

FEATURES OF HEAVY METAL MIGRATION IN TECHNOGENIC ZONES OF THE ABSHERON PENINSULA

Aliyev Ch.S.¹, Kazimova L.A.^{2*}

¹Ministry of Science and Education of the Republic of Azerbaijan,
Institute of Geology and Geophysics, Azerbaijan
119, H.Javid ave., Baku, AZ1143

²Department of Industrial Safety and Labor Protection,
Azerbaijan State Oil and Industry University, Azerbaijan
34, Azadlig ave., Baku, AZ1010

*Corresponding author: Latifa.ismaylova@gmail.com

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Summary. One of the principal indicators characterising the intensity of extraction and utilisation of chemical elements is technophilicity, defined as the ratio between the annual extraction or production of an element (tons per year) and its Clarke concentration in the lithosphere. Numerous chemically analogous elements, despite substantial differences in both Clarke values and production volumes, demonstrate similar or comparable degrees of technophilicity. Technophilicity is a highly dynamic parameter that evolves in response to anthropogenic activity. For example, the continuous increase in oil and gas extraction has contributed to the progressive growth of carbon technophilicity. Likewise, the large-scale production of phosphate fertilizers, dolomite, and magnesite has led to a marked increase in the technophilicity of phosphorus and magnesium. The present study involved comprehensive multi-aspect investigations aimed at assessing the distribution patterns of heavy metals across different environmental media. The Absheron Peninsula was selected as the study area, and numerous samples were collected from various oil-contaminated sites throughout the region. The results obtained from the field investigations and subsequent laboratory analyses revealed the accumulation of a wide spectrum of heavy metals in the soils, including Pb, As, Cr, Cu, Zn, Se, Al, Fe, and Mn. Significant correlations identified between soil pH, organic matter content, and the exchangeable and reducible fractions of most heavy metals indicate that the migration behaviour and mobility patterns of these elements can be reliably predicted in advance.

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1. Introduction

The Absheron Peninsula, located in the southwestern part of the Caspian Sea, is characterised by its unique geological and geomorphological structure as well as its complex landscape differentiation features. The formation of the relief of the peninsula has been primarily influenced by complex tectonic processes, its geographical position, and volcanic activity.

The earliest geological data concerning the south-eastern slope of the Greater Caucasus within the Azerbaijani territory (up to 1917) was obtained by V.H.Abikh, K.I.Bogdanovich and S.Simonovich's studies. Subsequent investigations conducted between 1917 and 1956 by K.N.Paffenholz, D.V.Drobyshev, V.V.Weber, A.N.Solovkin, A.Ch.Sultanov, M.M.Aliyev, I.V.Mushketov, N.S.Shatsky, V.Y.Khain, A.Ahmadov, F.Sh.Shikhaliyev, I.Valiyev, H.Hasanov,

A.Alizadeh, I.Guliyev and H.Aliyev further enriched the geological understanding of the region.

Based on the findings and references from these researchers, it can be stated that the area is predominantly composed of Tertiary (Neogene) and Quaternary (Anthropogenic) deposits.

Study Area. The lithological composition of the rocks within the Absheron Peninsula primarily consists of carbonate-terrigenous, clayey, and argillaceous flysch formations; coarse-grained continental marine formations; sandy-clayey formations; sandy-shale subformations; fine-grained molasse formations; folded continental marine red formations; sandy clays; limestones; clayey-gravel and pebble deposits; silts and clays; clayey-sandy mixtures; shell-bearing sands (including dune sands); and breccias of mud volcanoes (Aliyev, 1978; Milanovsky, Khain, 1963).

According to M.V.Abramovich, M.M.Aliyev and V.Y.Khain (1952), it is appropriate to distinguish eight geomorphological regions within the territory of the Greater Caucasus: the Main Caucasus Range encompassing the high mountainous zone; the southwestern part of the Main Caucasus Range; the southern slope of the Greater Caucasus; the southeastern termination of the Greater Caucasus (including the Shahdagh zone, Dubrar, Western Absheron–Gobustan, and Eastern Absheron); the piedmont Neogene zone; the Alazani–Ayrichay valley; the Qusar inclined plain; and the Caspian coastal lowlands (Abramovich et al., 1952).

It should be noted that the Absheron Peninsula represents a continuation of the folded structures of the Greater Caucasus extending southeastward. Due to the region's exposure to active tectonic movements during various geological periods, numerous anticlinal uplifts and fault lines are present across the territory.

