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# PHYSICOCHEMICAL PROPERTIES AND RESULTS OF SEM ANALYSIS OF SOILS IN THE REGIONS OF KARAKALPAKSTAN


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**Abstract**: This paper presents a comparative analysis of the morphology and elemental composition of two soil samples using scanning electron microscopy (SEM) combined with energy dispersive spectroscopy (EDS). Spectra and element distribution maps were obtained, revealing significant differences in the contents of carbon, oxygen, silicon, calcium, and other elements. Sample 1 is characterized by a higher content of silicon and aluminum, which may indicate the predominance of silicate minerals. Sample 2, on the other hand, contains increased levels of carbon and calcium, which could be associated with organic compounds and carbonates. The obtained data are important for assessing soil fertility, chemical reactivity, and for further research aimed at improving soil structure and properties using various additives. In addition, the sorption properties of the soil samples were studied. Benzene vapor adsorption was measured using the desiccator method and calculated using the classical BET model. It was found that the total pore volume of samples 1 and 2 is 0.176 and 0.164 $cm^3/g$, respectively. The results may be useful in agrochemistry, soil science, and environmental monitoring.



**Keywords:** soil, SEM analysis, elemental composition, sorption isotherm, porosity, specific surface area.


**Introduction.** Soil salinization remains one of the most pressing problems in regions with extensive irrigated agriculture, especially in arid and semi-arid climates. Irrigation under conditions of insufficient drainage and high evaporation leads to the accumulation of salts in the upper soil layers, degrading its agrophysical and chemical properties. Saline soils typically exhibit a disrupted structure, reduced porosity, impaired water-physical properties—particularly water retention capacity—and a decrease in organic matter content. This negatively affects soil microbial activity and other biological indicators, accelerating degradation processes. In such conditions, research aimed at restoring structure, improving the water regime, and enhancing the biological productivity of saline soils through the application of various organic and colloidal additives becomes highly relevant.

As discussed in sources [1, 2], soil salinization in vulnerable regions of Karakalpakstan significantly reduces soil fertility and disrupts the water balance. Therefore, the study of the physicochemical properties of soils is essential to determine their fertility, moisture retention capacity, and salinity level.

The study of soil porosity and its water-holding capacity is a key scientific issue for agriculture and sustainable water resource use. Soil porosity plays a crucial role in regulating water balance and plant moisture, especially in the dry climate of the region. Analysis of soil pore structure and the effect of organic and mineral additives on these characteristics, as well as water retention, can help optimize agricultural processes and improve productivity and land use efficiency. Along with other environmental factors, water availability greatly affects the yield and quality of agricultural crops and fertilizer effectiveness.

According to the Ministry of Agriculture of Uzbekistan, annual crop losses on irrigated lands in Karakalpakstan due to soil degradation can reach up to 30% [3]. The mineral part of the soil makes up 90–99% of its mass and has a complex mineralogical and chemical composition. About 90% of the total mineral mass consists of oxygen, silicon, and aluminum, while about 10% includes iron, potassium, calcium, magnesium, hydrogen, phosphorus, manganese, sulfur, and others. All other elements account for about 0.5%.

In [4] paper, the authors discuss the studies based on the microstructural properties of improved clay with SEM analysis. The results of the studies show that unexplained physical or mechanical behavior can be explained by the microstructural behavior of clay particles and additives.

The soils are the layer of material covering the ground surface and are formed from the weathering of rocks. Degradation and other geological processes that are effective on the surface of the earth's crust or rocks close to the surface enable soil formation. This processing consists of physical and chemical weathering. Decomposition caused by atmospheric effects changes the structure and composition of rocks chemically and physically. Physical or mechanical degradation causes the rocks to split into smaller pieces. The factors that cause physical degradation are freezing and thawing, heat exchange, erosion, and activities of plants and people [5].

Chemical degradation means the changes in the composition of minerals in rock with oxidation, reduction, carbonation, and other chemical processes. Generally, chemical degradation is more important than physical degradation in soil formation [6, 7].

