chemical yield of all analyzed elements using this method of dissolving the samples, as a rule, is 90-100 %.

The tolerance in the determination of the content of chemical elements using these methods and the application of an external standard is ≤ 6 %. Method detection limits for soils are hundredths of micrograms per gram ($\mu g/g$) for trace elements and hundredths of % for macrocomponents. The decomposition method and subsequent analysis of the obtained solution by ICP-MS + ICP-AES is described in detail in [38].

The content of mobile forms of rare-earth elements (REE) in soils was identified by ICP-MS + ICP-AES methods according to the certified method of Scientific Council on Analytical Research Methods No.500-MS "Determination of the elemental composition of nitric acid and acetate-ammonium extracts from soils by mass spectrometry with inductively coupled plasma". When extracting mobile REE forms from soils, an ammonium acetate extract (pH = 4,8) was used. The ratio of solid to liquid = 1:10.

2.3. Statistical processing

The average geochemical backgrounds of the elements for the region in general (Cϕp) in the soils of the Arboretum and the Caucasus Nature Reserve are calculated as the arithmetic mean values of the element contents at the 7th and 18th observation points, respectively. The calculation method took into account the small range of the gross contents of chemical elements (Cϕ).

The calculation of the clarkes of the elements concentration (K_k) in soils was made using the following ratio:$K_k = C\phi/K$ for soils, where K is the general content of elements in continental soils (soil clarkes) [39]. The whole range of values $1 > K_K > 1$ is considered in the present study; when interpreting the results, the traditional for geochemistry terminology is used: $K_K > 1$ – excessive elements, $K_K < 1$ – scarce chemical elements.

The degree of similarity of the elemental composition of soils of two background territories was determined by calculating the rank correlation coefficients for concentration clarkes (K_k).

To determine the degree of soil pollution, the total pollution index $Zc = \sum Kci - (n-1)$ was calculated, where Kci is the concentration coefficient of the ith element in the soil, equal to the ratio of its actual content at the observation point (Ci) to the local background (Cϕi) [40, 41]. The content of trace elements in terms of MPC (maximum permissible concentrations) (hygienic norms GB 2.1.7.2041-06) and APC (approximate permissible concentrations) (hygienic norms GB 2.1.7. 2511 – 09) was established.

To determine the sources of soil pollution in the subordinate urban landscapes, rank correlation coefficients were calculated using the Kci indices of the average structural and metamorphic horizon BM of the soil of the autonomous landscape (clay horizon (argic)) and the upper horizons of the soils of anthropogenic profile.

The approximate assessment scale of the danger of soil pollution by the Zc total pollution index has the following categories: acceptable - less than 16, moderately dangerous - 16-32, dangerous - 32-128, and extremely dangerous - more than 128 (Saet, 1990). Permissible gross concentrations (MPC, APC) of the elements in the soil under consideration are: Sb-4,5 (MPC) mg/kg, Mn-1500 (MPC) mg/kg, V-150 mg/kg (MPC), Pb 32 (MPC) and 130 (APC) mg/kg, As 2,0 (MPC) and 10,0 (APC) mg/kg, Cd-2,0 (APC) mg/kg, Cu–132 mg/kg (APC), Ni–80 mg/kg (APC), Zn–220 mg/kg (APC), (hygienic norms GB 2.1.7.2041-06, GB 2.1.7. 2511-09).

3. Results and discussion

3.1. General characteristics of urban soils

To understand the peculiarities of the formation of the geochemical composition of urban soils, it is important to have the information on the morphological structure of their profiles and physico-chemical properties caused by technogenesis. The features of changes in the soil structure of typical urban landscapes of the studied technogenic profile are clearly shown in the schematic diagram (Figure 2).

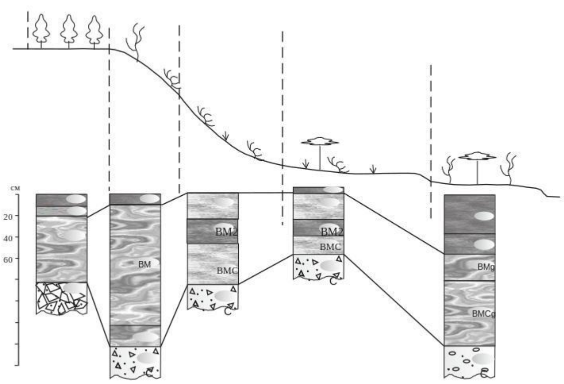

Figure 2: A generalized scheme of changes in the structure of soil profiles of characteristic urban landscapes of Sochi in the system of water divide - slope - coastline. Horizon indices are given in accordance with the Russian Soil Classification, 2008 (Shishov, 2008): AY - gray humus (fulvic); BM - structural-metamorphic (argic); BMg - structurally-metamorphic gleysolic (argic with gleysolic features); PB - agro-abrazem (hortic); W - poorly developed humus (fulvic); PU - agro dark humus (hortic with signs of chernic)

Typical burozems (Acrisols (Clayic)) with a natural profile structure are developed on an autonomous water-dividing surface in the area of minor technogenic impact (the vicinity of the weather station) in a virtually non-transformed hornbeam-beech forest.

For the upper parts of the slopes of Sochi, local plantations of subtropical cultures (used or abandoned gardens) are quite common. Within the studied profile, the soil of such a landscape on the territory of an abandoned hazelnut garden has been described. The upper soil horizon is formed here as a result of agrogenic transformation of the middle structural-metamorphic BM horizon (clayey (argic) horizon). The middle and lower parts of the profile have not been transformed. The soil can be defined as structural-metamorphic agro-abrazem (Fulvic Anthrosols (Aric, Clayic)).

Down along the terrain, on slopes with a steepness of about 20-2500, most common are soils altered to the state of structural-metamorphic abrazems (Technosols (Clayic)). As a result of excavation work carried out for terrain leveling, humus horizons have been completely lost (cut off). In view of the absence of well-developed grass cover (only the cover of the trimmed lawn) and shrubbery in such areas, the formation of humus horizons is difficult. On the surface of abrazems, lie mineral horizons, composed of displaced and mixed mineral matter, similar in morphological and mesomorphological characteristics to the material of structural-metamorphic BM horizons of the natural zheltozems and burozems.

In local areas of the long-standing transformation of natural soils, thin organic-mineral horizons have been formed on the surface of abrazems. Here, soils can be defined as structurally-metamorphic reclaimed abrazems (FulvicTechnosols (Clayic)).

