Analysis of the mineralogical composition of soil samples: Case study of Karmana district

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Abstract. This article deals with the issues of determining the mineralogical composition of soil samples in the city of Navoi and the Karmaninsky district (the settlement of Khazora, 24 km from the city) and identifying the degree of salinization of these old irrigated soils in the region. To determine the mineralogical composition of soil soils, the X-ray diffraction method of research was used, and to determine the functional groups of carbon, sulfur, and chlorine, IR spectrometric analysis of samples was used. The studies carried out made it possible to establish a carbonate type of salinity for the city of Navoi, and for the Karmaninsky district, the dominance was noted first of carbonate - 45.4%, then sulfate 28.8%, and only lastly did the third type of salinity appear, represented by chloride - 0.8%, found on the surface layer of the soil (0-0, mm).

1. Introduction

The relief of the Navoi region is diverse: in the north, the Kyzylkum desert stretches, and in the southeast, the territory passes into adyrs and mountains. In Kyzylkum, there are remnant mountains 500–900 m high, between which there are depressions. The climate is sharply continental: summers are hot and dry; winters are cold and relatively dry. The average temperature in January is from 0 to minus 4 °C, and in July - from plus 27 to plus 30 °C. There is little precipitation - from 108 mm in the north to 200 mm in the southeast. Soils are desert, sandy, gray-brown, takyr, and solonchak, in the Zarafshan valley - old-irrigated meadow gray soils [1-2].

Soil-forming rocks are alluvial-diluvial and proluvial deposits, solonetzes, conglomerates, sandstones, rubbly-pebble sediments, and loess-like loams. The main part of rainfed light gray soils is not saline, but in some areas, there are soils with medium and strongly saline horizons [3–.6].

Characteristic of the soils of the Navoi region is their mineralogical composition, represented by a mixture of primary and secondary minerals, which at one time formed from rock-forming minerals. In order to protect these types of soils from degradation processes while maintaining their high production potential, integrated production management systems are needed that promote the health of the agro-ecosystem and are socially, environmentally, and economically sustainable.

Therefore, to maintain a healthy agroecosystem, it is necessary to determine the mineralogical composition of soils in the Navoi region, and the purpose of the ongoing research for this was to determine the IR spectroscopic and structural mineralogical structure of soil samples in the Karmana district (Khazora) of the Navoi region.

2. Materials and Methods

The Karmana region is located in the oasis of the Zarafshan River, while the Navbakhor and Kanimekh regions border the Kyzylkum desert. On the territory of the Karmaninsky district, crop production is carried out by irrigation from the Zarafshan River. The object of research was soil samples from the city of Navoi, Karmaninsky district (village Khazora, 24 km from the city), sifted through a sieve with cells of 1.0 mm and dried at a temperature of 50 ° C in an oven for 48 hours.

Soil sampling was carried out as follows: a 1 m2 area was determined, which was divided into 3 parts - the upper, saline horizon (soil sampling to a thickness of 0.2-0.5 cm), the middle horizon (soil thickness 2-10 cm) and the lower horizon 10-30 cm).

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The control plot was a soil sample from the city of Navoi. Sampling was carried out as close as possible to homogeneous, i.e., so that the degree of salinity is relatively the same when visually inspecting the morphological structure of the appearance of the site.

Preliminary sampling of soils from the designated regions was carried out following GOST-28168-89 [7].

IR spectroscopic analysis of the samples was performed on a SHIMADZU instrument (laboratory of the Novosibirsk State Technical University, Department of Chemical Technology) IR-Fourier spectrometer IRTracer-100, using the method of preparing pressed tablets in KBr. The absorption bands of infrared light correspond to antisymmetric wavelengths in the range from 400 to 4000 cm-1. A comparison of the functional groups of elements was carried out according to the monograph by Nakamoto [8]. X-ray diffraction analysis was performed on a diffractometer, which was used to determine the mineralogical composition of soil samples. This method is based on the phenomenon of X-ray diffraction on a three-dimensional crystal lattice. The method makes it possible to determine the atomic structure of a substance, which includes the space group of an elementary cell, its size and shape, and also to determine the symmetry group of a crystal. To determine the shape and crystal lattice of minerals, before analysis, the soil sample was abraded, thoroughly mixed, and an average sample with an average content was obtained. From the prepared powder, an X-ray diffraction pattern was obtained on a “Panalytical Empyrean” diffractometer with 0.01 to 2theta steps from 4 to 80 2theta degrees using a “Scintillation” detector. Quantitative X-ray phase analysis was performed by the Rietveld method and was carried out using the Profex – Open source XRD and Rietveld Refinement software [9–10].

