Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Environment protection

ECOLOGICAL AND GEOCHEMICAL PECULIARITIES OF NATURALLY GROWING WOODY PLANTS IN THE MID-MOUNTAINOUS CONDITIONS OF THE VALVALACHAI-GUSARCHAI INTERFLUVE AREA (NORTHEASTERN SLOPE OF THE SOUTHEASTERN PART OF THE GREATER CAUCASUS, AZERBAIJAN)

I. F. Guliyev
Baku State University, Baku, Azerbaijan

ABSTRACT
The article deals with the ecological and geochemical peculiarities of naturally growing woody plants in the mid-mountainous conditions of the Valvalachai-Gusarchai interfluve area located on the northeastern slope of the Greater Caucasus. Comparing the average mass of elements in woody-shrub vegetation shows that some species of plants are distinguished by higher content of some elements). Hornbeam is characterized by larger amounts of Cr, Co, Pb, beech by Ni, Cu, and oak by Zn among the woody plants. Beech is distinguished by minimal amounts of Cr. Minimal amounts of Co, Ni, Cu, Zn are characteristic of birch, Pb of oak. The lowest amounts of Cr, Ni, Zn, Pb are observed in the hazelnut tree. The amount of cobalt in this tree is slightly higher. Ratios between maximal and minimal amounts are statistically reliable. The comparative analysis of the intensity of biological absorption of elements in terrestrial plant and woody-shrub vegetation of the landscape showed a significantly weaker level of absorption of all studied elements (except Cr) by woody-shrub vegetation. The absorption intensity of chromium is close to the absorption intensity of terrestrial vegetation. So, Cu, Zn, Pb move from intensive absorption order to moderate absorption order in terrestrial vegetation, and depending on plant species, their absorption intensity decreases by 5.3-9.0, 9-18 and 2.2-5.3 times, respectively. Ni is characterized by medium absorption intensity in terrestrial vegetation and woody shrub vegetation, but absorption intensity is 1.3-3.5 times lower in woody vegetation. Cobalt moves from moderate absorption in terrestrial vegetation to weak absorption in woody-shrub vegetation (with 7.5-12 times decrease in absorption intensity).

KEYWORDS:
ecological and geochemical peculiarities; northeastern slope of the Greater Caucasus; naturally growing woody plants; chemical elements (Cr, Co, Ni, Cu, Zn, Pb).

e-mail: ilgar.guliyev1@gmail.com
https://doi.org/10.53404/Sci.Petro.20240200065

Date submitted: 09.12.2024 ***Date accepted: 13.12.2024***

1. Intuduction

The mid-mountainous landscape of Valvalachai and Gusarchai area is located at an altitude of 1000 to 2000-2000 m above sea level. The relief of the mid-mountainous landscape is denudation-erosion with several well-defined structural steps. Steep slopes are dominated by synclinal folds and plateaus. Landslides and landslide-flood flows have developed widely on the slopes of valleys and highlands due to the spread of clayey-marly rocks of cretaceous flysch. The landscape is characterized by deep V-shaped river valleys and slopes, the steepness and shape of which depend on the lithological composition of the rocks, the geological structure and the exposure of the slopes. The general slope of the relief is towards the southeast. A network of valley-ravines has developed in that direction, and their density reaches 1.2-1.5 km/km^2, even 2 km/km^2 in some places. The density of the river network varies between 0.2-0.4 km/km^2 [1-4].

The average annual temperature is positive, ranging from 5 °C to 10 °C. The coldest month's (January) temperature ranges from minus 5 °C to minus 8 °C, while the hottest days (July) can reach 15 °C to 25 °C. The temperature varies from a maximum of +35 °C to a minimum of -25 °C, a range of 60 °C. The annual number of sunny hours is 1900-2000, and the total solar radiation value is 129 kcal/cm^2. The average amount of atmospheric precipitation reaches 900-1200 mm. In winter, precipitation averages 200-700 mm, while in summer it is 700-900 mm or more. Snow cover lasts for 80-120 days. Evaporation is slightly higher than the amount of atmospheric precipitation, and the landscape is characterized by moderate relative humidity. Overall, the landscape is defined by a humid climate type, even distribution of atmospheric precipitation, and a cold, dry winter [2, 5-7].