Based on the conducted studies, it can be stated that the Gobustan and western Absheron areas are underlain by the Cretaceous deposits belonging to the southeastern termination of the Greater Caucasus. Within the Absheron Peninsula, the eastern part is conventionally separated by the Fatmai–Zigh anticlinal structure (Milanovsky, Khain, 1963). It is known that the northern part of the peninsula is characterised by a complex tectonic framework. One of the main reasons for this structural complexity is that the anticlinal uplifts are primarily composed of the Upper Cretaceous deposits, while the younger Paleogene sediments of the Tertiary period overlie the synclinal zones.

It is also well established that Absheron is one of the regions with the highest density of mud volcanoes in the world. The cones and craters formed by their eruptions shape the peninsula's unique geomorphological landscape and contribute to the complex migration patterns of geochemical elements within its terrestrial environments.

The gravimagnetic field of the Absheron Peninsula is characterised by negative anomalies. Deeper minima are mainly observed in the marine areas located to the northeast and southeast of the peninsula. On land, a broad regional minimum is partially manifested in the eastern part of the peninsula within the area of the Kel fold. From this zone, the anticlinal structure rises toward the south, southwest, and west extending to the southern and southeastern "slopes" of the Dibrar gravitational maximum, which corresponds to the axial part of the southeastern termination of the Greater Caucasus. This constitutes the main regional principle of the gravity field. The field is complicated by a number of local anomalies whose number, complexity, and intensity increase

westward, which is associated with both the intensification of tectonic complexity and the proximity of denser deep-seated rocks to the surface.

The primary objective of this study is to identify the transformation processes occurring in technogenic landscapes under natural and anthropogenic geochemical anomalies within the Absheron Peninsula – an area characterised by complex geological and geomorphological conditions. The study also aims to determine the migration and accumulation patterns of pollutants that drive landscape transformations in such technogenic environments.

2. Research methods

The present study is based on the analysis of research materials collected over a period of 10 – 20 years. Comparative analyses were carried out using data and findings from previous investigations conducted by researchers such as B.A.Budagov, A.H.Ahmadov, Q.I.Rustamov, A.I.Gahramanov, E.K.Alizadeh, E.C.Karimova, and others. In selecting appropriate geochemical analytical methods and approaches, we relied on the scientific works of prominent scholars including B.B.Polynov, A.I.Perelman, M.A.Glazovskaya, V.V.Alekseyenko, S.G.Batulina, E.N.Borisenko, Y.Y.Sayet, M.A.Ivanova, B.F.Mitskevich, L.N.Shevchenko, A.N.Gulamadov and B.G.Shakuri. In addition to these classical sources, contemporary international research has also been thoroughly examined, including B.J.Alloway, M.K.Andersen, K.I.Raulund-Rasmussen, B.W.Strobel, D.L.Sparks, A.O.Splodytel, H.Alphan and other's works.

Considering the significant scientific and practical importance of studying the geochemical characteristics of landscapes contaminated by oil extraction activities in the traditional oil-producing region of the Absheron Peninsula, particular attention in this research was devoted to the eco-geochemical investigation of the most polluted areas – specifically the Balakhani, Sabunchu, and Ramana sites.

The landscapes of these territories are mainly characterised by sandy-gray and sandy gray-brown soils formed under *Artemisia-Alhagi* (wormwood–camelthorn) and *Artemisia*-ephemeral vegetation types.

The first stage of this research involved the collection of more than 130 samples of various origins from different sites, including rock specimens, followed by the determination of their geochemical composition. During soil sampling, factors such as weather conditions and sampling time (preferably morning hours) were taken into consideration. Pits with a depth of 100 cm were excavated, and samples were collected at 10 cm intervals along the soil profile. Sampling along the vertical soil profile is essen-

tial for assessing the penetration depth and migration patterns of chemical elements.

After collection, the soil samples were air-dried and prepared for subsequent laboratory analyses. Geochemical analyses were conducted using advanced analytical instruments, including an X-ray fluorescence spectrometer (RFA, S8 Tiger), an X-ray diffractometer, and an inductively coupled plasma mass spectrometer (ICP-MS 7700e), along with other complementary laboratory equipment (Aliyev, Kazimova, 2024).

According to the results of spectral analyses, the carbonate-terrigenous, clayey, and argillaceous flysch formations of the area are enriched in B, Mo, Cu, Mn, Zn, and V. The coarse-grained continental-marine formations contain elevated concentrations of Mo, As, Mn, Co, V and Ag; the sandy clays are enriched in B, Ni, Mo, Co, Ag and As; while the limestones, clay-gravel mixtures, silts, and clays are rich in B, Mo, Cu, Sn, Zn, V, Pb, Ni and Cr.

It is well known that landscapes and their components are formed on the Earth's surface, and therefore, when determining and comparing the concentrations of elements distributed within landscapes, it is appropriate to employ *Clarke values* as reference baselines (Yaroshevsky, 2006).

