

Article

Biogeochemical State of Salinized Irrigated Soils of Central Fergana (Uzbekistan, Central Asia)

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Abstract: The Central Fergana region is one of the overpopulated regions of Central Asia, which includes parts of Uzbekistan, Kyrgyzstan, and Tajikistan. Here, in the dry subtropical climate are the most ancient, irrigated oases used for agriculture. Fergana valley is the key to the food security of the region as a whole. The article provides information on diversity and chemical composition of newly developed, new and old-irrigated Calcisols soils formed on alluvial and alluvial-proluvial sediments. Soils are poor with organic matter (0.37–0.81% of organic carbon), with high nitrogen content (C/N ratio is 4.92–5.79), and with neutral (7.01–7.30) pH values. Data on the content and the ratio of the key components of soil salinity (Na_2CO_3 , $\text{Ca}(\text{HCO}_3)_2$, CaSO_4 , MgSO_4 , Na_2SO_4 , NaCl) and the bulk content of salts in soils under different irrigation regimes are presented. It was shown that Na_2CO_3 concentration is minimal in all the soils, and this salt presents only in ground waters (0.100–0.135 g L^{−1}). Newly irrigated soils are characterized by higher content of salts than old irrigated soils. All the soils investigated are characterized by increasing salinity rate within the soil depth with the highest content of all salts in ground waters. This chloride–sulfate type of salinization is most pronounced in all the soils studied. Gypsum content in agricultural soils results in limited water and nutrient retention and the potential for dissolution, primarily in response to irrigation. The soils of the Fergana Valley are also subjected to polychemical pollution, so the content of trace elements in them was studied. Irrigated meadow-takyr and meadow-saz soils show low levels of environmental hazard, but irrigation results in accumulation of such trace elements as nickel (30 mg kg^{−1}), arsenic (11.75 mg kg^{−1}), bromine (5.00 mg kg^{−1}), antimony (1.48 mg kg^{−1}), cesium (5.00 mg kg^{−1}), and hafnium (2.97 mg kg^{−1}). Irrigation also affects the soil texture and thus increases fine particle percentages in the superficial soil horizons. Thus, the complex chemical characteristics of salinized soils are presented for numerous irrigated landscapes of the region.

Keywords: Uzbekistan; agrosols; salinity; irrigation



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1. Introduction

Soil degradation in Central Asia is pronounced in Russia, Uzbekistan, Kazakhstan, and Kyrgyzstan [1]. Often, it is an irreversible process, especially when taking into account the intensive expansion of agricultural lands in this region [2]. At present, as a result of the degradation of cultivated areas—desertification and waterlogging, water and wind erosion, salinization and pollution—thousands of hectares of land fall out of agricultural turnover [3]. Secondary salinization is one of the decisive factors of deterioration of soil properties and reduction of its productivity. Salt composition of moisture used for irrigation and chemical composition of groundwater plays an essential role in this process [4–6]. In

the southeastern part of Uzbekistan this problem acquires a special dimension in connection with the intensive conduction of agriculture that, in turn, is connected with the very dense population of the Fergana valley region [7]. Salinization of soils has stretched far to the north; now saline soils have become typical not only for the southern regions of Russia, but also for the central sub-boreal regions, while they have increased their spread in the traditional areas of saline soil distribution [8,9]. Thus, soil salinization, previously restricted to traditional ranges associated with the geochemistry of the landscapes and water hydrochemistry has become a typical process for many soil types. In this connection the urgency of the study of soil salinization of long-range salinization scenarios in the Fergana valley as representative of the subtropical-piedmont area of Central Asia has not weakened.

Nowadays, soil and agricultural land salinization processes are being investigated in various aspects for Uzbekistan—with the use of satellite thermography [10], in terms of soil water quality [11], in terms of landscape dynamics and soil chemical property alteration [12], and in terms of investigation of soil biological stress and its regulation [13]. The reclamation practices of salinized soils of Uzbekistan with the use of cyanobacteria has been reported [14]. The quality and amount of mineral fertilizers make an essential contribution to bulk soil salinity and the quality and yield of crops [5,15] and essentially could affect environmental management effectiveness and practices in long term irrigated areas [5].

Among the large agricultural oases of Uzbekistan, the two largest oases stand out—Zeravshan and Fergana Valley. Both territories are characterized by a main problem—the deficit of available and cost-effective moisture. Salt composition of irrigation water as well as its secondary use in irrigation is also an acute problem. A large area of Central Fergana has been anthropogenically modified and almost all areas are irrigated with the exception of a few thousand hectares of the unique Yazvan sands with endemic flora and fauna. Flooding for half a year of paddy soil type under rice cultivation, shows degradation in the subtropical ecosystem of the Fergana valley, even under an environmentally adopted agricultural production system [16]. Depending on the initial condition of soil cover, the established hydromeliorative irrigation system structure, crop cultivation technologies, and several other phenomena, the evolution of irrigated soils has multidirectional character [17]. Another factor of salts distribution across the Fergana valley is the high speed of winds [18], thus salts could be redistributed not only through irrigation or ground waters [19] but also with the Aeolian factor. The study of trends in the spatial dynamics of biogeochemical indicators of soils in southern Uzbekistan is the most important problem of modern applied soil science and agroecology [4,6].