The subordinate landscapes of coastal terraces are actually occupied by sanatoriums along the entire city coast. The history of the development of this coastal area has been associated with the construction of a sanatorium infrastructure and the creation of arboretums of exotic plants [36]. To cultivate the soils, highly humified material of the organomineral soil horizons, delivered mainly from the chernozem area of Russia (chernozem horizons (chernic)), was applied to the surface of the local soils. The thickness of the newly created organomineral horizons of the cultivated soils of the sanatorium area of the Sochi agglomeration varies on average from 15 to 20 cm, sometimes reaching 30-35 cm. The soils have the parameters of structural-metamorphic dark agrozems (Chernic Teric Anthrosols (Aric, Clayic)).

The change in the physical and chemical properties of the soils within the technogenic profile was evaluated in comparison with the soils of the Arboretum park (Table 1). A significant transformation of their acid-alkali properties is noted, and for abrozems, additionally, the transformation of the humus parameters is observed. The pH-water index shifted from 5,8 to 7,5 (average values for the genetic horizons of soils), the degree of saturation with alkali increased 1,3 times in the upper horizon (from 72,9 to 97,7 %) and 1,5 times (from 64,8 to 97,3 %) in the structural-metamorphic BM horizon. Abrazems (technosols) are characterized by a decrease in the humus content relative to the background soils by about 2 times. The transformation of the acid-alkali properties of soils is caused by the ingress with surface runoff and drainage water of metal salts occurring in the water due to technogenesis and, as is known, having an alkaline reaction [33, 5, 34].

3.2. *Features of the geochemistry of zonal soils outside the area of active technogenesis*

The assessment of the features of the elemental composition of zonal soils (Table 2), which do not experience the active technogenic impact of the urban agglomeration, was carried out by calculating the clarkes of concentrations of chemical elements for the soils of the Arboretum park and soils of the Caucasus State Nature Reserve. A comparative analysis of the regional characteristics of the elemental composition of zonal soils with the general spread of elements in the continental soils (clarkes of soils) was performed [39]. For background samples of the abovementioned soils, geochemical formulas were constructed in which the clarkes of the elements concentration (K_k) were ranked in decreasing order (Table 3). In the formulas, above the line are the elements with regional background concentrations which exceed their values in continental soils or are close to them (hereinafter, excess elements with $K_k \geq 1$). Below the line are the elements which are deficient ($K_k < 1$).

In general, the zonal soils developed in this case on clays and mudstones with interlayers of siltstones and sandstones are characterized by a rich elemental composition in comparison with the average indices for the continental soils. Out of the total number of the studied chemical elements, the values of K_k exceeding or close to 1 are typical both for the soils of the Arboretum and for the soils of the Caucasus Nature Reserve, more than half (52 % of the elements for the soils of the Arboretum park, 68 % - for the nature reserve). The number of elements, whose contents significantly exceed clarke values of $K_k \geq 1.5$, is 10 for the soils of the Arboretum park and 36 for the soils of the reserve.

A richer composition of the soils of the reserve in comparison with the soils of the Arboretum is due to the genesis of rocks upstream the Achipse river. As indicated above, this place is characterized by the development of terrigenous (clastic) mudstones. Soils are formed here on considerably fragmented (due to the high steepness of the slopes reaching 35-400) mudstones that occur, as shown by the field morphological description of soils, close to the surface. Close contact with crushed rock rich in chemical elements is the cause of a relatively high content of elements in the soils of this area in comparison with soils of the Arboretum park.

On the whole, the rich elemental composition of soils in both territories is determined by the features of the geochemical composition of sedimentary clay rocks on most of the Sochi coast. According to the data on the clarkes of rocks that compose the upper part of the continental crust [42], the content of a large spectrum of chemical elements is increased in clays and shales relative to other sedimentary rocks. Elements whose clarks are approximately twice the clarks of other rocks are the following: Li, K, Rb, Cs,Al, Sn, P, As, Cu, Ni, Co, Ag, Zn, Sc, Cd, Th, Pb, Ta, V, Nb, Cr, W and rare-earth elements related (by analogy with [43]) to the groups of light and medium REE (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy).

A comparison of the geochemical properties of

Table 1: Physical and chemical properties of soils

Horizon	Depth (cm)	pH		Humus (%)	Ca^{+2}	Mg^{+2}	Hidrolytic acidity	Soil saturain with alkali
		water	KCl		$cmol_{(equiv.)}/kg$			(%)
The upper part of the Arboretum park, typical yellow soil (Acrisols (Clayic)), section 6								
AY	0–10	5,6	5,4	7,23	22,3	5,9	6,1	82,1
AYB	10–20	5,8	4,8	5,17	16,1	3,9	5,9	77,2
BM	20–70	6,5	5,8	4,61	19,9	5,3	2,0	92,7
Middle part of the park, gleysolic yellow soil (Stagnic Acrisols (Clayic)), section 3								
AY	0-10	5,6	4,9	7,2	18,3	2,9	5,9	78,2
BM	10-27	6,1	5,2	5,3	16,5	2,7	3,4	84,8
BMg1	27-60	6,2	4,7	4,2	14,6	4,1	3,6	83,7
BMg2	60-70	6,1	4,0	4,0	5,9	3,9	3,9	83,1
Lower part of the park, gleysolic yellow soil (Stagnic Acrisols (Clayic)), section 8								
AY	0-10	5,5	4,7	2,9	5,2	1,8	5,9	54,2
BM	10-30	5,7	4,1	1,9	2,9	1	5,5	41,6
BMg1	30-50	5,8	4,0	1,9	4,0	0,9	9,7	33,5
BMg2	50-70	5,6	3,7	1,8	6,1	3,1	17,6	34,3
Technogenic profile, water divide surface of the Bzugu River and Gnilushka stream, section 15, typical burozem (Acrisols (Clayic))								
AY	0-0,5	7,0	6,9	3,7	20	4,4	0,7	97,9
AYBM	0,5-12	7,2	6,9	2,5	21,4	3,9	0,6	97,6
BM	30-90	7,9	7,3	2,3	24,8	4	0,6	98,1
BMC	90-115	8,1	7,2	2,0	25,1	4,1	0,5	98,9
Upper part of the slope, typical agro-technosol, (Fulvic Anthrosols (Aric, Clayic)), section 9								
PB	0-2	6,7	6,6	5,3	39,8	5,3	1,9	96,1
BM	2-92	7,5	7,3	2,4	27,7	2,6	0,6	98,0
BMg	92-115	7,9	7,3	1,9	24,6	3,2	0,6	98,1
Middle part of the slope, structural-metamorphic technosol (Technosols (Clayic)), section 12								
BM1	0-20	7,6	6,9	2,4	26,2	2,1	0,6	98,7
BM2	20-45	8,2	7,4	2,3	24,9	2,5	0,4	98,0
Coastal terrace, "Avantgarde" sanatorium, dark structural-metamorphic agrozem (Chernic Anthrosols (Aric, Clayic)), section 2								
PU1	0-35	7,07	6,75	6,67	38,96	2,20	0,74	98,23
PU2	35-45	7,70	6,99	4,31	20,81	3,81	0,55	97,81
BMg	45-70	7,63	6,17	4,24	12,90	4,26	0,92	94,91
BMCg	70-120	7,35	6,00	4,06	20,27	4,62	1,20	95,40

the soils of the two studied areas reveals their similarity in the composition of both excess and deficient elements. The coefficient of K_k rank correlation for the soils of the Arboretum park and the soils of the Caucasus Nature Reserve is 0,799. Taking into account the amount of data used, $n = 53$, $r_{5\ \%\ crit} = 0{,}271$.

