Study of the physical and chemical characteristics of soils in Karakalpakstan

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Abstract. This study presents a comparative analysis of the chemical and mineralogical properties of soils from two different regions: Amudarya and Karauzyak regions. The article is based on a detailed study and comparison of the main constituent elements such as carbonates, chlorides, sulfates, metal ions and organic components in different soil layers. It was found that the soils of both regions show signs of increasing salinity and acidity with depth, with more pronounced indicators in the Karauzyak region. The influence of these factors on soil agrochemical properties and fertility potential is discussed in relation to cation exchange capacity measurements. The results highlight the need for careful planning of management and agricultural strategies, tailored to the specific conditions of each area, to maintain and improve soil health. Recommendations for the treatment and use of these lands can help improve their productivity and resistance to degradation.

1 Introduction

Soil and sand, as polymineral dispersed systems, play an important role in maintaining ecological balance and agricultural productivity. The development of new reagents that can improve their physical and chemical properties opens up broad prospects for increasing productivity and restoring disturbed lands. The relevance of the study of the physical and chemical characteristics of soils in Karakalpakstan is due to the significance of this issue for agriculture and ecology of the region. Karakalpakstan, suffering from an arid climate and problems with soil salinity, is experiencing serious difficulties in the agricultural sector [1, 2]. Studying the physical and chemical properties of the soil will help determine its fertility, ability to retain moisture and salinity levels. This is important research for developing effective methods for improving soil quality, increasing agricultural productivity and supporting sustainable land management [3, 4].

In modern conditions, the problem of soil degradation is becoming increasingly urgent, especially in such vulnerable regions as Karakalpakstan [5, 6]. Soil degradation caused by intensive farming, poor water management and environmental changes leads to decreased fertility, increased salinity and deterioration of soil structure. In its turn limits agricultural

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production, threatening food security and the economic well-being of the population. The study of the chemical-mineralogical composition and water-holding properties of degraded soils is an important step towards the development of effective methods for their restoration and improvement. Understanding the specifics of Karakalpakstan's soils will allow us to develop targeted strategies to combat salinity and improve soil structure using innovative technologies and materials.

2 Materials and methods

As part of a comprehensive analysis of the properties of soils in the Southern Aral Sea region, taking into account the degree of salinity and duration of irrigation, several soil areas were selected in the Amudarya (SA) and Karauzyak (SK) regions for study. These sites, classified based on their genetic characteristics were subjected to detailed morphological analysis.

Sampling was selected from various genetic horizons to study the agrochemical, chemical and agrophysical parameters of soils in laboratory conditions. Samples for determination of biological activity were collected from depths of 0-30, 30-50 and 50-70 cm in sterile containers and sampling was carried out at different times of the year.

To assess the cation exchange capacity of soils, various methods are used to determine the effective and standard cation exchange capacity, the amount of exchangeable bases, hydrolytic acidity and the composition of exchangeable cations [7].

To determine the main characteristics of soil various methods and standards are used [8]. These standards cover various aspects of soil analysis, including the determination of organic matter, macronutrients (nitrogen, phosphorus, potassium), density, permeability, acidity and other important parameters.

The following indicators were computed: specific gravity of soil in air (ρ_{air}), specific gravity of soil in an aquatic environment ($\rho_{wat.}$), specific gravity of soil in benzene (ρ_{ben}) and specific gravity of soil in a mercury environment (ρ_p).

Soil densities of air, water, benzene, and mercury refer to different types of densities that quantifiable to characterize the physical properties of soil. Air density (dry density) is the dry mass of soil divided by its volume. It is measured by drying a soil sample to constant weight at 105°C and determining its volume. This gives an idea of how much soil is actually contained in a given volume without taking into account water and air pores [9, 10].

The porosity values (Λ_1, %) were determined using the equation:

$$\Lambda_1 = \frac{\rho_{wat} - \rho_{air}}{\rho_{wat}} * 100,$$

what shows the percentage of pore volume to the total volume of the soil. In addition, porosity was figure out, indicating the proportion of pore volume relative to the volume of soil solids:

$$\Lambda_2 = \frac{\rho_{\text{ben}} - \rho_{\text{p}}}{\rho_{ben}} * 100.$$

Total pore volume calculated:

$$\Sigma_V = \frac{1}{\rho_{wat}} - \frac{1}{\rho_{ben}},$$

representing the difference between the reciprocal values of the specific gravity of soil in air and in benzene [11].

