






Scientific article

## GEOCHEMICAL ANALYSIS OF SOILS OF DRY STEPPE ECOSYSTEMS OF THE EREYMENTAU DISTRICT OF THE AKMOLA REGION

Gulzira Gataulina<sup>1,\*</sup>, Yerbolat Mendybaev<sup>1</sup>, Candidate of Biological Sciences, professor, Turgut Tüzün Onay<sup>2</sup>, PhD, professor

<sup>1</sup> L.N. Gumilyov Eurasian National University, Astana, Kazakhstan; [gulziragataulina@gmail.com](mailto:gulziragataulina@gmail.com) (GG), [mendybayev\\_yekh@enu.kz](mailto:mendybayev_yekh@enu.kz) (YM)

<sup>2</sup> Boğazici University, Istanbul, Turkey; [onayturg@boun.edu.tr](mailto:onayturg@boun.edu.tr) (TTO)

\*Corresponding author correspondent: Gulzira Gataulina, [gulziragataulina@gmail.com](mailto:gulziragataulina@gmail.com)

### KEY WORDS

heavy metals  
dry steppe zone Ereymentau district  
soil  
degradation

### ABSTRACT

This study is a long-term comparative analysis of the morphological and chemical characteristics of dark chestnut solonchaks soils in the dry-steppe zone of the Ereymentau district of the Akmola region for the period 1979-2024. Based on archival soil surveys and modern laboratory data, changes in the humus content, pH, ionic composition and heavy metal concentration were estimated. The use of geostatistical mapping and GIS technologies allowed us to identify spatial patterns of soil cover transformation. The results showed a significant decrease in the organic matter content in the upper horizons, relative stability of pH in the slightly alkaline range, redistribution of exchangeable cations and vertical migration of trace elements, including plumbum and cadmium. Despite the fact that heavy metal concentrations remain below the established maximum permissible levels, the identified trends indicate progressive degradation and the need for systematic monitoring. Recommendations for sustainable land use, taking into account regional climatic and anthropogenic factors, are proposed.

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### 1. INTRODUCTION

The study of soil composition, fertility, erosion, heavy metals, historical changes and recent events in Akmola region has become a critical area of research as they affect agricultural productivity, environmental sustainability and human health. The development of this area reflects the growing concerns about land degradation and environmental pollution, with initial studies focusing on soil fertility and land use dynamics [1, 2], and recent studies highlighting the anthropogenic impact and the influence of climate change on soil erosion and pollution [3, 4, 5]. Characterized by steppe landscapes and intensive agricultural use, Akmola region faces serious challenges including soil erosion rates reaching several tons per hectare per year [3, 6] and accumulation of heavy metals posing environmental and health risks [7, 8]. These issues have practical implications for food security and sustainable land management in Kazakhstan [9].

The specific problem under consideration relates to the complex interplay between soil degradation, heavy metal pollution and land use change in the Akmola region, which remains poorly understood in a comprehensive manner. Despite numerous studies on soil erosion [10], heavy metal pollution [7, 11] and land use dynamics [12], there is a notable gap in comprehensive assessments that take into account the physicochemical properties of soils, pollution levels and historical land use trends in this region [1, 3, 8]. Controversy remains regarding the relative contributions of natural and anthropogenic sources of heavy metals [13, 14] and the effectiveness of current soil conservation measures [3, 6]. Failure to address these gaps may worsen land degradation and undermine the sustainability of agriculture [9, 15].

Soil monitoring involves the assessment of chemical characteristics, including organic matter content, acidity levels, and macro- and micronutrient concentrations, which are key determinants of agronomic fertility and crop yields [16, 17]. Long-term analysis of soil

chemistry facilitates the development of strategies aimed at restoration and adaptive management of terrestrial resources in the context of changing environmental conditions [18, 19]. Modern soil monitoring methodologies prioritize not only the assessment of chemical metrics, but also complex geo-ecological systems using integrated methods that include remote sensing, geostatistics, and pollution detection techniques. Such complex systems have been effectively used to assess the state of the environment and manage pollution in river basins and agricultural ecosystems [20]. In the steppe ecosystems of Kazakhstan, this methodology is particularly relevant due to the combined effects of agricultural intensification and climate variability.

To improve soil fertility and promote sustainable land use in Northern Kazakhstan, internationally recognized methodologies are often applied. In Brazil, the widespread use of no-tillage systems significantly reduces mechanical soil disturbance, preserves vegetation cover, and mitigates humus depletion [21]. In China, liming and silicon-rich fertilizers are widely applied to prevent acidification under intensive agricultural practices [22]. The European Union enforces strict regulations on the use of phosphorus fertilizers containing heavy metals and applies wastewater filtration systems to prevent the accumulation of lead and cadmium in agricultural soils [23]. These international practices provide a valuable methodological context for understanding global approaches to soil protection and sustainable land management.

This study shows that degradation processes that have occurred over the past 45 years can be systematically quantified using geostatistical and remote sensing methodologies. The Eurasian steppe, a region of major global ecological importance, is undergoing land-use changes that remain poorly understood.

Remote sensing plays an important role in systematically monitoring spatial and temporal changes in the earth's soil cover. An analysis using the Normalized Difference Vegetation Index (NDVI) over the past three decades has shown that approximately 22% of the earth's surface has been degraded, with notable cases occurring in particular in the steppes of Russia, Ukraine and Kazakhstan [24].

