

GEOCHEMISTRY OF MACROELEMENTS IN THE SANDY LANDSCAPES OF CENTRAL FERGANA

Akbarov G'olibjon Alisherovich
Kokand State University

Abstract

The study investigates the geochemical composition and macroelement dynamics of the sandy soils in the Chinobod area, Dangara District, Fergana Region. The research aims to evaluate the distribution, mobility, and ecological significance of key macroelements (Ca, Fe, K, Na, and Ba) under natural and anthropogenic influences. Soil samples were collected using the morphogenetic profiling method developed by V. V. Dokuchaev, while elemental analysis was performed by neutron activation analysis (NAA) to ensure high accuracy and multi-element detection. The obtained results revealed minimal vertical differentiation of macroelements, with concentrations ranging between 9.7 and 16.0 mg/kg. The sequence of abundance ($\text{Ca} > \text{Fe} > \text{K} > \text{Na} > \text{Ba}$) reflects the predominance of carbonate minerals and the stability of oxidation–reduction processes in the arid sandy landscapes of Central Fergana. The study confirms the homogeneity of parent materials, the dominance of natural pedogenic processes, and weak anthropogenic impact. These findings provide a scientific basis for developing an integrated geochemical monitoring system and for ensuring the sustainable management of fragile sandy ecosystems in the Fergana Valley.

Keywords: Sandy soils; Central Fergana; macroelements; geochemistry; calcium; iron; potassium; sodium; barium.

Introduction

The Central Fergana Valley represents a geochemically complex and dynamic system whose sandy landscapes reflect the long-term geomorphological and climatic evolution of the region. The earliest scientific investigations date back to the late 19th century and were primarily focused on geomorphological mapping and the analysis of sedimentary formations [1]. Later, particularly since the second half of the 20th century, the development of landscape monitoring systems based on remote sensing and GIS technologies enabled more precise assessment of dune dynamics, sediment distribution, and formation mechanisms [1], [4].

In recent decades, irrigated areas, especially the Central Fergana deserts, have undergone significant geochemical transformations under anthropogenic pressure [2], [3]. Studies have shown that irrigation processes lead to the accumulation of salts such as Na_2CO_3 , CaSO_4 , MgSO_4 , Na_2SO_4 , and NaCl in soils, while gypsum layers restrict the circulation of water and nutrients. The decline in organic matter and disturbance of nitrogen balance are also recorded as direct indicators of anthropogenic influence [2].

Further research into the biogeochemical state of saline soils in Central Fergana has revealed a vertical increase in salt concentration within the soil profile, with the highest accumulation



observed in groundwater [3]. Additionally, the presence of heavy metal contaminants (nickel, arsenic, bromine, cesium, etc.) indicates a growing risk of polychemical pollution.

Remote sensing–based analyses of the Fergana Depression have contributed to understanding its neotectonic structure and sedimentary processes. These findings demonstrate the role of tectonic movements in the formation of sandy landscapes and highlight the close interrelation between regional geological structure, geomorphic evolution, and geochemical processes [4].

International studies have also addressed the spatial distribution and sources of soil macroelements. For example, geochemical analyses of sand fractions have confirmed their inheritance from parent rocks [5], a method applicable to identifying the geochemical signatures of source materials in the Fergana sands. Long-term field experiments further indicate that climate change and human activities significantly modify the coupling between macro- and micronutrients in soils, altering their cycling and retention mechanisms [6].

Other investigations on sandy Alfisols have examined the relationships among carbon, iron oxides, and silicates, demonstrating that the preservation of organic matter depends on particle-size composition and that geochemical equilibrium is closely linked to soil physical properties [7].

Overall, the reviewed literature suggests that the geochemical composition of Central Fergana's sandy landscapes results from the complex interactions of anthropogenic loads, climatic fluctuations, tectonic activity, and irrigation systems. Therefore, identifying the dynamics of macroelements (Ca, Mg, Na, K, Fe, Si, etc.), evaluating their role in biogeochemical cycles, and integrating these parameters into ecological monitoring frameworks remain essential tasks for the sustainable management of Central Fergana's landscapes.