Thus, saline soils of Uzbekistan in the whole and in the Fergana valley in particular have been investigated rather actively in various aspects. At the same time, the study of salinity dynamics, texture class, and heavy metal content in soils of the Fergana valley is demanded in the conditions of the development of irrigation farming practices. The study of dynamics and component composition of trace elements, in particular lanthanides, in soils of geochemically subordinate landscapes of irrigated areas of the Fergana valley is also of particular interest. The aim of this work was to study the complexity of soil transformation processes and their salt state under the influence of irrigational practices in the Fergana valley.

Thus, the objective of the study was to analyze soil chemical state alteration under the irrigation effect on soil of the Central Fergana region.

The following tasks were formulated to achieve the objective: (1) to study the basic chemical properties of saline irrigated soils of the region, (2) to study particle size composition of soils and trends of their dynamics under irrigated conditions, (3) to study the component and quantitative composition of readily soluble salts in saline irrigated soils, (4) to determine levels of heavy metal pollution in irrigated soils and assess the role of irrigation in this process, (5) to determine the chemical composition of trace elements and lanthanides in the saline irrigated soils of the region.

2. Materials and Methods

The object of the research were newly developed, new and old-irrigated meadow hydromorphic, meadow-takyr soils, formed on alluvial and alluvial-prolluvial sediment of Central Fergana. Geographically the landform belongs to Fergana sediment or Fergana depression, initial toponymal was the “Pargana”—“valley between mountains” [20]. The objects of investigation are located in the Yazvan district, Fergana region, Fergana valley, South-East Uzbekistan (Figure 1). Meadow-saz, meadow-takyr soils are formed under influence of saline groundwater in the desert zone, they are saline of different degrees and their parent rock consists of alluvial–prolluvial deposits that belong mainly to light and medium loamy and sometimes heavy loamy soils. In this study we used sections and samples of the following soil pits: **Section 1** (40,035'01" N, 71,046'18" E, h = 448 m. asl)—old irrigated meadow-takyr soils, **Section 12** (40,035'07" N, 71,046'48" E, h = 449 m. asl)—old-irrigated meadow-saz soils, **Section 20** (40,039'19" N, 71,042'29" E, h = 426 m. als)—recently irrigated meadow-saz soils, **Section 24** (40,040'15" N, 71,042'22" E, h = 425 m. asl)—recently irrigated meadow-takyr soils, **Section 28** (40,039'24" N, 71,044'05" E, h = 428 m. asl)—old irrigated meadow-saz soils, **Section 35** (40,023'58" N, 71,036'20" E, h = 486 m. asl)—recently irrigated meadow-saz soils.



Figure 1. Location of sample plots. Red button designates region of field survey.

There are no background soils in the area—they are fully involved in agriculture. The exception is the soils of barkhan (unstable migratory) sands, but they cannot serve as a background due to initial pronounced differences. According to the state soil maps of the “Uzgiprozem” Institute, in 1972 and 1984 soils distributed in the area of section 20 A belong to newly cultivated, and soils distributed in the area of sections 24 A and 35 A belong also to newly cultivated. Based on field investigations, changes in the morphological characteristics of soils, and the rules accepted in soil science, it can be noted that the level of their cultivation has changed, i.e., by now the soils of section 20 A have turned into newly-irrigated meadow saz soils. The newly irrigated soils of sections 24 A and 35 A were transferred to the category of old-irrigated meadow-saz and meadow-takyr soils. Additional soil sections—1, 12, and 28 were selected for verification of filed and laboratory data.

The general soil section formula is as follows: PJ (arable light gray humus horizon, 5YR 4/1 color, thickness up to 30 cm), BCAs (carbonate and gypsum accumulative horizon,

2.5 YR 8/6 color, depth from 30 to 70 cm), Cg (parent material with lithogenically inherited (from parent material) carbonates and gypsum and yellowish dark color—10 YR 6/4, due to development of the hydromorphic process as a result of irrigation effect). Pictures of the soil sections are given in Figure 2. Sample plot is located on current agricultural field placed inside the settlement, between roads and complexes of houses (“Makhalya” in Uzbek language).

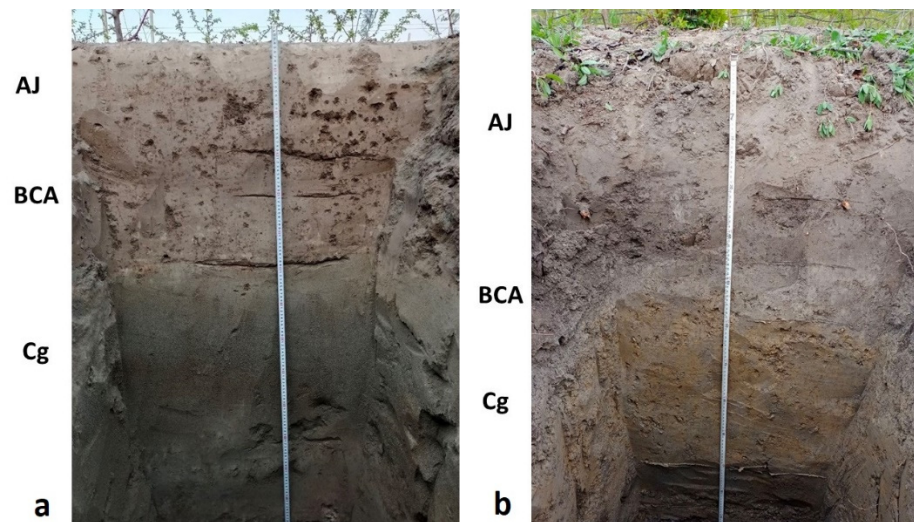


Figure 2. Soil sections of saz soils (a) and takyr soils (b).