In [8] report investigates the morphology and elemental composition of soils from Canterbury (UK), Dubai (UAE), Kerala (India). These soil samples were studied under a scanning electron microscope after heating at a certain temperature in order to remove moisture, which in turn was a challenge as to make sure none of the samples burned as each soil sample had different water retention capacities. A general comparison is done among each of these soils where can see the difference in their texture, color, composition etc. Moreover, this investigation helps us to see the difference in soils from different parts of the world, how they vary in size, shape, color and composition.

The porous structure of soils is characterized by several key parameters sufficient for its study: porosity and total specific pore volume, specific surface area of the pore system, and characteristic pore sizes and size distribution [9].

In case [10] static adsorption experiments were conducted to investigate the adsorption capacity of benzene vapor on natural silicate clay minerals (smectite, illite, chlorite and kaolinite) under different temperatures, moisture contents and mineral mixtures. The results of adsorption isotherms for oven-dried clay minerals implied that the distinct adsorption capacity for benzene was mainly attributed to the specific surface areas and pore volume of clay minerals.

Adsorption of benzene vapor is greatly influenced by soil texture, soil-water contents, environmental factors such as temperature and relative humidity, and contaminants properties (sorption activity, solubility, and volatility). The influence of relative humidity on adsorption process had been widely investigated [11-13].

**Materials and Methods.** The research objects were saline soils collected from various agroecological zones of the republic. Surface morphology was examined using a JSM-IT210LA scanning electron microscope at our institute. For SEM-EDS interpretation, databases and literature sources were used, such as the National Institute of Standards and Technology (USA) XPS Database (NIST XPS DB), and built-in software modules for SEM-EDS equipment—Bruker ESPRIT, Oxford INCA, EDAX Team, etc. Textural characteristics were assessed using water and benzene vapor adsorption isotherms, followed by calculation of specific surface area, pore volume, and radius using the classical Brunauer–Emmett–Teller (BET) model. All data were processed using Origin software, as well as based on sources [14] and [15].

**Results and Discussion.** SEM analysis provided detailed images of the soil particle surfaces and their structure at the nanometer level. This helped reveal various features such as composition, porosity, presence of microorganisms, and other structures. SEM also allowed visualization of how organic matter is distributed on the surface of soil samples, which is important for assessing fertility and erosion resistance.

Below is a comparative analysis of two soil samples studied by SEM-EDS (Table 1). The results focus on differences in elemental composition, which are important for understanding the effects of organic and surfactant additives on the soil's mineral matrix.

**Table 1**

**Comparative Elemental Composition of Soil Samples (wt.% and at.%)**

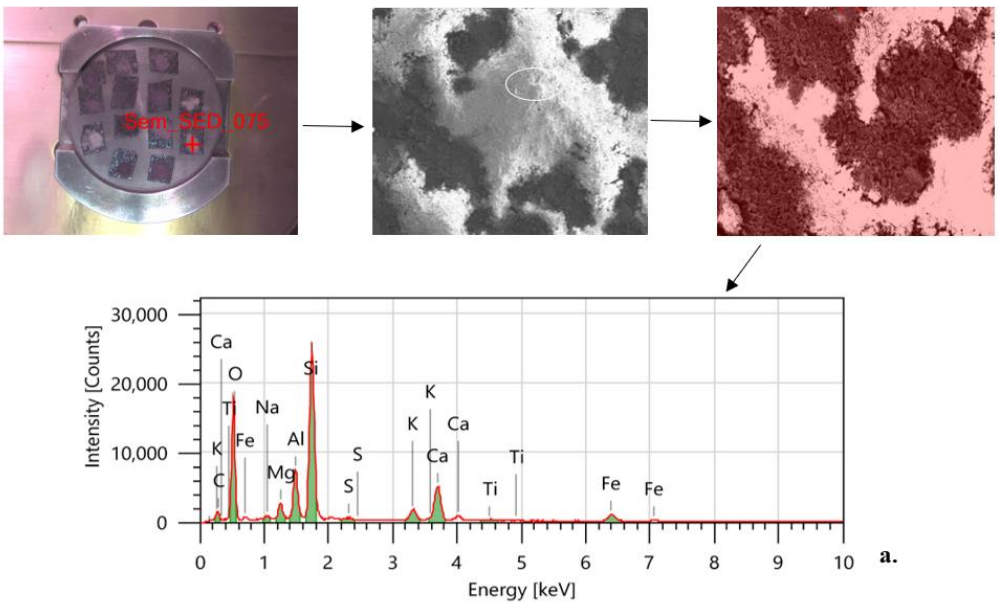
| Element | wt.% (Sample 1) | wt.% (Sample 2) | at.% (Sample 1) | at.% (Sample 2) |
|---|---|---|---|---|
| C | 10.68 ± 0.11 | 24.78 ± 0.15 | 16.92 ± 0.18 | 35.04 ± 0.22 |
| O | 49.42 ± 0.24 | 46.23 ± 0.26 | 58.80 ± 0.29 | 49.08 ± 0.27 |
| Na | 0.62 ± 0.02 | 0.47 ± 0.02 | 0.51 ± 0.02 | 0.35 ± 0.02 |
| Mg | 1.78 ± 0.03 | 2.61 ± 0.04 | 1.39 ± 0.02 | 1.82 ± 0.03 |