In addition to agronomic factors, the socio-political transformations that followed the collapse of the Soviet Union have had a significant impact on soil health. Historically, these steppes have undergone significant changes, particularly during the Soviet Virgin Lands campaign, which dramatically altered land use and ecosystem structure [25, 26]. Steppes provide key ecosystem services, including biodiversity conservation, carbon storage, and support for the livelihoods of pastoralists [27, 28]. Approximately 7.1% of Kazakhstan's territory is dry steppe, and the Akmola region is a key zone of typical steppe vegetation, dominated by species such as *Stipa lessingiana* [29]. The socio-economic and climatic importance of these ecosystems highlights the need for a comprehensive understanding and sustainable management [30].

The objective of this study is to assess long-term changes in soil cover and develop recommendations for sustainable land use. The study was conducted on the example of the Ereymentau district of the Akmola region. The dynamics of humus content, pH, heavy metals and salt concentrations in different soil horizons were analyzed for the period from 1979 to 2024. The study used eco-geographical methods, including geostatistical mapping, to identify spatial patterns of soil transformation. The results of the study will help to determine the influence of natural and anthropogenic factors, identify areas vulnerable to restoration and develop rational land use strategies. The study used ecological and geographical methodologies. The results of this study are expected to help clarify the impact of natural and anthropogenic factors, identify areas for restoration work, and develop rational land use strategies.

## 2. MATERIALS AND METHODS

The study was conducted in the Ereymentau district, located in the east of Akmola region within the dry steppe zone of the northern Kazakh Upland, 800 m from the village of Karagaily (Fig. 1). The relief represents a hilly plain composed mainly of Quaternary loess-like loams and alluvial deposits. The vegetation cover belongs to typical steppe and dry-steppe formations dominated by cereal and forb-cereal associations, with sod grasses on flat areas and halophytes in depressions [1, 31].

To assess the long-term dynamics of soil properties, archival materials from a 1979 soil survey were used, combined with the results of field studies conducted in 2024. As part of the comparative analysis, two key sites were selected. At each site, complete soil profiles were described and samples were collected by genetic horizons.

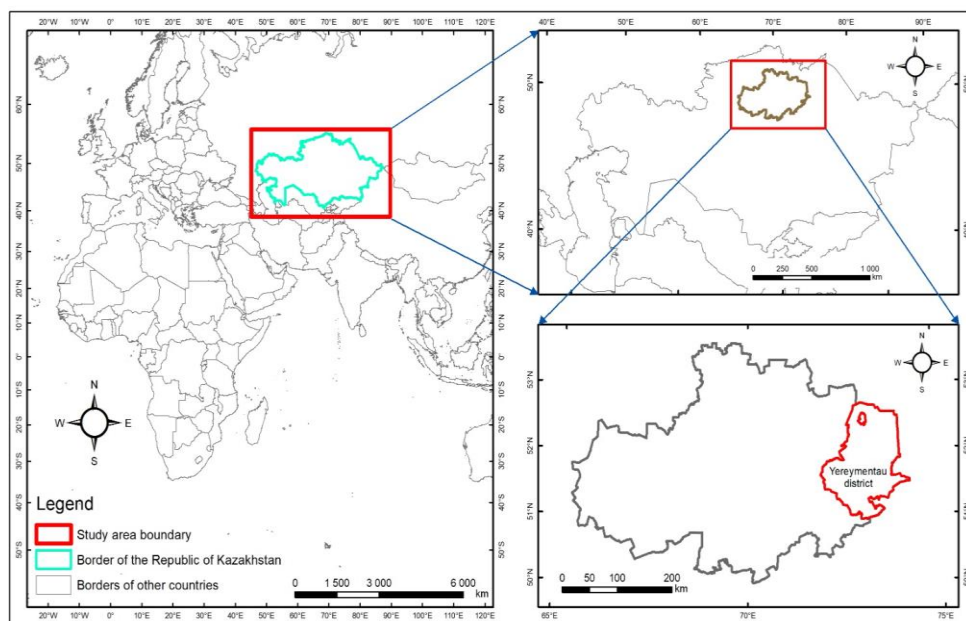
Field investigations were conducted on 5 October 2024, during stable dry autumn conditions. Soil samples were collected by genetic horizons from fully described soil profiles in accordance with ISO 10381-4:2003. For the surface layer, the standard sampling depth of 0–20 cm was used for arable soils and 0–10 cm for virgin land.

Laboratory analyses were carried out in the accredited laboratory of Eco Project Company LLP using certified analytical equipment and standard analytical procedures. Soil pH was measured using an ITAN pH meter (serial No. 300927) in accordance with GOST 26425-85. Chloride, sulfate, and nitrate concentrations were determined photocolometrically using a KFK-3 photocolorimeter (serial No. 2170221), following the requirements of the same standard. Calcium and magnesium contents were determined titrimetrically, while organic matter (humus) was analyzed in accordance with GOST 26213-2021. Concentrations of heavy metals (Pb, Cd, Zn, Cu, Co, Ni, Fe, and Mn) were measured by inductively coupled plasma atomic emission spectrometry (ICP-AES) using an ICPE-9820 spectrometer (Shimadzu, Japan), serial No. B42046101615 CZ, in compliance with GOST ISO 22036-2014.

Measurement uncertainty was assessed using the instrumental method, based on the certified accuracy of the equipment and the methodological documentation provided by the laboratory. For humus, a relative uncertainty of 20% was applied for contents up to 3%, and 15% for contents above 3%. For ionic indicators, the following relative uncertainties were used: chlorides - 15%, sulfates - 10%, calcium and magnesium - 5%, and pH - 1% (Table 1). For heavy metals, the methodological relative uncertainties specified for ICP-AES were applied: Pb — 25%, Cd - 50%, Zn - 20%, Cu - 20%, Co - 40%, Ni - 35%, Fe - 28%, and Mn - 30% (Table 2). Archival data from 1979 are presented without uncertainty estimation, as the original laboratory protocols did not contain information on measurement error.