Normally parent materials are presented by alluvial and proluvial sediments of the Fergana valley. The climate is dry, with an average precipitation rate of about 200 mm and average annual temperature of about 14.3 °C. Water deficit makes agriculture completely impossible without irrigation which completely depends on the supply region with waters of natural sources—river and artificial ones—and irrigation channels. Nowadays more than 95% of the region area is completely occupied by antropogenic soils, mainly of agrogenic origin.

Research was carried out on the basis of methods and techniques accepted in soil science, in the field, and in cameral and laboratory conditions; soil samples were taken from soil sections. Field research was conducted during the summer of 2015. Soil samples were air-dried, ground, and passed through a 2 mm sieve. Total organic carbon (TOC) was determined by a standard Tuvrin dichromate oxidation method [21], and total nitrogen was determined by the standard Kjeldahl procedure [22]. To determine the water-soluble salt gravimetric concentrations, we used the traditional method of analysis of aqueous extract at a ratio of soil:water of 1:5. Dry residue was determined by evaporating 50 mL of the extract and further drying to a constant weight at 105 °C with a gravimetric finalization. The calcium and magnesium contents were determined by titration in the presence of Trilon-B (EDTA disodium salt dehydrate). The sodium content was calculated from the difference in the abundances of anions and cations. The chlorine content was determined argentometrically by titration. The potassium and sodium contents were determined by flame-photometry. The particle size distribution of the soils was measured by the sedimentation (gravimetric) method [23]. Exchangeable phosphorous and potassium within the Olsen extract were detected with the use of molybdenum ammonium and flame photometry correspondingly. Elemental analysis of the soils' fine earths was carried out by the neutron activation method at the Institute of Nuclear Physics, ANRUz. Statistical treatment processing was carried out using the “Microelement” program according to the methodology of Kuziev et al. [24] and Kuziev and Sektimenko [25]. Figures, diagrams, and statistics (Pearson correlation coefficient) were performed using Macromedia Flash and Microsoft Excel software.

Statistical processing of the data was performed using correlation analysis and calculations of the basic soil characteristics (RMS deviation, coefficient of variation, Pearson correlation coefficient.). Data visualization was performed using GraphPad Prizm 9.0.0 and Golden Software Grapher 13.0.

3. Results and Discussion

Soil chemical properties are provided in Table 1. The arable horizons do not show a high organic matter content such as in northern most soils [26]. This is typical for Serozems [26–28] (this is a name of these soils in Russian and Soviet soil classifications [29,30]) or Calcisols according to WRB [31].

Table 1. Soil agrochemical properties.

Soil Section No	Depth, cm	pH H ₂ O	CaCO ₃ , %	MgCO ₃ , %	TOC, %	C:N	Bulk Gravimetric Concentrations, %			Available Gravimetric Concentrations, mg kg ^{−1}		
							N	P	K	NH ₄	P	K
1	0–29	7.01	5.60	2.10	0.66 ± 0.05	5.50	0.12	0.31	1.86	17.3	19.6	187
	29–44	7.05	7.20	2.68	0.54 ± 0.02	5.40	0.10	0.23	1.77	12.1	17.8	135
12	0–28	7.10	3.24	2.21	0.69 ± 0.05	4.92	0.14	0.32	1.90	18.5	20.1	210
	28–42	7.15	4.31	2.67	0.56 ± 0.05	5.09	0.11	0.25	1.81	13.2	18.5	143
20	0–30	7.30	7.50	2.30	0.48 ± 0.04	5.33	0.09	0.30	1.73	15.2	17.8	175
	30–45	7.30	7.60	2.20	0.37 ± 0.03	5.28	0.07	0.22	1.65	11.0	16.2	118
24	0–30	7.10	7.20	2.56	0.44 ± 0.05	5.50	0.08	0.26	1.70	14.9	17.0	168
	30–46	7.15	7.40	2.70	0.37 ± 0.05	5.28	0.07	0.21	1.61	10.6	15.7	112
28	0–35	7.10	6.78	2.80	0.81 ± 0.08	5.79	0.14	0.34	1.94	21.5	20.7	229
	35–54	7.25	6.90	2.95	0.53 ± 0.06	5.30	0.10	0.32	1.85	14.7	17.2	192
35	0–30	7.20	5.90	2.35	0.55 ± 0.05	5.00	0.11	0.30	1.86	16.8	17.1	172
	30–43	7.25	6.45	2.50	0.45 ± 0.08	5.62	0.08	0.25	1.75	11.2	12.0	114

