CRYSTAL PHASE ANALYSIS AND STRUCTURAL CHARACTERIZATION OF SOIL SAMPLE USING X-RAY DIFFRACTION: A CASE STUDY FROM THE KYZYLKUM DESERT

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Abstract

This study investigates the mineralogical and elemental characteristics of soils affected by mining and anthropogenic activities in arid regions of Uzbekistan, focusing on the southern Kyzylkum Desert. Soil samples were analyzed using X-ray diffraction (XRD) and elemental analysis to determine crystal phases, major nutrient contents (N–P–K), and the presence of secondary minerals such as gypsum. The results revealed that silica (SiO_2) dominates the mineral composition (41.4%), followed by phosphorus (21.5%), indicating significant technogenic enrichment linked to phosphorite mining residues and heavy metal contamination. Phase and elemental analyses were consistent, confirming the reliability of the findings. Low organic matter content and hydrogen levels suggest degraded ecological conditions and arid soil formation processes. The study highlights substantial impacts of mining on soil structure, geochemistry, and environmental stability, emphasizing the need for remediation strategies, including the use of native hyperaccumulator plants for phytoremediation.

Keywords

Soil mineralogy; X-ray diffraction (XRD); Phosphorus enrichment; Arid soils; Phytoremediation

Introduction

Natural processes and human activities have led to the large-scale release of metals into the environment. In particular, the sharp increase in metal emissions since the 1950s has resulted in serious environmental pollution. Metals have been dispersed across the Earth's surface, the atmosphere, and the pedosphere through various sources, including waste disposal, ore mining and smelting, coal combustion, fuel production, the application of sewage sludge and pesticides, as well as the accumulation of household waste [Han et al, (2002); Han et al, (2003); Ghosh & Singh (2005)].

Despite being a country rich in mineral resources, Uzbekistan is facing serious problems related to soil contamination as a result of industrial activities and mining operations. These contaminants, particularly heavy metals such as cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni), pose significant risks to the environment and human health. However, recent

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studies indicate that certain hyperaccumulator plant species native to Uzbekistan have a high capacity to accumulate these metals in their tissues, making them an important and effective tool in phytoremediation processes [Chen et al., (2009); Garbisu & Alkorta, (2001)].

Material and Method

The study was aimed at investigating the processes occurring in soils and plants under the influence of mining activities, salinization, and anthropogenic impacts in the territories of the Bukhara Region and Navoi Region. During the expedition covering these areas, the research was conducted in the southern parts of the Kyzylkum Desert. These territories differ in geomorphological and climatic conditions, which directly affect the spatial differentiation of biogeochemical processes occurring within soil–geomorphological structures and plant cover.

For the study, the gypsum content ($CaSO_4 \cdot 2H_2O$) of the U-1 RM-2 TR-1 soil sample, as well as the phase composition of major nutrient elements such as nitrogen, phosphorus, and potassium (N–P–K), were determined using X-ray diffraction (XRD) analysis. The samples were examined by the XRD method and analyzed using the MATCH! software. This approach enables high-precision identification of mineral phases in soils. In particular, it allows the detection of the presence or absence of sulfate, phosphate, and other crystalline structures, providing valuable information on soil origin, reclamation status, and ecological stability. The obtained diffraction results are presented in Figure 1 and allow for a comprehensive assessment of the soil mineral composition.

Results and Discussion

The phase analysis identified five major mineral phases in the soil samples, with silica (SiO_2) being the dominant component, accounting for 41.4% of the total composition. This high proportion of silica reflects the prevalence of sand–clay fractions in the soil texture and indicates that silicate minerals form the primary framework of soil mineralization in the studied area. Such dominance is characteristic of arid and semi-arid environments, where physical weathering processes prevail over chemical alteration.

Phosphorus was identified as the second most abundant component, constituting 21.5% of the total phase composition. This concentration is exceptionally high and markedly exceeds phosphorus levels typically observed in natural background soils. The presence of such elevated phosphorus content suggests a non-natural origin and is therefore attributed to technogenic inputs rather than primary geological processes. In particular, this enrichment is likely associated with the accumulation of waste materials derived from phosphorite mining activities in the Kyzylkum Desert region. In addition, the co-occurrence of elevated phosphorus with heavy metal contamination indicates a combined impact of mining residues and anthropogenic disturbances, which may significantly alter soil geochemistry, nutrient balance, and ecological stability. These findings highlight the strong influence of industrial activities on the mineralogical and chemical transformation of soils in mining-affected arid landscapes (Table 1).