The absolute uncertainty was calculated using the formula  $\Delta C = C \times \delta / 100$ , and all results are presented in the format  $C \pm \Delta C$ , ensuring correct representation of measurement uncertainty and compliance with analytical standards.

The coordinates of the sampling points were recorded using GPS, and the spatial referencing and visualization of the results were performed in the ArcGIS environment. Historical maps (Atlas of the Virgin Lands, 1964) were georeferenced using ArcGIS 10.8 based on control points and the WGS 84 projection, UTM Zone 42N [32].



**Figure 1.** Geographical location of the site

To present the obtained data, comparative graphs were constructed using Python software and the Matplotlib and Pandas libraries. The analysis covered the humus content, pH values, and  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  ion concentrations in soil horizons for 1979 and 2024. Each group of indicators was visualized as color-coded diagrams with digital signatures and error bars indicated by thin lines. Cartographic materials were exported in PDF and JPEG formats (scale 1:1,000,000).

### 3. RESULTS AND DISCUSSION

To characterize the soil cover of the study area, two soil pits (No. 1, No. 2) were laid on October 5, 2024, at a distance of 800 meters from the village of Karagaily. The vegetation cover is represented by forb-cereal (*Medicago falcata*, *Stipa capillata*) and feather grass-fescue-wormwood (*Stipa lessingiana*, *Festuca valesiaca*, *Artemisia lerchiana*) associations. The dominant species are *Stipa capillata* and *Festuca valesiaca* with an admixture of *Artemisia spp.*, *Agropyron spp.*, *Phlomis spp.*, *Thymus spp.*, *Phleum spp.*, *Agrostis alba*, *Salvia spp.* and *Elytrigia spp* [31].

Projected and true vegetation cover:

Section No. 1: projected – 80%, true – 40%;

Section No. 2: projected – 70%, true – 35%.

Morphological characteristics of soil profiles

Section P-1 (dark chestnut solonetzic)

Effervescence from 10% HCl is observed from 37 cm.

Horizon A (0–24 cm): dark chestnut with a grayish tint, moist, heavy loam, lumpy-nutty, compacted, many roots, gradual transition.

Horizon B (24–36 cm): brown-grayish, moist, heavy loam, blocky, dense, few roots, clear transition.

Horizon BC (36–72 cm): gray-brown, moist, heavy loam, lumpy-blocky, dense, no roots, gradual transition.

Horizon C (72 cm...): light brown, heavy loam with carbonate deposits in the form of white spots.

Section P-2 (dark chestnut solonetzic)

Effervescence from 10% HCl is observed from 40 cm.

Horizon A (0–29 cm): Dark chestnut with a grayish tint, moist, heavy loam, lumpy-nutty, compacted, many roots, gradual transition.

Horizon B (29–49 cm): brownish-gray, moist, heavy loam, columnar, dense, no roots, abrupt transition.

Horizon BC (49–78 cm): gray-brown, moist, heavy loam, lumpy-blocky, dense, no roots, gradual transition.

Horizon C (78 cm...): brownish-yellow, heavy loam, carbonates are expressed as concretions, coatings, light inclusions.

According to mechanical composition, all soils are classified as heavy loamy, which is confirmed by laboratory tests (Table 1). Analysis of water extract indicates the absence of salinization.

**Table 1**

Composition of water extract of soils

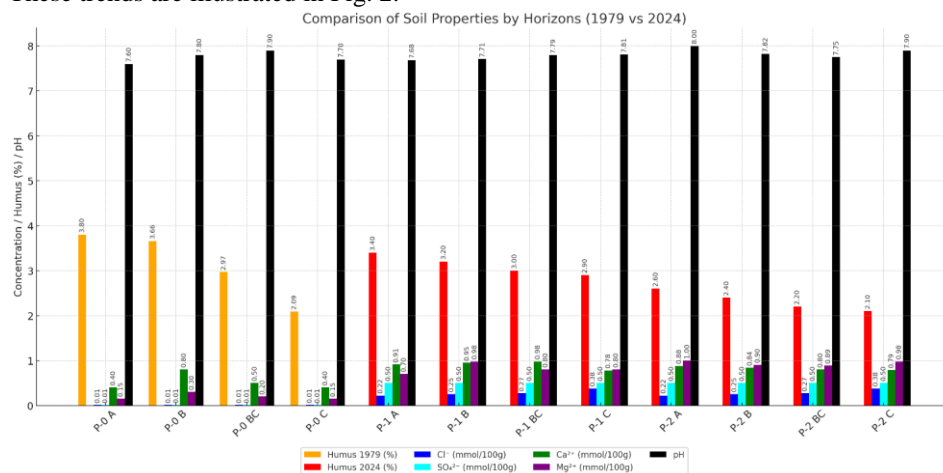
№	Soil	Horizon and sampling depth. cm	Humus. %	pH	Mg-eq/ 100 g of soil		%	
					Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>
1979								
1	P- 1 dark chestnut solo-netzic	A 0-21	3.8	7.6	0.005±0.08	0.005±0.10	0.40	0.15
		B 21-46	3.66	7.8	0.017±0.28	0.005±0.10	0.80	0.30
		BC 46-74	2.97	7.9	0.005±0.08	0.005±0.10	0.50	0.20
		C 74...	2.09	7.7	0.010±0.16	0.005±0.10	0.40	0.15
2024								
1	P-1 dark chestnut solo-netzic	A 0-24	3.4±0.51	7.68±0.08	0.221±0.033	<0.5	0.91±0.046	0.7±0.035
		B 24-36	3.2±0.48	7.71±0.08	0.254±0.038	<0.5	0.95±0.048	0.98±0.049
		BC 36-72	3.0±0.060	7.79±0.08	0.271±0.041	<0.5	0.98±0.049	0.8±0.040
		C 72...	2.9±0.58	7.81±0.08	0.38±0.057	<0.5	0.78±0.039	0.8±0.040
2	P-2 dark chestnut solo-netzic	A 0-29	2.6±0.52	8.0±0.08	0.221±0.033	<0.5	0.88±0.044	1.0±0.050
		B 29-49	2.4±0.48	7.82±0.08	0.254±0.038	<0.5	0.84±0.042	0.9±0.045
		BC 49-78	2.2±0.44	7.75±0.08	0.271±0.041	<0.5	0.8±0.040	0.89±0.045
		C 78...	2.1±0.42	7.9±0.08	0.38±0.057	<0.5	0.79±0.040	0.98±0.049