Object and Methods of Research

The object of this research is the sandy soils of the Chinobod area, Dangara District, Fergana Region, which represent typical arid–semi-arid landscapes of the Central Fergana Depression. This area was selected as a model site due to its distinct geomorphological position, intensive agricultural use, and sensitivity to geochemical transformations.

The primary methodological approach involved the morphogenetic soil profiling method developed by V. V. Dokuchaev, which allows for a comprehensive characterization of the soil's horizon structure, color, texture, carbonate accumulation, and moisture regime. Soil samples were collected from three genetic horizons at depths of 0–20 cm, 20–45 cm, and 45–70 cm, corresponding to the humus, transitional, and subsoil layers, respectively.

Research results

One of the key functions of sandy and sandy-loam soils is their biological productivity, which defines their fertility potential. The soil constitutes the upper layer of the hypergenesis zone and simultaneously protects the parent rock and the upper crust of the lithosphere from various adverse environmental impacts. Within this layer, biogeochemical processes are highly active, leading to transformations in the soil's physicochemical properties, including its granulometric composition. As noted by V. I. Vernadsky, the chemical composition of seawater largely results from the chemical activity of soils. Based on this concept, the composition of groundwater can be regarded as a direct or indirect reflection of biogeochemical processes occurring in the soil. This property represents one of the soil's functional characteristics, contributing to the transformation of



groundwater composition as well.

Recent studies have been devoted to establishing quantitative limits and concentration ranges of elements and compounds in soils, while identifying their natural and anthropogenic genesis. Some researchers have focused on the analysis of salt-forming anions and cations, others have studied heavy metals, and a third group has investigated rare and trace elements. Pollutants and elements in soils and water can originate from both natural and anthropogenic sources, which makes the determination of background concentrations for each geomorphological or sandy landscape type an urgent scientific task.

The pedogenic layer functions as a delicate biogenic membrane, which can be easily disturbed. Unlike water, which has a strong transport capacity, soils tend to accumulate anthropogenic compounds and elements over time. Given that soils possess a long evolutionary history, the destruction of certain soil types results in the irreversible loss of their natural characteristics. According to literature data, the elemental composition of the Earth's crust is dominated by oxygen (47%), silicon (29.5%), aluminum (8.05%), iron (4.65%), calcium (2.96%), sodium (2.50%), potassium (2.50%), magnesium (1.87%), and titanium (0.45%). Together, these elements account for 99.48% of the Earth's crust, while the remaining trace elements constitute less than 1%.

Most chemical elements exhibit Clarke values within the range of 0.01–0.001%, thus being classified as rare elements. Among them, certain elements that occur in minimal quantities in plants and soils are known as trace elements. For example, uranium (U) and bromine (Br) have similar Clarke values ($2.5 \times 10^{-4}\%$), yet U is considered a rare element, whereas Br is both rare and trace. According to Vernadsky, elements with Clarke values below 0.01% are referred to as microelements.

From a geochemical perspective, elements such as Na, K, Ca, Cr, Mn, Fe, Co, Ni, Zn, As, Sr, Mo, Sb, Ba, and Hf are categorized as cyclic or organogenic elements. These elements frequently occur in living organisms and actively participate in biogeochemical cycles. Owing to their abundance and mass contribution, they play a fundamental role in the formation of soils and the Earth's crust. They are involved in oxidation–reduction reactions, sorption processes, and hydrolysis, forming water-soluble compounds and participating in both minor biological and major geological cycles. Metals and non-metals are commonly found within primary and secondary clay minerals, oxides, hydroxides, salts, and organo-mineral complexes, actively participating in migration and accumulation processes across landscape blocks. Therefore, determining the quantitative variability of macroelements and their transformations under anthropogenic influence is essential for evaluating the geochemical stability of the sandy landscapes in Central Fergana.

