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Geochemical Approach to the Study of the Dynamics of Geosystems

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***Abstract*—The article presents a comparative analysis of the dynamics of geochemical indicators of natural and industrially transformed mid-mountain and high-mountain landscapes of the Western Caucasus. The high stability of geochemical processes for high-altitude geobotanical zones of subalpine and alpine meadows was established. The contents of plumbum (Pb) and cuprum (Cu) in soils of high-altitude geobotanical zones of the Teberda Nature Reserve and in soils of similar industrially transformed high-altitude geobotanical zones of Gondaray region were compared. The research showed a significant excess of the concentration of elements in the soils of high-altitude geobotanical zones of coniferous forests and the ecotone of the upper boundary of the forest of Gondaray region.**

Keywords—natural geosystem, partial geosystem, mid-mountain and high mountain landscapes, dynamics and evolution of geosystems, transformation of geosystems, high-altitude geobotanical zone, geochemical approach.

I. INTRODUCTION

Nowadays, the research of the functioning, dynamics and transformation of geosystems is becoming the central and most relevant problem of the entire geographical science. Poor development of theoretical foundations and research methods hinders the development of applied areas. At the same time, knowledge of these issues will make it possible to solve the problems of the forecasting, the sustainability of the functioning of natural geosystems and the features of their transformation [1].

The concept of transformation in recent years has gained significant spread and acceptance in the field of geographic publications [2, 3]. This concept in the Latin language means change, modification, mutation. Unfortunately, this concept is still little understood in the context of the study of geographic objects. In our opinion, these can be models of sustainable and unsustainable changes that allow considering the functioning of natural geosystems in the rank of environment phases using a chain of concepts reflecting various types of changes: "functioning" – "dynamics" – "evolution" [4].

The functioning of a geosystem reflects its sustainable, invariant condition, often having the rhythmic nature of changes in a cyclical mode of time (daily or annual). The concept of "landscape dynamics" came into landscape science about four decades ago. Initially, it identified any changes in the landscape and its properties. V.B. Sochava proposed to consider the dynamics of the landscape as diverse processes occurring (spontaneously or under the influence of human) in modern geosystems and causing various transformations in them that are not yet accompanied by changes in its structure, not going beyond the single invariant [5].

Under the influence of industrial (anthropogenic) factor, complex natural-social geosystems with their paired bonds, called partial are formed [6]. In the investigated region of the Western Caucasus, natural-recreational and natural-economic geosystems prevail [7]. In such geosystems, the dynamics are understood as a trend, showing not only certain changes in functioning, but also quantitative deviations from the norm of an invariant. In one case, such deviations do not cause changes in the structure of the natural geosystem and, taking into account time, such a system can return to its original condition. In another case, a critical state or a bifurcation point may arise, when destructive processes begin, turning into evolutionary changes. In order to study the dynamics of landscapes, it is possible to determined time series of quantitative geochemical indicators as well as the degree of their transformation.

II. MATERIALS AND METHODS

The research of the dynamics of geochemical indicators of landscapes was conducted on the Northern slope of the Western Caucasus. The objects of the research are the mid-mountain and high-altitude landscapes of the Teberda-Elbrus landscape district [8].

The first key area of the study is the Gondaray region. It is located in the valley of the Gondaray River (a confluent of the Kuban River) within the Gondaray medium mountain landscape of coniferous forests and the Aksko-Dzhalpakkolsky landscape of high-mountain meadows. The experimental facial sites of the Gondaray region of the study cover all high-altitude geobotanical zones in the altitude range of 1600–2800 m. (Fig. 1).