Table 1 presents the concentration coefficients (Clarke ratios) obtained by comparing the concentrations of chemical elements identified in rock samples collected from various locations across the Absheron Peninsula with the average abundances of those elements in the Earth's crust.

Based on the results presented in the table, the chemical elements contained within these rocks can be classified into three groups.

The **first group** includes elements such as Sr, Ba, F, and Ag, whose average concentrations approximately correspond to their respective Clarke values. If the mean contents of these elements reflect the typical geochemical characteristics of equivalent rock types in the Earth's crust, then the elements belonging to the other two groups represent specific geochemical features unique to the rocks of the Absheron Peninsula.

The **second group** comprises elements whose average concentrations in the studied rocks are significantly higher than the Clarke values (enrichment coefficient, $KK > 1$). These include Sc ($KK = 151-322$), Ca ($KK = 5.0-8.3$), and Cl ($KK = 95.6-708.2$).

The **third group** consists of microelements whose concentrations in the rocks are lower than the Clarke values ($KK < 1$), such as Mn ($KK = 0.1-0.3$), Fe ($KK = 0.1-0.2$),

V ($KK = 0.1-0.2$) and Zr ($KK = 0.1-0.2$) among others.

The composition of the rocks forming the lithological foundation of landscapes is also reflected in the composition of other landscape components (soils, waters, and vegetation) within the studied area.

The pronounced differentiation of the natural background levels of heavy metals complicates the development of strict threshold criteria for their concentrations in landscapes. For example, in acidic and alkaline soils, the MPCs of cadmium and lead may differ by nearly an order of magnitude. Therefore, MPCs must be established for major soil-geochemical regions and for geochemical soil associations with similar acid-alkaline and redox conditions, which exhibit comparable levels of resistance to pollutants (Yao et al., 2025). As an approximate reference indicator, the Clarke values of elements in the lithosphere and soils can be used (Ahnstrom, Parker, 2001; Khalid et al., 2017; Rustamov, Ismaylova, 2022)

3. Results and analysis

Landscape-Geochemical Analysis of the Study Area and Patterns of Pollutant (Heavy Metal) Accumulation

The relief of the Absheron Peninsula and the degree of its dissection create favorable conditions for the high chemical activity of waters and for an intensive water exchange between both soil-forming and underlying bedrock layers. As a result, the water, soil, and vegetation of the area—indeed, all components of the landscape—become enriched with chemical elements characteristic of the region. Therefore, the composition and concentration of chemical elements within the landscape components of the study area largely depend on the composition of the parent rocks (Abramovich et al., 1952).

It is essential to consider the physico-chemical parameters of the soil along the humus horizon while conducting a landscape-geochemical analysis. Parameters such as pH, humus content, and moisture should be analysed (Avessalomova, Ivanov, 2019).

Spectral analyses revealed the presence of a number of microelements in the sandy gray and sandy gray-brown soils of the study area. The analysis of the concentration clark values for these microelements (as exemplified in Table 7 on the Bala-khani area) indicates a notable accumulation of chlorine, boron, molybdenum, lead, cadmium, indium, bromine, antimony, palladium, silver and tin. Among these, several elements—particularly chlorine, cadmium, indium, palladium, and antimony—stand out for their especially high concentration clark values (Aliyev, Kazimova, 2024).

Table 1

Microelement composition of rock samples collected from the territories of the Absheron Peninsula
A-107 Balakhani. Oil-contaminated area

No.	Elements		Average content, %		Clarke concentration
	Atomic number	Chemical symbol	In the composition of the rock	Clarke value in the Earth's crust	
1	20	Ca	21.36	2.96	7.2
	21	Sc	0.26	0.001	260
	25	Mn	0.0087	0.1	0.087
	26	Fe	0.21	4.65	0.04
	33	As	0.0012	0.00017	7.06
	35	Br	0.00045	0.00021	2.14
	37	Rb	0.00034	0.015	0.02
	38	Sr	0.08	0.034	2.35
	39	Y	0.00023	0.0029	0.079
	40	Zr	0.0033	0.017	0.19
	47	Ag	0.00064	0.000007	91.43
	20	Ca	9.67	2.96	3.266
	25	Mn	0.015	0.1	0.15
	26	Fe	0.62	4.65	0.612
	33	As	0.00075	0.0017	0.44
	37	Rb	0.00082	0.015	0.05
	38	Sr	0.06	0.034	1.764
	39	Y	0.00024	0.0029	0.08
	40	Zr	0.0060	0.017	0.35
49	In	0.0015	0.000025	60	

