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MINERALOGICAL AND ELEMENTAL CHARACTERISTICS OF SOILS FROM THE ILYOSKO‘L BASIN, SOUTHERN KYZYLKUM DESERT, UZBEKISTAN

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Abstract This study evaluated the mineralogical and geochemical characteristics of soils from the Ilyoskol Basin in the Southern Kyzylkum Desert using X-ray diffraction (XRD), MATCH! software, and inductively coupled plasma optical emission spectrometry (ICP–OES). Soil pH values were determined, mineral phases were identified using XRD and the MATCH! program, and elemental composition was analyzed by ICP–OES. XRD analysis revealed that quartz (SiO_2) was the dominant mineral phase (46.5%), while gypsum (5.8%) was also detected in the soil samples. ICP–OES analysis showed the predominance of the major elements Na, Ca, Fe, Al, Mg, and K, whereas the concentrations of Pb, Cr, Ni, Cd, and As were relatively low. The investigated soils were characterized by a Ca–Na–Fe–Al geochemical composition, and a close relationship between the mineral phases and elemental distribution was identified. The findings provide valuable scientific information for evaluating the mineralogical and geochemical characteristics of soils in the Ilyoskol Basin and serve as a basis for future geological and soil science research in the region.

Keywords: Ilyoskol Basin, Southern Kyzylkum, soil, XRD, MATCH!, ICP–OES, mineral phases, geochemistry.

1. Introduction The mineral composition of soils and the distribution of elements are among the key factors determining their physicochemical properties, fertility, and geochemical evolution. Soil minerals are formed under the influence of parent material, climate, hydrological conditions, and pedogenetic processes, playing an essential role in element migration and bioaccumulation within ecosystems (Brady & Weil, 2017; Churchman et al., 2020). Therefore, the comprehensive investigation of the mineralogical and geochemical characteristics of soils represents an important research direction in geology, soil science, and environmental studies.

The Southern Kyzylkum Desert is characterized by an arid climate, high evaporation rates, and the widespread occurrence of evaporite deposits. The Ilyoskol Basin, located within this region, is rich in quartz-bearing and gypsum-bearing sediments, which significantly influence the mineral composition and elemental distribution of soils. Consequently, the assessment of the mineralogical and geochemical characteristics of soils in this area using modern instrumental techniques is of considerable scientific and practical importance.

X-ray diffraction (XRD) is one of the most reliable analytical methods for identifying crystalline minerals and determining their qualitative and quantitative composition (Harris & White,

2008). Mineral phases can be accurately identified by comparing XRD patterns with the MATCH! software and the International Centre for Diffraction Data (ICDD) database (Zhou et al., 2018). Likewise, inductively coupled plasma optical emission spectrometry (ICP–OES) is a modern analytical technique with high sensitivity and multi-element determination capability for the analysis of major, minor, and trace elements in soils. This method is widely applied in geochemical investigations and environmental monitoring (Hou & Jones, 2000; FAO, 2024).

A review of the available literature indicates that, although XRD and ICP–OES have been widely employed in studies of soil mineralogy and geochemistry, comprehensive investigations integrating XRD, MATCH!, and ICP–OES for the characterization of mineral phases and elemental composition of soils from the Ilyoskol Basin remain limited. Therefore, the aim of this study was to identify the mineral phases of soils from the Ilyoskol Basin, determine their major, minor, and trace element composition, and characterize their geochemical properties based on the obtained results.

2. Materials and Methods

2.1. Study Area The study was conducted in the Ilyoskol Basin, located in the Southern Kyzylkum Desert, Navoi Region, Republic of Uzbekistan (Figure 1). The study area is characterized by an arid continental climate, low annual precipitation, high evaporation rates, and the widespread occurrence of evaporite deposits. The geological structure of the area consists predominantly of quartz-rich sands, gypsum-bearing and carbonate sediments, which have a significant influence on the mineralogical and geochemical characteristics of the soils.



Figure 1. Location map of the soil sampling sites (No. 1 and No. 2) in the Ilyoskol Basin, Southern Kyzylkum Desert, Uzbekistan.

Two soil samples were collected from the Ilyoskol Basin. Sample No. 1 was collected at 41.6056024° N, 64.9079986° E, while Sample No. 2 was collected at 41.6214503° N, 64.9411599° E (Figure 1). Soil samples were collected from the 0–20 cm surface layer using standard field sampling procedures, placed in polyethylene bags, and transported to the laboratory. In the laboratory, the samples were air-dried at room temperature, cleaned of plant residues and other impurities, and passed through a 2 mm sieve. A portion of each sample was finely ground to obtain a homogeneous powder for mineralogical analysis.