3. Results and Discussion

Based on the results of infrared spectroscopy, it is possible to develop a chemically reliable, reproducible, and standardizable method for analyzing various systems [11–16].

The study of the IR spectra of soil samples from the Karmaninsky district (Khazora) of the Navoi region showed (Fig. 1) the localization of functional groups inherent in carbonate ions in the form of CO at wavelengths of 2500 cm-1, and CH groups - at wavelengths of 2900 cm-1. These functional groups were present in all 3 types of soils - saline to a greater extent, moderately saline to a lesser extent, and also manifested to a small extent in normal soil.

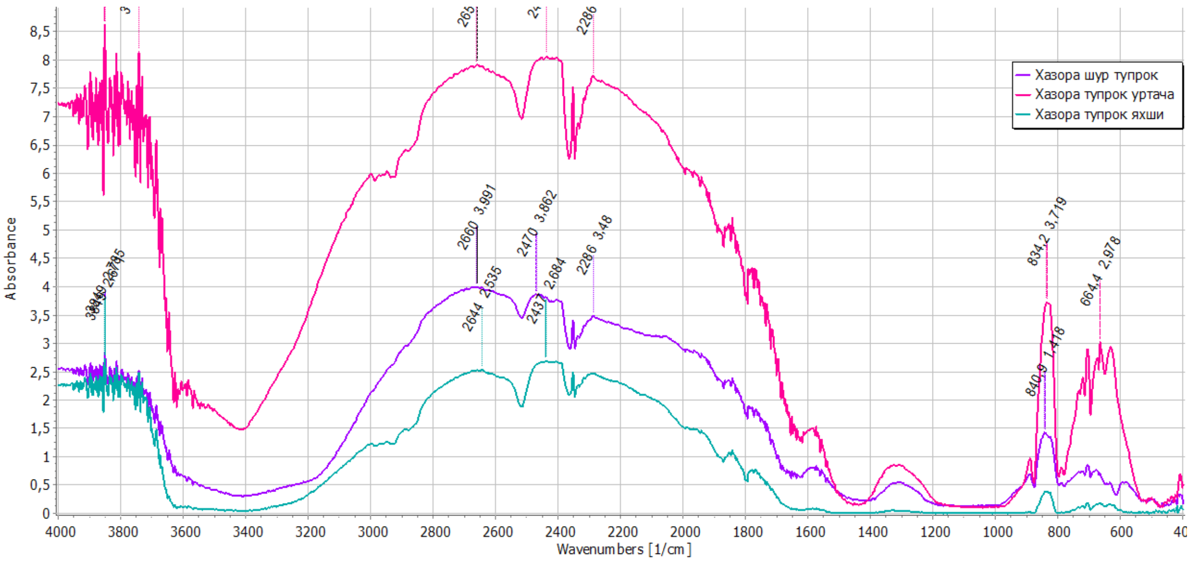

Fig. 1. IR spectroscopic appearance of soil structures in the Karmana region (Khazora, 40.140044, 65 362031) of the Navoi region

Functional groups characteristic of CH bonds were at the peaks of 2900 cm-1. On weakly saline soil, the CH peak was almost absent. Functional groups characteristic of sulfate ions were expressed as SO and SH groups, which were at wavelengths of 1800 cm-1 and 2400 cm-1. Also, the SO group is noted on a very broad peak located at wavelengths from 900 to 1200 cm-1. For functional groups inherent in chlorides, molecular bonds were characterized as ClO, and O-Cl-O groups, and functional bonds were localized mainly at wavelengths of 900, 800, and 500 cm-1.