Comparative data for 1979 and 2024 (Table 1) indicate a noticeable decrease in humus concentration in all genetic horizons:

Section P-1: Horizon A (0–24 cm): from 3.8% to 3.4%;

Section P-2: Horizon A (0–29 cm): from 3.8% to 2.6%;

These trends are illustrated in Fig. 2.



**Figure 2.** Comparison of Soil Properties Across Horizons (1979 vs. 2024)

The pH values in the studied soils remained in a stable alkaline range: from 7.6 to 7.9 in 1979 and from 7.68 to 8.0 in 2024. Minor pH fluctuations along the profile (see Fig. 2) reflect the preservation of the carbonate buffer potential of dark chestnut solonchaks, which is typical for areas with a moderately arid climate. The maximum pH value (8.0) was recorded in the upper horizon of section P-2, which may indicate the accumulation of exchangeable bases. (Fig. 2). The concentrations of Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> showed a clear increase in 2024 compared to 1979. Thus, the Cl<sup>-</sup> content in 1979 in all horizons did not exceed 0.017 mmol/100 g, whereas in 2024 it varied from 0.221 to 0.38 mmol/100 g, with the highest values in the C horizons (P-1 and P-2), which may indicate the accumulation of easily soluble salts in the lower part of the profile.

The concentration of SO<sub>4</sub><sup>2-</sup> in 1979 was at the level of 0.005 mmol/100 g, while in 2024, in all sections, a value of less than 0.5 mmol/100 g was recorded, conditionally interpreted as 0.5 mmol/100 g for the purposes of visualization and comparison. This may indicate the entry of sulfur-containing compounds, possibly of technogenic origin or associated with changes in moisture conditions.

In section P-1, a slight decrease in the Ca<sup>2+</sup> content was revealed in the upper horizon (0.91 mmol/100 g) compared to the subsurface (up to 0.98 mmol/100 g). This may be due to calcium leaching during surface moistening. In section P-2, the Ca<sup>2+</sup> and Mg<sup>2+</sup> content steadily decreases along the profile (Ca<sup>2+</sup>: from 0.88 to 0.79 mmol/100 g; Mg<sup>2+</sup>: from 1.0 to 0.98 mmol/100 g), which reflects the natural migration of exchangeable bases down the profile. Compared to 1979, in 2024 the concentrations of Ca<sup>2+</sup> and Mg<sup>2+</sup> increased by 2–3 times, which may indicate an increase in mineralization and may be associated with anthropogenic impact (grazing, fertilizers, changes in water regime). The content of heavy metals in the aqueous extract is presented in Table 2.

**Table 2**

The concentration of heavy metals in the aqueous extract of soils

№	Soil	Horizon and Depth of sampling, cm	mg/kg							
			Pb	Cd	Zn	Cu	Co	Ni	Fe	Mn
	MPC*, mg/kg		32	0.5	23	3	5	4	Not stand.	1500
1	P-1 dark chestnut solonchak	A 0-24	0.051±	0.0012±0.	0.01±0	0.0015		0.35		
			0.013	0006	.0020	3	0.0032	2	0	1.5±0.45
		B 24-36	0.042±	0.0013±0.	0.009±	0.0011		0.07±0	0.3±	11.0±3.0
			0.011	0007	0.0018	2	.028	0.10	8	1.5±0.45
		BC 36-72	0.045±	0.002±0.0	0.01±0	0.0012		0.05±0	0.4±	13.0±3.6
			0.045	010	.0020	2	.020	0.14	4	0.9±0.27

2 P-2 dark chestnut solonetzic

C 72...	0.04±0.010	0.0023±0.0012	0.008±0.0016	0.0012	±0.0002	0.06±0.024	0.3±0.10	15.0±4.20	1.0±0.30
A 0-29	0.054±0.014	0.0035±0.0018	0.004±0.0008	0.0013	±0.0003	0.08±0.032	0.5±0.18	12.0±3.36	1.1±0.33
B 29-49	0.045±0.011	0.0015±0.0008	0.006±0.0012	0.005±0.0010	0.08±0.032	0.44±0.1	11.0±3.05	0.9±0.27	
BC 49-78	0.046±0.012	0.004±0.0020	0.005±0.0010	0.004±0.0008	0.09±0.036	0.35±0.1	10.0±2.80	0.8±0.24	
C 78...	0.051±0.013	0.0035±0.0018	0.005±0.0010	0.001±0.0002	0.08±0.032	0.31±0.1	13.0±3.64	1.0±0.30	

\* Maximum permissible concentrations (MPC) of heavy metals in agricultural soils

All values of heavy metal concentrations in soils of sections P-1 and P-2 are below the established MAC.