2.2. Determination of Soil pH Soil pH was determined in accordance with the ISO 10390:2021 international standard. Soil samples were mixed with distilled water at a 1:2.5 (w/v) ratio and allowed to equilibrate for 30 min. The pH of the soil suspension was then measured using a calibrated laboratory pH meter. Each sample was analyzed in triplicate, and the results were expressed as mean values.

2.3. Determination of Mineral Phases by X-ray Diffraction (XRD)

The mineral composition of the soil samples was determined by X-ray diffraction (XRD) analysis. Measurements were performed using an X-ray diffractometer equipped with a CuKα radiation source (λ = 1.5406 Å). Diffraction patterns were recorded over a 2θ range of 5–70°, and the scanning parameters (step size and scan speed) were selected according to the instrument's standard analytical conditions.

The obtained diffraction patterns were processed using the MATCH! software and compared with the International Centre for Diffraction Data (ICDD) database. Mineral phases were identified based on the 2θ positions, peak intensities, and d-spacings of the diffraction peaks. The principal crystalline minerals present in the samples were identified, and their relative abundances were estimated.

2.4. Determination of Elemental Composition by ICP–OES

The concentrations of major, minor, and trace elements in the soil samples were determined using inductively coupled plasma optical emission spectrometry (ICP–OES). Prior to analysis, the samples were digested in a microwave digestion system using a mixture of concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). The resulting digests were diluted to the required volume with deionized water and subsequently analyzed using an ICP–OES instrument.

The concentrations of the major elements Ca, Mg, Na, K, Al, and Fe, as well as the minor and trace elements Mn, Zn, Cu, Cr, Co, Pb, As, Sr, Mo, and other trace elements, were determined by ICP–OES. Quantitative measurements were performed using calibration curves prepared from certified standard reference solutions. Each sample was analyzed in triplicate, and the results are presented as mean values.

3. Results and Discussion

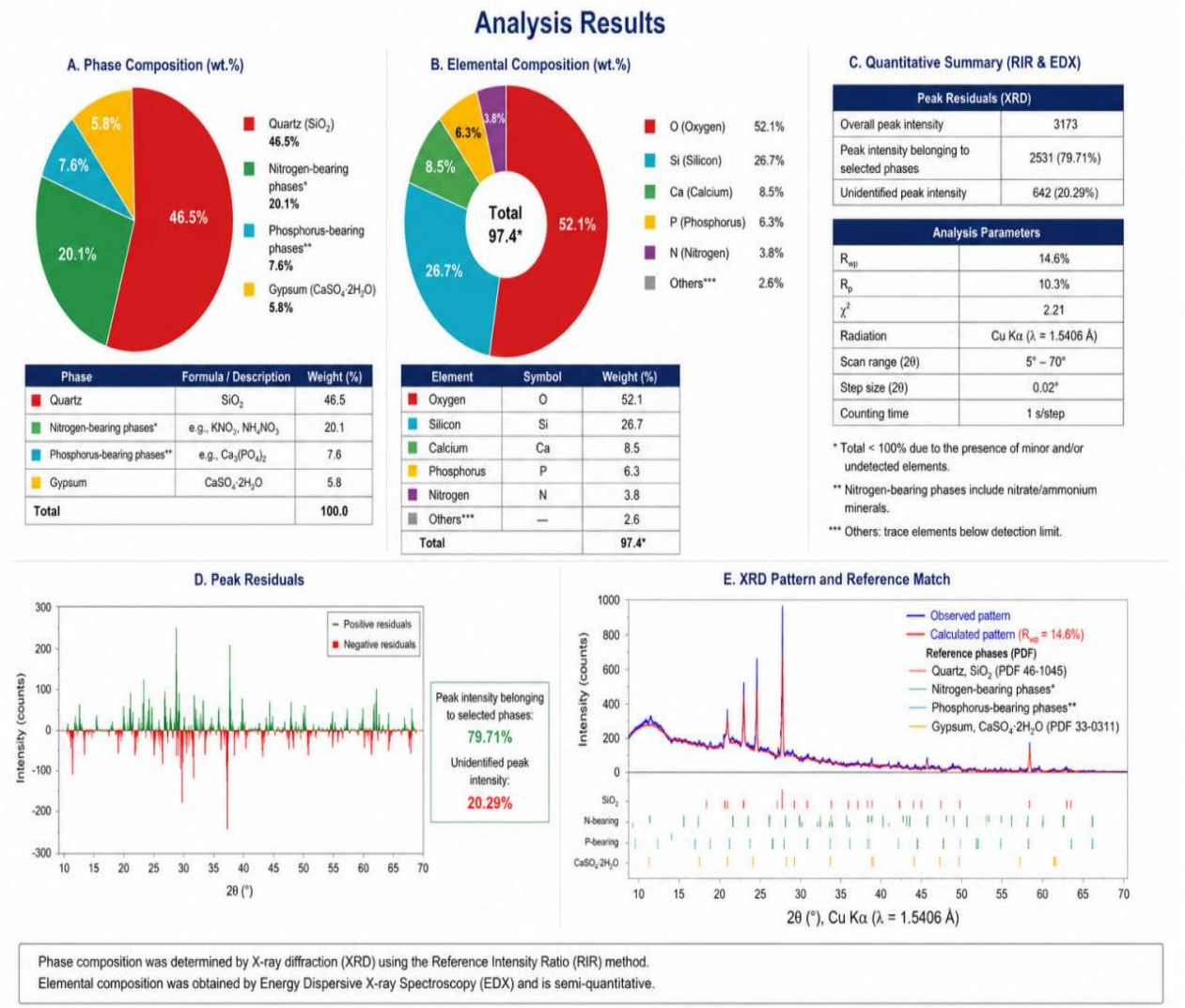
3.1. Soil pH Characteristics of the Ilyoskol Basin Soil pH is one of the most important parameters governing the physicochemical properties of soils, the stability of mineral phases, and the mobility of chemical elements (Brady & Weil, 2017; Sparks, 2022). According to the results obtained, the soil samples collected from the Ilyoskol Basin exhibited neutral to slightly alkaline conditions. Such conditions are characteristic of arid environments and can be attributed to high evaporation rates and the accumulation of alkaline cations, particularly Ca^{2+}, Mg^{2+}, and Na^{+}, within the soil profile (FAO, 2021).