| | | | | |
|---|---|---|---|---|
| Al | 5.09 ± 0.05 | 3.44 ± 0.04 | 3.59 ± 0.03 | 2.17 ± 0.02 |
| Si | 19.09 ± 0.09 | 12.87 ± 0.07 | 12.94 ± 0.06 | 7.78 ± 0.04 |
| S | 0.29 ± 0.01 | 0.48 ± 0.01 | 0.17 ± 0.01 | 0.26 ± 0.01 |
| K | 1.88 ± 0.03 | 1.42 ± 0.03 | 0.92 ± 0.01 | 0.61 ± 0.01 |
| Ca | 7.01 ± 0.06 | 4.41 ± 0.05 | 3.33 ± 0.03 | 1.87 ± 0.02 |
| Ti | 0.33 ± 0.02 | 0.22 ± 0.01 | 0.13 ± 0.01 | 0.08 ± 0.01 |
| Fe | 3.80 ± 0.07 | 3.07 ± 0.06 | 1.29 ± 0.02 | 0.93 ± 0.02 |

The SEM images show that the substances in the samples are uniformly distributed (Fig. 1a, b).

SEM-EDS analysis revealed clear compositional differences. Sample 1 (Fig. 1a) showed higher silicon (19.09 wt.%) and calcium (7.01 wt.%) content, indicating the predominance of silicate and carbonate minerals—likely quartz and calcite.

In contrast, Sample 2 (Fig. 1b) showed significantly higher carbon content (24.78 wt.%), suggesting a greater presence of organic matter or residual polymeric/surfactant additives. Elevated sulfur levels in Sample 2 further support the hypothesis of surfactant treatment.