This makes it possible to refer both areas to the same geochemical category, according to the analysis of which the group of excess elements ($K_k \geq 1,5$) should include: Zn, Mn, Cs, Sn, As, Ta, W, Li, Bi, Cu, Ni, Pb, Co, Th, Sc, Ag, Rb, Tl, while the group of excess elements ($K_k \leq 0.5$) should include: Mo, Hf, Zr, Sr, Ca. As can be seen from the above list of excess chemical elements, most are included in the spectrum of elements contained in elevated concentrations in clay and shales, characteristic of the territories under consideration and for the region as a whole. It is only necessary to note the absence of excess elements in soils of rare-earth elements, as well as the absence of Mn and Bi.

The high content in the soils of the Arboretum park of Zn ($K_k = 5,9$) should also be noted. For the soils of the reserve with relatively elevated contents of most elements, the K_k level of Zn is also high, but it is 2,3 times lower than in the Arboretum. This feature is due to the local geochemical features of the geological foundation of the Arboretum park territory. In accordance with the scheme of mineralogical zoning upwards the terrain of this region, upstream the Sochi and Bzugu rivers, there are several mineralogenic zones and ore areas with different compositions of excess elements. Two geochemical anomalies are characterized by the presence of excess Zn in the

Table 2: The content of chemical elements in the soil of Sochi and in the continental soils (Clarke-K). Na, Mg, Al, K, Ca, Ti, Mn, Fe in %. Other elements in mg/kg.

Element	K	Arboretum background	Reserve background	Eluvial landscape		Transeluvial landscape				Superaquatic landscape		
				Soil Index (point number)								
				BZ (15), AY horizon	BZ (15), BM horizon	AZ (17)	AGZ (9)	AZ (18)	AZR (12)	AZ (19)	AZR (20)	AG (2)
Li	30	40,77	83,60	43,10	57,00	53,60	38,10	51,90	39,90	39,90	46,20	35,20
Be	1,5	1,22	2,70	1,45	1,79	1,70	1,22	1,72	1,42	1,27	1,53	1,19
Na	0,63	0,75	0,93	0,66	0,84	0,75	0,50	0,68	0,65	0,53	0,61	0,73
Mg	0,63	0,37	0,84	0,53	0,67	0,61	0,50	0,68	0,49	0,36	0,78	0,65
Al	7,13	5,05	8,84	5,40	7,35	6,61	4,85	6,56	4,90	4,97	6,14	5,08
K	1,36	0,92	1,67	1,19	1,51	1,34	1,05	1,36	1,09	0,81	1,38	1,00
Ca	1,37	0,42	0,14	1,07	0,34	0,75	1,21	2,93	2,24	0,91	5,36	3,02
Sc	8	9,90	16,90	11,20	14,40	13,10	10,40	14,10	10,50	10,40	13,60	10,40
Ti	0,37	0,37	0,40	0,29	0,34	0,32	0,24	0,31	0,25	0,44	0,35	0,34
V	90	80,57	150,90	90,70	122,90	108,9	76,30	115,8	91,60	92,70	108,8	90,90
Cr	60	60,40	78,70	55,90	73,30	66,30	50,00	74,90	48,00	60,70	70,90	70,90
Mn	0,05	0,08	0,29	0,12	0,06	0,06	0,05	0,09	0,07	0,15	0,06	0,12
Fe	3,8	2,51	4,66	2,69	3,76	3,38	2,48	3,83	3,23	3,29	3,32	3,64
Co	9	9,56	23,40	11,00	13,20	11,20	7,56	17,20	11,60	19,30	11,40	11,20
Ni	20	24,13	51,80	37,10	42,50	41,70	28,80	42,50	38,00	24,00	41,50	34,80
Cu	23	26,10	63,40	33,60	40,00	57,00	43,30	42,30	38,00	26,60	35,30	104,3
Zn	60	352,5	155,70	99,70	109,30	98,90	126,3	107,1	95,80	73,50	98,90	977,8
Ga	20	12,08	24,20	14,50	18,90	17,10	12,70	17,60	13,40	12,20	17,00	12,50
As	6	9,28	23,50	8,08	8,81	8,83	7,46	10,80	11,50	9,73	9,28	11,60
Rb	70	78,90	133,40	94,20	119,60	109,3	83,10	108,3	86,70	73,90	108,5	77,40
Sr	220	82,37	75,00	84,50	77,80	95,30	83,40	127,8	118,8	83,80	177,1	175,9
Y	25	15,73	14,10	17,30	20,00	20,80	16,90	20,60	19,20	14,90	21,60	15,20
Zr	300	136,8	84,50	123,90	129,60	135,7	101,8	110,9	104,0	140,2	141,9	95,70
Nb	11	14,37	15,00	11,30	12,20	12,00	9,14	11,10	9,70	16,00	12,90	12,00
Mo	2	1,03	0,94	0,96	1,08	0,93	0,70	1,16	1,85	1,21	1,22	1,64
Ag	0,1	0,12	0,19	0,05	0,05	0,05	0,05	0,05	0,10	0,05	0,05	2,65
Cd	0,16	0,21	0,16	0,44	0,25	0,22	0,29	0,25	0,69	0,15	0,23	0,93
Sn	1,1	2,62	3,59	2,60	2,69	2,66	2,27	3,45	2,23	2,42	2,66	9,55
Sb	0,9	0,94	0,99	0,91	0,92	0,96	0,72	1,06	1,19	0,96	0,73	1,61
Cs	3	4,57	12,80	5,70	7,67	7,07	5,18	7,10	5,21	4,79	7,03	4,03
Ba	500	372,2	457,00	306,30	303,90	306,9	242,8	334,8	283,1	278,4	310,6	467,0
La	40	26,47	22,00	24,50	28,20	31,20	22,80	30,30	25,00	26,10	28,30	25,60
Ce	50	61,03	57,80	58,80	67,60	68,90	52,10	72,60	60,90	70,80	63,40	56,90
Pr	7	5,97	5,54	5,96	6,54	7,07	5,31	6,94	6,25	6,25	6,44	5,69
Nd	33	25,47	25,70	26,60	30,20	31,30	22,90	31,30	27,90	26,60	28,90	23,70
Sm	5	4,68	5,89	5,01	5,89	6,28	4,64	6,19	5,48	4,96	5,65	4,50
Eu	1	0,96	1,18	1,07	1,15	1,27	1,00	1,26	1,15	0,95	1,18	1,00
Gd	4	4,02	4,70	4,59	4,90	5,34	4,20	5,29	4,98	4,15	5,04	3,98
Tb	0,7	0,56	0,63	0,65	0,69	0,76	0,60	0,77	0,71	0,56	0,74	0,55
Dy	5	3,38	3,44	3,96	4,13	4,60	3,56	4,58	4,10	3,53	4,46	3,20
Ho	0,6	0,60	0,54	0,63	0,69	0,81	0,63	0,73	0,73	0,60	0,77	0,54
Er	2	1,88	1,60	2,03	2,10	2,37	1,89	2,16	2,07	1,86	2,37	1,55
Tm	0,4	0,26	0,21	0,28	0,28	0,32	0,26	0,30	0,28	0,28	0,33	0,21
Yb	3	1,96	1,55	2,08	2,07	2,40	2,05	2,10	2,00	2,02	2,42	1,47
Lu	0,35	0,26	0,21	0,28	0,27	0,33	0,26	0,29	0,28	0,29	0,33	0,22
Hf	7	3,51	2,18	3,00	3,04	3,37	2,68	2,62	2,50	3,53	3,37	2,16
Ta	1	2,12	2,30	1,24	1,51	1,72	1,35	1,51	1,24	1,74	1,57	1,15
W	1	2,13	2,11	1,69	1,79	1,81	1,73	1,71	1,33	2,36	2,65	1,86
Tl	0,3	0,38	0,49	0,39	0,47	0,42	0,36	0,41	0,35	0,44	0,45	0,37
Pb	20	29,87	43,70	28,30	23,50	32,40	22,40	24,90	22,00	34,40	17,60	149,5
Bi	0,2	0,32	0,50	0,30	0,34	0,29	0,26	0,30	0,24	0,31	0,30	1,15
Th	6,5	10,90	11,90	9,97	11,30	10,80	9,22	10,70	9,31	11,60	10,90	7,59
U	1,5	2,10	1,44	1,84	2,05	2,06	1,47	1,72	1,82	2,59	1,98	1,61
∑REE	185	163	162	165	189	197	150	200	172	188	186	155
Zc				7,45	12,14	12,94	5,31	19,56	13,06	6,66	24,02	46,59