Table 1

**Results of the analysis of the phase composition of the soil sample
U-1 RM-2 TR-1 based on the Match! program.**

№	Phase Name	Chemical Formula	Content (%)	Key Phase Information
A	Potassium Nitrate (KNO_3)	K–N–O_3	11.6 %	Orthorhombic; SG: Pmn2; Density: 0.948 g/cm³
B	Gypsum	CaH_4O_6S	19.5 %	Monoclinic; SG: C12/c1; Density: 2.332 g/cm³
C	Silica (SiO_2)	SiO_2	41.4 %	Monoclinic; Density: 2.799 g/cm³
D	Phosphorus (P)	P	21.5 %	Monoclinic; Density: 2.361 g/cm³

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E	Nitrogen (N)	N	6.1 %	Orthorhombic; Density: 0.702 g/cm³
—	Unidentified Phases	—	7.7 %	Peaks not matched in MATCH! software

The elemental composition further confirms the identified phase structure. Oxygen accounts for the dominant proportion (32.9%), primarily associated with anionic groups present in silicates, sulfates, and nitrates. The relative abundances of phosphorus (21.5%), silicon (19.3%), potassium (11.6%), and nitrogen (6.1%) are in close agreement with the results of the phase analysis, indicating strong consistency between mineralogical and elemental data.

Calcium (4.5%) and sulfur (3.6%) further support the presence of gypsum in the soil matrix. The hydrogen content is notably low (0.5%), which is considered typical given that the soil samples were subjected to high-temperature calcination; during this process, most carbonates, organic compounds, and moisture are decomposed or volatilized.

The total proportion of light elements (LE) reaches 39.5%, indicating a substantial contribution of light elements to the soil composition. However, this also confirms that the organic matter (humus) content is extremely low, a characteristic feature of soils formed under arid conditions and intensified by anthropogenic disturbances. These observations, illustrated in Figure 1 and 2, provide additional evidence of the degraded ecological status of the studied soils.
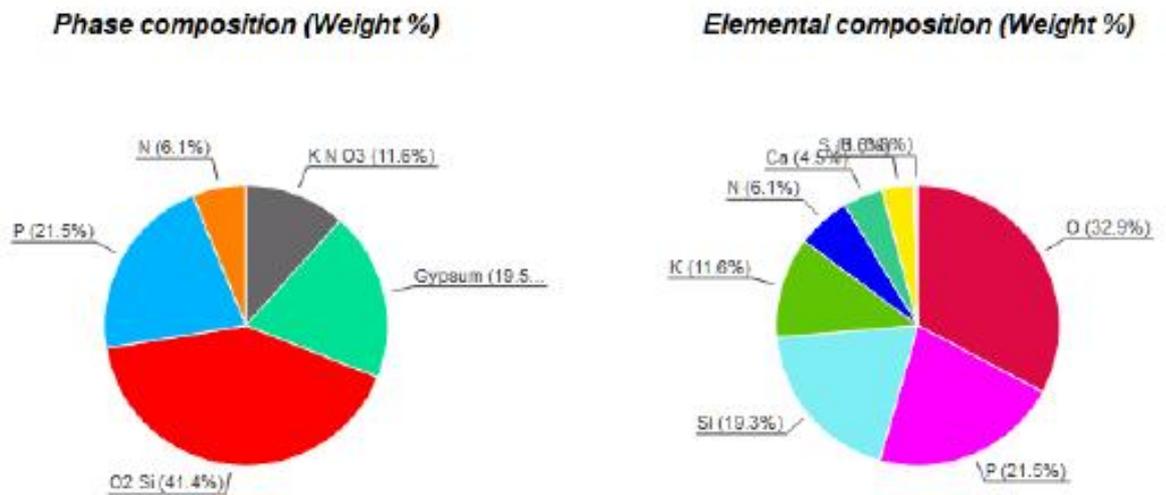