A neutral to slightly alkaline pH provides favorable conditions for the stability of minerals such as quartz (SiO_2) and gypsum ($CaSO_4 \cdot 2H_2O$), which is consistent with the XRD results. Moreover, under these pH conditions, the stability of Ca, Mg, and K increases, whereas the solubility of certain micronutrients, including Fe, Mn, Zn, and Cu, decreases (Kabata-Pendias, 2011; Dixon & Schulze, 2002). Therefore, soil pH is an important factor for interpreting the mineralogical composition and geochemical distribution of elements in the soils of the Ilyoskol Basin.

3.2. Mineral Phases of the Soil Based on XRD and MATCH! Analysis

The mineralogical composition of the soil sample collected from the Ilyoskol Basin was investigated using X-ray diffraction (XRD) in combination with the MATCH! software. The obtained diffraction patterns were compared with the International Centre for Diffraction Data

(ICDD) database, allowing the identification of the principal crystalline mineral phases present in the sample (Figure 2).



Phase	Formula / Description	Weight (%)
Quartz	SiO_2	46.5
Nitrogen-bearing phases*	e.g., KNO_3, NH_4NO_3	20.1
Phosphorus-bearing phases**	e.g., $Ca_3(PO_4)_2$	7.6
Gypsum	$CaSO_4 \cdot 2H_2O$	5.8
Total		100.0

Element	Symbol	Weight (%)
Oxygen	O	52.1
Silicon	Si	26.7
Calcium	Ca	8.5
Phosphorus	P	6.3
Nitrogen	N	3.8
Others***	—	2.6
Total		97.4*

Figure 2. X-ray diffraction (XRD) patterns (a) and MATCH! software-based quantitative phase analysis (b) of soil sample collected from the Ilyaskul saline basin.

Following XRD and MATCH! analysis, quartz (SiO_2) was identified as the dominant mineral phase in the soil sample, accounting for 46.5% of the total mineral composition (Figure 2A). The high abundance of quartz indicates that the soils of the Ilyoskol Basin were developed predominantly from silicate-rich parent materials and that silica has accumulated as a result of long-term mechanical weathering processes. Owing to its high chemical stability and resistance to weathering, quartz persists under arid climatic conditions and represents one of the principal mineral constituents of desert soils (Moore & Reynolds, 1997; Dixon & Schulze, 2002).

