CHEMICAL AND BIOGEOCHEMICAL FEATURES OF DESERT SOILS OF THE CENTRAL FERGANA

AVAZBEK TURDALIEV¹, GULOM YULDASHEV¹, KAMOLIDDIN ASKAROV¹,
EVGENY ABAKUMOV^{2,3*}

¹Fergana State University, Fergana, Uzbekistan

²Saint Petersburg State University, Saint-Petersburg, Russia

³All Russia Institute of Agricultural Microbiology, Saint-Petersburg, Russia

Turdaliev, A., Yuldashev, G., Askarov, K. and Abakumov, E.: Chemical and biochemical features of desert soils of the Central Fergana. *Agriculture (Pol'nohospodárstvo)*, 67(1), 16–28.

The Fergana Valley is a region critically important for food safety in Central Asia. The human-altered soils in Fergana are considered a key component of the transboundary region between sub-boreal and sub-tropic climatic zones. As the results of the investigation of irrigated chloride-sulfate saline soils near the surface showed the deep petrocalcic and petrosalic horizons at various depths with extremely low water and air permeability. The chemical, pedogeochemical, and biogeochemical properties of soils, the content of macroelements, trace elements, lanthanides and radionuclides, and the general geochemical characteristics of desert zone soils were investigated and determined. The background contents of the mentioned elements were recognized. The irrigic, salic, gleyic, and gypsic horizons in soils were identified by WRB 2015. They can be used as reference horizons for biogeochemical studies and soil management activities. The irrigic, gleyic, carbonate-gypsum horizons, evaporation, oxygenic, and other geochemical barriers were studied and revealed. The processes of accumulation, migration, and differentiation of chemical elements in solum as well as in parent materials occur with the joint effects of exogenous, endopedogenic, and artificial factors. These fluxes of elements, in turn, are affected by the nature of soils and parent materials. In this process, unexplored elements form only scattering fluxes. During the vegetation season, as well as the leaching period, considering the various horizons features will help to save significant amounts of irrigation water.

Key words: trace elements, irrigation, geochemical barriers, salinization

Nowadays, as a result of the soil degradation processes of arable land, e.g. alternation of desertification and moistening, water and wind erosion, salinization, and pollution, thousands of hectares were abandoned. About 40% of irrigated land has some human-induced kind of salinization. At the same time 7 million hectares of the country are facing degradation, and every year 25 million hectares of agricultural land have trends of

conversion to a gradual desert status. As a result, these facts are reflecting in different barriers of geochemical terrains, therefore, the assessment of the processes of accumulation and differentiation of chemical elements belong to the urgent issues. The study of the chemical and geochemical characteristics of saline soils (respecting the pedo-geochemical point of view), and having unfavourable poor water and air permeability is one of the most

Avazbek Turdaliev, Gulom Yuldashev, Kamoliddin Askarov, Fergana State University, Murabiylar st. 19, Fergana, 1501006, Uzbekistan

Evgeny Abakumov (*Corresponding author), Saint Petersburg State University, Faculty of Biology, Department of Applied Ecology, 16 line V.O., Saint-Petersburg, 29199178, Russia. E-mail: e_abakumov@mail.ru; e.abakumov@spbu.ru

Evgeny Abakumov, All Russia Institute of Agricultural Microbiology, Pushkin, Podbelskog st., Saint-Petersburg, 3196698, Russia

crucial issues for agricultural practice in irrigated areas (Arboev *et al.* 2019). This issue is especially important for the Fergana Valley region which can be considered as a key food safety factor in Central Asia. The total agricultural land area of the Fergana Valley is about 1,289.1 hectares, including 1,188.6 thousand hectares of irrigated lands. This land suffers from soil wind erosion and various stages of salinization.

Intensively irrigated soils of the Fergana Valley are formed from the parent materials of alluvial, proluvial, and alluvial-proluvial genesis. The origin of these sediments is associated with the processes of weathering and re-sedimentation, which results in significant changes in the elemental and mineralogical composition of parent materials and horizon sequences in solum. At the same time, massive rocks of adjacent mountains ridges of the region sharply change their element's composition and turn into a crushed, clayey textured mass. Thus, the geochemical state of soils and agroecosystems in the Fergana Valley are quite temporally dynamic and spatially heterogeneous. Soil-forming materials of the Central Fergana consist of alluvial-proluvial sediments; and their genesis can be associated with lacustrine deposits of the Fergana Valley, as well as with the fluvial activities of the rivers Sokh, Isfara, Shakhimardan, and other rivers flowing from the south of the Fergana Valley. Primary salinization of soil is caused by the presence of salts in the parent materials. Secondary salinization is normally affected by irrigation practices and evaporation processes of salinized waters from deeper soil layers to superficial ones.

There are two key soil and environmental problems of the Fergana region: 1) wind erosion and soil protection against it; 2) the soil protection against salinization and discharge problems causing by waste collector-drainage waters.

Due to wind erosion and the collector-drainage water discharge, a huge amount of chemical elements, ions, and their compounds have been leaching from the soil.

In the context with the above mentioned, the evaluation of Fe, Ca, Mg, Na, Ba, K, Sr, and other macro- and microelements, toxic metals and metalloids such as Yb, Li, Sr, Cs, Au, Sc, La, Sm, Sn, U, Th in a system of vegetation-soils-parent ma-

terials (soil type Calcisols) is a quite urgent issue for current basic and applied studies. This allows a better understanding of these soils behaviour and can set an appropriate system of agricultural practices management. In this context, the study of typomorphic as well as paragenetic groups of elements in individual soil samples and parent materials can be recognised as of great scientific and practical importance.