composition. Under such conditions, the increased content of this element in the soils of the adjacent territories is quite likely.

The relatively high concentrations of chemical

Table 3: Clarkes of concentrations of chemical elements for zonal natural soils in comparison with the total element contents for continental soils

Area	Geochemical formula
Arboretum park	Zn(5.9)-Sn(2.4)-W. Ta(2.1)-Th(1.7)-Bi, As(1.6)-Cs, Mn, Pb(1.5)-U, Li(1.4)-Cd, Nb,Tl(1.3)-Sc, Ce, Ni, Ag, Na(1.2)-Cu, Rb(1.1)-Co, Sb, Ti, Cr, Gd, Ho, Eu(1.0) Er, Sm, V, Pr(0.9)-Be, Tb, Nd, Lu(0.8)-Ba, Al, K, Dy, La, Fe, Tm, Yb (0.7)-Y, Ga,; Mg(0.6)-Mo, Hf, Zr(0.5)-Sr(0.4)-Ca(0.3)
Caucasian Reserve	Mn(5.7)-Cs(4.3)-As(3.9)-Sn(3.3)-Li, Cu(2.8)-Co, Zn, Ni(2.6)-Bi(2.5)-Ta(2.3)- Pb(2.2)-Sc, W(2.1)-Rb, Ag(1.9)-Th, Be(1.8)-V(1.7)-Tl(1.6)-Na(1.5)-Nb(1.4)- Mg, Cr(1.3)-Al,K, Fe, Ga, Eu, Sm, Gd, Ce(1.2)-Sb, Ti (1.1)- Cd(1.0)-U(1.0) Ba, Ho, Tb (0.9)-Er, Pr, Nd (0.8)-Dy(0.7)-Lu, Y, La(0.6)-Tm, Yb, Mo(0.5)-Sr, Hf, Zr(0.3)-Ca(0.1)
Regional averaged background	Zn(4.2)-Mn(3.6)-Cs(2.9)-Sn(2.8)-As(2.7)-Ta(2.2)-W,Li,Bi(2.1)-Cu(2.0)-Ni(1.9)-Pb, Co(1.8)-Th,Sc(1.7)- Ag(1,6)-Rb,Tl(1.5)-Nb,Na,Be,V(1.3)-Ce,U,Cr,Cd(1.2)-Gd,Sb,Eu,Sm,(1.1)-Ti,Al,Mg,K,Ho (1.0) Fe,Ga,Er,Tb(0.9)-Ba,Pr,Nd(0.8)-Dy,Lu(0.7)-La,Y,Tm,Yb(0.6)-Mo(0.5)-Hf,Zr,Sr(0.4)-Ca(0.2)

elements in the soils of the two studied areas are confirmed by the assessment of their contents relative to the established MPC and APC (Table 4). The content of some elements in actually natural soils are increased relative to normalized values. Maximum excess values were registered for As (4,6 - 11,8 MPC and 2,3 APC) and for Zn (1,6 MPC). In the soils of the Caucasian reserve, additionally, the excess value for Pb (1,4 MAC) was registered.

3.3. Geochemical features of urban soils

The geochemical features of urban soils studied within the technogenic profile were estimated by calculating the concentration coefficients of chemical elements. The average content of elements in the soils of the Arboretum park was taken as a geochemical background. These soils, as shown above, do not significantly differ in the qualitative composition of the elements from the soils of the Caucasus Nature Reserve, which are not affected by anthropogenic impact.

The total pollution index (Zc) of soils is expected to increase from an autonomous landscape to a subordinate one (Table 2). In the eluvial landscape in the upper humus horizon of soils, the value of Zc is 7,5; on a slope, the indicator increases on average 1,5 times; on a flat surface adjacent to the slope, the value of Zc increases in relation to the autonomous position by 3,2 times; and in the coastal zone (the territory of the sanatorium "Avantgarde") this value increases by 6,2 times.