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Environment protection

The higher areas of the landscape consist of Cretaceous sediments composed of marl and limestone. Paleogene, Neogene and Quaternary sediments are distributed in the lower parts, they are composed of sandstones, limestones, conglomerates, clays, sandy clays and pebbles. It was formed by soil-forming eluvial-deluvial layer on the fracturing products of the parent rocks and directly on the core sediments. Their thickness and structure vary depending on the shape and steepness of the slopes [4, 7, 8].

In the studied area, typical mountain-forest soils have developed, with the thickness of their upper horizon not exceeding 125 cm. The humus content in the soil and the horizon varies between 8.34% and 11.6% (averaging around 10%). Fulvic acids dominate in the composition of humus, which means it can be classified as fulvate humus. The high humus content is associated with the leaf shedding of trees and the fact that the primary mass of roots is located up to 40 cm in depth. These soils are characterized by richness in elements like Co, Mg, Ni, and others (36.9±4.5 mg-eq/100 g). In the absorbed complex, calcium (22-32 mg-eq) and magnesium (8-12 mg-eq) dominate. The nitrogen content does not exceed 0.61%. In the upper horizon, the reaction of the soil solution ranges from 6.8 to 5.82 (averaging 6.2) [1, 3, 7].

The soil is gravelly and classified as medium to heavy clay in terms of its granulometric composition. The amount of clay particles (<0.001 mm) is not high (21.4±3.9%), while the amount of physical clay (<0.01 mm) is 2.61%. The landscape is characterized by the development of broad-leaved forests, mainly featuring hornbeam, oriental beech, and oak. In addition to these, forests include birch, elm, hazelnut, medlar, and others. The herbaceous cover consists of species from the Asteraceae family (e.g., wormwood and yarrow), Poaceae (e.g., black millet), Dipsacaceae (e.g., scabiosa), and others [2, 4, 9].

This study is dedicated to the biogeochemistry of land plants and its use for ecological-biological environmental assessment. Its relevance is determined by the need to identify and study the key factors influencing the chemical composition of plants in various growth conditions. Without this, practical applications of plant biogeochemistry in various branches of modern science and the national economy are impossible. The biogeochemistry of plants is of great importance for soil science, particularly in studying the biogeochemical cycling of chemical elements, for issues related to controlling human biogeochemical activity, environmental protection, and other scientific and practical applications of data on the chemical (elemental) composition of plants [10-13].

During the agricultural use of soils, a significant loss of organic matter is observed, leading to a deficit in the plowing layer of the agro-landscape. To assess the impact of organic matter on the mineral component of the landscape's mountain-forest soils, correlation coefficients between humus and chemical elements have been calculated.

2. The main results of the research

Beech, oak, hornbeam and birch have been studied among the woody plants that grow in natural mid-mountain conditions. Shrub vegetation is expressed in hazelnuts (table 1). As you can see from this information, plant species in the same landscape geochemical conditions are characterized by common biogeochemical indicators and several differences. So, woody-shrub vegetation is characterized by 100% occurrence of nickel and copper, while cobalt has a very low occurrence. Birch is an exception, in which this element is not observed. The frequency of occurrence of elements in woody plants is within the following limits: Cr – 84 (beech)-100 (birch) %, Zn – 60 (beech) – 80 (oak) %, Pb – 80 (birch) – 100 (oak) %. Cr – 50%, Co – 10%, Zn – 7%, Pb – 90% were observed in hazelnut tree (as percentage of samples).

The distribution of most element amounts in woody-shrub plants follows a normal law. The exception is: in lognormal oak – Pb; Co – not observed in all plant species; Cr, Cu, Zn were not observed in hazelnut tree [1, 3, 5].