Previously, only a few investigations of soils and their anthropogenic dynamics were published. Mirzazhanov *et al.* (1993) reported about sandy texture soils of the Fergana region and their reclamation after an anthropogenic intervention. The soil hardpan was described for the Fergana region by Isakov (1982). General problems of soil salinization and modelling of this process were discussed by Stulina *et al.* (2005), Smalley *et al.* (2006), and Evett *et al.* (2007.) The problems of groundwater dynamics in the context of salinization were referred by Karimov *et al.* (2014) and Kenjabaev *et al.* (2020). Not only the secondary salinization can be considered an environmental problem of Fergana valley, but also accelerated the development of wind erosion (Kulikov *et al.* 2020). In adjacent areas of Central Asia, the issue of irrigation affecting the soil salinity was also investigated, e.g. in Kyrgyzstan (Djenbaev *et al.* 2012; 2016; Arboev *et al.* 2019; Kulikov *et al.* 2020), Kazakhstan (Artamonova *et al.* 2014; Baishenova *et al.* 2016), and the Tuva region (South of Russian Siberian part) (Dubrovskiy *et al.* 2007).

Some papers (Orlov & Bezuglova 2000) present the migration of trace elements with the notion of migration factors, ion characteristics, the form of the elements, and its properties, etc. Also, other features like alkaline-acidic and redoxi-morphic conditions, water and temperature terms, pressure, the activity of organisms were taken into account. In some works (Bashkin 2008) the biogeochemical cycle of elements in various spheres was stated, where special attention is paid to the cycle of carbon, hydrogen, silicon, oxygen, nitrogen, calcium, phosphorus, iron, etc.

Soils of the central part of Fergana valley were investigated by Pankov (1957), Besedin (1981), Komilov and Isakov (1992), Mirzazhanov *et al.* (1993), Smalley *et al.* (2006), Yuldashev *et al.*

(2013). Currently, the biogeochemistry of these soils is still poorly investigated. In the arid zone, the compilation of soil-geochemical maps indicating the migration of chemical elements into geochemical barriers was carried out by Glazovskaya (1974), Perelman (1989), and other authors. Soil type Calcisol (Evapocrustic, Salic, Gypsic, Yermic) (WRB 2015) is formed in Central Fergana under intensive irrigation, saline, having soil horizons of salts accumulations at different depths require systematic study from a pedogeochemical point of view. The general sequence of the benchmark soil profile is A-BCA-PCA-Cca. The designation “CA” after horizon index in the capital means secondary calcium carbonate accumulation, while “ca” in lower case indicates lithogenic calcium carbonate.

The crucial goal of the study is to determine and evaluate the pedogeochemical and agroggeochemical qualitative properties of irrigated and saline soils having features characterized by horizons relating to arid zone (petrocalcic, petrogypsic) in the central part of the Fergana Valley.

MATERIAL AND METHODS

The study sites

The objects of investigation are newly developed, newly irrigated, old-irrigated meadow soils of the Central Fergana formed on alluvial, alluvial-proluvial deposits, having a saline, evaporative, and crusted horizons at different depths of a soil profile.

The map of the study sites is shown in Figure 1. Soil irrigation in the studied regions has a long-term history. The content of chemical composition in irrigation waters is provided in Table 1.

The climate of the Fergana valley is classified as a “Fergana climatic district” with subtropics conditions, which is mainly characterized by the raw data, derived from the meteorological stations of Kuva, Fergana, and Kokand. The key generalized climate data for the Fergana valley are provided in Table 2.

The hydrological conditions are classified as an arid subtropical climate with deficit type of soil water regime. The evaporation in the soils of Fergana valley is about 1,800 mm, so, the hydrological re-

T a b l e 1

Average long-term chemical compositions of irrigation waters [g/L]

Solid residue	CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺
1.140	0.000	0.075	0.09	0.650	0.148	0.082	0.035	0.052

T a b l e 2

Annual average temperature / annual rainfall

Meteorological station	Month												Annual rainfall
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Air temperature [°C]													
Kuva	−2.4	1.1	8.0	16.0	21.2	25.2	26.6	24.6	19.5	19.1	5.5	0.2	13.6
Fergana	−2.4	0.8	7.6	15.6	20.6	25.0	26.9	25.2	19.8	12.8	8.6	0.4	13.7
Kokand	2.4	9.5	7.7	16.1	21.3	25.1	26.8	25.0	19.9	13.0	7.1	0.3	14.5
Precipitation [mm]													
Kuva	20	18	27	19	18	10	5	3	2	12	20	18	172
Fergana	19	23	30	20	17	9	5	2	3	13	22	19	182
Kokand	13	11	17	12	11	7	3	2	1	8	13	11	109

gime is classified as an evaporation one. The water penetration rate into the soil is very high and ranges in about 390–400 mm/min.

Sampling strategy

The soil samples has been taken from 32 sampling plots on the territory of Yazyavan (10 samples), Ulungar (samples 11), and Mingbulak (11 samples) administrative regions of the Central Fergana region. These regions are located in one geochemical province, including all elementary and geochemically sub-ordered areas. The total area of an investigated irrigated land is about 20,000–22,000 ha. Each soil profile has been sampled from 5–6 depths.