Table 2

A-108, Balakhani area

No.	Elements		Average content, %		Clarke concentration
	Atomic number	Chemical symbol	In the composition of the rock	Clarke value in the Earth's crust	
1	20	Ca	7.24	2.96	2.45
	25	Mn	0.0098	0.1	0.098
	26	Fe	0.51	4.65	0.11
	37	Rb	0.00083	0.015	0.05
	38	Sr	0.015	0.034	0.44
	39	Y	0.00048	0.0029	0.17
	40	Zr	0.0073	0.017	0.43

Table 3

A-109 Ramana area

№	Elements		Average content, %		Clarke concentration
	Atomic number	Chemical symbol	In the composition of the rock	Clarke value in the Earth's crust	
1	20	Ca	26.97	2.96	9.11
	21	Sc	0.36	0.001	360
	25	Mn	0.01	0.1	0.1
	26	Fe	0.29	4.65	0.062
	35	Br	0.00068	0.00021	3.24
	37	Rb	0.00034	0.015	0.02
	38	Sr	0.09	0.034	2.65
	39	Y	0.00015	0.0029	0.05
	40	Zr	0.0021	0.017	0.12

Table 4

A-110 Sabunchu. Lake Area

№	Elements		Average content. %		Clarke concentration
	Atomic number	Chemical symbol	In the composition of the rock	Clarke value in the Earth's crust	
1	20	Ca	19.28	2.96	6.51
	21	Sc	0.16	0.001	160
	30	Zn	0.0031	0.0083	0.37
	33	As	0.00092	0.0017	0.54
	37	Rb	0.00054	0.015	0.036
	38	Sr	0.12	0.034	3.53
	39	Y	0.00031	0.0029	0.11
	22	Ti	0.23	0.45	0.51
	25	Mn	0.09	0.1	0.9
	26	Fe	3.25	4.65	0.7
	39	Y	0.0013	0.0029	0.45
	40	Zr	0.0049	0.017	0.29

Table 5

A-111 Lokbatan

№	Elements		Average content, %		Clarke concentration
	Atomic number	Chemical symbol	Atomic number	Chemical symbol	
	25	Mn	0.08	0.1	0.8
	26	Fe	0.5	4.65	0.1
	37	Rb	0.0008	0.015	0.05
	38	Sr	0.01	0.034	0.29
	39	Y	0.0004	0.0029	0.14
	40	Zr	0.002	0.017	0.12
	50	Sn	0.001	0.00025	4
	51	Sb	0.001	0.00005	20
	20	Cd	11.11	2.96	3.75
	22	Ti	0.06	0.45	0.13
	25	Mn	0.09	0.1	0.9
	37	Rb	0.002	0.015	0.13
	39	Y	0.001	0.0029	0.34
	41	Nb	0.0002	0.002	0.1
	20	Ca	2.96	2.96	6.61
	21	Sc	0.001	0.001	130
	33	As	0.0010	0.0017	0.59

Table 6

Results of chemical analyses of soils in the Absheron area

Profile No.	Depth, cm	pH	humus, %	Hygroscopic Moisture, %
1	2	3	4	5
K-107 Balakhani	0-10	8.4	3.90	0.73
	10-35	9.3	5.16	1.80
	35-60	9.0	5.00	2.07
K-108 Balakhani	0-10	8.4	7.41	0.82
	10-30	9.8	2.68	2.47
	30-60	10.4	2.50	0.63
K-109 Sabunchu	0-10	8.8	3.75	1.12
	10-35	8.9	3.48	0.80
	35-70	9.2	2.57	1.02