The average amount of elements is within the limits of reliability. In cases where no regularity in the distribution of element amount can be observed, the average amount is adjusted to the arithmetic mean values. Variations of average amounts of elements in woody plants are in the range of 38-95 %. These elements are distributed as follows: Cr-55 (hornbeam) – 65% (oak) %, Ni – 38 (oak) – 55 (birch) %, Cu – 71 (hornbeam) – 95 (birch) %, Zn – 64 (oak) – 77 (birch) %, Pb – 44 (hornbeam) – 63 (beech) %.

So, hornbeam with the lowest distribution of average amounts of Cr, Cu, Pb, and oak with Ni, Zn is typical. Oak is distinguished by greater variations in the amount of copper, birch – Ni, Cu, Zn and beech – Pb.

Comparison of the average amounts of elements in woody-shrub vegetation shows that some species of plants are distinguished by higher amounts of some elements (table 2). Hornbeam is characterized among woody plants by larger amounts of Cr, Co, Pb, beech by Ni, Cu, and oak by Zn. Beech is characterized by minimal amounts of Cr. Minimal amounts of Co, Ni, Cu, Zn are characteristic of birch, Pb – oak. The lowest amounts of Cr, Ni, Zn, Pb are observed in the hazelnut tree. The amount of cobalt in this tree is slightly higher. Ratios between maximal and minimal amounts are statistically reliable [12, 14, 15]. However, it differs in plants where the amounts of the elements are close.

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Environment protection

Table 1

Statistical distribution parameters of the concentration of elements in the woody-shrub vegetation (in leaves) of the mid-mountainous natural landscape of the Valvalachai-Gusarchai interfluves

Elements	*R*, %	Range of fluctuation	Distribution law	$\bar{X}$	Reliable interval, $\bar{X}$	V, %	CC	DC	Ax	C_C
Beech (N=50.0)										
Cr	84	0-8.0	N	2.1	1.6-2.7	59	-	4.0	0.2	-
Co	8	0-3.0	N	0.16	-	-	0.1	11.3	0.1	1.1
Ni	100	1.0-20.0	N	6.5	4.1-6.5	32	1.1	-	0.8	1.2
Cu	100	2.0-50.0	N	10.0	4.6-10.1	77	2.1	-	1.9	1.2
Zn	60	0-80.0	N	22.0	20.9-39.3	71	2.6	-	2.7	1.1
Pb	94	0-8.0	N	2.7	2.2-3.9	63	1.7	-	1.1	-
$R_6^+(BGA) = 1.88$ $R_6^- = 7.65$										
Oak (N=40.0)										
Cr	90	0-7.0	N	2.8	2.3-3.3	65	-	3.0	0.3	1.1
Co	5	0-4.0	-	0.18	-	-	-	10.0	0.1	1.2
Ni	100	2.0-10.0	N	5.6	5.1-6.2	38	4.0	1.0	1.1	-
Cu	100	1.0-30.0	-	9.0	-	-	1.9	-	1.7	1.1
Zn	80	0-50.0	N	23.2	18.9-27.4	64	2.7	0.4	2.8	1.1
Pb	100	0-8.0	LN	2.1	1.7-2.5	48	1.3	0.8	0.9	-
$R_6^+(BGA) = 1.96$ $R_6^- = 6.5$										
Hornbeam (N=37.0)										
Cr	92	0-8.0	L	3.2	2.6-3.8	55	0.4	2.6	0.3	1.2
Co	6	0-6.0	-	0.24	-	-	0.1	7.5	0.1	1.6
Ni	100	1.0-50.0	N	5.2	4.4-5.9	43	0.9	1.1	0.6	-
Cu	100	1.0-50.0	N	8.5	6.5-10.5	71	1.8	0.6	1.6	-
Zn	70	0-60.0	N	20.1	15.6-24.7	70	2.4	0.4	2.4	-
Pb	98	0-8.0	N	3.8	3.3-4.3	44	2.5	0.4	1.6	1.4
$R_6^+(BGA) = 2.2$ $R_6^- = 3.7$										
Birch (N=10.0)										
Cr	100	1.0-5.0	N	2.3	1.4-3.1	63	0.3	3.6	0.2	-
Co	0	-	-	-	-	-	-	-	-	-
Ni	100	1.0-10.0	N	4.6	3.1-6.0	55	1.3	1.3	0.6	-
Cu	100	2.0-20.0	N	5.9	2.6-9.2	95	0.8	0.8	1.1	-
Zn	80	0-40.0	N	16.3	9.1-20.3	77	2.0	0.5	2.0	-
Pb	100	0-5.0	N	2.5	1.1-3.2	50	1.6	0.6	1.0	-
$R_6^+(BGA) = 1.63$ $R_6^- = 1.63$										
Woody plants in general (N=137.0)										
Cr	91.5	0-8.0		2.6	-	-	0.3	3.2	0.2	-
Co	26.3	0-6.0		0.15	-	-	0.08	12.0	0.09	-
Ni	100	1.0-50.0		5.5	-	-	0.9	1.1	0.7	-
Cu	100	1.0-50.0		8.4	-	-	1.8	0.6	1.6	-
Zn	70	0-80.0		20.4	-	-	2.5	0.4	2.5	-
Pb	93	0-8.0		2.8	-	-	1.8	0.6	1.2	-
$R_6^+(BGA) = 2.03$ $R_6^- = 5.43$										
Hazelnut (N=20.0)										
Cr	50	0-2.0	-	0.9	-	-	-	0.1	9.2	0.08
Co	10	0-3.0	-	0.3	-	-	-	0.2	6.0	0.2
Ni	100	1.0-20.0	N	3.5	2.8-3.9	38	4.0	0.6	1.6	0.4
Cu	100	2.0-40.0	N	6.2	5.9-10.1	75	1.9	1.3	0.8	1.2
Zn	70	0-50.0	-	12.0	-	-	2.7	1.4	0.7	1.4
Pb	90	0-3.0	N	1.4	1.5-2.3	48	1.3	0.9	1.1	0.6
$R_6^+(BGA) = 1.36$ $R_6^- = 4.48$										
CC- Clark Concentration, DC – Distribution Concentration BGA - biogeochemical activity, Ax - biological absorption, N-normal, LN-lognormal										