Laboratory analyses and methodology

The morphogenetic, comparative-geographical analysis according to V.V. Dokuchaev was used as the primary soil survey approach. The soils were categorized with the WRB international soils classification system (IUSS Working Group WRB 2015). Also, our research is based on the systematic pedo-geochemical methods proposed by Glazovskaya (1974, 1977); Perelman (1989); Bashkin (2008). The fine earth samples were prepared by the crushing of soil mass and passing it through a 2 mm sieve. Soil chemical analyses were performed according to the routine methods normally used in soil science (Arinushkina 1970): total carbon (Tyurin's method), pH (conductometric method). Total nitrogen, phosphorous, and potassium content was determined

according to the Maltseva and Grisenko method (1964). It means, 2 g of fine earth was put into a flask and amended by 5 ml of H_2SO_4 and $HClO_4$ mixture. After 30 min of reaction, the mixture was boiled on the electric stove. The mixture was poured into the measuring flask and passed through the filter. A 2 ml aliquot was taken and poured into a 50 ml flask and further amended by Rochelle's salt. Then the mixture was neutralized by sodium hydroxide, the final solution was used for colour-metrical determination of the oxides with a colouring reagent (Nessler solution.)

The neutron activation method was used for elemental analysis at the Institute of Nuclear Physics, ANRUz (Kuznetsov 1974). The Microelement software was applied for statistical processing using the methodology by Kuziev *et al.* (2004), Kuziev and Sektimenko (2009.) The figures, diagrams, and some mathematics were processed with Macromedia Flash and Microsoft Excel software. On the base of analytical data following indexes have been calculated: Cartledge potential (CP), Clarke concentration (CC), and dissipation factor (DF).

RESULTS AND DISCUSSION

The soil particle size distribution analysis (Table 3) is a critically important feature for the interpretation of salt movement and salinization evolution

Figure 1. Location of the study area and the soil section of the meadow salinized soil. A Google Earth image (Section 7A: 40° 33' 50" N, 71° 43' 21" E; section 6A: 40° 38' 46" N, 71° 43' 10" E; section 8A: 40° 42' 49" N, 71° 41' 15" E).

over time. All the soils showed the essential content of the loess-derived silt fraction: 0.05–0.01 mm, which can confirm the combination of aeolian and fluvial genesis of parent materials. Deeper soil horizons are more clayey textured in comparison with topsoil, which indicates a possibility of the formation of geochemical barriers. The skeletal fraction was not measured; the sand fraction is presented by fine fractions of sand. This indicates a deep degree of exogenous transformation of the soil mineral phase.

In the Central Fergana with desert conditions, with an average high degree of mineralization and weak drainage of saline groundwater, saline soils with a low humus content and C: N ratio is low (Table 4). Total values of organic carbon in fine earth are also low, which is typical for this region (Turdaliev & Yuldashev 2015). Calcaric soils with petrocalcic horizons are formed (Karimov *et al.* 2014). Also some petrocalcic horizons at different depths were revealed. The depth of the hardpan horizons varies at the subsoil in the direction from the south to the north parts of Fergana Valley (Turdaliev & Yuldashev 2015, 2016; Turdaliev *et al.* 2019a, b; Tur-

daliev & Askarov 2019). In the irrigated soils of the Mingbulak region, this depth is about 93–111 cm, and in the Yazyavan region, 32–55 cm, in the Ulugnor region, 18–33 cm. The distribution of hardpan horizons has a mosaic and discontinuous character. The soil texture of these soils is mainly sandy and loamy. A characteristic feature of these soils is a visible absence of humus in the hardpan horizons and cementation (Turdaliev & Yuldashev 2016). Under these conditions, i.e. in arid regions, characterizing by a weak degree of natural drainage, and even a low content of salts in groundwater leads to salt accumulation, hence to soil salinization. Under irrigated conditions, the salt content in irrigation water in the amount of 1–1.5 g/L serves as an additional source of salt accumulating in soils. In this case, salt balance and its quality are disturbed. However, the simple salts affect the energetics state of soils and key physical, chemical, and biogeochemical soil properties. Also, various biogeochemical processes in soils are strongly affected by salts (Komilov & Isakov 1992; Evett *et al.* 2007; Turdaliev *et al.* 2019b; Kenjabaev *et al.* 2020). There is a need to mention that the period of salinization

T a b l e 3

Particle size distribution in the studied soils [%]

Section No.	Depth [cm]	Particle size fractions [mm]							Clay <0.01
		>0.25	0.25–0.1	0.1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	
7A	0–28	3.52	33.80	21.43	8.40	8.26	9.39	15.20	32.85
	28–36	3.60	21.47	19.20	30.77	8.20	5.36	11.40	24.96
	36–93	21.40	15.49	18.10	17.11	7.10	13.10	7.70	27.90
	111–140	11.30	15.20	18.10	15.20	16.90	12.20	11.10	40.20
	200–180	10.27	13.10	25.20	11.33	12.80	13.10	14.20	40.10
6A	0–18	4.02	27.80	19.10	27.11	6.35	5.46	10.16	21.97
	18–32	6.71	19.40	17.20	32.37	5.26	11.26	7.80	24.32
	55–80	22.30	16.10	19.21	18.58	6.14	10.31	7.36	23.81
	80–140	12.10	14.20	15.50	30.70	6.20	10.20	11.10	27.50
	140–200	11.30	14.10	26.20	2.04	14.66	15.80	15.90	46.36
8A	0–18	6.04	28.10	23.15	22.74	6.35	7.41	6.21	19.97
	33–83	7.71	17.10	22.20	31.31	6.41	9.12	7.15	22.68
	83–121	20.10	15.10	20.50	25.74	5.05	7.15	6.36	18.56
	121–157	18.10	13.20	16.48	26.20	6.35	10.31	9.36	26.02
	157–202	11.20	17.20	24.60	12.57	9.60	10.71	14.12	34.43
9A	0–40	4.20	21.48	16.12	17.40	7.10	15.34	18.36	40.80
	40–55	7.10	21.45	21.10	20.07	6.28	14.20	9.80	30.28
	55–89	15.30	19.20	19.20	19.00	5.90	13.10	8.30	27.30
	89–143	13.60	10.15	21.80	31.10	8.80	7.15	7.40	23.35
	143–212	10.20	15.20	17.00	10.18	14.67	13.25	19.50	47.42

harms the growth and yield of wheat in irrigated soils (Francois *et al.* 1994; Stringer *et al.* 2010). By irrigation induced salinization is significant not only for the Central Fergana but for numerous regions of the world (Umali 1993). Our data can be comparable with the data from Egyptian (Ali *et al.* 2001) and Indian researchers (Sajjad *et al.* 1993).