The second most abundant group consisted of nitrogen-bearing phases (20.1%). According to the MATCH! software, these phases corresponded to diffraction patterns associated with nitrate- and ammonium-bearing crystalline compounds. However, this result should be interpreted with caution because XRD identifies crystalline nitrate or ammonium minerals rather than elemental

nitrogen itself. Therefore, confirmation of these phases by complementary chemical analyses is recommended.

In addition, phosphorus-bearing phases accounted for 7.6% of the identified mineral composition. The presence of these phases suggests the occurrence of phosphate-containing minerals, which may be related to the mineralogical composition of the parent material or to secondary geochemical processes operating within the basin. Phosphate minerals play an important role in regulating the availability and storage of phosphorus in soils.

XRD analysis also identified gypsum ($CaSO_4 \cdot 2H_2O$), representing 5.8% of the mineral composition. The occurrence of gypsum reflects the natural accumulation of calcium and sulfate ions and indicates the influence of evaporative geochemical processes in the study area. Gypsum is a common secondary mineral in arid environments and significantly influences the physicochemical properties of soils, including soil structure, salinity, and water movement.

3.3. Elemental Composition of the Soil Based on ICP–OES Analysis

ICP–OES analysis revealed considerable variations in the concentrations of major elements and heavy metals in the soil samples collected from the Ilyoskol Basin (Tables 2 and Figure 3). Among the major elements, Na, K, Ca, Fe, and Al were present at relatively high concentrations, reflecting the mineralogical and geochemical characteristics of the soils. The concentrations of Al, Fe, Ca, Mg, and Na ranged from 2,180–3,008 mg/kg, 3,567–3,635 mg/kg, 3,856–4,687 mg/kg, 1,158–1,262 mg/kg, and 457.2–8,077 mg/kg, respectively.

In particular, the exceptionally high Na concentration (8,077 mg/kg) observed in Sample No. 2 indicates the accumulation of soluble sodium salts and the influence of intense evaporative processes within the study area. Likewise, the relatively high Ca concentrations (3,856–4,687 mg/kg) are consistent with the occurrence of gypsum ($CaSO_4 \cdot 2H_2O$) identified by XRD analysis, confirming the widespread presence of calcium-bearing minerals. Furthermore, the elevated concentrations of Al and Fe suggest the predominance of aluminosilicate minerals and iron oxides in the soil matrix (Kabata-Pendias, 2011; Sparks, 2022).

Table 1.

Elemental Analysis of Soil Samples Collected from the Ilyaskul saline basin.

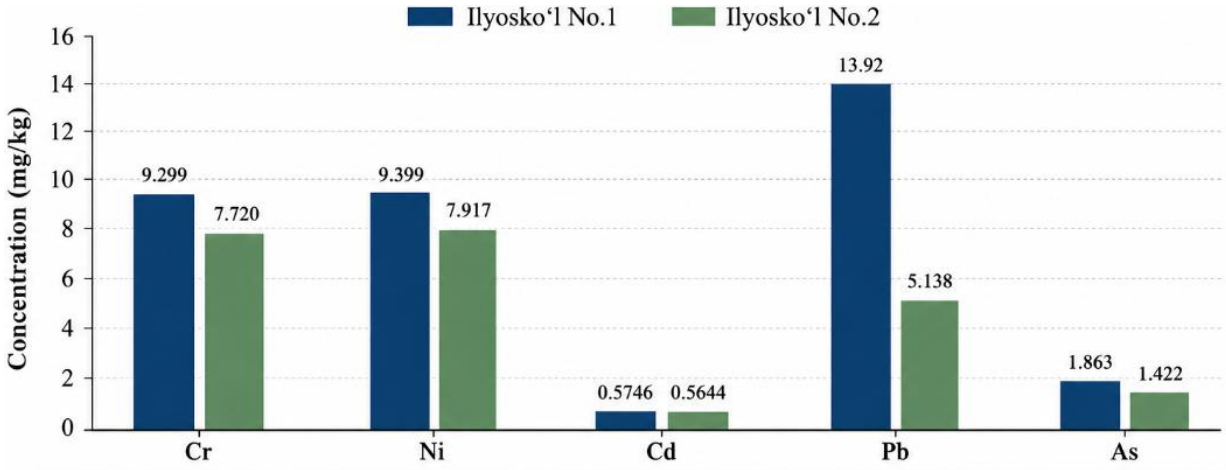
№	Sample Name / Metals	Ilyaskul №1 (mg/kg)	Ilyaskul №2 (mg/kg)
1	Ag	0.5431	0.4225
2	Al	3008	2180
3	Ba	27.36	34.07
4	Be	0.3591	0.3280
5	Ca	3856	4687
6	Co	1.987	2.424
7	Cu	10.97	5.565
8	Fe	3567	3635
9	K	4229	672.7
10	Li	10.10	6.796
11	Mg	1262	1158
12	Mn	73.99	130.8
13	Na	8077	457.2
14	Se	1.174	1.052