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Environment protection

Table 2

Rank graded by average amounts of elements ($\overline{X} \cdot 10^{-3}$ %) in the woody-shrub vegetation of a mid-mountain landscape

Elements	Rows of plants	max/min
Cr	hornbeam>oak>birch>beech>hazelnut 3.2 2.8 2.3 2.1 0.9	3.6
Co	hazelnut> hornbeam>oak>beech> birch 0.3 0.24 0.12 0.16 0	>1.9
Ni	beech>oak> hornbeam> birch> hazelnut	1.9
Cu	beech>oak> hornbeam>hazelnut>birch	1.7
Zn	oak>beech>hornbeam>birch>hazelnut	1.9
Pb	hornbeam>beech>birch>oak>hazelnut	2.7

For example, beech and oak are characterized by equal amounts of Co, Zn, oak and hornbeam by equal amounts of Ni, Cu.

Cr (3.6) was most contrasted, and Pb (2.7) was partially contrasted, and Cu, Co, Ni, Zn were equally distributed in the woody-shrub vegetation of the landscape. According to contrast coefficients, woody-shrub vegetation is characterized by Pb, Cr (2.7-3.6) with medium intensity differentiation, by Cu, Ni, Zn, Co (1.7-1.9) with weak differentiation. So, these series reflect the general peculiarities of the biogeochemical differentiation of the woody-shrub vegetation of the mid-mountainous landscape separately for each element. At the same time, the generalized order (hornbeam→beech, oak-birch-hazelnut) of biogeochemical differentiation in the woody-shrub vegetation reveals hornbeam as a concentrator of the complex of studied elements; beech is distinguished by a weak concentration of elements, and birch among woody plants is distinguished [14-18].

3. Discussion of the results

During biogeochemical studies, it is important to clarify not only element composition (a systematic peculiarity of plants), but also the concentration intensity of the elements in relation to the lithosphere with different species of plants [9, 19].