The lowest Zc is typical for agro-abrazems developed on the territory of a hazelnut garden (point 9), where the impact of technogenesis has been weak. A small spectrum of excess elements and their low Kc values are similar to those for the soil of an autonomous landscape.

The features of chemical pollution of urban soils are clearly reflected in geochemical formulas (Table 5), which show elements with Kc over 1,3, ranked in decreasing order of this indicator.

The maximum concentration coefficients for chemical elements located in the first place of geochemical formulas grow sequentially from 2,6 on the eluvial surface to 2,2–6,7 on the slope and to 12,1–17,1 in the subordinate coastal landscape.

The dominant position in most of the above formulas is occupied by Ca, which once again confirms the conclusion about a significant alkalization of soils as a result of urban technogenesis. Pollutants with elevated Kc in all elemental landscapes should include: Cu, Ni, Mg, Mn, Cd and K. In addition, elevated Kc in subordinate urban landscapes contain: Cs, Ga, Be, Rb, V, Fe, Li, Al, as well as 9 REE: Dy, Tb, Sm, Ho, Eu, Gd, Sc, Y, Er. The content of REEs is due to the geochemical features of the rocks of the territory, which differ, as noted above, by their elevated clarkes. On the one hand, most of the listed chemical elements are typical of almost any technogenic geochemical anomaly [40]. Their source is emissions of vehicles, local heating systems, household waste and runoff. On the other hand, they all determine the geochemical specialization of the clayey rocks of the territory [42] and can enter the soil during excavation works and the backfilling of construction sites and roads with local soil.

Table 4: Gross microelements content in MPC (p) and APC (o)

Territorial levels		V	Mn	Ni	Cu	Zn	As		Cd	Sb	Pb	
		p		o			p	o	p		p	o
Regional background	Arboretum	0,54	0,50	0,30	0,40	1,60	4,64	0,93	0,21	0,21	0,93	0,23
	Reserve	1,01	1,91	0,65	0,96	0,71	11,75	2,35	0,16	0,22	1,37	0,34
Urban soils. Soil indices (point numbers)	BZ (15), A horizon	0,60	0,83	0,46	0,51	0,45	4,04	0,81	0,44	0,20	0,88	0,22
	BZ (15), BM horizon	0,82	0,40	0,53	0,61	0,50	4,41	0,88	0,25	0,20	0,73	0,18
	AZ (17)	0,73	0,40	0,52	0,86	0,45	4,42	0,88	0,22	0,21	1,01	0,25
	AGZ (9)	0,51	0,33	0,36	0,66	0,57	3,73	0,75	0,29	0,16	0,70	0,17
	AZ (18)	0,77	0,57	0,53	0,64	0,49	5,40	1,08	0,25	0,24	0,78	0,19
	AZR (12)	0,61	0,50	0,48	0,58	0,44	5,75	1,15	0,69	0,26	0,69	0,17
	AZ (19)	0,62	0,98	0,30	0,40	0,33	4,87	0,97	0,15	0,21	1,08	0,26
	AZR (20)	0,73	0,39	0,52	0,53	0,45	4,64	0,93	0,23	0,16	0,55	0,14
	AG (2)	0,61	0,78	0,44	1,58	4,44	5,80	1,16	0,93	0,36	4,67	1,15

Table 5: Concentration factors of chemical elements for urban soils exceeding the value of 1,3. Values of Kc are given in parentheses

Elemental landscapes	Soil indices (point numbers)*	Chemical elements and their concentration factors
Eluvial	BZ (15), AY horizon	Ca(2,6)-Cd (2,1)-Mn (1,6)-Mg (1,4)-K (1,3)-Cu (1,3)
	BZ (15), BM horizon	Mg (1,8)-Ni (1,8)-Cs (1,7)-K (1,6)-Ga (1,6)-Cu (1,5)-V (1,5)-Rb (1,5)-Fe, Be, Al (1,5)-Sc (1,4)-Co (1,4)-Y (1,3)-Sm (1,3)
Transeluvial	AZ (17)	Cu (2,2)-Ca (1,8)-Ni (1,7)-Mg(1,6)-Cs, K (1,5)-Ga, Be, Rb, Dy, Tb (1,4), V, Fe, Sm, Ho, Eu, Gd, Sc, Y, Li, Al, Er (1,3) 9REE
	AGZ (9)	Ca (2,9)-Cu (1,7)-Cd (1,4)-Mg (1,4)
	AZ (18)	Ca (6,7)-Mg, Co, Ni, Cu (1,8)-Cs, Sr, Fe, K, Ga (1,5)-V, Sc, Be, Tb, Rb, Dy (1,4), Sm, Eu, Sn, Gd, Y, Al, Al, Li (1,3) 7REE
	AZR (12)	Ca (5,3)-Cd (3,3)-Mo (1,8)-Ni (1,6)-Cu (1,5)-Sr (1,4)-Mg, Fe, Sb, Tb (1,3) 1REE
Super-aquatic	AZ (19)	Ca(12,1)-Mg(2,2)-Sr (2,1)-Ni (1,8)-Cs, K (1,6)-Cu, Ga (1,5)-Fe, Sc, V, Rb, Tl, Y, Li, Be (1,4)-Al, Tb, Dy, Ho, Gd, Co, Sm, Eu (1,3) 8REE
	AZR (20)	Ca(12,8)-Sr, Mg (2,1)-Ni (1,7)-Cs, K (1,5)-Ga, Rb, Sc, Y, Cu, V (1,4), Fe, Tb, Dy, Ho, Er, Be (1,3) 5REE
	AG (2)	Ag(17,1)-Ca (7,2)-Pb (5,0)-Cd (4,4)-Cu (4,0)-Sn, Bi (3,6)-Zn (2,8)-Sr (2,1)-Mg (1,7)-Sb (1,7)-Mo, Mn (1,6)-Fe, Ni (1,4)-Ba, As (1,3)

This is confirmed by the similarity of the range of excess elements of the close-to-rock BM horizon of the soil of eluvial position (point 15, BM horizon) with the composition of chemical elements that accumulate below the relief in structural metamorphic abrazems.

The calculation of the rank correlation coefficients (PKK) by the Kc indicator between the BM horizon and the upper horizons of the soils of the technogenic profile showed the highest values of the PKK (0,78 on average, at $r_{5\,\%\,\text{crit}} = 0{,}271$) for structural-metamorphic abrazems (Table 6). As these soils evolve into abrazems that are regraded, with thin primitive humus horizons developed on the surface, their geochemical connection with the BM horizon weakens.

The PKK index decreases from 0,78 to 0,52 on the slope and from 0,77 to 0,68 in the subordinate landscape.