The reason for the low carbon content is the high organic matter mineralization rate [26], thus only stabilized fractions of calcium humates accumulate in soils [26]. The nitrogen content is low, but the C/N ratio is narrow, which indicated high enrichment of humus by nitrogen. This could be the result of soil amendment by fertilizers, and, simultaneously, be affected by intensive organic matter mineralization in the dry semi desert conditions in a subtropical climate. The superficial horizon of these soils is well fitted to the definition of light humus horizon (AJ) in Russian soil taxonomy [30] due to the alkaline reaction of the fine earth and low humus content. Some of these horizon could be additionally named as takyric according to WRB [31]. The lower horizons are defined as BCA [26] due to accumulation of secondary carbonates in diffusive forms without formation of nodules or other evident pedological features; this is the typical form of irrigated Serozems/Calcisols of Uzbekistan [32,33]. There are not statistical differences in soil carbon and nitrogen content between pairs of old irrigated–recently irrigated soils and takyr-saz soils. Thus, there is not an effect of long-term irrigation on the parameter of the soil humus state in terms of Orlov’s grade systems [26]. The soil bulk phosphorous content is low, but there is biological accumulation in the superficial arable layers. Our data is in good correspondence with the recently published concentration of bulk phosphorous in the so-called “Light Serozems” of the Fergana valley [34]. Apparently high potassium content is typical for soils of the Fergana valley, formed on a loess type of parent materials [35] dominating in this region [36]. There is also increased content of potassium in bulk form and available nutrient content in the superficial arable horizons due to biological accumulation and vertical pulling of soil solutions under the evaporation process. Available potassium is about 1–2% of the bulk form, while the form of phosphorous is about 5–7%. Thus, phosphorous seems to be more mobile than potassium; at the same time the reserve of potassium in the soil is higher, which could be a reason for the apparent lower ratio of the available form of potassium to the bulk form compared to the case of phosphorous. In

general, the content of nutrients is higher in old, irrigated soils than in recently irrigated ones. The biological accumulation of ammonium in superficial soil horizons is more pronounced than the mobile forms of phosphorous and potassium. The pH is neutral or slightly alkaline which is an indicator of the absence of sodium salinization [26]. The content of carbonate of calcium and magnesium is also not very high, which is caused by year by year leaching of these materials from soil under the influence of the irrigation process.

Data on soil particle distribution are given in Table 2. The soil investigated belongs to the loamy or sandy loam class according to the texture triangle (Figure 3). Fine particle content is increased in topsoils in comparison to middle and deep soil horizons. It could be the result of colmatage (accumulation of fine particles in the topsoil from turbid water with suspended matter) [37].

Table 2. Particle size distribution in soil sections.

Soil Section	Depth, cm	Particle Size, mm							
		1–0.25	0.25–0.1	0.1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01 mm
1	0–29	12.7	18.4	17.2	12.8	13.5	11.3	14.1	38.9
	29–44	13.5	17.3	18.4	14.1	12.3	11.0	13.4	36.7
	44–67	15.4	21.6	17.9	13.7	11.7	10.4	9.3	31.4
	67–102	12.1	24.9	19.2	15.7	8.5	9.4	10.2	28.1
	102–132	17.3	25.4	20.7	17.3	6.2	7.6	5.5	19.3
12	0–28	18.1	15.6	17.0	11.9	12.9	10.7	13.8	37.4
	28–42	12.6	13.9	18.5	14.3	15.2	13.3	12.2	40.7
	42–72	14.3	17.6	23.5	15.8	8.4	7.8	12.6	28.8
	72–131	17.2	25.7	18.1	19.4	6.5	5.3	7.8	19.6
	131–152	19.7	20.8	21.6	16.3	6.8	6.5	8.3	21.6
	152–200	16.8	21.6	19.5	15.7	9.1	7.8	9.5	26.4
20	0–30	10.6	14.3	21.4	19.2	11.4	11.0	12.1	34.5
	30–45	12.7	15.4	19.1	20.1	10.3	10.6	11.8	32.7
	45–62	10.2	17.4	12.3	11.6	14.2	18.7	15.6	48.5
	62–97	18.4	21.7	17.6	15.5	8.6	10.3	7.9	26.8
	97–120	17.6	23.2	20.4	15.8	8.2	8.1	6.7	23.0
24	0–30	11.2	17.5	19.2	18.4	10.7	13.2	9.8	33.7
	30–46	12.7	15.4	19.1	22.1	8.9	10.6	11.2	30.7
	46–75	14.9	16.5	21.6	19.7	7.4	9.6	10.3	27.3
	75–92	21.4	18.9	19.9	15.3	8.6	7.4	8.5	24.5
	92–109	14.5	17.2	21.4	18.7	8.7	10.2	9.3	28.2
28	0–35	10.2	14.7	16.2	11.4	13.5	15.3	18.7	47.5
	35–54	9.5	16.1	17.7	10.6	12.0	16.7	17.4	46.1
	54–72	13.1	15.3	18.4	12.6	10.5	13.9	16.2	40.6
	72–91	12.7	18.6	19.2	15.3	8.3	14.5	11.4	34.2
	91–140	10.6	13.5	15.6	12.0	15.9	14.6	17.8	48.3
35	0–30	10.4	14.6	20.4	18.2	12.3	11.5	12.6	36.5
	30–43	12.5	14.9	19.1	20.1	10.9	11.9	11.5	34.3
	44–86	15.0	17.7	21.8	21.8	9.1	7.2	7.4	23.7
	86–129	24.7	14.6	15.7	16.4	8.6	10.3	9.7	28.6
	129–195	15.4	17.5	20.3	18.9	10.5	9.6	7.8	27.9

In most Eurasian soils, the content of fine particles strongly depends on the humus content, but in this case, a very low humus content did not affect the granulometric composition of the soil [26]. One could assume that the vertical distribution of fine particles is inherited from the parent materials and may therefore be non-homogeneous, but the content of sand and fine sand fractions shows no heterogeneity, hence fine particles were accumulated during soil formation, in particular under the influence of irrigation. The presence of the fraction with diameter 0.05–0.01 mm in soils and sediments is one of the key indicators of loess origin of material [38]; thus, our soils belong to the loess soil group

in terms of lithology. The more intensive accumulation of fine particles in the upper horizons of old irrigated soils compared to recently irrigated soils also testifies in favor of the irrigational hypothesis of the transformation of the particle size distribution.