3 Result and discussion

The average characteristics of soils SA and SK are given in table 1 and 2.

Table 1. Soil characteristics SA

D	C_c, %	C_{ch}, %	Cs, %	C_{Me}, %	C_g, %	C_n, %	C_{ph}, %	ϖ, %	pH*
0-10	0,058	0,031	0,061	0,019	1,01	0,16	0,09	8,9	5,1
10-20	0,061	0,023	0,043	0,020	1,22	0,14	0,13	12,3	5,0
20-50	0,063	0,023	0,056	0,031	0,65	0,20	0,13	14,5	4,9

D – depth, cm; Cc – total carbonate content, C_X *– total chloride content;* C_C *– total sulfate content;* C_{ME} *– total ion content* Me^{2+}*; Cg – total humus content; ϖ – humidity;* C_n *– total nitrogen content;* C_{ph} *– total phosphorus content;*

** - pH 10% suspension.*

Table 2. Soil characteristics PC

D	C_c, %	C_{ch}, %	Cs, %	C_{Me}, %	C_g, %	C_n, %	Cph, %	ϖ, %	pH*
0-10	0,061	0,038	0,065	0,021	1,00	0,09	0,06	7,3	5,0
10-20	0,065	0,029	0,049	0,024	1,05	0,11	0,09	9,5	4,9
20-50	0,066	0,027	0,055	0,035	0,62	0,13	0,09	15,8	4,8

Analyzing presented data on the characteristics of soils from the Amudarya (SA) and Karauzyak (SK) regions, it can be noted that these samples differ slightly in characteristics. Total carbonate content (*Cc*) shows a slight increase with depth for both areas, which may indicate penetration of carbonate compounds into deeper soil layers. At the same time, in the soils of the SK region the content of carbonates is slightly higher than in the SA. Total chloride (C_{ch}) and sulfate (C_s) contents also increase with depth, which may indicate soil salinity. Soils in the SK region have slightly higher contents of chlorides and sulfates compared to SA which may indicate a higher degree of salinity.

The total content of Me^{2+} ions (CM_e) increases with depth, this is especially noticeable in the SK region, which may indicate the presence of certain metals in the soil that contribute to its heaviness and possibly affect the microelement composition.

The highest humus content is observed in the upper soil layers of both regions, which is typical for most soils due to the activity of microorganicms and the accumulation of organic residues. In the deep layers, the humus content decreases, which may indicate its decomposition and a decrease in biological activity. Humidity (ϖ) shows an increase with depth, especially noticeable in the SK region, which may indicate a higher level of soil water retention at greater depths. The pH values in the 10% suspension decrease with increasing depth, indicating an increase in soil acidity with depth. This may be due to a decrease in carbonate content and an increase in the content of other acid-forming components. In general, soils in both areas show signs of salinization and increasing acidity with depth. At the same time, SK soils have slightly higher salinity and acidity levels compared to SA, which can affect their agrochemical properties and require special measures for the treatment and use of these lands.

Table 3. Mineralogical composition of the sample SA

D	C^*, g/kg	S^{**}, g/kg	S^{***}, g/kg
0-10	440	296	196
10-20	312	412	285
20-50	321	523	124

**C – clay;* ***S – sand;* ****S- silt.*

Table 4. Mineralogical composition of the sample PC

D	C*, g/kg	S**, g/kg	S***, g/kg
0-10	396	245	202
10-20	331	396	312
20-50	309	428	308

From the presented data on the chemical and mineralogical composition of soil samples SA and SK, it can be seen that the content of clay (C) and other components differ for these samples. SA soil samples show a decrease in clay content from the surface to depth, indicating a lighter soil texture at depth. In the SK soil samples, the clay content also decreases with depth, but in the top layer (0-20 cm) the clay content is higher than in the similar SA soil layer.

In SA soils, sand content increases with increasing depth, indicating a decrease in soil water-holding capacity with depth. SK soils also show an increase in sand content with depth, with higher sand content at depths of 20–40 cm and 40–50 cm than in SA soils at similar depths. In SA soils, the silt content also fluctuates with increasing depth, with a significant decrease observed at a depth of 20–50 cm. In SK soils, the silt content increases at a depth of 20-40 cm and remains approximately the same at a depth of 40-60 cm, indicating a more uniform distribution of silt along the soil profile.