In section P-1, a slight increase in the content of Pb and Cd with depth is observed. Fe accumulation is noted in the C horizon (72+ cm), where its concentration reaches 15.0 mg/kg.

In section P-2, the maximum Fe content (12.0 mg/kg) is recorded in the B horizon (29–49 cm). Increased levels of Pb and Cd are noted in the upper horizons compared to the underlying layers.

Concentrations of Ni and Co in all soil horizons remain low and well below the MPC. Ni ranges between 0.3–0.5 mg/kg, while Co varies from 0.05 to 0.09 mg/kg, with no indication of accumulation in the upper horizons. The stable vertical distribution of both elements suggests their predominantly geogenic origin, associated with loess-like loams that constitute the parent material of dark chestnut soils. The low mobility of Ni and Co is further explained by the slightly alkaline soil reaction (pH 7.7–8.0), which promotes the formation of poorly soluble hydroxide and carbonate compounds. This limits their migration within the profile and reflects their natural background levels and conservative geochemical behavior under dry steppe conditions.

The dynamics of heavy metals are shown in Figures 3–10 (vertical and spatial distribution).

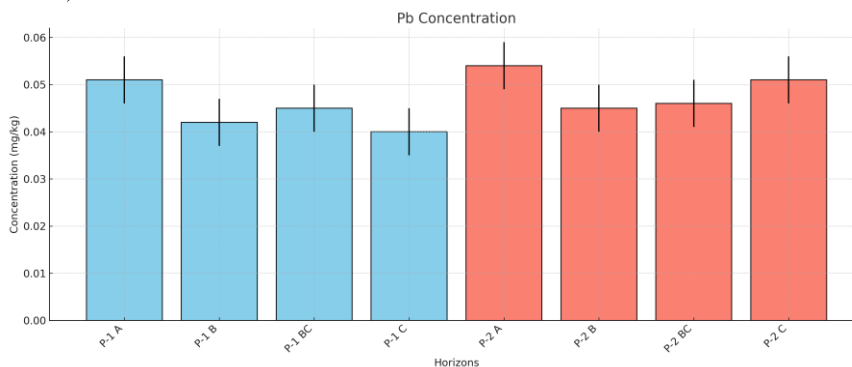