1	2	3	4	5
K-110 Ramana	0-20	8.4	5.17	1.93
	20-40	8.8	0.25	1.69
	40-100	8.9	0	1.11
K-111 Ramana	0-10	10.5	10.85	0.69
	10-30	9.2	5.80	0.60
	30-60	9.0	1.87	1.17
	60-100	9.2	2.34	0.99
K-112 Balakhani, “Tamiz shahar”	0-10	9.0	0.87	1.17
	10-30	9.0	0.87	1.86
	30-60	9.2	2.63	2.30
K-113 Zabrat I	0-10	9.0	0.88	1.62
	10-60	9.8	6.85	1.28
	60-100	9.0	12.44	1.71
K-114 Ramana	0-10	9.8	4.64	1.46
	10-35	9.6	4.66	1.47
	35-70	9.2	11.17	1.06
K-115 Sabunchu	0-10	8.9	14.51	1.03
	10-35	8.9	5.53	0.90
	35-70	9.5	3.44	1.23
K-116 Sabunchu, Duzlu lake	0-10	9.2	5.32	0.62
	10-35	9.0	3.49	0.44
	35-70	8.6	2.96	1.34
K-117 Haci Zeynalabdin	0-10	8.1	0.25	0
	10-30	8.1	0.46	0
	30-60	8.5	0.20	0
	60-100	8.0	0.51	0
K-118 Yeni Yashma	0-10	7.8	0.27	4.45
	10-30	7.9	0.80	4.50
	30-60	7.8	0.91	4.45
K-119 Shurabad	0-10	8.3	2.11	2.71
	10-20	8.4	1.07	4.27
	20-60	8.1	0.80	4.28
K-120 Khirdalan, Bozdag, Guzdak	0-10	7.9	0.27	4.22
	10-30	7.8	0.27	5.13
	30-70	8.0	0.37	3.94
K-121 Bayanata mountain. Guzdak	0-10	7.8	0.73	2.50
	10-30	8.1	0.64	4.45
	30-60	8.0	1.0	2.86
	60-100	8.0	0.73	3.03
K-122 Sungurdag	0-10	7.8	1.95	5.07
	10-30	7.7	0.60	7.34
	30-60	8.1	0.91	7.05
K-123 Lokbatan	60-100	8.0	1.0	7.33
	0-10	8.0	3.16	2.15
	10-30	7.9	1.27	3.32
	30-60	7.7	1.11	2.95
	60-100	8.0	1.84	2.82
K-124 Garadagh	0-10	7.9	3.69	1.45
	10-30	8.2	1.58	2.70
	30-60	7.9	1.04	1.50
	60-100	8.1	0.52	2.60
K-125 Sangachal	0-10	7.5	0.89	2.53
	10-30	7.4	1.58	1.52
	30-60	7.5	4.22	1.85
	60-100	7.7	3.92	1.92

1	2	3	4	5
K-126 Shixlar	0-10	7.8	1.29	0
	10-30	8.0	3.62	0
	30-60	7.9	0.62	0
	60-100	7.7	0.93	0
K-127 Gobustan	0-10	7.4	1.03	0
	10-30	7.7	1.70	0
	30-60	7.7	0.25	1.52
	60-100	7.8	3.16	2.76
K-128 Fatmai	0-10	7.8	3.10	0
	10-30	8.1	0.93	0
	30-60	8.3	0	0
	60-100	8.2	0.10	0
K-129 Dubandi	0-10	8.0	0.62	0
	10-30	7.8	0.25	0
	30-60	7.9	0.77	0
	60-100	7.8	1.29	0
K-130 Zira	0-10	8.0	0.78	1.41
	10-30	7.8	1.08	0
	30-60	7.9	1.70	0
	60-100	7.9	2.32	0

Table 7

Microelement composition of soil samples collected from the territories
of the Absheron peninsula
K-107 Balakhani. Oil-contaminated area

Elements		Average Amount, %		Clarke of concentration
No-si	Chemical symbol	In the soil composition	Clarke of the Earth's crust	
(0-10 sm)				
17	Cl	2.6699	0.017	157.05
26	Fe	0.1166	4.65	0.03
37	Rb	0.00058	0.015	0.04
38	Sr	0.00289	0.034	0.09
39	Y	0.00017	0.0029	0.06
40	Zr	0.0020	0.017	0.12
(10-35 sm)				
26	Fe	0.1295	4.65	0.03
37	Rb	0.00066	0.015	0.04
38	Sr	0.00317	0.034	0.009
39	Y	0.00031	0.0029	
40	Zr	0.0030	0.017	0.10
(35-60 sm)				
26	Fe	0.1747	4.65	0.03
7	Rb	0.00068	0.015	0.04
38	Sr	0.0037	0.034	0.11
39	Y	0.00029	0.0029	0.1
40	Zr	0.0040	0.017	0.23

Soil samples collected from different sites vary in their microelement content. In the soil of the Balakhani area, the chlorine concentration fluctuates between 157.1 and 164.4, averaging 142.9. It should be noted, however, that in technogenically transformed landscapes, the distribution patterns of microelements differ sharply from those in natural landscapes. This divergence is not solely due to anthropogenic transformation but also depends on the presence of water bodies or river valleys within the area. In his research (Khalid et al., 2017) noting that the lowest metal concentrations are typically recorded in river valleys. Based on their migration capacity, metals can be categorised as follows: elements with moderate migration ability (iron and nickel), and those with high migration potential—zinc, manganese, lead and copper (Chen et al., 2017).

Before proceeding with the analysis of the table data, it is necessary to first consider the normative reference values and conduct comparisons accordingly. The relevant international standards are presented in Table 8 (Huixia Liu et al., 2025).