The concentration of Cu (1.3-2.1 CC), Zn (1.4-2.7 CC), Pb (1.3-2.4 CC) (except for the hazelnut tree, Pb (1.1 DC) in this plant is slightly less than the amount in the lithosphere) is observed in the woody-shrub vegetation of the natural landscape. Cr (2.6-9.2 DC) and Co (6.6-11.3 DC and above) concentrations are not observed in woody-shrub vegetation (table 1). The amount of Ni in woody plants is around Clark (except birch). Beech with the highest concentration of Cu (2.1 CC), Zn (2.7 CC) – oak, and Pb – hornbeam is typical. The strongest distribution of Cr (9.2 DC) is distinguished in the hazelnut tree, and Co (11.3 DC) in beech.

Ni, Cu, Pb, Zn (0.9-2.5 CC) are distinguished by medium, weak and very weak absorption with medium concentration and strong capture in woody plants (Cu 0.7 CC - Co, Cr (0.08-0.3 CC)). As a result, biogeochemical activity in woody plants varies from 1.63 (birch) to 2.2 (hornbeam) and is assessed as 2.03 on average. However, despite the relatively high activity of concentration of elements in woody plants, concentration $(R_6^+ = 2.03)$, distribution coefficients $(R_6^- = 5.43)$ and their ratio $(R_6^- / R_6^+ = 2.7)$ as a whole reveal the deconcentration of the studied elements in woody plants. Beech $(R_6^- / R_6^+ = 5.5)$ is distinguished by the greatest deconcentration among them. A balance is observed in concentrations and deconcentrations of element of birch (table 1).

Cu, Zn (1.2-1.4 CC) are released with medium concentration and strong capture in shrub vegetation (hazelnut), Cr, Cu, Ni, Pb (0.08-0.6 CC) with weak and very weak capture, as a result, the hazelnut tree is characterized by minimal biogeochemical activity (BGA=1.35) [6, 9, 18]. Comparison of CC and DC (fig. 1) of elements in terrestrial vegetation and woody-shrub vegetation of natural landscape revealed very important differences in element concentrations. Terrestrial (continent) vegetation is characterized by concentrations of Zn, Cu, Pb, and distribution of Co differs – and to the highest extent – Cr differs. The amount of nickel is equal to lithospheric clark. At the same time, the concentrations of elements decrease from maximum zinc to minimum Cr. Continental vegetation is characterized by intensive and moderate concentration of Zn, moderate concentration and strong capture of Cu, Pb, Ni, Co, moderate, weak and very weak capture of Cr. As a result, the biogeochemical activity of terrestrial vegetation is assessed as 7.3, i.e. the enrichment of terrestrial vegetation relative to the lithosphere is observed. Confirmation of enrichment is also shown in $R_6^- / R_6^+ = 3.5$, which also shows a preponderance of element concentrations in terrestrial vegetation.

The concentrations of Zn, Cu, Pb and especially Co

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Environment protection

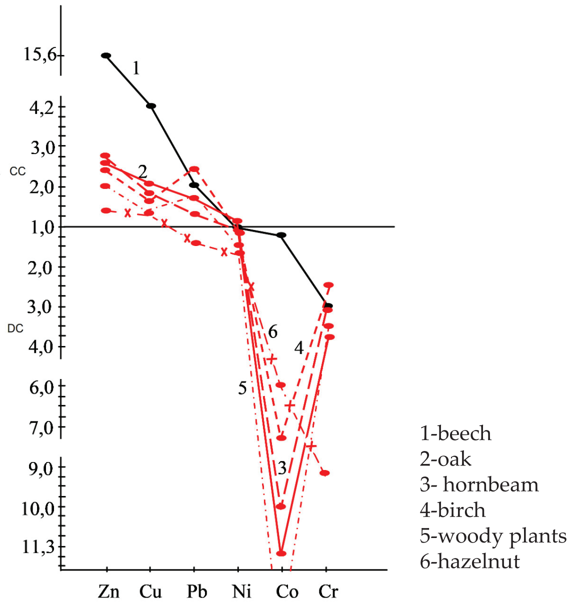

Fig. 1. Comparison of CC and DC of elements in terrestrial vegetation and woody-shrub vegetation of natural landscape