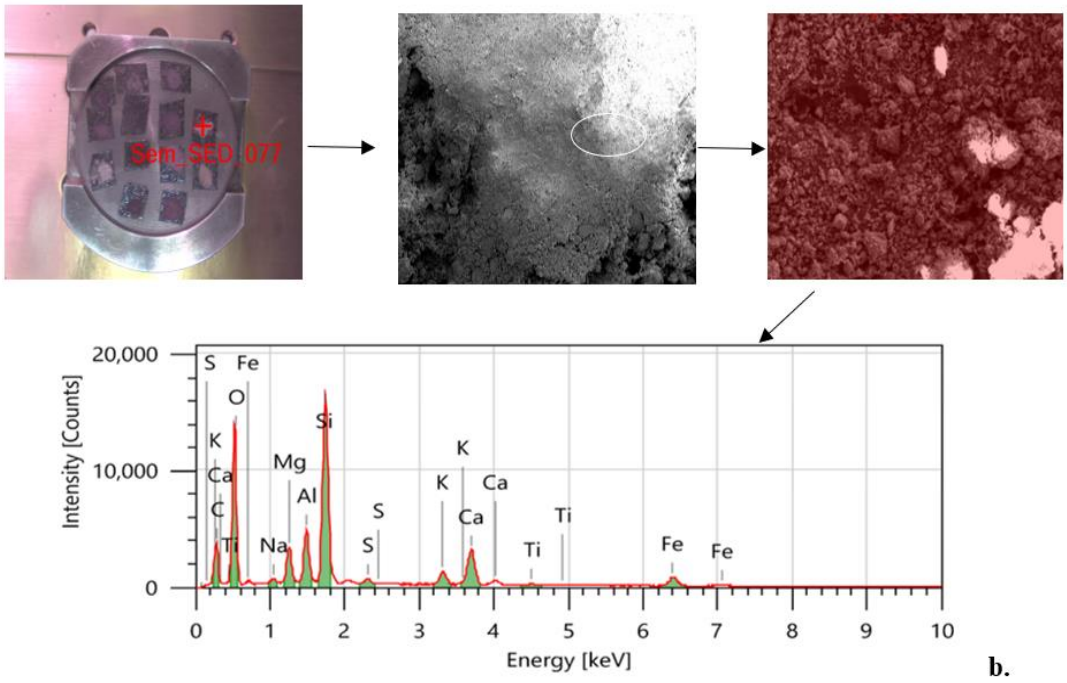



**Fig. 1.** SEM images of soil samples: a - sample 1; b - sample 2

Reduced Al, Fe, and Si levels also indicate partial replacement or coverage of mineral phases by organic or amorphous components.

Figure 2 shows the benzene vapor adsorption isotherms. For both soil samples, the isotherms demonstrate increased adsorption at high relative pressures, indicating that benzene is primarily adsorbed in larger pores and on less polar surface areas, as it does not interact with hydrophilic micropores.

The parameters of the porous structure calculated by the BET method based on the adsorption isotherms of benzene vapor for sample 1 and sample 2, respectively, are: monolayer capacity (mol/kg) – 0.454 and 0.422; specific surface area (m2/g) – 109.4 and 101.7; total pore volume (cm3/g) - 0.176 and 0.164; average pore radius (Å) – 32.1 and 32.3.

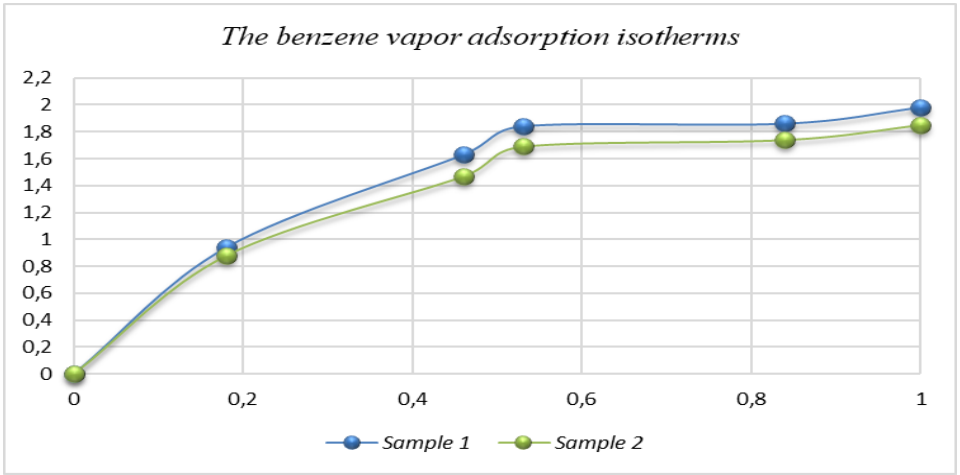



**Fig. 2.** Isotherm of benzene vapor sorption by soil samples

**Conclusion.** SEM analysis confirms that high Si and O levels suggest the presence of silicates (e.g., quartz, clays), while Al, Mg, Ca, and Fe confirm a clay-based composition. The presence of carbon may indicate organic matter or sample preparation residues. The combination of clays, Fe/Al oxides, and a porous structure implies a high sorption capacity.

SEM-EDS analysis revealed that Sample 1 has a higher content of silicon and calcium, implying a dominance of silicate and carbonate minerals. Based on benzene adsorption isotherms, the total pore volumes for Sample 1 and Sample 2 were 0.176 and 0.164 $cm^3/g$, respectively, and the monolayer capacities were 0.454 and 0.422 mol/kg.

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