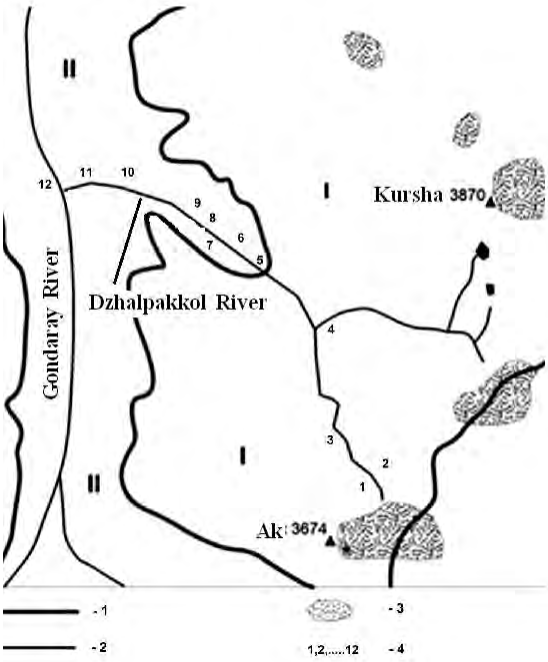


Fig. 1. The fragment of the map of the Gondaray region.

***Conventional symbols to Fig. 1*:** 1 – landscape boundaries; 2 – hydrography; 3 – glaciers; 4 – experimental facial sites:

I – Aksko-Dzhalpakkolsky landscape of high-mountain meadows

Alpine meadows altitude zones: 1 – the terminal moraine in the area of the ancient cirque composed of moraine deposits, with alpine vegetation; 2 – lateral moraine in the area of an ancient cirque, composed of moraine deposits, with alpine vegetation.

Altitude zone of subalpine meadows: 3 – the cone and the colluvial slope of the eastern exposure, composed of colluvial and proluvial sediments, with forb-grassy meadows on mountain meadow soils; 4 – Western exposure cone, folded colluvial, overgrown with meadow vegetation.

II –The Gondaray Coniferous Forest Landscape

Ecotone altitude zone of the upper forest boundary: 5 – terminal moraine of the bottom of the trough valley of the Dzhalpakkol River with forb-grassy meadows on mountain-meadow soils; 6, 8 – the cones of the lower third of the steep slopes of the Western exposure, composed of colluvial-proluvial sediments, with forb-grassy meadows on mountain meadow soils; 7 – steep and scarp slopes of the Eastern valley of the trough valley, composed of granitoids and colluvium, with birch horns on mountain-shrub soils; 9 – steep and scarp slopes of the trough valley of the Dzhalpakkol River of the South-Western exposure, composed of granitoids and colluvium, with pine forests and pine light forests on rough-skeletal soils.

Highland zone of coniferous forests: 10 – the upper part of the slope of the trough valley of the Dzhalpakkol River composed of Paleozoic granitoids and colluvium, with pine forests on mountain forest soils; 11 – the lower part of the slope of the Gondaray River trough valley, folded with a colluvium, with pine forests on mountain-forest brown soils; 12 – the bottom of the Gondaray River composed of alluvium and fluvio-glacial sediments, with spruce-birch forests on mountain-forest soils.

The landscapes of the Gondaray region have historically formed complex partial natural-economic systems of the Karachai ethnic culture. For several centuries in the bottom of the valley of the Gondaray Region, in alpine and subalpine meadows of the Dzhalpakkol River grazing was carried out by several “families” of Karachai. Their summer koshs (camps) were located there. In Soviet times, this type of economic activity was maintained. Nowadays, there is only one kosh in the valley of the Dzhalpakkol River located in the high-altitude zone of the ecotone of the upper boundary of the forest. Natural complexes of coniferous forests underwent significant changes in connection with repeated logging. In the second half of the 20th century, ecological tourism began to actively develop. All this led to the transition of landscapes of the Gondaray region into the category of natural-economic geosystems.

The second key area of the study the Teberda region was chosen in order to compare the first one with the undisturbed natural geosystems.

It is located on the territory of the Malaya Khatipara ridge within the Teberda State Biosphere Nature Reserve. This ridge occupies part of the left slope of the valley of the Teberda River, in which two landscapes are determined – the Teberda middle mountain coniferous forests and the Khatipara high-mountain meadows. The set of high-altitude geobotanical zones of these landscapes is identical with the landscapes of the Gondaray area. On the high-altitude profile of the Malaya Khatipara ridge, 14 experimental facial sites were laid, which are confined to the dominant phases of the high-altitude zones (Fig. 2).