A very wide peak at wavelengths of 3000-3800 cm-1 is characteristic of the O-H hydroxyl group, which is due to the presence of crystalline hydrate-bound water.

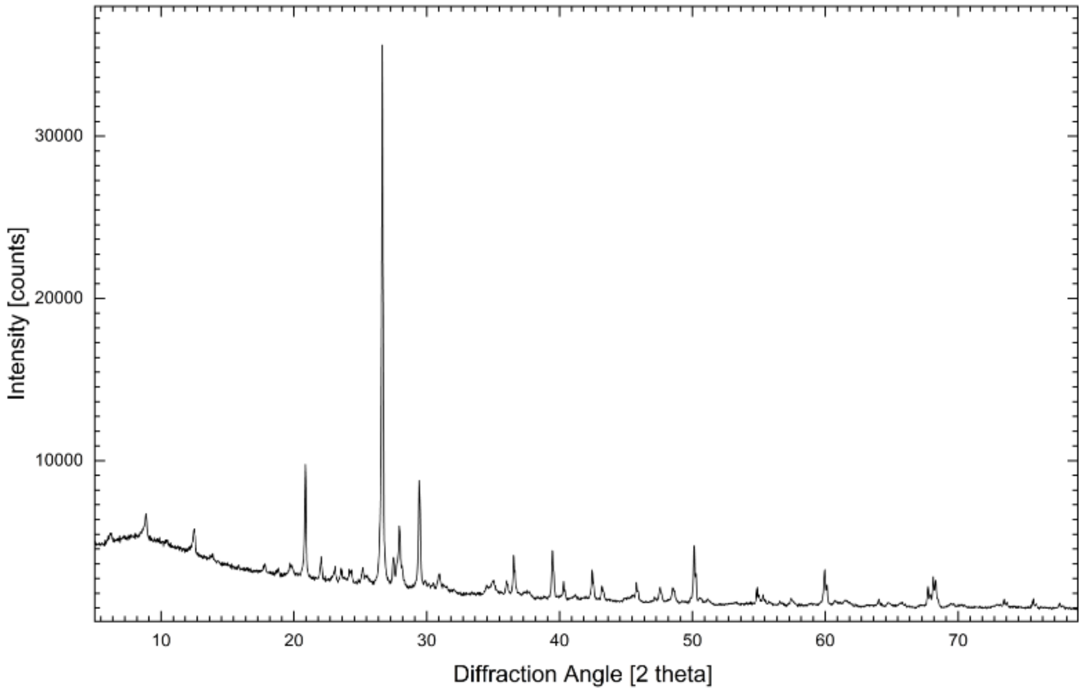

Fig. 2. Diffractometric diagram of the soil from the city of Navoi, NSTU

Table 1. Mineral composition of a soil sample from the city of Navoi, NSTU

Mineral	Formula	Quantity, %	PCO
Quartz	SiO_2	37,3	0,4
Chlorite	$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2{\cdot}(Mg,Fe)_3(OH)_6$	7,3	0,4
Albite	$NaAlSi_3O_8$	15,3	0,3
Calcite	$CaCO_3$	11,2	0,2
Muscovit 2M1	$[KAl_2(AlSi_3O_{10}(FOH)_2]$	19,4	0,5
Actinolite	$Ca_2(Mg_{4.5\text{-}2.5}Fe^{2+}_{0.5\text{-}2.5})Si_8O_{22}(OH)_2$	1,3	0,2
Rutile	TiO_2	0,3	0,1
Gypsum	$CaSO_4{\cdot}2H_2O$	0,4	0,1
Dolomite	$CaMg(CO_3)_2$	2,1	0,2
Astrakhanit	$Na_2Mg(SO_4)_2{\cdot}4H_2O$	0,6	0,1
Microcline	$(KAlSi_3O_8)$	4,8	0,3

Such chemically bound water is represented by the OH hydroxyl group with organic and organomineral compounds, clay minerals, and whole water molecules of crystalline hydrates, mainly salts - hemihydrate - CaSO4 * ½H2O, gypsum - CaSO4 * 2H2O and mirabilite - Na2SO4 * 10H2O. Crystal-hydrated water is a part of the solid phase of the soil and is not an independent physical body, it does not have the properties of a solvent [10]. At the next stage, when studying soil samples by X-ray diffraction methods, the level of absorption of the radiation used is of great importance. It determines the depth of penetration of X-rays and features of the detection of defects. Therefore, it is expedient to separately consider the cases of weak and strong absorption. From this point of view, the most typical representatives of crystals with weak absorption are crystals and molecules of various soil minerals.