Based on the results of the conducted analyses and tests, we will refer to the classifications established by prior researchers to determine the level of contamination in the area.

Note: These standards are based on the "World Reference Base for Soil Resources" (2022) and the "FAO Guidelines for Soil Description" (1999) documents by the Food and Agriculture Organization (FAO).

Pollutants are classified according to their hazard levels (Cheng et al., 2020; Geng et al., 2024):

- **Class I (highly hazardous):** As, Cd, Hg, Se, Pb, Fe, benzo[a]pyrene, Zn;
- **Class II (moderately hazardous):** B, Co, Ni, Mo, Cu, Sb, Cr;
- **Class III (low hazard):** Ba, V, W, Mn, Sr and others.

In the practice of ecological–geochemical research, indicative hazard assessments of contamination in anomalous zones are commonly employed to evaluate environmental conditions. Each hazard level is associated with specific types of morbidity in the population, particularly among children:

- **Level I:** increased overall morbidity;
- **Level II:** higher incidence of chronic respiratory diseases and functional disorders.
- **Level III:** increased incidence of reproductive dysfunction, disorders of the immune system, and other long-term adverse effects.

Using the existing classification and the results of the obtained analytical data, it is possible to determine both the level of technogenic pollution and the specific pollutants present in the study area.

As shown in Table 1, in area A107, only a trace amount of arsenic (As, 0.0012%) was detected among the classified heavy metals, while no other heavy metals were found. Therefore, the A107 sampling site can be classified as a Level I pollution zone.

In area A108, manganese (Mn) and chromium (Cr) were detected, indicating that this site can be classified as a Level III pollution zone.

In area A109, no significant concentrations of the listed heavy metals were observed; hence, according to the classification, it does not belong to any pollution level.

In area A110, the presence of arsenic (As) and iron (Fe) was recorded, which allows this site to be classified as a Level I pollution zone.

In area A111, both arsenic (As) and cadmium (Cd)—which belong to the category of hazardous heavy metals—were detected, and therefore this area is also classified as a Level I pollution zone.

Based on the conducted analyses, it can be concluded that highly hazardous heavy metals occur in the soil of the study area only in very low concentrations.

Table 8

Comparative analysis of key indicators on semi-desert, gray, and gray-brown soil types with the corresponding parameters of the Absheron Peninsula

Soil Type	Indicators			
	Soil horizon	Ph (WRB-FAO)	humus (WRB-FAO)	Absheron
Semi-desert (Desert Soil)	Topsoil / A horizon (0–20 cm)	7.0–8.5	1-6%	0,3-1,5%
	Subsoil / B horizon (20–60 cm)	8.5–9.0	0,5-4%	0,1-0,3%
	Parent material / C horizon (60–100 cm)	8.5–9.0	0,2-3%	≤0,1%
(Brown Soil)	Topsoil / A horizon (0–20 cm)	pH 5.5–6.5	0,3-1%	0.4-1.0%
	Subsoil / B horizon (20–60 cm)	5.5–6.0	0.1-0.3%	0.1-0.3%
	Parent material / C horizon (60–100 cm)	6.0–7.0	≤0.1	≤0.1%
(Chestnut soils)	Topsoil / A horizon (0–20 cm)	6.5–8.0	0.5-0.9%	0.8-1.5%
	Subsoil / B horizon (20–60 cm)	6.0–7.8	0.9-1.5%	0.3-0.6%
	Parent material / C horizon (60–100 cm)	6.0–7.5	1.0-1.5%	0.1-0.3

Excluding the sections located in Balakhani, Ramana, Zabrat, and Sabunchu, as well as Lokbatan, Garadagh, and Sangachal—areas that are more heavily contaminated with oil (sections K107–K116 and K123–K125)—the soil profiles of other sections show that the humus content varies between 0.20% and 3.62%, gradually and consistently decreasing from the upper horizons toward the lower layers.

In oil-free areas, the highest humus content was recorded in the Shykhlar area (section K126) within the 10–30 cm horizon, amounting to 3.62%, while the lowest value was observed in the Haji Zeynalabdin Taghiyev settlement (section K117) within the 30–60 cm horizon, where it was 0.20%.

The results indicate that the maximum levels of mineral compounds are found in areas that are relatively more contaminated with oil, whereas the minimum levels are characteristic of areas unaffected by oil pollution.

Tables 2–7 present the results of the chemical analyses of soil samples collected from the study area. These soils, which are predominantly characterised by alkaline to strongly alkaline conditions (pH = 8.4–10.5), exhibit humus contents reaching up to 10.15% and 14.51% in the upper layers of the sections located in Ramana village and the Sabunchu area, respectively. The humus content gradually decreases toward the lower soil horizons, ranging from 1.87% to 3.44%.