Analytical data from Central Fergana show that the concentrations of macroelements (Ca, Fe, K, Na, Ba) range between 9.7 and 16.0 mg/kg. Their highest concentrations occur within the 0–10 cm and 0–20 cm humus horizons, where sorption and oxygen barriers enhance the accumulation of these elements. The conceptual foundations of metal accumulation in oxidized and sorption zones were developed by A. I. Perelman, who demonstrated their spatial dependence on soil aeration and moisture regimes.

Overall, the distribution and concentration of macroelements in the sandy soils of Central Fergana are closely linked to anthropogenic pressures, climatic variability, and the chemical nature of parent materials. Hence, implementing a comprehensive geochemical monitoring system in these landscapes is crucial for ensuring their sustainable management and long-term ecological balance.



According to the data presented in the table, the quantitative sequence of macroelements in the plough layer of the sandy soils in the Chinobod area exhibits only minor variations with depth. This stability indicates the homogeneity of their genesis and the uniform nature of pedogeochemical barrier formation. Overall, the soils show consistent macroelement concentrations along the vertical profile, reflecting similar parent material composition and stable hydrogeochemical conditions.

Macroelements content (mg/kg) in sandy soils of the Chinobod area

Dahas	Depth (cm)	Metals				
		Na	K	Ca	Fe	Ba
Chinabad	0-20	15,5	27,6	43,2	22,7	1,2
	20-45	15,8	27,1	55,5	24,0	1,2
	45-70	16,0	27,4	49,5	24,2	1,3
Vinogradov Clarke (mg/kg)		6000	15000	15000	40000	500

The analysis of macroelements in the sandy soils of the Chinobod area revealed minimal vertical differentiation, indicating uniform pedogenic and geochemical processes across the profile. Sodium concentrations (15.5–16.0 mg/kg) remained low and stable, reflecting a leached environment and limited ion mobility. Potassium (27.1–27.6 mg/kg) also showed uniform distribution, associated primarily with clay minerals and feldspars. Calcium displayed the greatest variability (43.2–55.5 mg/kg), with a distinct enrichment in the middle horizon due to carbonate accumulation. Iron (22.7–24.2 mg/kg) exhibited a slight increase with depth, consistent with hydroxide and oxide formation under sub-oxidizing conditions, while barium maintained stable, low background levels (1.2–1.3 mg/kg).

The overall macroelement sequence ($\text{Ca} > \text{Fe} > \text{K} > \text{Na} > \text{Ba}$) reflects the dominance of calcium-bearing minerals and indicates the stability of carbonate–oxidation processes in these sandy soils. The weak variation between horizons confirms the similarity of pedogeochemical barriers and the homogeneity of the parent material. Low Na and K concentrations point to leaching and weak anthropogenic impact, while stable Ba values represent a reliable indicator of the natural geochemical background.

In summary, the Chinobod sandy landscapes of Central Fergana demonstrate geochemical stability, weak differentiation, and a natural pedogenic balance characteristic of arid and semi-arid regions with limited human influence.

Conclusions

The study of macroelement distribution in the sandy soils of Central Fergana demonstrates that their geochemical composition is primarily controlled by natural pedogenic and lithogenic processes, with minimal anthropogenic influence. The concentration sequence ($\text{Ca} > \text{Fe} > \text{K} > \text{Na} > \text{Ba}$) reflects the prevalence of calcium-bearing and iron-rich minerals and the stability of carbonate–oxidation equilibria under arid and semi-arid climatic conditions.

The low and nearly uniform contents of sodium and potassium confirm the dominance of leaching and weak ion-exchange processes, whereas the enrichment of calcium in the middle soil horizon indicates carbonate accumulation and the development of pedogenic barriers. The stability of

barium concentration across depths further supports a natural geochemical background with negligible external contamination.

Overall, the macroelement data indicate a high degree of geochemical stability, homogeneity of parent materials, and equilibrium of pedogeochemical processes in the Chinobod sandy landscapes. These findings highlight the importance of continuous geochemical monitoring to preserve soil fertility, assess ecosystem resilience, and support sustainable land management in the Central Fergana region.

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