One of the most difficult issues in the study of micro-and macro-elements in soils is the correct diagnostics of material traces of migration, depending on the properties of soils and micro-, macro-elements (Table 5). It can be seen from the above that there is no direct relationship between the ionic radius, the Cartledge potential, and the ordinal number, the ionic radius. Taking into account their properties in our soils the studied elements have the following distribution series:

$$\frac{\text{Fe}}{2.19} > \frac{\text{Ca}}{2.05} > \frac{\text{K}}{1.48} > \frac{\text{Mg}}{1.0} > \frac{\text{Na}}{0.96} > \frac{\text{Sr}}{0.39} > \frac{\text{Ba}}{0.1} > \frac{\text{Rb}}{0.008}$$

and comprise the background concentrations for soils mentioned.

It was shown that the elements pairs Na-Mg, Ca-Fe, Ba-Sr, Na-Ca, Mg-Fe, Rb-Ba, and Na-Fe can be correlated with each other, that is why they could be considered as paragenetic elements (Table 6), thus their accumulation and relocation within horizons are connected.

It should be emphasized that the correlation coefficients between the Cartledge potentials

and average content of elements Na^+ , Mg^{2+} , K^+ , Ca^{2+} , Fe^{3+} , Rb^+ , Sr^{2+} , Ba^{2+} is moderate positive = (0.46). The Clarke contents of these elements in profile 6A depend on their properties and form the following series: $\text{Fe} > \text{Na} > \text{K} > \text{Rb} > \text{Mg} > \text{Ca} > \text{Ba} > \text{Sr}$. The difference in the radial distribution of elements between the petrocalcic horizons and the solums (without petrocalcic features) are following: $\text{Sr} > \text{Mg} > \text{Ca} > \text{Na} > \text{K} > \text{Rb} > \text{Fe} > \text{Ba}$ (for section 6A), $\text{Rb} > \text{Fe} > \text{Ba} > \text{Na} > \text{Sr} > \text{Mg} > \text{K} > \text{Ca}$ (for in profile 9A – without petrocalcic features). The geochemical distribution of elements in the soil and petrocalcic, deep horizons are presented in the Figure 2.

The background content of these trace elements are as follows:

$$\frac{\text{Ni}}{144.12} > \frac{\text{Cr}}{46.5} > \frac{\text{As}}{11.32} > \frac{\text{Co}}{8.25} > \frac{\text{Sc}}{7.3} > \frac{\text{Cs}}{6.39} > \frac{\text{Sb}}{4.27} > \frac{\text{Hf}}{3.8} > \frac{\text{W}}{2.98} > \frac{\text{Br,Ta}}{0.91-0.92} > \frac{\text{Cd}}{0.56} > \frac{\text{Hg}}{0.28} > \frac{\text{Au}}{0.0012}$$

Between some of these elements, such as Sc and Cr, Cs and Hf, Cd and Sb, Co and Ni are positive correlation ($r = 0.5-0.97$). There are observed inversed relations between As and Ba, Ta and Hg contents ($r = 0.11-0.25$). The Clarke concentrations and scattering of these elements are related to their background content.

In the radial geochemical distribution of the studied elements, the general regularity in soils and petrocalcic horizons is preserved, with some exceptions (Figures 3–6). Deviations from the general

Figure 2. Section 6A – Geochemical distribution of the trace elements content in the petrocalcic hardpan horizons

pattern are typical for W, Br, Mo, Hg, Ta, Ni, Cr, Co, Au, Sc, As, Cs in the petrocalcic horizon of section 6A, where KK is greater than unity. The migration of lanthanides and radioactive elements has a special character. The valence and ionic radius are close according to these indices of the Cartledge potential. Their valence is mainly 3+, and their ionic radii fluctuate in the range 0.88–1.08 Å, the Cartledge potential is 2.14–4.54.

Background concentrations in the soils investigated 10–4%:

$$\frac{\text{La}}{30.43} > \frac{\text{Ce}}{43.12} > \frac{\text{Nd}}{18.36} > \frac{\text{Sm}}{3.79} > \frac{\text{Eu}}{0.81} > \frac{\text{Tb}}{0.45} > \frac{\text{Yb}}{1.83} > \frac{\text{Lu}}{0.20} > \frac{\text{Th}}{12.4} > \frac{\text{U}}{0.49}$$

Cartledge potential (CP):

$$\frac{\text{La}}{2.14} > \frac{\text{Ce}}{2.94} > \frac{\text{Nd}}{3.03} > \frac{\text{Sm, Eu}}{3.09} > \frac{\text{Tb}}{3.37} > \frac{\text{Yb}}{3.7} > \frac{\text{Lu}}{3.75} > \frac{\text{Th}}{2.78} > \frac{\text{U}}{2.88}$$

Clarke concentrations (CC) and dissipation factor (DF) are dependent on background concentrations