In addition to a decrease in the PKK index in regraded abrazems relative to structural and metamorphic abrazems, the following parameters also decrease: the number of excess REEs with Kc above 1,3 (from 9 to 1) (Table 5) and the total gross content of the REE group under discussion (by about 13 % on the slope and, insignificantly, by 1,4 % in the subordinate landscape) (Table 2). It is likely that the decrease in REE contents in abrazems regraded at the initial stage of organic matter accumulation is due to their inclusion in the composition of mobile organomineral complexes. The latter are removed from the

Table 6: Coefficients of Kc rank correlation of the upper horizons of soils with Kc transition horizon BM of the soil of the autonomous landscape

Soils in accordance with the Classification of Soils of Russia, 2008	Soils in accordance with WRB	Soil indices (point numbers)	BZ (15), BM horizon
Typical burozem	Acrisols (Clayic)	BZ (15)	0,685
Structural metamorphic abrazem	Technosols (Clayic)	AZ (17)	0,803
Structural metamorphic agro-abrazem	Fulvic Anthrosols (Aric, Clayic)	AGZ (9)	0,586
Structural metamorphic abrazem	Technosols (Clayic)	AZ (18)	0,756
Structural metamorphic abrazem, reclaimed	Fulvic Technosols (Clayic)	AZR (12)	0,521
Structural metamorphic abrazem	Technosols (Clayic)	AZ (19)	0,774
Structural metamorphic abrazem, reclaimed	Fulvic Technosols (Clayic)	AZR (20)	0,685
Dark agrozem	Chernic Terric Anthrosols (Aric, Clayic)	AG (2)	- 0,026

soil and accumulate at geochemical barriers, as evidenced by a significant (4,3-fold) increase in the percentage of REE mobile forms (relative to gross contents) from the autonomous landscape to the subordinate (Table 7).

Agro-abrazems and agrozems typical for the Sochi agglomeration stand out from the described scheme of geochemical transformation of urban soils. Agro-abrazems were also formed in the material of the BM horizons but experienced an additional factor during the cultivation of subtropical fruit crops.

Dark agrozem, developed in a subordinate landscape on a coastal lowland in the territory of the "Avantgarde" sanatorium, has a negative correlation of geochemical connection with the BM horizon, since its upper humus horizon is composed of genetically alien material for the region, imported, as noted above, from the chernozem strip of Russia (chernic horizons).

The soil of the territory of the "Avantgarde" sanatorium has a different qualitative composition of excess elements and relatively high values of their Kc. Here, the following elements are added to the range of pollutants: Ag, Pb, Zn, Sn, Sb, and As. This is one of the rare areas within the landscape profile where the location of Ca is typical for soils not at the beginning of the geochemical series, but after silver. The analysis of the geological conditions of the studied area makes it possible to regard the presence of Ag, As, and Sb at the beginning of a series of priority elements as a possible natural geochemical anomaly. As noted above, in the upper reaches of the Sochi and Bzugu rivers mineralogical zones and ore regions are quite widespread. Among them are two zones of gold sulfide mineralization, for which Ag and As and, in some cases, Sb are always the main complementary elements [40].

Analysis of the qualitative composition of excess elements in the soils of different elementary landscapes of the urban area makes it possible to identify two main factors in the formation of geochemical features of the topsoil of the city.

The first factor is natural-technogenic, due to the high content of chemical elements in the rocks of the subtropics of the Black Sea coast, which is reflected in the composition of natural soils and their urban derivatives. For urban soils, an additional source of elements is the excavated deep BM horizons and fragmented local rocks used for the backfilling of roads and construction sites.

The second factor is technogenic, which manifests itself mainly in the coastal sanatorium zone of the city. The relatively high content of elements in the soils of sanatoriums is due to:

1. the subordinate position in the terrain of this territory,
2. the high content of chernozem humus in the soils, which has a high absorption capacity and
3. a long period of absence of excavation work related to the construction of new facilities.

The sanatorium zone of Sochi was built quite a long time ago (30–40 years of the last century) [36, 44]. After that, the work accompanied by

Table 7: Percentage of the content of mobile forms of REE relative to their gross concentrations

Elements	Soil indices (point numbers)							
	Bz (15)	Az (17)	Agz (9)	Az (18)	Azr (12)	Az (19)	Azr (20)	Ag (2)
Sc	0,03	0,02	0,02	0,17	0,06	0,55	0,35	0,02
Y	0,45	0,41	0,19	1,31	0,99	1,36	1,76	0,30
La	0,16	0,16	0,11	0,63	0,52	0,75	1,06	0,16
Ce	0,14	0,10	0,07	0,50	0,41	0,60	0,91	0,11
Pr	0,20	0,21	0,13	0,75	0,56	0,71	1,10	0,17
Nd	0,23	0,26	0,15	0,77	0,61	0,71	1,04	0,20
Sm	0,32	0,35	0,19	0,87	0,73	0,76	1,13	0,24
Eu	0,46	0,46	0,26	1,19	0,87	1,07	1,53	0,33
Gd	0,41	0,43	0,24	1,10	0,90	0,97	1,41	0,30
Tb	0,38	0,39	0,20	1,03	0,80	0,92	1,27	0,29
Dy	0,30	0,30	0,15	0,87	0,66	0,89	1,14	0,22
Ho	0,35	0,28	0,15	0,97	0,66	0,88	1,18	0,24
Er	0,22	0,19	0,10	0,74	0,48	0,73	0,97	0,19
Tm	0,16	0,15	0,08	0,60	0,43	0,69	0,88	0,17
Yb	0,12	0,10	0,05	0,48	0,32	0,50	0,70	0,12
Lu	0,12	0,11	0,06	0,48	0,33	0,58	0,73	0,13
Average value (AV)	0,25	0,25	0,14	0,78	0,58	0,79	1,07	0,20
AVi/AV(15)		1,00	0,56	3,12	2,32	3,16	4,28	0,80

the replacement, displacement, and mixing of the upper soil horizons was rare and limited in terms of area size. At the same time, in the urban area, outside the coastal sanatorium zone, in recent years, the upper soil horizons have been quite actively displaced and renovated during construction work in preparation for the Olympic games.

On-site studies of the ecological and geochemical state of soils in sanatorium territories have revealed separate areas (mainly in the floodplains of small streams flowing into the sea) that refer to an extremely dangerous level of soil contamination (Zc above 128) [45].