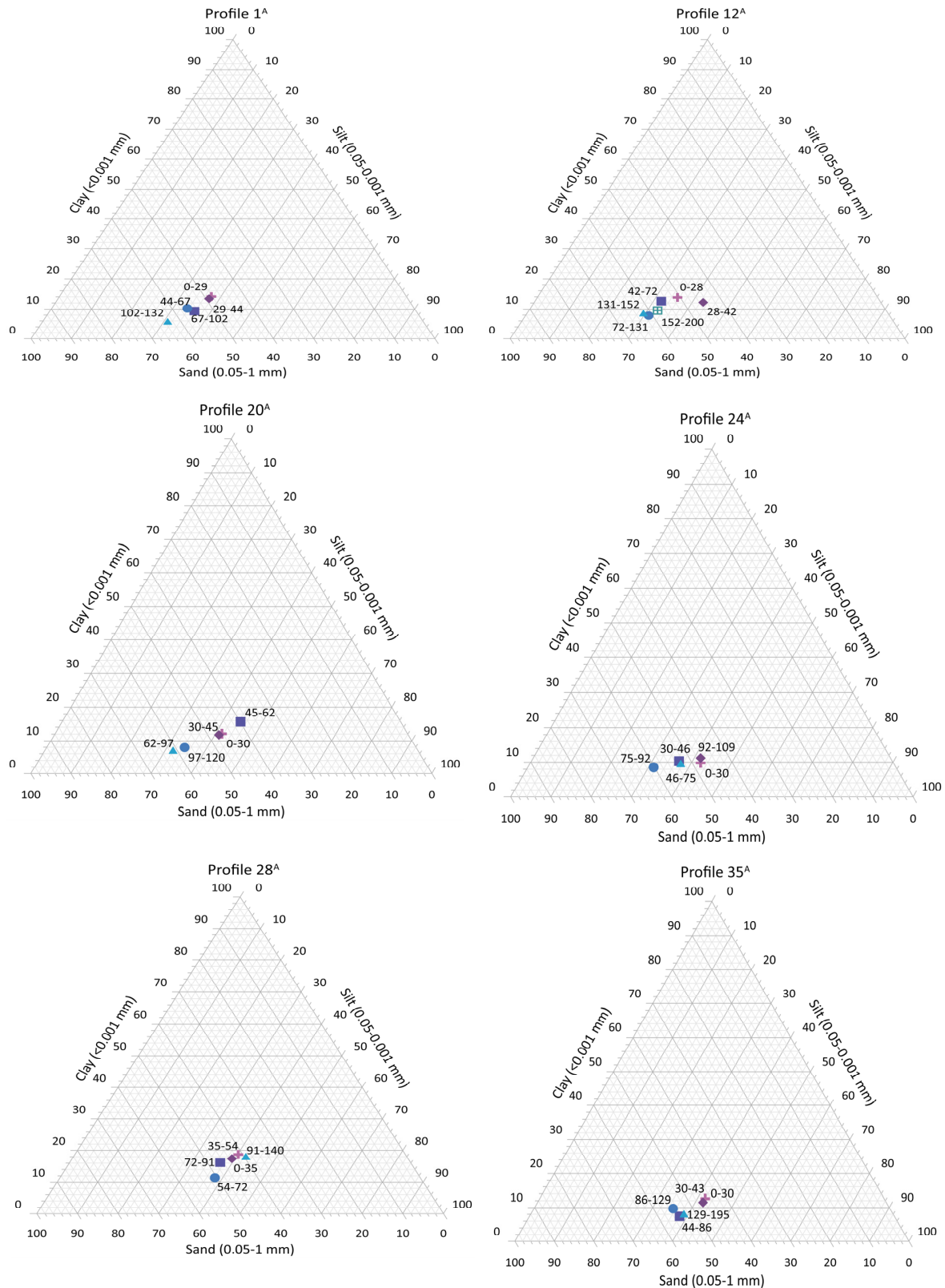


Figure 3. Texture triangles of soils investigated.

Data on water-soluble salt content are given in Table 3. Due to specific soil-climatic conditions of Central Fergana, these soils are gypsum and carbonate and chloride–sulfate salinity type, dry residue after leaching is relatively high, dry residue in studied meadow saz and meadow takyr soils varies by about 0.505–0.926% as expected, while the highest indicator corresponds to gypsum. Magnesium sulfate stands second after gypsum and the positive correlation between them is 0.9; the process of leaching out of chloride salts is observed up to limits of the threshold concentration. The results of research are presented on the number and migration of macroelements in the soil, the geoenergetic properties, and the amounts of trace elements, the geochemical properties of biogenic microelements, the assessment of heavy metals and metalloids in the soil and their pollution levels, the quantity and differentiation of the heavy metals and metalloids in the soil. According to the obtained data, the content of Na^+ and Mg^{2+} in genetic horizons of old-irrigated and newly irrigated meadow-takyr, meadow-saz soils varies between 0.42–2.57%.

Table 3. Content and amount of salts in irrigated meadow soils, %.