Section 6A, 32–55 cm, DF:

$$\frac{\text{Lu}}{1.81} > \frac{\text{Nd}}{1.51} > \frac{\text{Tb}}{1.48} > \frac{\text{Sm}}{1.36} > \frac{\text{Eu}}{1.33} > \frac{\text{La}}{1.24} > \frac{\text{Ce, Th}}{1.22} > \frac{\text{U}}{1.19} > \frac{\text{Yb}}{1.12};$$

Section 7A, 93–111 cm, DF:

$$\frac{\text{U}}{2.12} > \frac{\text{Eu}}{1.58} > \frac{\text{La}}{0.93} > \frac{\text{Tb}}{0.84} > \frac{\text{Yb}}{0.51} > \frac{\text{Ce}}{0.48} > \frac{\text{Lu}}{0.47} > \frac{\text{Sm}}{0.44} > \frac{\text{Th}}{0.42} > \frac{\text{Nd}}{0.38};$$

Section 8A, 18–33 cm, DF:

$$\frac{\text{Th}}{2.03} > \frac{\text{Eu}}{1.7} > \frac{\text{U}}{1.57} > \frac{\text{La}}{1.53} > \frac{\text{Lu}}{1.50} > \frac{\text{Sm}}{1.42} > \frac{\text{Nd}}{1.39} > \frac{\text{Tb}}{1.37} > \frac{\text{Ce}}{1.36} > \frac{\text{Yb}}{1.14}.$$

The law correlation between the background contents in the hardpan and other soil horizons and the Cartledge potentials ($R = -0.63$), this is obviously

T a b l e 4

Key chemical properties of the studied soils

Section No.	Depth [cm]	pH	TOC [%]	TN [%]	C:N
7A	0–28	7.2	0.71	0.135	5.26
	28–36	7.3	0.64	0.127	5.04
	36–93	7.3	0.24	0.055	4.36
	93–111	7.4	0.14	nd	nd
	111–140	7.6	0.19	0.031	6.13
	140–180	7.6	0.12	0.025	4.80
6A	0–18	7.4	0.54	0.110	4.90
	18–32	7.4	0.42	0.089	4.71
	32–55	7.5	0.05	nd	nd
	55–80	7.6	0.16	0.035	4.57
	80–140	7.5	0.15	0.021	7.14
	140–200	7.4	0.12	0.019	6.31
8A	0–18	7.3	0.47	0.095	4.94
	18–33	7.3	0.05	nd	nd
	33–83	7.4	0.36	0.071	5.07
	83–121	7.4	0.18	0.035	5.14
	121–157	7.5	0.17	0.035	4.86
	157–202	7.6	0.13	0.019	6.84
9A	0–40	7.2	0.88	0.179	4.19
	40–55	7.3	0.75	0.155	4.84
	55–89	7.4	0.36	0.071	5.07
	89–143	7.4	0.18	0.040	4.50
	143–212	7.6	0.12	0.027	4.44

Note: TOC – total organic carbon; TN – total nitrogen

because the lanthanides are included in the group of trace elements. In the hardpan horizons of soils, the distributions of Ca and Cr have the same character, except for La and Ce, as well as U and Sm, which in

T a b l e 5

Chemical and geochemical features of the elements analyzed

Chemical element	Na	Mg	K	Ca	Fe	Rb	Sr	Ba
Ordinal number	11	12	19	20	26	37	38	56
Atomic mass	23	24.3	39	40	56	85.5	87.6	137
Valence	1+	2+	1+	2+	2+	1+	2+	2+
Ion radius Å	0.98	0.74	1.33	1.04	0.80	1.43	1.20	1.38
Cartledge potential	1.02	2.70	0.75	1.92	2.50	0.70	1.67	1.45
Energy constant	0.45	2.10	0.36	1.75	1.125	0.30	1.53	1.35
Energy share in the crystal structures	482.28	2,250.65	385.83	1,875.54	1,205.71	321.71	1,639.76	1,446.85

Figure 3. Section 7A – Geochemical distribution of the radial migration coefficients for the trace elements (CD – Clark distribution)

T a b l e 6

Correlation coefficients between the cation contents

Mx [%]	Mi [%]	Average error $\pm m$	Square deviation, $\pm \delta$	Confidence level, p [%]	Variation coefficient, v [%]	Number of samples n	Correlation coefficient r
Na and Mg							
0.96	1.0	6.69	0.32	6.97	33.44	32	0.72
Ca and Fe							
2.05	2.19	1.88	0.90	9.29	44.54	32	0.47
Ba and Sr							
0.39	0.10	9.65	0.46	24.61	118.04	32	0.23
Na and Ca							
0.43	0.52	8.41	0.15	12.56	85.01	32	0.63
Mg-Fe							
0.25	0.37	9.24	0.35	11.41	95.21	32	0.53
Rb-Ba							
0.81	0.75	2.69	0.75	7.24	75.12	32	0.67
Na-Fe							
0.43	0.37	1.32	0.41	3.21	56.12	32	0.67

Note: Mx – maximal rate; Mi – minimal rate; m – average error; δ – square deviation; p – confidence level; v – variation coefficient; n – number of samples; r – correlation coefficient

some cases stand out from the rest.

The pedogeochemical barriers in the soil and hardpan horizons of the studied soils are presented in the Figure 7. The accumulation and migration of elements in the petrocalcic horizons of irrigated meadow soils in the Central Fergana can serve as a model for similar desert soils (Turdaliev & Yuldashev 2015).

The scheme of salt sedimentation in evaporation barriers coincides with the depths of 0–28, 0–18, 0–33 cm, which can be schematically represented (Figure 8).