4. Conclusion

In general, the natural zonal soils of the Black Sea Sochi area developed on clay shales and mudstone contain a wider range of chemical elements in comparison to their content in continental soils. The group of excess elements includes: Zn, Mn, Cs, Sn, As, Ta, W, Li, Bi, Cu, Ni, Pb, Co, Th, Sc, Ag, Rb, Tl. Most of them are included in the spectrum of elements contained in elevated concentrations (in comparison with other elements) in clays and shales, characteristic of the territories under consideration and for the region as a whole.

In the process of urban anthropogenesis, zonal soils have been transformed in urban conditions to the state of agro-abrozems, abrozems, degraded abrozems and agrozems. They differ in the structure of the soil profile, morphology, and humus content, but, at the same time, they are characterized by similar acid-alkali properties.

The highest concentration coefficients for urban soils are typical for Ca, which is due to their alkalization as a result of the penetration of metal salts associated with technogenesis, which are known to have an alkaline reaction, into soils with surface runoff and drainage water. Other pollutants with elevated Kc in all elemental landscapes include: Cu, Ni, Mg, Mn, Cd, and K and, additionally, in subordinate urban landscapes: Cs, Ga, Be, Rb, V, Fe, Li, Al, as well as 9 rare earth elements (REE): Dy, Tb, Sm, Ho, Eu, Gd, Sc, Y, Er.

Relatively low urban soil pollution has been established, for which Zc on the slopes in most cases is within the permissible level of pollution ($Zc > 16$), and in the abrazems of the subordinate landscapes can be referred to a moderately hazardous pollution category ($Zc = 16 - 32$). The soils of the sanatorium coastal zone are most polluted (Zc of over 32 referring to the dangerous category of pollution), requiring detailed monitoring to identify areas with a high level of pollution requiring reclamation.

5. References

[1] B. F. Aparin and E. Y. Sukhacheva, "Principles of soil mapping of a megalopolis with St.Petersburg as an example," *Eurasian Soil Science*, vol. 47, no. 7, pp. 650–661, 2014.

[2] W. Burghardt, "Soil in urban and industrial environments," *Journal of Plant Nutrition and Soil Science*, vol. 157, no. 3, pp. 205–214, 1994.

[3] University of Essen, *First International Conference on soils of urban, industrial, traffic and min-ing areas*, W. Burghardt and C. Dornauf, Eds. Universitat-GH Essen, 2000.

[4] A. Lehmann and K. Stahr, "Nature and Significance of Anthropogenic Urban Soils," *Journal of Soils and Sediments*, vol. 7, no. 4, pp. 242–260, 2007.

[5] M. A. Naeth, H. A. Archibald, C. L. Nemirsky, L. A. Leskiw, J. A. Brierley, M. D. Bock, A. J. Vanden Bygaart, and D. S. Chanasyk, "Proposed classification for human modified soils in Canada: Anthroposolicorder," *Canadian Journal of Soil Science*, vol. 92, no. 1, pp. 7–18, 2012.

[6] T. V. Prokof'eva, M. I. Gerasimova, O. S. Bezuglova, S. N. Gorbov, K. A. Bakhmatova, N. N. Matinyan, A. A. Gol'eva, E. A. Zharikova, E. N. Nakvasina, and N. E. Sivtseva, "Inclusion of soils and soil-like bodies of urban territories into the russian soil classification system," *Eurasian Soil Science*, vol. 47, no. 10, pp. 959–967, 2014.

[7] D. G. Rossiter, "Classification of Urban and Industrial Soils in the World Refer-ence Base for Soil Resources," *Journal of Soils Sediments*, vol. 7, no. 2, pp. 96–100, 2007.

[8] M. N. Stroganova, M. I. Gerasimova, and T. V. Prokofieva, "Approaches to grouping the technogenic soils," *Eurasian Soil Science*, vol. 38, no. 1, pp. 66–71, 2005.

[9] M. N. Stroganova and A. V. Rappoport, "Specific features of anthropogenic soils in botanical gardens of metropolises in the southern taiga subzone," *Eurasian Soil Science*, vol. 38, no. 9, pp. 966–972, 2005.

[10] E. Sukhachev and B. Aparin, "Principles of soil mapping of urban areas," in *Abstract book of 9th International Soil Science Congress on "The soul of soil and Civilization"*, Turkey, Antalya, Side, 2014.

[11] Z.-Q. Wei, S.-H. Wu, S.-L. Zhou, J.-T. Li, and Q.-G. Zhao, "Soil Organic Carbon Transformation and Related Properties in Urban Soil Under Impervious Surfaces," *Pedosphere*, vol. 24, no. 1, pp. 56–64, 2014.

[12] M. A. Bashir, A. Rehim, J. Liu, M. Imran, and S. Naveed, "Soil survey techniques determine nutrient status in soil profile and metal retention by calcium carbonate," *CATENA*, vol. 173, no. 141–149, 2019.

[13] K.-L. Hu, F.-R. Zhang, H. Li, F. Huang, and B.-G. Li, "Spatial Patterns of Soil Heavy Metals in Urban-Rural Transition Zone of Beijing," *Pedosphere*, vol. 16, no. 6, pp. 690–698, 2006.

[14] K. Bu, D. Freile, V. James, and C. J. Richards, "Virinder Sidhu and Nurdan S. Duzgoren-Aydin.Geochemical Characteristics of Soils on Ellis Island. New York-New Jersey. Sixty Years after the Abandonment of the Hospital Complex," *Geosience*, vol. 8, no. 1, p. 13, 2018.

[15] E.-Q. Hou, H.-M. Xiang, J.-L. Li, J. Li, and D.-Z. Wen, "Soil Acidification and Heavy Metals in Urban Parks as Affected by Reconstruction Intensity in a Humid Subtropical Environment," *Pedosphere*, vol. 25, no. 1, pp. 82–92, 2015.

[16] F. Fordyce, S. Nice, T. Lister, B. O Dochartaigh, R. Cooper, M. Allen, M. Ingham, C. Gowing, B. Vickers, and A. Scheib, "Urban soil geochemistry of Glasgow," British Geological Survey, OpenReport OR/08/002, 2012.

[17] S. Islam, K. Ahmed, and M. H. Al-Mamun, "Distribution of trace elements in different soils and risk assessment: a case study for the urbanized area in Bangladesh," *Journal of Geochemical Exploration*, vol. 158, pp. 212–222, 2015.

[18] M. S. H. Khorshid and S. Thiele-Bruhn, "Contamination status and assessment of urban and non-urban soils in the region of Sulaimani City," *Environmental Earth Sciences*, vol. 75, p. 1171, 2016.

[19] X. S. Luo, S. Yu, Y. G. Zhu, and X. D. Li, "Trace metal contamination in urban soils of China," *Sciences of the Total Environment*, vol. 421–422, pp. 17–30, 2012.