Figure 3. Lead (Pb) Concentration

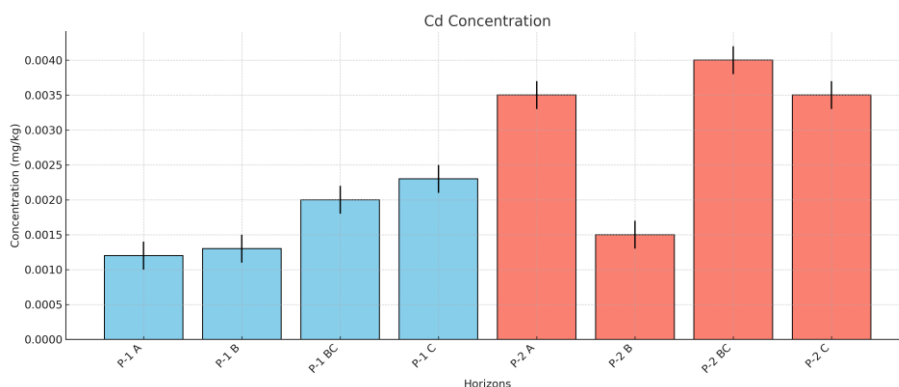


Figure 4. Cadmium (Cd) Concentration

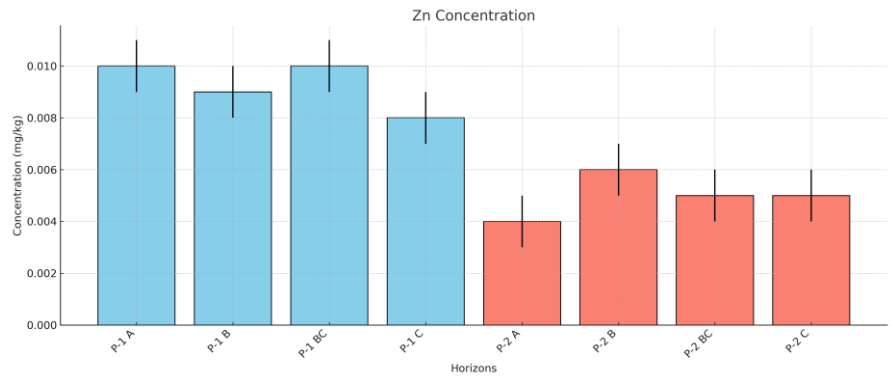


Figure 5. Zinc (Zn) Concentration

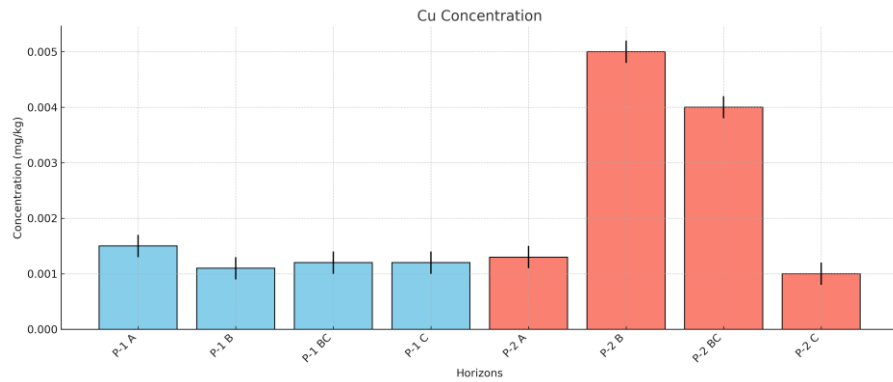


Figure 6. Copper (Cu) Concentration

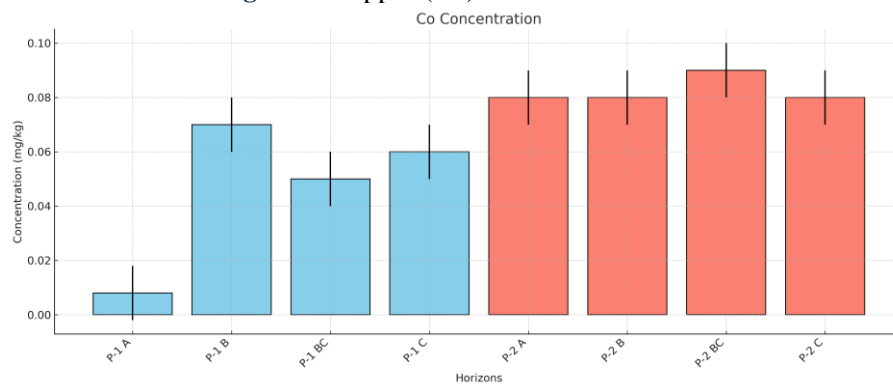


Figure 7. Cobalt (Co) Concentration

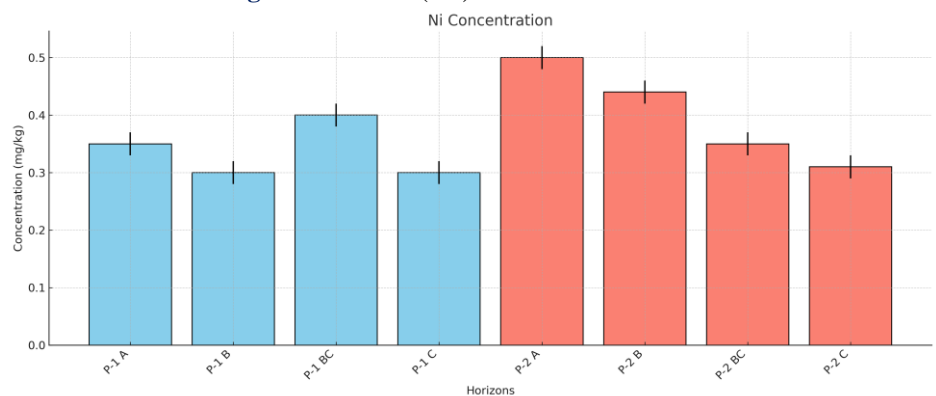
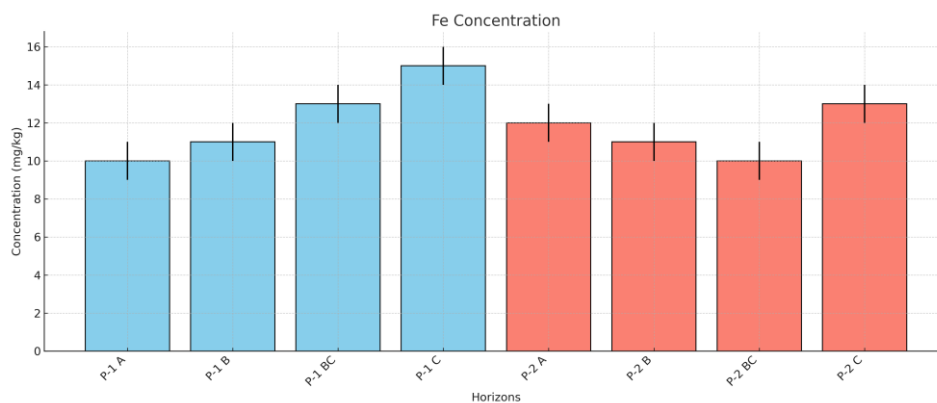
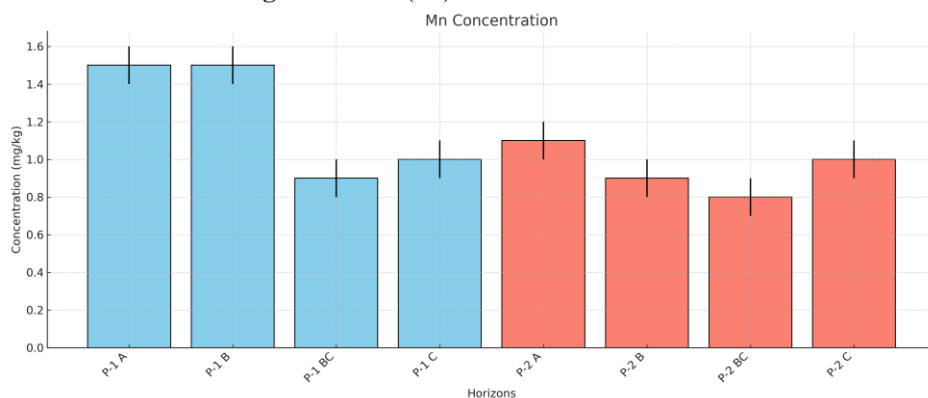


Figure 8. Nickel (Ni) Concentration



**Figure 9. Iron (Fe) Concentration**



**Figure 10. Manganese (Mn) Concentration**

A comparative analysis of the chemical and morphological characteristics of dark chestnut solonchic soils for the period 1979-2024 revealed signs of soil degradation. The main indicator is a pronounced decrease in the humus content in all genetic horizons (Table 1, Fig. 2), which indicates the occurrence of dehumification processes. Humus depletion over the observation period was approximately 10.5% for P-1 and about 28.9% for P-2. This confirms the adverse effects of anthropogenic impact, including the cultivation of virgin lands, insufficient introduction of organic matter and disruption of soil formation processes [33-35].