Comparing chemical and mineralogical composition of both soil samples, we can conclude that SK soils have a more uniform distribution of clay, sand and silt across the soil profile compared to SA soils, where more significant changes in the content of these components are observed with depth. This may indicate differences in soil formation processes and physical properties of soils in these areas.

Based on the analysis of the chemical and mineralogical composition of degraded soils in the Amudarya and Karauzyak regions, the following conclusion can be drawn: soil degradation in these regions is manifested in changes in the content of the main components - clay, sand and silt. There is a decrease in clay content and an increase in sand content with depth, indicating a deterioration in water retention capacity and an increase in erosion processes in the SA region. The SK region is characterized by a more uniform distribution of the main components over depth which indicates less degradation compared to SA. These data highlight the need to develop targeted measures to restore and improve the structure and functional characteristics of degraded soils in each specific region.

The soil CEC obtained during the study are shown in figure 2 and 3.

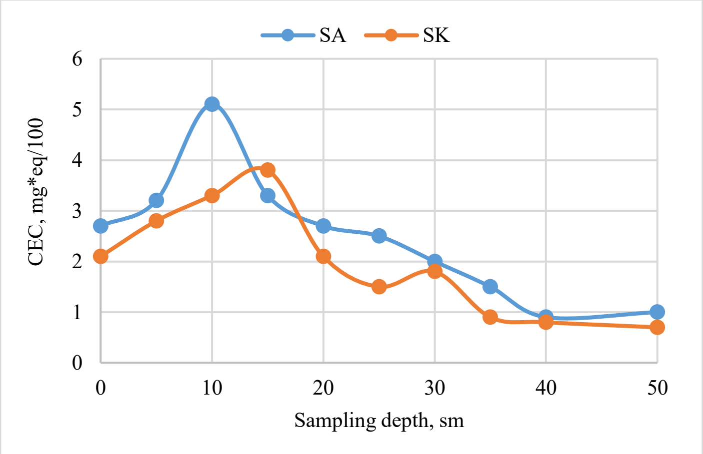

Fig. 1. Change in soil CEC depending on depth.

The data show the change in cation exchange capacity (CEC) at different depths for two different areas, SA and SK. For both areas, the CEC first increases as depth increases from 0 cm to 10 cm. In SA, the CEC increases sharply reaching a peak of 5.1, while in SK it increases more uniformly to 3.3 at the same depth. This may indicate the presence of a rich layer of nutrients, possibly due to the accumulation of organic matter or the presence of clay particles that typically have a higher CEC.

Peak CEC values differ between the two areas with a peak in SA at 10 cm depth and in SK at 15 cm depth. This peak indicates the depth at which the soil holds the maximum amount of exchangeable cations. Such differences may result from differences in soil texture, organic matter content or soil formation processes. After reaching peak CEC values, a decline was observed in both areas. The decrease CEC in SA is more noticeable than in SK. A decrease in CEC with increasing depth is common because organic matter and clay content generally decrease with increasing soil depth.

The lowest CEC values are observed at depths of 35 cm or greater for both areas indicating limited nutrient retention capacity. These levels may correspond to subsoil layers that are less exposed to organic matter from the surface and have fewer clay minerals that are responsible for most of the cation exchange.

At all depths SA consistently showed higher CEC values than PC indicating that SA may have higher fertility potential. Soil in SA may contain more clay and organic matter, both of which contribute to higher CEC.