The unusually high humus content, which is not typical for the Absheron region should not be interpreted as an indicator of an abundance of humified organic compounds or decomposed materials characteristic of fertile topsoils. Rather, it should be viewed as a consequence of oil contamination. This interpretation is further supported by the unexpected discovery of “buried humus layers” in the deeper horizons (60–100 cm and 35–70 cm) of the soil profiles taken from the more heavily polluted Zabrat I and Ramana village areas.

As shown in Table 2, the humus content in Zabrat I increases with depth: 0.88% in the 0–10 cm layer, 6.85% in the 10–60 cm layer, and reaching 12.44% in the 60–100 cm layer. A similar trend is observed in the Ramana area, where the humus content, instead of decreasing with depth, shows an anomalous upward pattern—from 4.64% in the upper 0–10 cm layer to 11.17% in the 35–70 cm horizon (section 114).

This inverse distribution pattern clearly indicates that the downward migration of oil and petroleum products under the influence of gravity has led to the accumulation of hydrocarbons in the deeper soil layers, resulting in artificially elevated “humus” values at those depths.

4. Conclusion

Except for the areas that are more heavily contaminated with oil, the soils in all investigated sites are characterised by neutral to slightly alkaline conditions, with pH values ranging from 7.4 to 8.5. The leaching of carbonates from the upper soil layers contributes to the formation of a weakly alkaline environment (pH = 7.4–8.2) near the surface, while their accumulation in deeper horizons results in a more strongly alkaline environment (pH = 8.0–8.5).

Excluding the oil-contaminated sections K107–K116, as well as K123, K124, and K125 located in Balakhani, Ramana, Zabrat, Sabunchu, Lokbatan, Garadagh, and Sangachal, the humus content in the soil profiles of the remaining study areas varies between 0.20% and 3.62%, showing a regular and gradual decrease from the upper horizons toward the lower layers.

In non-contaminated areas, the highest humus content was recorded in the Shykhlar area (section K126) within the 10–30 cm horizon (3.62%), while the lowest value was observed in the Haji Zeynalabdin Taghiyev settlement (section K117) within the 30–60 cm horizon (0.20%).

The results indicate that the maximum levels of mineral compounds occur in areas relatively more contaminated with oil, whereas the minimum levels are observed in non-contaminated soils.

In the oil-contaminated areas, the upper soil horizons show a higher accumulation of microelements such as chlorine (Cl), palladium (Pd), antimony (Sb), terbium (Tb), cadmium (Cd), indium (In), and silver (Ag). Conversely, elements such as strontium (Sr), zirconium (Zr), vanadium (V), rubidium (Rb), and iron (Fe) are found in smaller quantities in the upper layers compared to the lower horizons. The concentration of other elements varies irregularly along the soil profile.

Based on the analytical data, three levels of contamination zones were identified within the study area:

Level I contamination zones – observed in sites A107, A110, and A111;

Level III contamination zone – identified in site A108, where manganese (Mn) and chromium (Cr) were detected;

No contamination level – assigned to site A109, where no heavy metals were observed according to the adopted classification.

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ОСОБЕННОСТИ МИГРАЦИИ ТЯЖЁЛЫХ МЕТАЛЛОВ В ТЕХНОГЕННЫХ ЗОНАХ АБШЕРОНСКОГО ПОЛУОСТРОВА

Алиев Ч.С.¹, Казимова Л.А.^{2*}

¹Министерство науки и образования Республики Азербайджан, Институт геологии и геофизики, Азербайджан AZ1073, Баку, просп.Г.Джавида, 119

²Кафедра промышленной безопасности и охраны труда, Азербайджанский государственный университет нефти и промышленности, Азербайджан AZ1010, Баку, просп. Азадлыг, 34

*Автор, отвечающий за переписку: latifa.ismaylova@gmail.com

Резюме. В представленной статье рассматриваются особенности миграции тяжёлых металлов в нефтезагрязнённых почвах, а также потенциальные угрозы для здоровья человека и окружающей среды в районах их накопления. Миграционные свойства тяжёлых металлов в почве зависят от множества различных факторов. В статье приведены результаты разносторонних исследований, направленных на изучение закономерностей распределения тяжёлых металлов в различных средах. В качестве района исследования был выбран Абшеронский полуостров, откуда были отобраны многочисленные пробы с различных участков, загрязнённых нефтью. В данном исследовании рассматриваются физико-химические и геохимические характеристики почв в нефтяных и незагрязнённых районах. Результаты показывают, что большинство почв являются нейтральными или с увеличением щёлочности в более глубоких горизонтах слегка щёлочными из-за карбонатных процессов. Содержание гумуса значительно варьируется от более высоких значений в поверхностных слоях до их постепенного снижения по глубине в незагрязнённых почвах. Нефтяное загрязнение меняет эту структуру и связано с повышением концентрации минеральных соединений. Полученные результаты исследований и лабораторных анализов показывают значительное накопление в почвах различных тяжёлых металлов, таких как Pb, As, Cr, Cu, Zn, Se, Al, Fe и Mn. В целом, результаты указывают на значительное влияние загрязнения нефтью на состав почвы, распределение элементов и качество окружающей среды. Значимая корреляция между pH почвы, содержанием органических веществ и обменными и восстановимыми фракциями большинства тяжёлых металлов подтверждает возможность предварительного прогнозирования закономерностей их миграции.