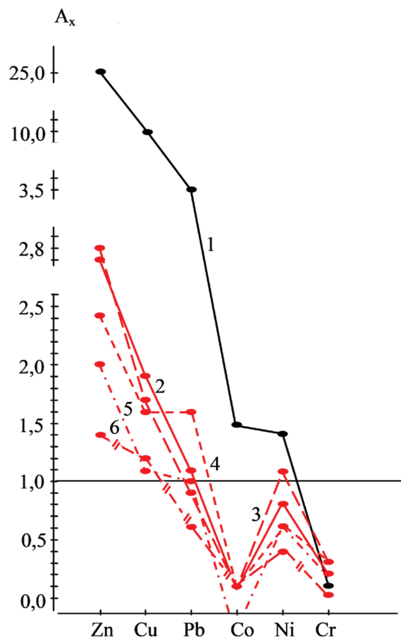

Fig. 2. Ratio of biological absorption of elements in terrestrial vegetation to soil clarks

in the woody-shrub vegetation of the natural landscape is much lower. There are no big differences in Ni and Cr concentrations toplanmalar, except for chromium, the concentration of the latter is very low in hazelnut tree. The distribution peculiarity of Zn, Cu, Pb, Ni concentrations in woody-shrub vegetation is similar to the terrestrial vegetation - but with lower concentrations. There are big differences in concentrations of chromium: the amount of this element in beech, oak, hornbeam and birch is close to the concentrations in terrestrial vegetation (3 times lower in hazelnuts). As a result, Zn moves from the order of intense concentration and strong capture in terrestrial vegetation to the order of moderate concentration and strong capture of woody-shrub vegetation, and Co moves from the order of moderate concentration and strong capture to moderate, weak and very weak capture in terrestrial vegetation. It is characterized by medium concentration and strong capture in terrestrial vegetation and woody vegetation of the natural landscape, and by medium, weak and very weak capture in shrub vegetation (hazelnut). Moderate concentration and strong capture of Cu, Pb and moderate, weak and very weak capture of chromium are characteristic in terrestrial vegetation and woody-shrub vegetation of the natural Middle Jurassic landscape [1].

The biogeochemical activity (BGA) of woody vegetation is assessed as 2.03, BGA of shrub plants is 1.35, which is 3.6 and 5.4 times lower than the biogeochemical activity of terrestrial vegetation, respectively.

The effect of environmental conditions on vegetation is manifested when the concentration of elements in plants is compared with the amount in soil. The calculated global coefficients of biological absorption of elements [3, 13, 15] in terrestrial vegetation relatively to soil Clark showed that the intensity of biological absorption of Cr, Co, Ni, Cu, Zn, Pb decreases from maximum absorption of Zn to minimal absorption of Cr (fig. 2) [13, 18].

The geochemical conditions of the mid-mountain landscape introduce their own correction to the absorption intensity of elements by the landscape vegetation (table 2). The concentrations of Cr, Ni, Pb (1.3-1.5 CC) in the soil above the clark, Zn, Cu (1.0-1.1 CC) around clark and the clark amounts ending with Zn, Cu (1.0-1.1 CC), Co (1.1 CC), the woody-shrub species of the landscape vegetation absorb the elements with different intensity (table 2; fig. 2). For example, beech – Zn, Cu, oak – Zn, Ni, hornbeam – Pb are characterized by the most intense absorption. There are no significant differences in the concentration of Zn in beech and oak, as well as Co and Cr in woody-shrub vegetation.