In these barriers: petrocalcic and gypsum-carbonate Clarke concentration of elements has the following distribution pattern. Section 8A, depth 18–33 cm. Trace elements CC:

$$\frac{\text{Sb}}{34.5} > \frac{\text{As}}{11.12} > \frac{\text{Cs}}{9.4} > \frac{\text{W}}{8.07} > \frac{\text{Cd}}{6.61} > \frac{\text{Ni}}{4.82} > \frac{\text{Hf}}{3.26} > \frac{\text{Au}}{3.25} > \frac{\text{Hg}}{1.25} > \frac{\text{Co}}{1.0} > \frac{\text{Sc}}{0.98} > \frac{\text{Cr, Ta}}{0.95} > \frac{\text{Br}}{0.49}$$

Lanthanides and radionuclides CC:

$$\frac{\text{Yb}}{7.57} > \frac{\text{U}}{2.76} > \frac{\text{Th}}{2.22} > \frac{\text{La}}{2.0} > \frac{\text{Eu}}{1.31} > \frac{\text{Nd}}{1.05} > \frac{\text{Ce}}{0.97} > \frac{\text{Sm}}{0.85} > \frac{\text{Lu}}{0.49} > \frac{\text{Tb}}{0.17}$$

If we compare the petrocalcic and petrogypsic horizons and oxidative barriers in them, the

Figure 4. Section 6A – Geochemical distribution of the radial migration coefficients for the trace elements
Note: CD – see Figure 3

Figure 5. Section 8A – Geochemical distribution of the radial migration coefficients for the trace elements
Note: CD – see Figure 3

following differences can be easily detected. Section 7A, depth 140–200 cm (oxidative barrier).

Macro-elements CC:

$$\frac{\text{Sr}}{7.94} > \frac{\text{Ca}}{0.63} > \frac{\text{Rb}}{0.53} > \frac{\text{K}}{0.46} > \frac{\text{Fe}}{0.40} > \frac{\text{Na}}{0.28} > \frac{\text{Mg}}{0.27} > \frac{\text{Ba}}{0.15}$$

Micro-elements KK:

$$\frac{\text{Sb}}{11.5} > \frac{\text{As}}{6.12} > \frac{\text{Cs}}{6.0} > \frac{\text{Cd}}{2.92} > \frac{\text{Ni}}{2.76} > \frac{\text{W}}{2.2} > \frac{\text{Br}}{1.86} > \frac{\text{Hg}}{1.25} > \frac{\text{Au}}{0.8} > \frac{\text{Hf}}{0.73} > \frac{\text{Sc}}{0.70} > \frac{\text{Cr}}{0.61} > \frac{\text{Co}}{0.50} > \frac{\text{Ta}}{0.25}$$

Lanthanides and radionuclides CC:

$$\frac{\text{U}}{6.6} > \frac{\text{Yb}}{4.54} > \frac{\text{La}}{0.72} > \frac{\text{Th}}{0.68} > \frac{\text{Ce}}{0.60} > \frac{\text{Nd}}{0.51} > \frac{\text{Eu}}{0.44} > \frac{\text{Sm}}{0.34} > \frac{\text{Lu}}{0.18} > \frac{\text{Tb}}{0.07}$$

Section 6A, depth 140–200 cm, (oxidative barrier), macro-elements CC:

$$\frac{\text{Sr}}{8.82} > \frac{\text{Ba}}{1.54} > \frac{\text{Ca}}{0.58} > \frac{\text{Fe}}{0.50} > \frac{\text{Rb}}{0.47} > \frac{\text{K}}{0.46} > \frac{\text{Mg}}{0.30} > \frac{\text{Na}}{0.28}$$

Microelements CC:

$$\frac{\text{Sb}}{14.0} > \frac{\text{Hg}}{13.75} > \frac{\text{As}}{7.82} > \frac{\text{Cs}}{6.2} > \frac{\text{Cd}}{3.15} > \frac{\text{Ni}}{2.41} > \frac{\text{Au}}{1.62} > \frac{\text{Br}}{1.05} > \frac{\text{Hf}}{0.9} > \frac{\text{W}}{0.67} > \frac{\text{Sc}}{0.60} > \frac{\text{Cr}}{0.43} > \frac{\text{Co}}{0.37} > \frac{\text{Ta}}{0.32}$$

Lanthanides and radionuclides CC:

$$\frac{\text{Yb}}{5.15} > \frac{\text{U}}{1.48} > \frac{\text{Ce}}{1.01} > \frac{\text{La}}{0.80} > \frac{\text{Th}}{0.68} > \frac{\text{Eu}}{0.5} > \frac{\text{Nd}}{0.44} > \frac{\text{Sm}}{0.35} > \frac{\text{Lu}}{0.20} > \frac{\text{Tb}}{0.07}$$

Section 8A, depth 157–202 cm, (oxidative barrier), macro-elements CC:

$$\frac{\text{Sr}}{2.35} > \frac{\text{Ba}}{1.50} > \frac{\text{Rb}}{0.67} > \frac{\text{Ca}}{0.61} > \frac{\text{K}}{0.56} > \frac{\text{Mg, Fe}}{0.41} > \frac{\text{Na}}{0.33}$$

Microelements CC:

$$\frac{\text{Sb}}{13.5} > \frac{\text{Cs}}{9.3} > \frac{\text{As}}{7.41} > \frac{\text{Ni}}{3.96} > \frac{\text{Cd}}{3.85} > \frac{\text{Br}}{2.08} > \frac{\text{Au}}{1.57} > \frac{\text{Hf}}{1.37} > \frac{\text{Hg}}{1.25} > \frac{\text{Sc}}{1.1} > \frac{\text{Cr}}{0.78} > \frac{\text{Co, W}}{0.67} > \frac{\text{Ta}}{0.45}$$