Soil Section	Depth, cm	Na_2CO_3	$\text{Ca}(\text{HCO}_3)_2$	CaSO_4	MgSO_4	Na_2SO_4	NaCl	Bulk Salts Content
1	0–29	-	0.015	0.236	0.214	0.023	0.014	0.502
	29–44	-	0.029	0.294	0.255	0.027	0.012	0.617
	44–67	-	0.016	0.296	0.235	0.021	0.012	0.580
	67–102	-	0.017	0.301	0.245	0.027	0.014	0.604
	102–132	-	0.020	0.408	0.245	0.027	0.019	0.719
	Ground water, g L^{-1}	0.135	0.201	3.795	2.104	0.801	0.604	7.640
12	0–28	-	0.021	0.341	0.228	0.024	0.013	0.627
	28–42	-	0.031	0.338	0.275	0.024	0.011	0.679
	42–72	-	0.015	0.358	0.245	0.028	0.012	0.658
	72–131	-	0.016	0.421	0.256	0.038	0.014	0.745
	131–152	-	0.017	0.460	0.301	0.032	0.014	0.824
	152–200	-	0.020	0.478	0.310	0.038	0.018	0.864
	Ground water, g L^{-1}	-	0.301	4.201	2.204	0.821	0.505	8.032
20	0–30	-	0.035	0.381	0.238	0.028	0.015	0.697
	30–45	-	0.039	0.341	0.301	0.027	0.015	0.723
	45–62	-	0.038	0.328	0.304	0.038	0.064	0.772
	62–97	-	0.051	0.438	0.333	0.041	0.014	0.877
	97–120	-	0.058	0.470	0.337	0.041	0.020	0.926
	Ground water, g L^{-1}	0.100	0.585	4.308	2.308	0.841	0.644	8.786

Their content in arable horizons is 0.71–0.92%. Concentrations of sodium and magnesium in genetic horizons of old-irrigated soils are practically equally located, but in general the quantity of Mg^{2+} is more than Na^+ . The gypsum content in agricultural soils results in limited water and nutrient retention and the potential for dissolution, primarily in response to irrigation [39]. The absence of Na_2CO_3 in soil horizons and its presence in ground waters concerns the low stability of this chemical compound in soil porous media. The soil concentrations of water-soluble salts are quite important in the regulation of osmotic and physiological states of agricultural plants [40,41] and should be taken into account in planning of land-use practices.

The content of trace elements is given in Table 4. At the end of the table the lithosphere clarke is given for every chemical element in Table 4.

Table 4. Trace elements content in soils, mg kg^{−1}.

Soil Section	Depth, cm	Sc	Cr	Co	Ni	As	Br	Sb	Cs	Hf	Ta	W	Au
1	0–29	7.3	43.9	9.13	20	16.7	4.1	1.67	6.5	3.63	0.71	4.19	0.0055
	29–44	7.3	43.2	9.13	35.4	15.9	4.6	1.6	6.7	3.42	0.81	3.2	0.006
	44–67	7.6	44.6	9.80	16	19.8	3.4	1.94	7.2	3.06	0.74	2.8	0.0076
	67–102	6.9	40.6	8.83	12.9	17.0	1.7	1.6	6.5	2.72	0.65	<0.1	0.0062
12	0–28	5.0	29.3	6.46	400	11.3	5.9	2.28	3.9	2.23	0.43	<1.0	<0.001
	28–42	7.5	49.5	8.10	25	13.0	5.5	1.26	5.3	3.62	0.62	<1.0	0.0042
	42–72	6.4	36.4	8.0	15	12.5	2.3	1.39	5.5	2.94	0.63	<1.0	0.0051
	72–131	5.7	32.5	8.30	14	12.7	1.5	1.37	4.8	3.32	2.7	<1.0	0.0060
	131–152	9.0	53.5	8.49	13	8.3	1.9	1.40	6.7	4.31	0.76	<1.0	0.0085
	152–200	7.6	45.8	7.65	14	8.3	1.1	1.62	5.5	2.97	0.62	<1.0	0.0056
20	0–30	7.5	44.7	8.83	19.9	9.5	5.9	1.4	6.1	2.86	0.59	<0.1	0.0037
	30–45	6.4	40.2	8.48	250	26.0	3.8	1.6	6.0	1.73	0.46	<0.1	<0.001
	45–62	8.8	53.3	10.9	35	10.6	4.4	1.42	7.7	3.41	0.79	<0.1	0.0052
	62–90	3.9	23.7	4.0	42	7.10	1.7	0.67	2.8	2.30	0.36	<0.1	0.0033
24	0–30	6.2	38.0	7.20	<5.0	15.4	10	1.40	4.5	3.05	0.64	<1.0	0.0064
	30–46	5.6	35.7	6.55	24	8.7	12	1.12	3.9	2.96	0.46	<1.0	0.0048
	46–75	4.9	32.0	3.41	140	7.25	5.7	1.24	3.5	2.20	0.69	<1.0	<0.001
	75–92	4.6	25.7	6.60	49	10.0	4.9	1.47	3.1	2.80	0.59	<1.0	0.0043
	92–109	5.7	38.6	6.76	7.3	3.9	3.0	1.48	3.9	2.98	0.51	<1.0	0.0049
	109–159	6.1	36.0	6.80	<5.0	2.8	0.98	1.30	4.2	2.87	0.43	2.7	<0.001
28	0–35	6.4	49.2	7.22	34.1	7.24	7.5	1.1	4.4	3.76	0.80	<1.0	0.0047
	35–54	6.7	44.5	7.58	19	9.1	5.6	1.16	5.4	3.56	0.65	<1.0	0.0045
	54–72	6.9	41.7	7.03	11.5	10.2	3.4	1.49	5.9	3.50	0.68	3.6	0.0067
	72–91	4.3	46.0	8.48	52	8.7	7.0	1.67	5.6	3.93	0.77	<0.1	0.0054
	91–140	6.4	36.9	7.6	16	8.90	3.4	1.04	4.0	3.44	0.67	<1.0	0.0042
35	0–30	6.6	42.9	7.57	21.2	6.35	7.6	0.76	3.9	3.18	0.61	<0.1	0.0043
	30–43	6.9	43.1	7.40	18.9	7.08	1.9	0.95	4.3	3.51	0.59	<0.1	0.0042
	44–86	6.2	42.1	7.33	317	6.83	6.9	0.85	3.8	2.67	0.53	<1.0	0.0031
	86–129	7.8	51.3	9.0	19.7	7.73	11.5	1.2	5.0	3.85	0.78	<0.1	0.0042
	129–195	7.0	44.2	8.28	24.0	10.0	9.0	1.1	4.6	3.23	0.65	<0.1	0.0040
Lithosphere clarke		10	83	18	58	1.7	2.1	0.5	3.7	1	2.5	1.3	0.0043
Average for meadow-takyr soils		6.2	37.8	7.42	30.5	11.75	5.00	1.48	5.00	2.97	0.62	1.29	0.0046
Average for meadow-saz soils		6.6	42.5	7.84	68.1	10.07	4.90	1.29	5.10	3.22	0.73	0.18	0.0043