Table 2. Diffractometric diagram and mineral composition of soil samples of the Karmaninsky district (Khazora settlement). (designations - 1-normal; 2-medium-salty; 3-salty soil)

1. Mineral	**Formula**	**Quanity, %**	**PCO**
Quartz	SiO_2	36,7	0,4
Chlorite	$(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2 \cdot (Mg,Fe)_3(OH)_6$	7,4	0,4
Albite	$NaAlSi_3O_8$	12,6	0,3
Rutile	TiO_2	0,4	0,1
Calcite	$CaCO_3$	13,0	0,2
Muscovit 2M1	$[KAl_2(AlSi_3O_{10}(FOH)_2]$	20,4	0,5
Actinolite	$Ca_2(Mg_{4.5-2.5}Fe^{2+}_{0.5-2.5})Si_8O_{22}(OH)_2$	0,8	0,2
Gypsum	$CaSO_4 \cdot 2H_2O$	0,7	0,1
Dolomite	$CaMg(CO_3)_2$	3,3	0,2
Astrakhanit	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	0,4	0,2
Microcline	$(KAlSi_3O_8)$	4,4	0,3
2. Mineral	**Formula**	**Quantity, %**	**PCO**
Quartz	SiO2	39,3	0,4
Chlorite	(Mg,Fe)3(Si,Al)4O10 (OH)2· (Mg,Fe)3 (OH)6	6,6	0,4
Albite	NaAlSi3O8	13,3	0,3
Rutile	TiO2	0,2	0,1
Calcite	CaCO3	12,7	0,2
Muscovit 2M1	[KAl2(AlSi3O10(FOH)2]	18,1	0,5
Actinolite	Ca2(Mg4.5-2.5Fe2+0.5-2.5)Si8O22(OH)2	0,3	0,1
Gypsum	CaSO4·2H2O	0,6	0,1
Dolomite	CaMg(CO3)2	4,2	0,3
Microcline	(KAlSi3O8)	4,6	0,3
Astrakhanit	Na2Mg(SO4)2·4H2O	0,3	0,1
3. Mineral	**Formula**	**Quantity,%**	**PCO**
Quartz	SiO2	34,1	0,4
Chlorite	(Mg,Fe)3(Si,Al)4O10 (OH)2 ·(Mg,Fe)3(OH)6	4,5	0,3
Albite	NaAlSi3O8	10,4	0,3
Rutile	TiO2	0,3	0,1
Calcite	CaCO3	11,4	0,2
Muscovit 2M1	[KAl2(AlSi3O10(FOH)2]	7,5	0,2
Gypsum	CaSO4·2H2O	1,7	0,2
Dolomite	CaMg(CO3)2	4,1	0,2
Microcline	(KAlSi3O8)	4,4	0,3
Astrakhanit	Na2Mg(SO4)2·4H2O	18,8	0,3
coquimbit	AlFe3(SO4)6(H2O)12 · 6H2O	2,0	0,2
Halite	NaCl	0,8	0,1

For a comparative analysis in Fig. 2 and Table 1 show the diffraction diagram of the soil from the city of Navoi, on the territory of the Navoi Mining and Technological University (NSTU) and indicate the peaks of the main, common soil minerals. The RSO designation in the table shows the degree of analysis error. The lower the indicator in the RSO designation, the higher the probability of the accuracy of the results obtained.

The main soil mineral is quartz (37.3%), followed quantitatively by the mineral muscovite (19.4%), followed by albite (15.3%). Then calcite (11.2%) and chlorite (7.3%). Other minerals - actinolite, rutile, gypsum, dolomite, astrakhanite and microcline are contained in small amounts within the experimental error.