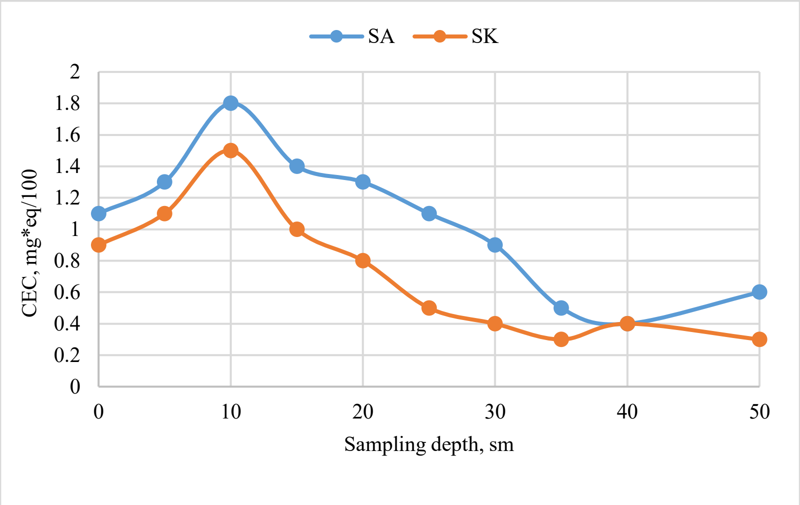

Fig. 2. Change in the sum of potassium and sodium ions (mg*eq/100 g).

As is evident from fig. 2, 3 that shows the change in the sum of Na^+ and K^+ ions depending on the depth of the soil the total content of these ions differs for the two samples. For the SA region the peak ion content is observed at a depth of 10 cm (1.8), after which their concentration gradually decreases with increasing depth, reaching a minimum value at a depth of 35 cm (0.5), then a slight increase is observed at a depth of 50 cm (0 ,6). In the SK region, the maximum ion content also occurs at a depth of 10 cm (1.5), but the drop in concentration is sharper and more prolonged with a minimum value already at a depth of 35 cm (0.3) and it remains unchanged up to a depth of 50 cm.

Both observations may indicate vertical migration of ions in soil that can be caused by various factors, including water regime, soil structure, as well as agricultural activities and natural processes. Higher values in the upper layers indicate possible accumulation of these elements due to the application of fertilizers and/or vegetation residues. Decreased concentrations at greater depths may result from leaching, less biological activity and ion availability to plants.

Analysis of cation exchange capacity (CEC) results shows that for both SA and SK sites, CEC tends to increase at initial depths of up to 10-15 cm, which may indicate higher levels of organic matter, and clay minerals that facilitate cation exchange. Peak CEC values differ for both areas, indicating differences in soil formation processes and soil composition. With deepening, a general decrease in CEC is observed, which corresponds to a decrease in the amount of organic and clay components.

Overall, SA exhibits higher CEC values, which may indicate higher fertility potential compared to SK.

Soil moisture retention plays a key role in maintaining water balance and providing water to plants. It is directly related to factors such as soil texture, organic matter and soil profile structure.

In this part of the study, we will study how different soil samples - in particular those selected in the previous sections - behave in adsorption and retention of water. Soil moisture, which is the amount of water the soil can hold against gravity, is a critical parameter that affects the availability of water to plants and the overall health of the soil ecosystem.

Table 5. Structural and porous characteristics of soil samples

Sample	ρ_{air}, g/cm^3	ρ_{wat}, g/cm^3	ρ_{ben}, g/cm^3	ρ_p, g/cm^3	Λ_1, %	Λ_2, %	Σ_V, g/cm^3
SK	1,71	2,56	2,71	1,96	33,2	27,7	0,022
SA	1,56	2,48	2,53	1,57	37,1	37,9	0,008

The table presents the structural and porous characteristics for two soil samples, SK and SA, indicating different parameters of density and porosity. P_{air} (air density of soil) indicates the overall density of the soil, including pores and air spaces. The air density values for SK and SA are 1.71 g/cm³ and 1.56 g/cm³ respectively. This means that SK soil is more compacted compared to SA soil.

Soil density based on water reflects soil density measured using water as a dispersion medium. The values for SK and SA are 2.56 g/cm³ and 2.48 g/cm³, respectively, indicating high soil solids density for both samples.

P_{ben} и ρ_p are used to more accurately determine soil porosity. Benzene and mercury have different properties of interaction with soil, which allows a more detailed assessment of the pore structure. The values for SK and SA vary, indicating different degrees of porosity and pore structure in these soils.

The values of Λ1 and Λ2 for SK are 33.2% and 27.7% and for SA - 37.1% and 37.9%, respectively. This suggests that SA soil has higher porosity and better aeration compared to SK soil.

For SK, the total pore volume value is 0.022 g/cm³ and for SA it is only 0.008 g/cm³, indicating that SK soil has significantly more pores than SA soil, which may affect its ability to retain water and air.

From the data analysis, it is clear that soil sample SA has a lower total density and higher porosity level compared to sample SK. This can affect the agronomic properties of the soil, its ability to exchange water and air, as well as its resistance to erosion and overall fertility.