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Environment protection

Conclusion

1. So, the comparative analysis of the intensity of biological absorption of elements in terrestrial vegetation and woody-shrub vegetation of the landscape showed that there is a much weaker level of absorption of all studied elements (except Cr) by woody-shrub vegetation. The absorption intensity of chromium is close to the absorption intensity of terrestrial vegetation (fig. 2). Despite the abovementioned differences, the curve of biological absorption intensity of elements in woody-shrub vegetation is like the curve of terrestrial vegetation. Ni is an exception here; its absorption intensity is higher than the absorption intensity of cobalt unlike terrestrial vegetation. As a result, woody-shrub vegetation is characterized by moderate absorption intensity and weak absorption intensity of Cr.
2. So, Cu, Zn, Pb move from intensive absorption order to moderate absorption order in terrestrial vegetation, and depending on plant species, their absorption intensity decreases by 5.3-9.0, 9-18 and 2.2-5.3 times, respectively. Ni is characterized by medium absorption intensity in terrestrial vegetation and woody shrub vegetation, but absorption intensity is 1.3-3.5 times lower in woody vegetation. Cobalt moves from moderate absorption in terrestrial vegetation to weak absorption in woody-shrub vegetation (with 7.5-12 times decrease in absorption intensity).
3. Low absorption of chromium is typical for terrestrial (continental) vegetation and mid-mountain landscape - shrub vegetation, but more intensive (1.4-2.1 times) absorption is observed in woody vegetation compared to terrestrial vegetation, and shrub vegetation (hazelnut tree) is distinguished with slightly weaker absorption [8, 20]. The abovementioned differences do not actually affect the distribution on size of the biological absorption coefficients of the elements. The series (Zn>Cn>Pb>Co>Ni>Cr) of absorption intensity decrease in terrestrial vegetation revealed a similar nature of the biological absorption intensity of elements in oak (Zn>Cu>Ni>Pb>Cr>Co), hornbeam (Zn>Cu>Pb>Ni>Cr>Co), birch (Zn>Cu>Pb>Ni>Cr>Co), and hazelnut trees (Zn>Cu>Pb>Ni>Co>Cr): absorption intensity decreases from maximum Zn to minimum Co, Cr. Differences in absorption of Ni and Pb are observed: absorption intensity of nickel in terrestrial vegetation is weaker than absorption intensity of Co, absorption intensity of lead in oak is lower than absorption intensity of nickel.

References

1. Hajiyeva, A., Jafarova, F. (2024). Analysis of the regularity of distribution of natural landscapes in the Greater Caucasus Depending on physical-geographical characteristics using GIS technology. *Proceedings of the Bulgarian Academy of Sciences*, 77(2), 221–229.

2. Hajiyeva, A., Jafarova, F. Hajiyeva, G. (2024). Structural-genetic characteristics of landscapes of the southeastern slope of the Great Caucasus and study of their modern state. *Proceedings of the Bulgarian Academy of Sciences*, 77(1), 62–72.

3. Huseynov, J., Tagiyev, A., Balammadov, S. (2024). Characteristics of air temperature on the southern and southeastern slopes of the Greater Caucasus in the modern period. *Journal of Geology, Geography and Geoecology*, 33(3), 475-484.

4. Mammadova, J. S. (2020). Factors influencing to formation of geosystems of southern slope of the Greater Caucasus in the Republic of Azerbaijan and assessment of landscape & environmental capacity. *RUDN Journal of Ecology and Life Safety*, 28(3), 237–251.

5. Mardanov, I. I. (2023). Study of time dynamics of erosion processes in the high mountains of Greater Caucasus by satellite information. *Geodesy and Cartography*, 49(2), 94–98.

6. Mikhailenko, A. V., Ruban, D. A., Ermolaev, V. A. (2024). Three landscape-dominating mountains of the Western Caucasus: case studies of local heritage and cultural inferences. *Heritage*, 7, 4227–4248.

7. Sadullayev, R. R., Ahmadova, G. B., Abasova, N. A., Fatih, A. I. (2024). Anthropogenic transformations in natural landscapes of the Great Caucasus. *Acta Scientific Agriculture*, 8(7), 02-07.