Conventional symbols to Fig. 2: 1 – Landscape boundaries; 2 – boundaries of high-altitude geobotanical zones; 3 – experimental facial sites.

The Khatipara landscape of highland meadows:

II. Alpine meadows altitude zone:

1. Steep slopes of Eastern exposure with geranium-oatmeal vegetation on sod-meadow soils;

2. The upper third of the very steep slopes of the North-Eastern exposure with sulla-grass vegetation on thin, coarse-skeletal soils.

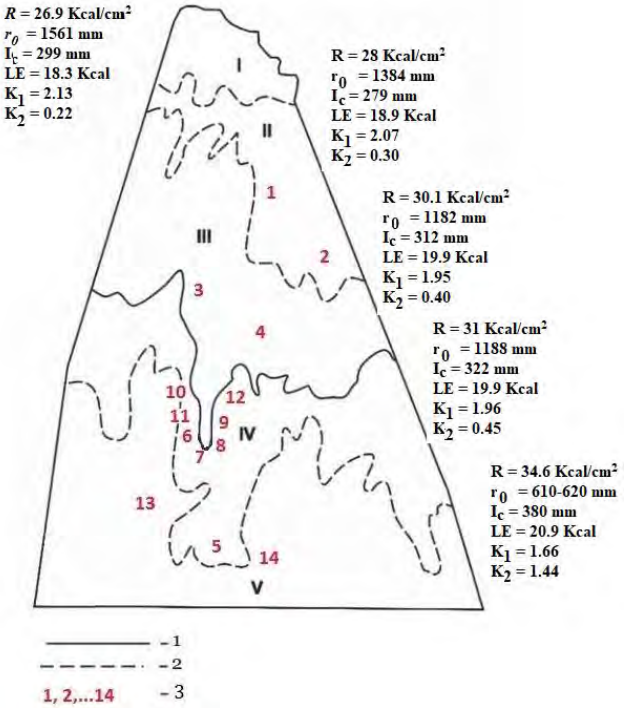


Fig. 2. The fragment of a landscape map of the Malaya Khatipara ridge [9].

III. Subalpine meadow altitude zone:

3. The upper part of the slopes of the south-eastern exposure with forbs-motley and perennial and motley-diversified meadows on sod-meadow subalpine soils;

4. Steep slopes of third-order of the North-Eastern exposure with forb-grassy meadows and rhododendron thickets on mountain-meadow and mountain-shrub soils.

The Teberda landscape of coniferous forests:

IV. The high-altitude belt of the ecotone of pine woodlands, birch curvilia and high-grass subalpine meadows:

5. Bottoms of ancient cirque, filled with colluvium and moraine deposits, with weeds and grass subalpine vegetation;

6. Very steep slopes of the Southern exposure with forb-grassy meadows on thin mountain-meadow soils;

7. The same North-Eastern exposure with forb-grassy meadows;

8. The same Eastern exposure with forb-grassy meadows;

9. The upper part of the very steep slopes of the North-Eastern exposure with fir-birch curls on brown sod-forest-mountain soils;

10, 11. The upper part of the very steep slopes of the South-Eastern exposure with pine light forests on primitive brown mountain-forest soils;

12. Bottoms of erosion and avalanche troughs with birch crooked forest and rhododendron thickets.

V. Highland zone of coniferous forests:

13. The steep and very scarp slopes of the South-Eastern exposure with pine forests on the highly skeletal brown mountain forest soils;

14. Steep slopes of erosion beams of South-Eastern exposure with fir forests on brown mountain-forest soils.

Fig. 2 also shows the data on the thermal and radiation balance, which reveal the peculiarities of heat and water circulation in the mid-mountain and high-mountain landscapes of the Teberda Nature Reserve. They also determine the formation of high-altitude geobotanical zones and the location of their boundaries.