15	V	8.380	6.902
16	Zn	26.35	50.16

According to the ICP–OES analysis, the concentrations of the heavy metals Pb, Ni, Cr, Cd, and As varied among the soil samples. The concentrations ranged from 5.138–13.92 mg/kg for Pb, 7.917–9.399 mg/kg for Ni, 7.720–9.299 mg/kg for Cr, 0.564–0.575 mg/kg for Cd, and 1.422–1.863 mg/kg for As. The highest Pb concentration (13.92 mg/kg) was observed in Sample No. 1, whereas Cd exhibited nearly identical concentrations in both samples. Overall, the distribution of heavy metals appears to be primarily controlled by the mineralogical composition of the parent material and natural geochemical processes rather than by significant anthropogenic contamination (Alloway, 2013; Kabata-Pendias, 2011).

The relationship between major elements and heavy metals is of considerable geochemical significance. The elevated concentrations of sodium (Na) and calcium (Ca) influence the ionic composition of the soil solution, thereby affecting the mobility and migration of various chemical elements. In addition, iron (Fe) and manganese (Mn) oxides play a crucial role in the adsorption and immobilization of many heavy metals, thereby reducing their bioavailability (Essington, 2015; Sparks, 2022). These findings suggest that the distribution of heavy metals in the soils of the Ilyoskol Basin is predominantly controlled by natural geochemical processes rather than by anthropogenic influences.

The ICP–OES results demonstrated that the soils of the Ilyoskol Basin are characterized by a Ca–Na–Fe–Al geochemical composition. These findings are consistent with the mineral phases identified by XRD and MATCH!, particularly the predominance of quartz and the presence of gypsum, confirming a close relationship between the mineralogical composition and the elemental composition of the soils.



Element	Ilyosko'l No.1 (mg/kg)		Ilyosko'l No.2 (mg/kg)		Difference (No.1 – No.2) (mg/kg)
	Concentration	Rank	Concentration	Rank	
Cr	9.299	2	7.720	2	1.579
Ni	9.399	1	7.917	1	1.482
Cd	0.5746	5	0.5644	5	0.0102
Pb	13.92	1	5.138	1	8.782
As	1.863	4	1.422	4	0.441

Note: Concentrations are expressed in mg/kg (milligrams per kilogram of dry soil).

Figure 2. Heavy Metal Analysis of Soil Samples from the Ilyaskul saline basin.

According to the analysis results, the concentrations of all heavy metals were higher in the Ilyosko‘l No.1 soil sample than in the Ilyosko‘l No.2 sample. Lead (Pb) exhibited the highest concentration, reaching 13.92 and 5.138 mg/kg in the two samples, respectively. Nickel (Ni) and chromium (Cr) were also detected at relatively high concentrations, whereas arsenic (As) was present at lower levels and cadmium (Cd) showed the lowest concentration. Overall, the results indicate an uneven distribution of heavy metals in the soils of the Ilyosko‘l area, reflecting differences in geochemical conditions between the sampling sites.

Conclusion The present study provided a comprehensive characterization of the physicochemical, mineralogical, and geochemical properties of soils collected from the Ilyosko‘l Basin using pH measurement, XRD, MATCH!, and ICP–OES analyses. The soils exhibited neutral to slightly alkaline conditions, which favor the stability of quartz and gypsum under arid environmental conditions. XRD and MATCH! analyses identified quartz (46.5%) as the dominant mineral phase, together with nitrogen-bearing phases, phosphorus-bearing phases, and gypsum, indicating the influence of silicate parent materials and long-term evaporative processes.

ICP–OES analysis showed that the soils are characterized by a Ca–Na–Fe–Al geochemical composition, while heavy metals were generally present at low to moderate concentrations. Lead (Pb) showed the highest concentration among the analyzed heavy metals, whereas cadmium (Cd) occurred at the lowest level. The observed spatial variations in elemental composition reflect differences in natural geochemical conditions between the sampling sites. Overall, the results indicate that the mineralogical composition and elemental distribution of the Ilyosko‘l Basin soils are predominantly controlled by natural geological and geochemical processes, providing valuable baseline data for future environmental monitoring and soil resource assessment in arid regions.

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