8. Mikhailenko, A. V., Ruban, D. A. (2020). Epikarst 'ruining' Jurassic reefs in the Lagonaki Highland, Western Caucasus. *International Journal of Earth Sciences*, 109, 2773–2774.

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Environment protection

9. Emeis, K., Eggert, A., Flohr, A., et al. (2018). Biogeochemical processes and turnover rates in the Northern Benguela Upwelling System. *Journal of Marine Systems*, 188, 63–80.

10. Abrahams, A., Schlegel, R. W., Smit, A. J. (2021). Variation and change of upwelling dynamics detected in the world's eastern boundary upwelling systems. *Frontiers in Marine Science*, 8, 626411.

11. Aguirre, C., Rojas, M., Garreaud, R. D., Rahn, D. A. (2019). Role of synoptic activity on projected changes in upwelling-favorable winds at the ocean's eastern boundaries. *NPJ Climate and Atmospheric Science*, 2, 44.

12. Rodionov, A., Bauke, S. L., von Sperber, C., et al. (2020). Biogeochemical cycling of phosphorus in subsoils of temperate forest ecosystems. *Biogeochemistry*, 150(3), 313-328.

13. Alfredsen, J. S. G. (2024). From deadwood to forest soils: quantifying a key carbon flux in boreal ecosystems. *Biogeochemistry*, 13 August, 1225 – 1242.

14. Amos, C. M., Castelao, R. M., Medeiros, P. M. (2019). Offshore transport of particulate organic carbon in the California Current System by mesoscale eddies. *Nature Communications*, 10(1), 4940.

15. Espinoza-Morribero´n, D., Echevin, V. (2021). Evidences and drivers of ocean deoxygenation off Peru over recent past decades. *Scientific Reports*, 11(1), 20292.

16. Are´valo-Martı´nez, D. L., Kock, A., Lo¨scher, C. R., et al. (2015). Massive nitrous oxide emissions from the tropical South Pacific Ocean. *Nature Geoscience*, 8(7), 530–533.

17. Lachkar, Z., Cornejo-D'Ottone, M., Singh, A., et al. (2024). Cycling of greenhouse gases in coastal upwelling systems. *Elementa: Science of the Anthropocene*, 12(1), 2-25.

18. Lontsi, R. T., Corre, M. D., Addris, N. A., Veldkamp, E. (2020). Soil greenhouse gas fluxes following conventional selective and reduced-impact logging in a Congo Basin rainforest. *Biogeochemistry*, 151(2/3), 153-170.

19. Dontsova, K., Balogh-Brunstad, Z., Le Roux, G. (2021). Evaluating the impact and reach of biogeochemical cycles. *Eos*, 102.

20. Lachkar, Z., Cornejo-D'Ottone, M. (2024). Biogeochemistry of greenhouse gases in coastal upwelling systems: Processes and sensitivity to global change. *Science of the Anthropocene*, 12(1), 14-25.

21. Brochier, T., Echevin, V., Tam, J., et al. (2013). Climate change scenarios experiments predict a future reduction in small pelagic fish recruitment in the Humboldt Current system. *Global Change Biology*, 19(6), 1841–1853.

22. Burger, J. M., Moloney, C. L., Walker, D. R., et al. (2020). Drivers of short-term variability in phytoplankton production in an embayment of the Southern Benguela upwelling system. *Journal of Marine Systems*, 208, 103341.

23. Capone, D. G., Hutchins, D. A. (2013). Microbial biogeochemistry of coastal upwelling regimes in a changing ocean. *Nature Geoscience*, 6(9), 711–717.

24. Tarikhazer, S., Karimova, E., Kuchinskaya, I. (2023). Quantitative assessment of mudflow risk in the Greater Caucasus of Azerbaijan (on the example of the northeastern slope). *Journal of Geology, Geography and Geoecology*, 31(4), 722-735.

25. Van Hinsbergen, D. J. J., Torsvik, T. H., Schmid, S. M., et al. (2020). Orogenic architecture of the Mediterranean region and kinematic reconstruction of its tectonic evolution since the Triassic. *Gondwana Research*, 81, 79–229.