Fig. 1. Diagram of the results of the analysis of the composition of the soil sample U-1 RM-2 TR-1, taken from the vicinity of the botanical station, according to the MATCH! program.
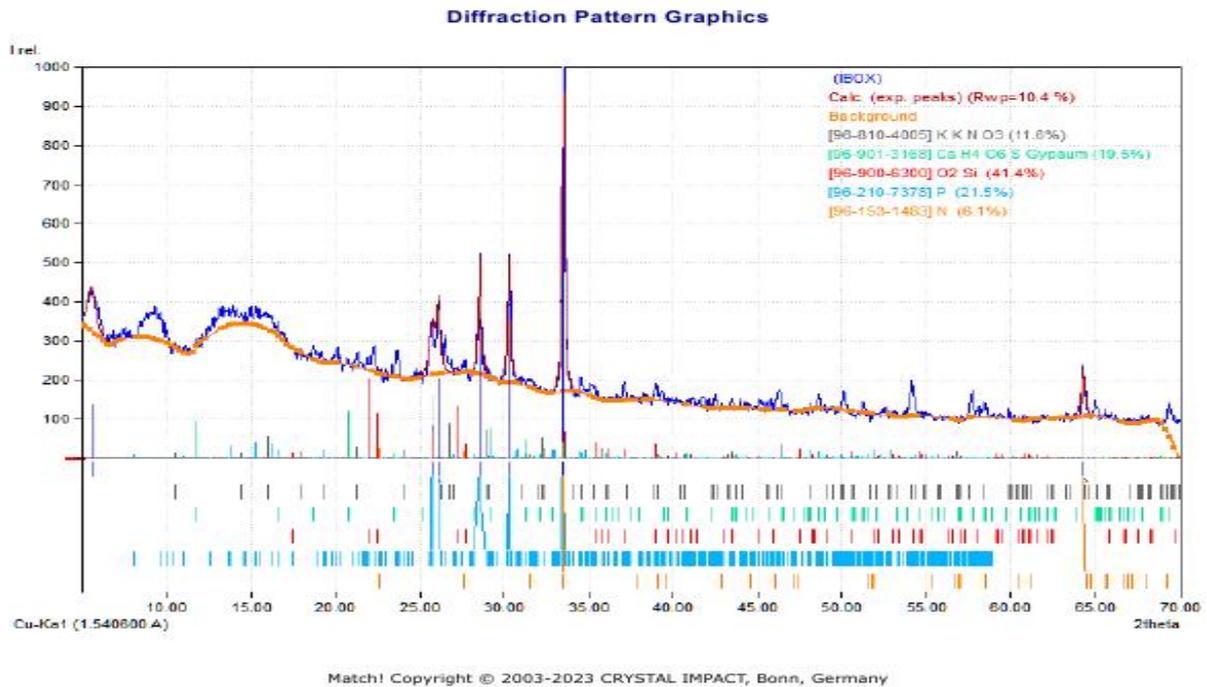
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Fig. 1. Graph of diffraction peaks of the composition of soil sample
U-1 RM-2 TR-1.

Conclusion

This study demonstrates that soils affected by mining and anthropogenic activities in arid regions of Uzbekistan, particularly in the southern Kyzylkum Desert, exhibit substantial mineralogical and geochemical alteration. XRD and elemental analyses revealed the dominance of silicate phases, reflecting sand–clay–rich soil textures typical of arid environments. Exceptionally high phosphorus concentrations, far exceeding natural background levels, indicate a strong technogenic origin linked to phosphorite mining residues and associated industrial waste.

The presence of gypsum, supported by elevated calcium and sulfur contents, highlights secondary mineral formation driven by salinization and mining-induced processes. The extremely low organic matter content further confirms the degraded ecological status of the studied soils. Overall, the results emphasize the significant impact of mining activities on soil structure, nutrient balance, and environmental stability, underscoring the need for targeted remediation strategies, including phytoremediation using native plant species, to restore soil functionality in mining-affected arid landscapes.

References:

1.	Han F.X., Banin A., Su Y., Monts D.L., Plodinec J.M., Kingery W.L., Triplett G.E. Industrial age anthropogenic inputs of heavy metals into the pedosphere // Naturwissenschaften. 2002. Vol. 89. P. 143–190.

2.   Han F.X., Su Y., Monts D.L., Plodinec J.M., Banin A., Triplett G.B. Assessment of global industrial-age anthropogenic arsenic contamination // Naturwissenschaften. 2003. Vol. 90. P. 395–401.

3.   Ghosh M., Singh S.P. A review on phytoremediation of heavy metals and utilization of its byproducts // Applied Ecology and Environmental Research. 2005. Vol. 3. P. 1–18.

4.   Chen J., Zhimin Y., Yi S., Fengxiang X.H., David L.M. Phytoremediation of Heavy Metal/Metalloid-Contaminated Soils // Soil Pollution and Remediation. New York: Nova Science Publishers, 2009. P. 181–206.

5.   Garbisu C., Alkorta I. Phytoextraction: A cost-effective plant-based technology for removal of metals // Bioresource Technology. 2001. Vol. 77. P. 229–236.