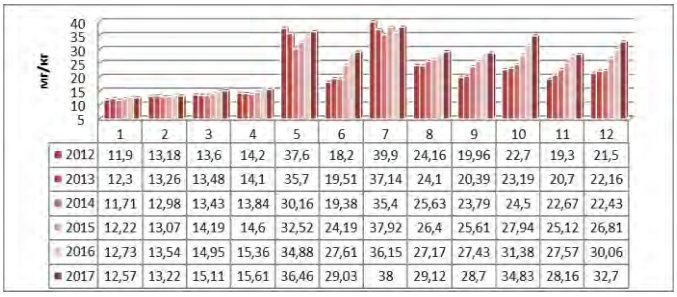
Soil-geochemical studies on experimental facial sites were carried out for six years in the valley of the Gondaray River (2012-2017) and for two years in the valley of the Teberda River (2016-2017). The soil samples were taken from a depth of 5-10 cm (horizon A) in summer annually. With the help of the method of inversion voltammetric analysis on the polarograph “ABC-1.1” the determination of the acid-soluble forms of cuprum and plumbum of the soil was carried out. These micro-elements present the most common environmental pollutants [10-12].

III. Results

At the first stage, the authors studied the dynamics of geochemical indicators of landscapes of the Gondaray region. An important factor in the distribution of microelements in landscape soils is alkaline-acid conditions. The change in the concentration of hydrogen ions in the soil solution affects the mobility of many chemical elements [13, 14]. The pH fluctuation limits in the soils of the Gondaray region were small (4.5-5.7) and could be classified as acidic. Mountain meadow soils of the Alpine zone have the higher acidity in, where during six years of observation, it ranged from 4.5 to 4.7 units. The least acidic soil in 2012 was in the coniferous forest zone at the upper part of the slope of the trough valley, where during the observation period the figures dropped by 0.4 units (from 5.7 to 5.3). The average indicatir for the years of observation had not changed.

The role of soil organic matter in the binding of microelements was very large, resulting in a high correlation between the content of chemical elements and humus in the soil [15]. Fluctuations of soil humus in soils of various phases were significant. The lowest humus content was found in the mountain-shrub soils of the ecotone zone of the upper forest boundary (8.4%). Most humus content was in the soils of alpine meadows (12.1-13.1%). For the period of 6 years of observations, the average humus content was 9.7-10.3%.

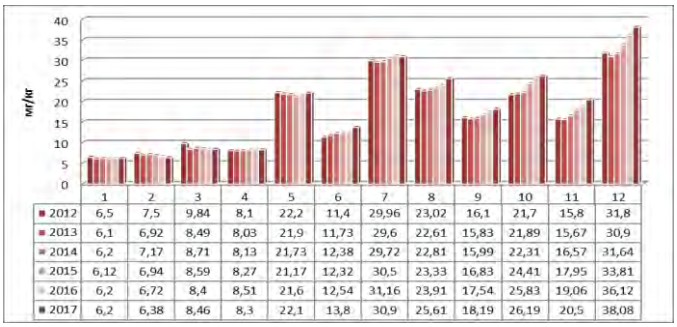
The changes in plumbum content in the soils of the high-altitude zones of subalpine and alpine meadows for 6 years of sampling were insignificant (Fig. 3). This indicated a more stable nature of geochemical processes in these geosystems. More intensive dynamics in the change in plumbum (lead) content was typical of the soils of the high-altitude zone of the ecotone of the upper forest boundary, especially within the cones and pine forests. The high intensity of the dynamics of plumbum content over 6 years was typical of the soils of pine forests (30-35%).



	1	2	3	4	5	6	7	8	9	10	11	12
2012	11,9	13,18	13,6	14,2	37,6	18,2	39,9	24,16	19,96	22,7	19,3	21,5
2013	12,3	13,26	13,48	14,1	35,7	19,51	37,14	24,1	20,39	23,19	20,7	22,16
2014	11,71	12,98	13,43	13,84	30,16	19,38	35,4	25,63	23,79	24,5	22,67	22,43
2015	12,22	13,07	14,19	14,6	32,52	24,19	37,92	26,4	25,61	27,94	25,12	26,81
2016	12,73	13,54	14,95	15,36	34,88	27,61	36,15	27,17	27,43	31,38	27,57	30,06
2017	12,57	13,22	15,11	15,61	36,46	29,03	38	29,12	28,7	34,83	28,16	32,7

Fig. 3. Plumbum content in the soils of the high-altitude geobotanical zones of the Gondaray region in 2012-2017: 1, 2,…12 – the numbers of facial sites.