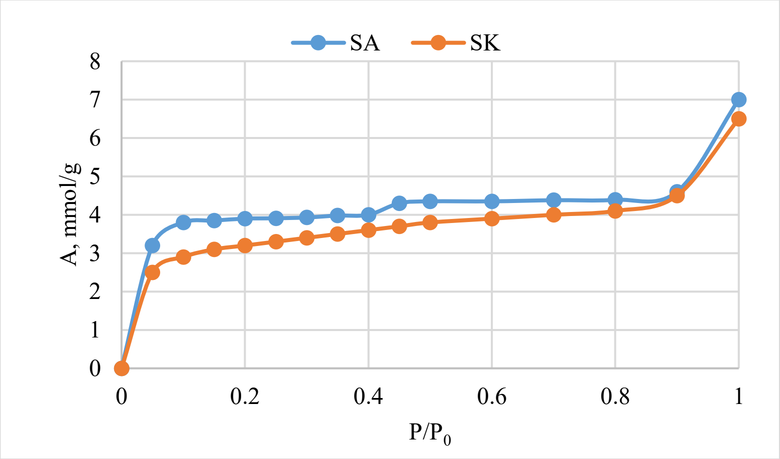

Fig. 3. Water vapor adsorption isotherms on soil samples.

The graph of water vapor adsorption isotherms for soil samples SA and SK shows the change in the amount of adsorbed water (A, mmol/g) depending on the relative pressure (P/P_0). It can be seen that for both samples the amount of adsorbed water increases with increasing relative pressure.

At the beginning of the curve (at low P/P_0) there is a rapid increase in the amount of adsorbed water, which may indicate the adsorption of water in micropores or the presence of active centers with high adsorption energy on the surface of the samples.

As the relative pressure increases, the increase in the amount of adsorbed water slows down and the curves enter a plateau, which indicates the filling of available micropores and the onset of multilayer adsorption of water on external surfaces. This plateau continues until a certain point, after which there is a sharp increase in the amount of adsorbed water as $P/P_0 = 1$ is approached, which is associated with the condensation of water vapor in macropores or on the outer surfaces of the samples.

The difference in the behavior of the curves for SA and SK may be due to differences in the porous structure, pore size and distribution, as well as the chemical composition of the soils. For example, sample SA shows a higher amount of adsorbed water throughout the curve, which may indicate greater overall porosity or the presence of more active sites compared to SK. This suggests that SA may have greater moisture retention capacity that is an important factor for soil fertility and agricultural value.

When further analyzing these data, it is important to consider not only the amount of adsorbed water, but also the pore structure to better understand the water holding capacity of the soil and its impact on plant growth and soil drought tolerance.

As can be seen from the data obtained water adsorption activity correlates with soil CEC values. CEC is a measure of a soil's ability to hold and exchange cations, which directly affects its fertility and structure. Water adsorbed by the soil is usually retained at the same cation exchange sites as nutrient ions.

Comparing these data with water vapor adsorption isotherms, it can be assumed that soils with higher CEC values will exhibit more pronounced water adsorption at low relative pressures, indicating greater water availability for plants during the early periods of the growing season or under drought conditions. Soils with high CEC typically have more clay minerals and organic matter, which help retain water and nutrients.

Also, at high P/P_0 values where water vapor condenses, soil with a high CEC can hold more water which helps prevent drought stress and support plant growth in low-moisture conditions. This is especially true for agriculture where water management is a key aspect of sustainable development.

4 Conclusions

A study of the chemical and mineralogical characteristics of soils in the Amudarya and Karauzyak regions revealed a general trend of salinity and an increase in acidity with depth, while the soils of the Karauzyak region showed higher levels of these indicators. The observed decrease in clay content and increase in sand in the soils of the Amudarya region may signal a decrease in water-holding capacity with depth. A distinctive feature of the soils of the Karauzyak region is a more uniform distribution of clay, sand and silt, which may indicate better stability and less erosion.

The cation exchange capacity of soils from both areas increases in shallow layers, reflecting the availability of nutrients and organic matter, and decreases with depth. These results highlight the importance of individual agrochemical strategies for each area, taking into account their specific characteristics for maintaining fertility and resistance to degradation processes.

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