Increased soil aeration as a result of intensive cultivation contributes to the acceleration of organic matter mineralization and humus loss [31]. An additional factor is climate change: rising temperatures and decreased precipitation in the steppe zone of Kazakhstan intensify mineralization processes [21, 36].

The pH value analysis (Table 1, Fig. 2) remains slightly alkaline, which reflects carbonate buffering.

The dynamics of the content of exchangeable cations  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  shows multidirectional changes. In the P-1 profile in the upper horizon (A), the concentration of  $\text{Ca}^{2+}$  decreased compared to the 1979 data, which may be associated with leaching processes under conditions of a changed water regime or with active biological absorption of calcium by vegetation. At the same time, a decrease in the  $\text{Mg}^{2+}$  content was recorded in a number of horizons, especially in the P-2 profile, which may reflect the general depletion of magnesium reserves in the soil. These changes may be the result of both natural biogeochemical processes and the impact of agricultural practices that lead to the removal of macroelements with the harvest and their subsequent loss from the soil profile (Table 1).

The chemical changes identified are not unique to the territory of the Ereimtau district. Similar trends have been recorded in other dry steppe regions of Kazakhstan, including a decrease in humus content, increased salinization processes, and vertical migration of dissolved substances. A good example is Betpak-Dala, where the shallow occurrence of saline groundwater in combination with the heavy granulometric composition of the soils contributes to the capillary rise of moisture and the accumulation of salts under the root layer [37].

The content of heavy metals requires special attention (Table 2, Fig. 3-10). The increase in Pb and Cd concentrations in the upper horizons (by 10–15%) indicates their

accumulation due to emissions from transport, fertilizers, pesticides, and industrial sources. The accumulation of Fe and Mg in deeper horizons, especially in profiles P-1 and P-2, indicates vertical migration of elements associated with changes in the soil water regime and secondary enrichment [38].

Comparative interpretation of humus and heavy metal concentrations in the upper horizons reveals a possible correlation between the loss of organic matter and the increased mobility and accumulation of Pb and Cd. As humus content decreases, the ability of the soil to bind metals decreases, increasing the bioavailability and upward migration of toxic elements. This suggests that dehumification may increase the mobility of heavy metals, especially under conditions of intensive land management and low levels of organic fertilizers [39].

To restore degraded soils, it is necessary to understand the mechanisms underlying the accumulation and desorption of various elements. Studies show that sorption and desorption dynamics play a key role in regulating the mobility of heavy metals in soils characterized by different humus contents and pH levels. The use of materials such as biochar, bentonite, and organic compounds enhances the capacity of soils to retain elements while reducing the leaching of heavy metals [40]. Furthermore, phytoremediation strategies using tolerant plant species have demonstrated significant effectiveness in immobilizing and extracting lead (Pb) and cadmium (Cd) from contaminated soil matrices [39]. Implementing these methodologies into land management systems can promote long-term soil restoration.

The following measures are recommended for Kazakhstan:

- limit the use of fertilizers with high heavy metal content;
- introduce phytoremediation and use of green manures on contaminated soils;
- promote the use of organo-mineral fertilizers;
- introduce GIS and remote sensing technologies for spatial monitoring of land degradation [35, 38, 41].

The results of the investigation highlight the need to develop an integrated methodology for soil protection and restoration. The sustainability of agroecosystems requires regular soil monitoring, the introduction of adaptive agronomic technologies and the use of evidence-based land management practices. In the context of climate change, preserving soil organic carbon and minimizing heavy metal pollution are critical to ensuring food security and achieving the UN Sustainable Development Goals (SDGs) [42].

#### 4. CONCLUSION

During the observation period from 1979 to 2024, a decrease in the humus content in the upper horizons was revealed: by 10.5% in the P-1 profile and 28.9% in the P-2 profile, which indicates the development of dehumification processes. At the same time, the pH of the environment remains slightly alkaline (pH 7.68-8.0), which is associated with a stable carbonate buffer. Concentrations of  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  in 2024 increased significantly compared to 1979, especially in the upper layers, which may indicate a decrease in technogenic load or increased salt leaching under the influence of changed climatic conditions.

The analysis of exchangeable cations revealed various trends: in the P-1 profile, the concentration of  $\text{Ca}^{2+}$  in the upper horizon decreased, and at several horizons, especially in P-2, a decrease in the  $\text{Mg}^{2+}$  content was observed, indicating depletion of macronutrient reserves. The levels of heavy metals (Pb, Cd, Zn, Cu, Co) at all horizons are significantly below the maximum permissible concentrations, indicating the absence of technogenic pollution. Nevertheless, elevated concentrations of Pb and Cd in the upper horizons, as well as the accumulation of iron in the lower layers, indicate vertical migration and secondary enrichment of elements.

#### DATA AVAILABILITY

The data used in this study were obtained as a result of laboratory analysis of soil samples.