[20] M. Vinha, M. Cabral, P. A. Dinis, and L. Mandavela, "Geochemistry of Urban Soil in the Fast-Growing Kuito City (Angola)," in *Conference of the Arabian Journal of Geosciences: Petrogenesis and Exploration of the Earth's Interior*, 2018.

[21] P. Tume, E. González, F. Reyes, J. P. Fuentes, and G. Medina, "Sources analysis and health risk assessment of trace elements in urban soils of Hualpen," *CATENA*, vol. 175, pp. 304–316, 2019.

[22] X.-S. Wang and Y. Qin, "Some characteristics of the distribution of heavy metals in urban topsoil of Xuzhou, China," *Environmental Geochemistry and Health*, vol. 29, no. 1, pp. 11–19, 2007.

[23] K. Zhao, L. Zhang, J. Dong, J. Wu, and W. Fu, "Risk assessment spatial patterns and source apportionment of soilheavymetals in a typical Chinese hickory plantation region of southeastern China," *Geoderma*, vol. 360, no. 15, p. 114011, 2020.

[24] N. Adimalla, "Heavy metals contamination in urban surface soils of Medak province, India, and its risk assessment and spatial distribution," *Environmental Geochemistry and Health*, vol. 42, no. 21, pp. 59–75, 2020.

[25] M. S. Islam, M. K. Ahmed, M. H. Al-Mamun, and

S. M. A. Islam, “Sources and Ecological Risks of Heavy Metals in Soils Under Different Land Uses in Bangladesh,” *Pedosphere*, vol. 19, no. 5, pp. 665–675, 2019.

[26] P. Yang, J. Patrick, D. M. Yang, and H. Li, “Spatial variability of heavy metal ecological risk in urban soils from Linfen,” *CATENA*, vol. 190, p. 104554, 2020.

[27] M. Rachwal, K. Kardel, T. Magiera, and O. Bens, “Application of magnetic susceptibility in assessment of heavy metal contamination of Saxonian soil (Germany) caused by industrial dust deposition,” *Geoderma*, vol. 295, no. 1, pp. 10–21, 2017.

[28] H. Zhuo, H. Liu, S. Fu, H. Song, and L. Ren, “Source analysis and risk assessment of heavy metals in development zones: a case study in Rizhao, China,” *Environmental Geochemistry and Health,*, no. 42, pp. 135–146, 2020.

[29] M. S. Islam, M. K. Ahmed, M. H. Al-Mamun, and D. W. Eaton, “Human and ecological risks of metals in soils under different land-use types in an urban environment of Bangladesh,” *Pedosphere*, vol. 30, no. 2, pp. 201–213, 2020.

[30] S. Fernández, T. Cotos-Yáñez, J. Roca-Pardiñas, and C. Ordóñez, “Geographically Weighted Principal Components Analysis to assess diffuse pollution sources of soilheavymetal: Application to rough mountain areas in Northwest Spain,” *Geoderma*, vol. 311, pp. 120–129, 2018.

[31] M. Gaberšek and M. Gosar, “Geochemistry of urban soil in the industrial town of Maribor, Slovenia,” *Journal of Geochemical Exploration*, vol. 187, pp. 141–154, 2018.

[32] A. Petrik, M. Thiombane, S. Albanese, A. Lima, and B. de Vivo, “Source patterns of Zn, Pb, Cr and Ni potentially toxic elements (PTEs) through a compositional discrimination analysis: A case study on the Campanian topsoil data,” *Geoderma*, vol. 331, pp. 87–99, 2018.

[33] P. J. Craul, *Urban soils: Applications and practices*. New York: John Wiley and Sons, 1999.

[34] M. N. Stroganova, “Urban Soils: genesis, taxonomy and environmental significance,” Dissertation for the degree of Doctor of Biological Sciences, Higher Attestation Commission of the Russian Federation, Moscow, 1998.

[35] L. Yang, Y. Li, K. Peng, and S. Wu, “Nutrients and heavy metals in urban soils under different green space types in Anji,” *CATENA*, vol. 115, pp. 39–46, 2014.

[36] A. L. Korkeshko, “The history of park construction on the territory of Sochi (1866-1969) The history of park construction on the territory of Sochi (1866-1969) ,” in *Reports of the Sochi Department of the Geographical Society of the USSR*. Leningrad: Glavpoligrafprom, 1971, vol. II, [in Russian].

[37] L. L. Shishov, V. D. Tonkonogov, I. I. Lebedeva, and M. I. Gerasimova, *Classification of Russian soils*. Moscow: Institute of soil studies named after V.V. Dokuchaev of the Russian Academy of Agricultural Sciences, 2008.

[38] V. K. Karandashev, A. N. Turanov, T. A. Orlova, A. E. Lezhnev, S. V. Nosenko, N. I. Zolotareva, and I. R. Moskvitina, “Use of the inductively coupled plasma mass spectrometry for element analysis of environmental objects,” *Inorganic Materials*, vol. 44, no. 14, pp. 1491–1500, 2008.

[39] A. A. Yaroshevsky, *Problems of modern geochemistry*. Novosibirsk: Novosibirsk State University, 2004.

[40] A. I. Achkasov, I. L. Basharkevich, T. L. Onishchenko, L. N. Pavlova, B. A. Revich, Y. E. Saet, S. S. Sargsyan, R. S. Smirnova, N. Y. Trefilova, and E. P. Yanin, *Geochemistry of the environment*. Moscow: Nedra Publishers, 1990, [in Russian].

[41] A. P. Solovov, *Geochemical methods of prospecting for mineral deposits*. Moscow: Nedra Publishers, 1985.

[42] N. A. Grigor’ev, “Average concentrations of chemical elements in rocks of the upper continental crust,” *Geochemistry International*, vol. 41, no. 7, pp. 711–718, 2003.

[43] D. Aubert, P. Stille, A. Probst, F. Gauthier-Lafaye, L. Pourcelot, and M. Del Nero, “Characterization and migration of atmospheric REE in soils and surface waters,” *Geochimica et Cosmochimica Acta*, vol. 66, no. 19, pp. 3339–3350, 2002.

[44] L. I. Prasolov, I. N. Antipov-Karataev, and V. N. Filippova, *Soils of the Sochi station.* Leningrad: Publishing house of the All-Union Scientific Research Institute of Fertilizers and Agricultural Soil Studies named after D.N. Pryanishnikov, Leningrad branch, 1934.

[45] L. V. Zakharikhina and A. V. Burtovoy, “Anthropogenic Evolution of the zheltozems (acrisols) of the Sanatorium Zone of Sochi,” *Soil Science*, vol. 53, no. 6, pp. 820–828, 2020.