The changes in the cuprum content for the soils of high-mountain subalpine and alpine meadows for 6 years were in the range of 3-7%. The changes in the element content in the soils of the ecotone zone — about 10%, and in the soils of pine forests — up to 19–20% were a little bit higher (Fig. 4).



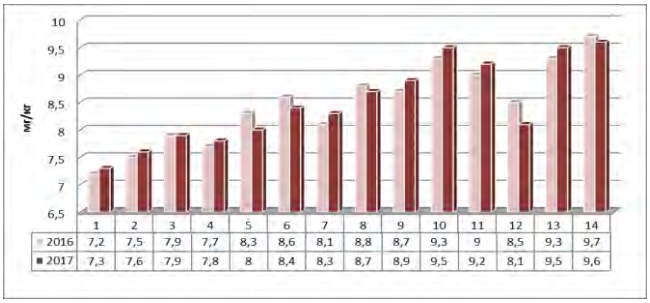
	1	2	3	4	5	6	7	8	9	10	11	12
2012	6,5	7,5	9,84	8,1	22,2	11,4	29,96	23,02	16,1	21,7	15,8	31,8
2013	6,1	6,92	8,49	8,03	21,9	11,73	29,6	22,61	15,83	21,89	15,67	30,9
2014	6,2	7,17	8,71	8,13	21,73	12,38	29,72	22,81	15,99	22,31	16,57	31,64
2015	6,12	6,94	8,59	8,27	21,17	12,32	30,5	23,33	16,83	24,41	17,95	33,81
2016	6,2	6,72	8,4	8,51	21,6	12,54	31,16	23,91	17,54	25,83	19,06	36,12
2017	6,2	6,38	8,46	8,3	22,1	13,8	30,9	25,61	18,19	26,19	20,5	38,08

Fig. 4. The content of cuprum in soils of high-altitude geobotanical zones of Gondaray region in 2012-2017: 1, 2,…12 – the numbers of facial sites.

Next, the authors consider the dynamics of geochemical indicators of landscapes of the Teberda region. The pH and humus values in the soils of the landscapes of the Teberda Nature Reserve were close to the data from the Gondaray area. The distribution of the average contents of chemical elements in the soils of the high-altitude zones of landscapes of the Teberda region also had a similarity with the distribution of the landscapes of the Gondaray region in the high-altitude zones. The minimum concentrations of elements were characteristic of the mountain-meadow soils of landscapes of high-mountain meadows. The depletion of soil by microelements was reasoned by the vigorous acid leaching in cold and humid climates [16].

The increase in the content of elements was characteristic of the soil of the ecotone zone of the upper forest boundary. The highest levels of chemical elements were found in mountain forest soils of the coniferous forest zone. The accumulation of elements was caused by biological absorption and retention on organic and mineral biogeochemical barriers [17]. Slightly elevated concentrations of microelements were also formed due to the accumulation of substances intensively removed from the higher altitudinal zones.

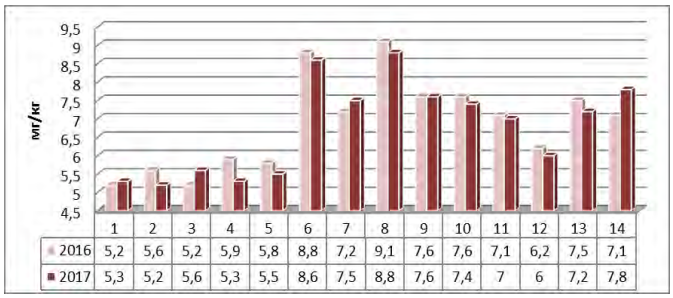
The plumbum content in mountain meadow soils of the Alpine and subalpine zones was in the range of 7.2-7.8 mg/kg (Fig.5). In the soils of the ecotone zone, the microelement concentrations were 8.1-8.8 mg / kg (meadow facies) and 8.0-8.5 mg/kg (birch crooked forest). The mountain-forest soils of pine forests of plumbum contained 9.3-9.5 mg/kg, and pine forests – 9.6-9.7 mg/kg.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2016	7,2	7,5	7,9	7,7	8,3	8,6	8,1	8,8	8,7	9,3	9	8,5	9,3	9,7
2017	7,3	7,6	7,9	7,8	8	8,4	8,3	8,7	8,9	9,5	9,2	8,1	9,5	9,6