The scandium content is lower than the clarke in the lithosphere. These rare elements do not show any trends in vertical soil distribution within the soil profile, in spite of the recently published fact of biogenic accumulation in some soils of boreal climatic belt [42]. According to Ladonin's data, scandium adsorbs very quickly in soils, making it similar to the alkaline earth elements [43]. The chromium content is also lower than the clarke but higher in saz soils than in takyr ones. According to some reports, chromium accumulation in soils may be associated with alluvial deposits and river waters [44], which is quite possible in the Fergana Valley. Mobility of cobalt increases in wet soils, in connection with what is the possible removal of this element in irrigation; in any case, its accumulation is at a level two times lower than clarke [45]. Accumulation of nickel above the clarke occurs in saz soils, it does not occur in takyr soils. Nickel is known as an element which may accumulate on the surface of aluminosilicate chemicals [46] and, especially in soils, enriched by smectite. There is an essential accumulation of arsenic in both saz- and takyr-soils and exceedance of clarke is up to 8–9 times. Recently, a high content of arsenic was reported for Western Siberia [46,47], but high concentrations are not obligatorily dangerous, cause the

bulk forms are higher than water soluble. As for bromide salt concentration which exceed clarke by 2.5 times, it has been reported that this element may be immobilized by calcium carbonate salts [48]. Antimony in soils is very poorly studied; it is assumed that it may be related to iron hydroxides [46,49,50], but it is not clear whether correlation of antimony content with iron in alkaline conditions of soils in the Fergana Valley is possible. In any case, the clarke in irrigated soils is exceeded twice or more, which may indicate the role of irrigation in the accumulation of this element. Antimony is considered as an active part of biological food chains [50], thus, exceeding its content in comparison with clarke could be a possible predictor of crop production, planted on irrigated soils.

Cesium concentration exceeded clarke in irrigated soils, taking into account the fact that cesium is characterized by its low ability to dissolve in water; its migration and accumulation are affected by suspended particles of clay minerals in topsoils which corresponds well with the results of particle size distribution in soil sections. Probably irrigation by water enriched by suspended clays could be a reason for cesium accumulation in both types of soil investigated as was suggested for antimony. Hafnium accumulation normally deals with translocation from parent materials or accumulation in the lowlands form of adjacent uplands [51]. Both these factors could be possible predictors of hafnium accumulation in both types of soils investigated. Hafnium behavior in the soil-plant system is poorly studied, nevertheless it is known that even different grains are characterized by different selectivity in hafnium absorption from soils with different levels of contamination [52]. Hafnium accumulation could be essentially affected by loess type of mineral material in the environment [53].

As for tantalum content its content deals normally with thecnogenic sources [54], thus due to that fact that clarke is not exceeded, the role of thecnogenic factor in soil chemical composition is low. Tantalum is known as a very conservative element in biogeochemical terms but real understanding of its cycle and reactivity would require extensive and meaningful data collection [55]. The content of tungsten and aurum in soil is low and does not exceed the clarke concentration, thus it corresponds with the background level. At the end of this section we conclude that trace elements like nickel, arsenic, bromine, antimony, cesium, and hafnium could be accumulated in irrigated soil during their agrogenic transformation. In opposite, such elements as scandium, chromium, cobalt, tantalum, tungsten, and aurum are supposedly inherited from parent materials and are not incoming with irrigation waters in both types of the soils investigated.

Statistical treatment of chemical analyses (Figure 4) showed that there is strong positive correlation between magnesium sulfate and potassium sulfate, thus the binding of cations by sulfate is a simultaneous process in the soils investigated. Thus, the sulfate type of salinization could be dominant in soils.

The percentage of fine particles is in strong positive correlation with Br and Ni as it was grouped with those elements which accumulate under the irrigation process. The key sulfates are negatively correlated with fine particles; this is understandable since the accumulation of salts is the reverse process of sorption of substances and cations in the soil absorbing complex [26]. The totality of positive and negative correlation between the main components of the chemical composition of soils indicates that irrigation significantly disturbs the chemical state of soils, resulting in the soil becomes a kind of polychemical matrix with an extremely heterogeneous component and a cationic composition.