Lanthanides and radionuclides CC:

$$\frac{\text{Yb}}{6.67} > \frac{\text{U}}{1.76} > \frac{\text{La}}{1.31} > \frac{\text{Th}}{1.09} > \frac{\text{Eu}}{0.77} > \frac{\text{Nd}}{0.75} > \frac{\text{Ce}}{0.65} > \frac{\text{Sm}}{0.60} > \frac{\text{Lu}}{0.34} > \frac{\text{Tb}}{0.13}$$

Figure 6. Section 9A – Geochemical distribution of the radial migration coefficients for the trace elements
Note: CD – see Figure 3

Figure 7. A soil profile diagram of the geochemical barriers (F_1 – pedogeochemical barriers; F – evaporation; S-Ca – Arzyk-Shokh; Ca-S – Shokh-Arzyk; Ca – carbonate; Ca_1 – low carbonate; A – aerobic; C_1 – gleyic)
Legend: An – arable horizon; Π_1 – hardpan, Arzyk-Shokh; Π_{II} – hardpan, Shokh-Arzyk; B – calcaric horizons; C – alluvial-proluvial sediments, parent materials

Figure 8. Structure of the evaporation barriers in desert soils (Continuous line (————) designate the barrier; double points (: :: :: :: ::) designate the dynamic area of soil gravimetric water; slate lines (////////) designate the evaporation barriers, located at various soil depths; A,B,C – soil horizons)

Presented data confirm that the pedogeochemical provinces are directly related to the properties of geochemical barriers. For example, in the salinized horizons of section 7a in S-Ca barriers Sr, Ba, Rb, as well as Sb, As, Cd, Cs, Br, Hg and lanthanides and radionuclides Yb, U indicate their provinces with increased Clarke contents. Almost all investigated soil horizons contain pedogeochemical provinces for Sr, Cs, Ba, Sb, As, Yb, U, and other elements.

The high indices of the province are typical for the horizon of 18–33 cm, where the provinces of Sr, Ba, Ca, Mg, Sb, As, Cs, W, Cd, Ni, Hf, Au, Hg are observed. In addition to these cases, there are provinces with a high content of Yb, U, Th, La, Eu, Nd.

It can be result from the above findings that the provinces with increased content of several chemical elements are associated with the barrier properties of petrocalcic horizons. Pedogeochemical provinces are also located depending on the location of the barriers. Provinces with increased Sr, Sb, Ba, Yb, U contents can be observed in all studied barriers.

CONCLUSIONS

Our findings show that the fluxes of chemical elements and their compounds are connecting to all studied genetic soil horizons, as well as hardpan horizons and elementary areas, and create a single geochemical area. These fluxes represent an integral

system of interdependent chemical, biogeochemical cycles of the studied elements. The processes of accumulation, migration and differentiation of chemical elements in the soil and hardpan's horizons and parent materials occur simultaneously in mutual interaction of pedogenic, exogenous, endopedogenic, and artificial factors. These fluxes of elements, in turn, affect the nature of the substrate, i.e. soils, hardpans, and parent materials.

Various evapo-crustic horizons of irrigated seasonally over-moistened soils and their genetic horizons (hardpans of various kinds) were investigated. These horizons resulted from long-term irrigation activities and various agricultural practices. They are gradually losing their basic properties and demonstrate intensive and harmful degradation. The close chemical composition and Clarke concentration, accumulation, differentiation in evapo-crustic horizons at the depths of 93–111 cm, 32–55 cm, 18–33 cm indicates similar genesis of these horizons. The scattering and accumulation of chemical elements in the blocks of elementary areas depend, along with the properties of the area, on the properties of the elements themselves. In the studied soils, with an increase in the atomic mass and charge of elements, their scattering decreases, therefore, their accumulation increases.

For soils investigated and for petrogypsic horizons, the content of macro-nutrients Na, Mg, K, Ca, Fe, Rb, Sr, Ba and trace elements Sc, Cr, Co, Ni,

As, Br, Cd, Sb, Cs, Hf, Ta, W, Au, Hg, lanthanides and radioactive elements La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Th, U could be considered as background concentration. Taking into account the depth of the hardpan horizons and background content of chemical elements, crops should be cultivated. It is also recommended to consider the presence of the hardpan horizons zone in relation to remove the excess water-soluble salts from the soil layer.

Acknowledgements. This study is a part of V. Agriculture, Biotechnology, Ecology, and Environmental Protection initiative for the priority development of science and technology in the Republic of Uzbekistan. The work is part of the projects of Fergana State University A-7-455 Study of Genetic and Geographical Patterns of irrigated Soils Formation in the Fergana Region, Land Resources and Diagnostics (2006–2008), (2009–2011), FSH 07-011 Improving the irrigated Soils Fertility in the Fergana Valley (2013–2020.) This paper is supported by the Ministry of Science and University Education of the Russian Federation under agreement No. 075-15-2020-922 dated 16.11.2020 for providing a Russian federal grant. The grant is intended to provide national support for the establishment and development of the Agro-technologies for the Future World-class Research Centre.