Ключевые слова: образцы почв, технофильность, значения Кларка, геохимические характеристики, миграция

ABŞERON YARIMADASININ TEXNOGEN DƏYİŞİLMİŞ ZONALARINDA AĞIR METALLARIN MİQRASIYA XÜSUSİYYƏTLƏRİ

Əliyev Ç.S.¹, Kazımova L.A.^{2*}

¹Azərbaycan Respublikası Elm və Təhsil Nazirliyi, Geologiya və Geofizika İnstitutu, Azərbaycan
AZ1073, Bakı, H.Javid pros., 119

²Sənaye təhlükəsizliyi və əmək mühafizəsi kafedrası, Azərbaycan Dövlət Neft və Sənaye Universiteti, Azərbaycan
AZ1010, Bakı, Azadlıq pros., 34

*Yazışmalara məsul: latifa.ismaylova@gmail.com

Xülasə. Təqdim olunan məqalədə Ağır metalların neftlə çirklənmiş torpaqlarda miqrasiya xüsusiyyətləri və bu metalların toplandığı ərazilərdə insan sağlamlığı və ətraf mühit üçün yarada biləcəyi təhlükələr şərh olunur. Ağır metalların torpaqda miqrasiya xüsusiyyətləri bir çox müxtəlif amillərdən asılıdır. Məqalədə müxtəlif aspektli tədqiqatlar aparılaraq ağır metalların fərqli mühitlərdə paylanma qanunauyğunluqları tədqiq olunmuşdur. Tədqiqat ərazisi olaraq, Abşeron yarımadası seçilmişdir və ərazidə fərqli neftlə çirklənmiş ərazilərdən çoxsaylı nümunələr götürülmüşdür. Təqdim olunan tədqiqat neftlə çirklənmiş və çirklənməmiş ərazilərdə torpaqların fiziki-kimyəvi və geokimyəvi xüsusiyyətlərinin tədqiqinə həsr olunmuşdur. Nəticələr göstərir ki, torpaqların əksəriyyəti karbonat prosesləri səbəbindən neytral və ya bir qədər qələvidir. daha dərin qatlarda isə qələvilik artır və humus tərkibi əhəmiyyətli dərəcədə dəyişir. səth təbəqələrində daha yüksək həddə çirklənməmiş qatlarda isə dərinlik artdıqca tədricən azalır. Tədqiqatlar və laboratoriya analizlərindən əldə edilən nəticələr torpaqlarda Pb, As, Cr, Cu, Zn, Se, Al, Fe və Mn müxtəlif ağır metalların əhəmiyyətli dərəcədə toplandığını göstərir. Ümumilikdə, nəticələr neft çirklənməsinin torpaq tərkibinə, element paylanmasına və ətraf mühitin keyfiyyətinə əhəmiyyətli təsirini göstərir. Torpaq pH, üzvi maddələrin tərkibi və əksər ağır metalların dəyişdirilə bilən və azaldıla bilən fraksiyaları arasında əhəmiyyətli bir korrelyasiya onların miqrasiya modellərinin ilkin proqnozlaşdırılmasının mümkünlüyünü təsdiqləyir. Aparılan tədqiqatlar və laborator analizlərin nəticələri göstərir ki, torpaqlarda kifayət qədər müxtəlif ağır metalların Pb, As, Cr, Cu, Zn, Se, Al, Fe, Mn toplanması müşahidə olunur. Torpaq pH-ı, üzvi maddələri və ağır metalların əksəriyyətinin mübadilə oluna bilən və reduksiya olunan fraksiyaları ilə əhəmiyyətli korrelyasiyası sübut edir ki, ağır metalların miqrasiyası qanunauyğunluqlarını öncədən proqnozlaşdırmaq mümkündür.

Açar sözlər: torpaq nümunələri, texnofillik, Klark ədədi, geokimyəvi xüsusiyyətlər, miqrasiya