This section can be divided by the subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

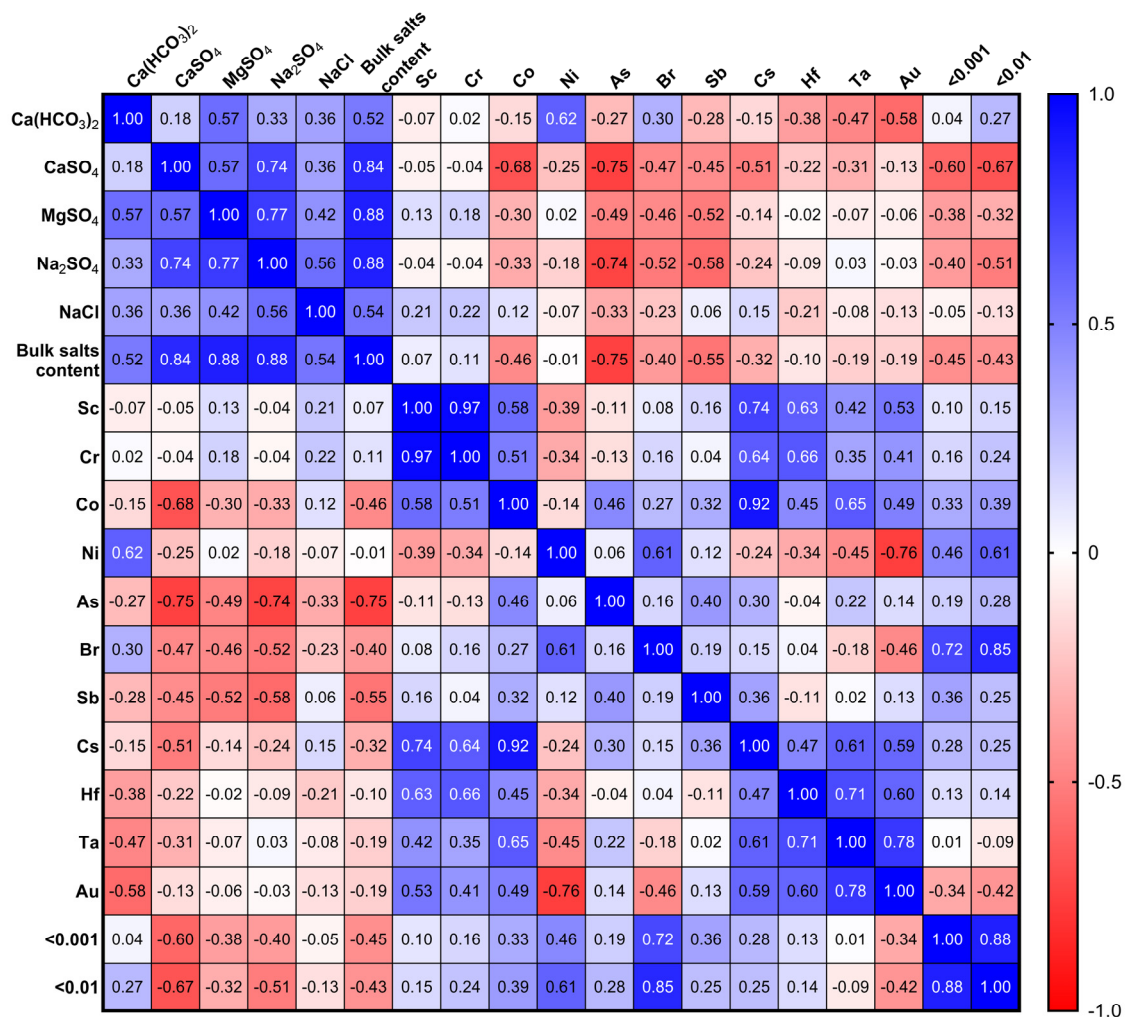


Figure 4. Pearson correlation coefficient rates.

4. Conclusions

Almost the entire territory of the Fergana Valley is occupied by agricultural land, except for a small area of barkhan sands, where farming is impossible. Irrigated soils are conditionally divided into two large groups—takyr and saz soils. It was established that the content of humus in the relatively thick in-depth humus horizon is small and slightly higher than its content in the middle soil horizon, which corresponds to the zonal norm for Serozems (Calcisols). The studied agricultural soils are characterized by high enrichments rate of nitrogen, gross bulk, and mobile ammonium forms, as well as mobile forms of potassium. The soil salinity type is relatively favorable. At least, there is no soda salinization; the low salt concentration can be attributed to good leaching of the soil by irrigation waters and the occurrence of groundwater at a depth of about 3 m, which provides drainage of the soil column. In terms of the texture of the fine earth, the soils investigated were loams or sandy loams; the arable horizons are enriched by fine particles, supposedly due to colmatage, initiated by irrigation practices. This corresponds well with accumulation of nickel, arsenic, bromine, antimony, cesium, and hafnium in soils in amounts higher than clarke. Other elements, like scandium, chromium, cobalt, tantalum, tungsten, and aurum are probably inherited from parent materials. Thus, irrigation results in the partial transformation of soil of biogeochemical composition, mainly in terms of trace elements, while such soil properties as the nutrient state, remain more stable in the temporal scale. Further monitoring of soil chemical properties should be continued for the entire region of the Fergana valley.

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