#### AUTHORS' CONTRIBUTION

Conceptualization – GG, YM, TTO, KA; resources – GG; formal analysis – GG, YM, KA; methodology – GG, YM; software – GG; supervision – YM, TTO; visualization – GG; writing—original draft preparation – GG; writing—review and editing – GG.

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## АҚМОЛА ОБЛЫСЫ ЕРЕЙМЕНТАУ АУДАНЫНЫҢ ҚҰРҒАҚ ДАЛА ЭКОЖҮЙЕЛЕРІНІҢ ТОПЫРАҚТАРЫН ГЕОХИМИЯЛЫҚ ТАЛДАУ

Гульзира А. Гатаулина<sup>1,\*</sup> , Ерболат Х. Мендыбаев<sup>1</sup> , биология ғылымдарының кандидаты, профессор, Тургут Тузун Онай<sup>2</sup> , PhD, профессор

<sup>1</sup> Л.Н. Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан; [gulziragataulina@gmail.com](mailto:gulziragataulina@gmail.com) (ГАГ), [mendybayev\\_yekh@enu.kz](mailto:mendybayev_yekh@enu.kz) (EXM)

<sup>2</sup> Богазичи Университеті, Стамбул, Түркия; [onayturg@boun.edu.tr](mailto:onayturg@boun.edu.tr) (ТТО)

\*Автор корреспонденциясы: Гульзира А. Гатаулина, [gulziragataulina@gmail.com](mailto:gulziragataulina@gmail.com)

**ТҮЙІН СӨЗДЕР**

ауыр металдар  
кұрғақ дала аймағы  
Ерейментау ауданы  
топырақ  
деградация




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**АБСТРАКТ**

Берілген зерттеме Ақмола облысы Ерейментау ауданының құрғақ дала аймағындағы күңгірт-каштан сортаңды топырақтарының морфологиялық және химиялық сипаттамаларына жүргізілген, 1979-2024 жылдар кезеңін алып жатқан мерзімді салыстырмалы талдау болып табылады. Мұрағаттан алынған топырақ зерттеулері мен заманауи зертханалық мәліметтер негізінде гумус, рН, иондық құрам және ауыр металдар концентрациясының өзгеруі бағаланды. Топырақ жамылғысының өзгеруінің кеңістіктік заңдылықтарын анықтау мүмкіндігін геостатистикалық картография мен ГАЗ технологиялары берді. Алынған нәтижелер жоғарғы горизонттардағы органикалық заттардың айтарлықтай төмендеуін, аз сілтілі ауқымдағы рН-тың салыстырмалы тұрақтылығын, алмасу катиондарының қайта бөлінуінің және микроэлементтердің, қорғасын мен кадмий-ді қоса алғанда, жоғарыдан төмен таралуын көрсетті. Ауыр металдардың шоғырлануы белгіленген шекті рұқсат етілген деңгейден төмен болып тұрса да, анықталған үрдістер үдемелі деградацияның барын көрсетіп, жүйелі бақылау қажеттілігін көрсетеді. Аймақтық климаттық және антропогендік факторларын ескере отырып, жерді тұрақты пайдалану бойынша ұсыныстар ұсынылды.

## ГЕОХИМИЧЕСКИЙ АНАЛИЗ ПОЧВ СУХОСТЕПНЫХ ЭКОСИСТЕМ ЕРЕЙМЕНТАУСКОГО РАЙОНА АҚМОЛИНСКОЙ ОБЛАСТИ

Гульзира А. Гатаулина<sup>1,\*</sup> , Ерболат Х. Мендыбаев<sup>1</sup> , кандидат биологических наук, профессор, Тургут Тузун Онай<sup>2</sup> , PhD, профессор

<sup>1</sup> Евразийский национальный университет имени Л.Н. Гумилева, Астана, Казахстан; [gulziragataulina@gmail.com](mailto:gulziragataulina@gmail.com) (ГАГ), [mendybayev\\_yekh@enu.kz](mailto:mendybayev_yekh@enu.kz) (EXM)

<sup>2</sup> Университет Богазичи, Стамбул, Турция; [onayturg@boun.edu.tr](mailto:onayturg@boun.edu.tr) (ТТО)

\*Автор корреспонденции: Гульзира А. Гатаулина, [gulziragataulina@gmail.com](mailto:gulziragataulina@gmail.com)

**КЛЮЧЕВЫЕ СЛОВА**

тяжёлые металлы  
сухостепная зона  
Ерейментауский район  
почва  
деградация

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**АБСТРАКТ**

Данное исследование представляет собой долгосрочный сравнительный анализ морфологических и химических характеристик темно-каштановых солонцеватых почв сухостепной зоны Ерейментауского района Ақмолинской области за период 1979–2024 гг. На основе архивных почвенных обследований и современных лабораторных данных оценены изменения содержания гумуса, рН, ионного состава и концентраций тяжёлых металлов. Применение геостатистического картографирования и технологий ГИС позволило выявить пространственные закономерности трансформации почвенного покрова. Результаты показали значительное снижение содержания органического вещества в верхних горизонтах, относительную стабильность рН в слабощелочном диапазоне, перераспределение обменных катионов и вертикальную миграцию микроэлементов, включая свинец и кадмий. Несмотря на то, что концентрации тяжёлых металлов остаются ниже установленных предельно допустимых уровней, выявленные тенденции указывают на прогрессирующую деградацию и необходимость систематического мониторинга. Предложены рекомендации по устойчивому землепользованию с учётом региональных климатических и антропогенных факторов.

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