Fig. 5. Plumbum content in soils of high-altitude geobotanical zones of the Teberda region in 2016-2017: 1, 2,…14 – the numbers of facial sites.

The cuprum content in the soils of different altitudinal belts was not contrasted (Fig. 6). Lower concentrations were characteristic of mountain meadow soils of alpine and subalpine meadows (5.2-5.9 mg/kg). In the soils of meadow facies of the ecotone of the upper boundary of the forest, the cuprum content was 8.8 mg / kg (on the slopes of the Southern exposure) and 9.1 mg/kg (Northern exposure). In pine light forests, the cuprum content limits were 7.0-7.6 mg/kg, in birch logs – 6.0-6.2 mg / kg; and in coniferous forests, 7.0-7.8 mg/kg.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2016	5,2	5,6	5,2	5,9	5,8	8,8	7,2	9,1	7,6	7,6	7,1	6,2	7,5	7,1
2017	5,3	5,2	5,6	5,3	5,5	8,6	7,5	8,8	7,6	7,4	7	6	7,2	7,8

Fig. 6. Cuprum content in soils of high-altitude geobotanical zones of the Teberda region in 2016-2017: 1, 2,…14 – the numbers of facial sites

The changes in plumbum content in soils of high-altitude zones for two years of observations amount was 1-3%. The dynamics of the cuprum content in the soils of the zone of high-mountain meadows was up to 10%; in the soils of meadow facies of the ecotone zone was 2.2-3.2%; soils of pine forests – 3.2%; in the soils of pine forests – 8.9%. The resulting dynamics of indicators was insignificant. It proved the steady functioning in the summer season of the majority of the facial geosystems of the Teberda region.

The comparative analysis of the data from the Gondaray and Teberda regions for two years of observation (2016 and 2017) using averaged data for altitudinal zones allowed drawing certain conclusions. The smallest changes in the content of chemical elements in the high-altitude zones of landscapes of the Gondaray region were observed in the soils of high-mountain meadows. Maximum indicators were obtained for the ecotone zones of the upper boundary of the forest and coniferous forests (Fig. 7, 8). At the same time, in the landscapes of the Teberda Nature Reserve these fluctuations were not so noticeable, especially in plumbum. According to the cuprum content, there was a slight increase

in the indicators also in the ecotone zones of the upper boundary of the forest and coniferous forests.

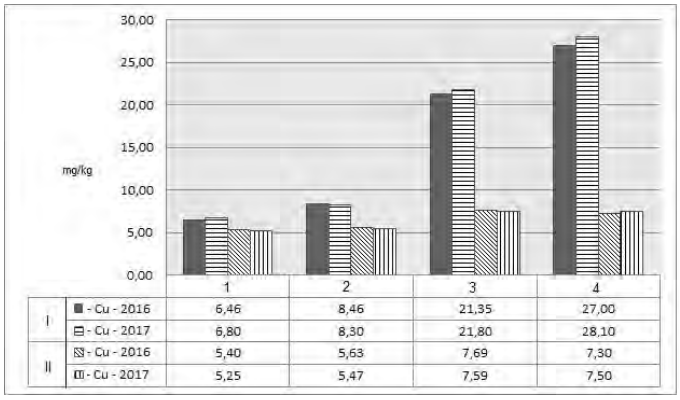


Fig. 7. The dynamics of Pb content in soils of geobotanical zones in 2016-2017:

The regions of investigation: I – The Gondaray region; II – The Teberda region. High-altitude geobotanical zones: 1 – Alpine meadows; 2 – subalpine meadows; 3 – ecotone of the upper forest boundary; 4 – coniferous forests.