In table 2, number 1 indicates the diffraction diagram and presents an analysis of the mineralogical composition of a normal soil sample from the Karmaninsky district (Khazora), located 24 km from the city of Navoi. Characterization of a normal soil sample from Karmana (Khazora) in terms of quartz content (37.3 and 36.6) showed a similar result when compared with a sample from the city of Navoi. However, the amount of carbonate-bearing mineral calcite $CaCO_3$ (13.0%) and dolomite $CaMg(CO_3)_2$ exceeded the amount of calcite in the sample from Navoi (11.2%) by almost 2 and 1.1%. This result indicates the presence of carbonate salinization of the soil.

The results obtained for the moderately saline soil of Karmana (Khazora) showed (Table 2, designation 2) similar to the normal sample from Karmana (Khazora) with the presence of a carbonate salinity character.

In Table 3, under the designation 3, the characteristics of the soil sample from the salty part of the soil located on the soil surface are presented. The results obtained showed that in the salty crust of the soil, the predominant amount of the sulfate type of salinization was noted, due to the increased amount of the astrakhanite mineral ($Na_2Mg(SO_4)_2$ $4H_2O$) up to 18.8%. In addition to astrakhanite, a new sulfate-containing mineral cokimbite ($AlFe_3(SO_4)6(H_2O)12$ $6H_2O$) appeared in an amount of 2.0% and chlorine-containing halite (NaCl) with a content of 0.8%. The selection of individual types of salinity in the form of carbonate, sulfate and chloride are presented in table 3.

Table 3. Characteristics of the main types of salinization of soil samples in the city of Navoi and Karmana district (Khazora)

Mineral	**Formula**	**Soil characteristics**			
		Navoi city	**Karmana (Khazora)**		
		norms. priming	norms. (10-30 cm)	slightly salty. (2-10 cm)	Salt (02-05 cm)
		Carbonate salinization			
Calcite	$CaCO_3$	11,2	13,0	12,7	11,4
Dolomite	$CaMg(CO_3)_2$	-	-	4,2	4,1
Total, %		11,2	13,0	16,9	15,5
		sulfate salinity			
Gypsum	$CaSO_4 \cdot 2H_2O$	0,4	0,7	0,6	1,7
Astrakhanit	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	0,6	0,4	4,6	18,8
coquimbit	$AlFe_3(SO_4)_6(H_2O)_{12} \cdot 6H_2O$	-	-	-	2,0
Total, %		1,0	1,1	5,2	22,5
		chloride salinity			
Halite	NaCl	-	-	-	0,8
Total, %		-	-	-	0,8

Table 3 shows that in Navoi, the carbonate type of salinization prevails, represented by the mineral calcite in the amount of 11.2%. The amount of sulfate salinity is insignificant and is represented by only 1.0%. A normal soil sample from Karmana (Khazor) (10-30 cm) almost does not differ from the soil from the city of Navoi and is also represented by a carbonate type of salinization. Analysis of weakly saline (2-10 cm) and saline soils (0.2-0.5 cm) Karmana (Khazora) showed that along with carbonate (16.9%) there is sulfate salinization in the amount of 22.5%, and also noted the appearance of the chloride type of salinity in the amount of 0.8%.

4. Conclusions

The results of the analysis of the IR spectra of soil samples from the city of Navoi showed the presence of two types of functional groups containing carbon (11.2%) and sulfur (1.0%). And in the soil from Karmana (Khazor), the dominance was noted first of the carbonate type - 45.4%, then the sulfate type of salinity 28.8%, and only in the last place the third type of salinity appears, represented by chloride - 0.8%. All types of soil salinization are found on the soil surface at a depth of 0-10 cm.

Thus, carbonate salinization was noted on the surface soil layer in the city of Navoi, and in the Karmana district (Khazora), also on the surface soil layer, along with the dominance of carbonate, there is sulfate and chloride salinization appears. In the carbonate type, salinization is due to the main carbon-bearing minerals calcite and dolomite, gypsum, astrakhanite, and cokimbite are sulfur-bearing minerals, and halite is the chlorine-bearing mineral..

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