In the landscapes of the Gondaray region the differences in cuprum content ranged from 2% (subalpine, ecotone) to 4-5% (coniferous forests and alpine). In the landscapes of the Teberda Nature Reserve, these differences did not exceed 2.8%. There were no significant differences in plumbum content. In the Gondaray group of altitude zones, these values ranged from 0.9 to 1.7%, and in protected areas they were even lower (1.3%).

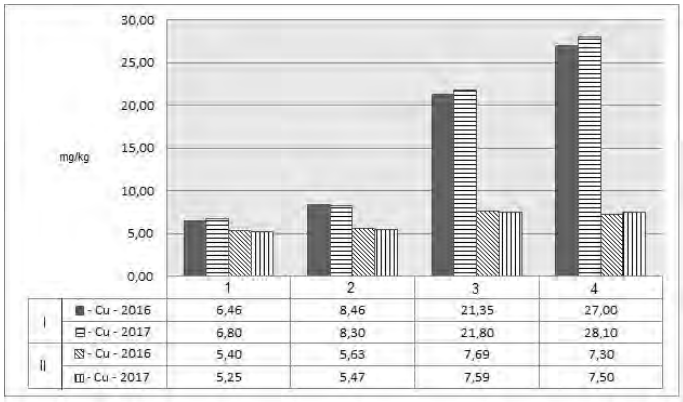


Fig. 8. The dynamics of Cu content in soils of geobotanical zones in 2016-2017:

The regions of investigation: I – The Gondaray region; II – The Teberda region. High-altitude geobotanical zones: 1 – Alpine meadows; 2 – subalpine meadows; 3 – ecotone of the upper forest boundary; 4 – coniferous forests.

The plumbum content in the soils of the high-altitude zone of the alpine and subalpine meadows of the Gondaray region was 44% higher than the lead content in the soils of the same high-altitude zone of the Teberda region. The excess of the plumbum content in the Gondaray region compared with the Teberda region in the soils of the ecotone zone of the upper forest boundary was 72.3%, and in the soils of the belt of coniferous forests – 71%. Cuprum had other indicators. The excess of cuprum content in the Gondaray region compared to the Teberda Nature Reserve in the soils of alpine meadows was 22%, in subalpine meadows – 35%. The highest differences in cuprum content were found in the soils of coniferous forest zones (73.3%) and in the ecoton soils of the upper forest boundary (65%).

IV. Conclusion

There are similarities in the distribution of the average plumbum and cuprum contents over the soils of the high-altitude zones of the landscapes of the Teberda Nature Reserve and landscapes of the Gondaray region. The minimum concentrations of elements are characteristic of mountain meadow soils in landscapes of high-altitude subalpine and alpine meadows. The soil levels of the ecotone of the upper forest boundary are characterized by average levels of elements. The highest values of the content of chemical elements are observed in the soils of the zone of coniferous forests.

The anthropogenic transformation of the landscapes of the Gondaray region into natural-economic geosystems led to the increase in the dynamic development processes of the geosystems facies of this region. A more intensive dynamics in changes in the content of plumbum and cuprum over 6 years of observations is characteristic of the soils of the high-altitude zones of coniferous forests and the ecotone of the upper forest boundary.

In the soils of the high-altitude zones of the high-mountain subalpine and alpine meadows of both the Teberda and Gondaray regions, the dynamics in the change in the content of plumbum and cuprum during the whole period of research was not revealed. This fact proved the steady character of geochemical processes in these altitudinal zones.

The comparison of the results of geochemical studies in the soils of the zones of the Teberda Nature Reserve and in the soils of the similar altitude zones of the Gondaray region showed significant differences in the concentrations of plumbum and cuprum. In the industrially transformed Gondaray region, the excess concentrations of plumbum and cuprum are highest in the soils of the coniferous forest zones and the ecotone of the upper forest boundary.

The time series of quantitative geochemical indicators identified as a result of the study will be the basis for further research on the dynamics of high-mountain and mid-mountain landscapes and determination of the degree of their transformation.

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