REFERENCES

- Ali, A.M., Van Leeuwen, H.M. and Koopmans, R.K. (2001). Benefits of draining agricultural land in Egypt: Results of five years' monitoring of drainage effects and impacts. *International Journal of Water Resources Development*, 17(4), 633–646. DOI:10.1080/07900620120094136.
- Arboev, T.C., Kaldybayev, B.K. and Abdylbaev, K.K. (2019). Ecologic-biogeochemical studies of soil and vegetation cover of high mountain areas of the Sary-jazz river basin. In *News of Universities of Kyrgyzstan*, no. 9, 33–36.
- Arinushkina, E.V. (1970). *Guidance on chemical analysis of soils*. Moscow: MGU, 488 p.
- Artamonova, E.N., Evlampieva, E.P. and Kasymova, J.S. (2014). Ecological and geochemical assessment of soil cover of man-made territories of north-east of Kazakhstan. *Journal of Basic Research*, no. 9 (part. 4), 789–793.
- Baishenova, A.E. and Kedelbaev, B.Sh. (2016). Problems of soil degradation. Analysis of the current state of fertility of irrigated soils of the Republic of Kazakhstan. *Journal of Scientific Review. Biological Sciences*, no. 2, 5–13.
- Bashkin, V.N. (2008). *Biogeochemistry*. Moscow: Higher school, 585 p.
- Belousov, M.N. (1977). *Methods of agrochemical, agrophysical and microbiological surveys in irrigated regions*. Tashkent: SOUZNII XI, 137 p.
- Besedin, P.N. (1981). Peculiarities of soil salinity in Central Fergana. *Sat scientific works. Distribution and movement of salts in irrigated soils and methods of regulation of salt processes* Moscow, pp. 9–21.
- Dubrovsky, N.G., Ondor, S.O. and Ochur-Ool, A.O. (2007). Biogeochemical characteristic of the soils of the Kemchik basin. *Electronic Scientific Journal Modern Problems of Science and Education*, no. 12 (Part 1), 146–148.
- Evett, S., Ibragimov, N., Kamilov, B., Esanbekov, Yu., Sarimsakov, M., Shadmanov, J., Mirhashimov, R., Musaev, R., Radjabov, T. and Muhammadiyev, B. (2007). Neutron moisture meter calibration in six Soils of Uzbekistan affected by carbonate accumulation. *Vadose Zone Journal*, 6(2), 406–412.
- Francois, L.E., Grieve, C.M., Maas, E.V. and Lesch, S.M. (1994). Time of salt stress affects growth and yield components of irrigated wheat. *Agronomy Journal*, 86(1), 100–107.
- Glazovskaya, M.A. 1974. *Actual problems of theory and practice of terrain geochemistry*. Moscow: Bulletin of Moscow State University MGU, 26 p.
- Glazovskaya, M.A. 1977. *Methodology and technique of soil and terrain-geochemical research*. Moscow: Moscow State University, 188 p.
- Isakov, V.Y. 1982. Distribution and agronomic properties of Shokh and Arzyk (Hardpan) soils of the Fergana depression in Uzbekistan. *Soviet Soil Science*, 14(6), 19–27.
- Djenbaev, B.M. and Imatali, K.K. 2016. Modern ecological biogeochemical state of the mercury province of Aiderken (Haidarkan, Kyrgyzstan) (Russian). *Universum: Chemistry and Biology* (Electronic scientific journal), no. 1–2 (20). Available at: URL: <http://7universum.com/ru/nature/archive/item/2909>.
- Djenbaev, B.M. and Mursaliev, A.M. (2012). Biogeochemistry of natural and man-made ecosystems of Kyrgyzstan. *Bishkek Ilim Publishing House*, 404 p.
- Karimov, A.Kh., Šimůnek, J., Hanjra, M.A., Avliyakov, M. and Forkutsa, I. (2014). Effects of the shallow water table on water use of winter wheat and ecosystem health: Implications for unlocking the potential of groundwater in the Fergana Valley (Central Asia). *Agricultural Water Management*, 131, 57–69. DOI:10.1016/j.agwat.2013.09.010.
- Kenjabayev, S., Frede, H.G., Begmatov, I., Isaev, S. and Matyakubov, B. (2020). Determination of actual crop evapotranspiration (ETC) and dual crop coefficients (KC) for cotton, wheat and maize in Fergana Valley: Integration of the FAO-56 approach and budget. *Journal of Critical Reviews*, 7(5), 340–349.
- Komilov, O.K. and Isakov, V.Y. (1992). *Genesis and properties of carbonated-gypsum soils in Central Fergana*. Tashkent: FAN, 107 p.
- Kulikov, M., Schickhoff, U., Gröngroft, A. and Borchardt, P. (2020). Modelling soil erodibility in mountain rangelands of southern Kyrgyzstan. *Pedosphere*, 30(4), 443–456.
- Kuziev, R.K. and Sektimenko, V.E. (2009). *Soils of Uzbekistan*. Tashkent: Extremum Press, 351 p.
- Kuziev, R.K., Yuldashev, G.Yu., and Akramov, I.A. (2004). *Bonitization of soils*. Tashkent: Science and technology, 127 p.
- Kuznetsov, R.A. (1974). *Activation analysis*. Moscow: Atomizdat, 344 p.
- Maltseva I.I. and Grytsenko L.P. (1963). Determination of the bulk nitrogen, phosphorous and potassium in one sample. Methods of agrochemical, agrophysical and microbiological investigations in irrigated cotton zones. Tashkent, 142–144.
- Mirzazhanov, K.M., Paganyas, K.P. and Kamilov, B.S. (1993).

- Soil formation on the sands of Central Fergana. *Eurasian Soil Science*, 25(10), 101–104.
- Orlov, D.S. and Bezuglova, O.S. (2000). *Biogeochemistry*. Moscow: Phoenix, 76 p.
- Pankov, M.A. (1957). *Soils of the Fergana region*. Tashkent: FAN, 53 p.
- Perelman, A.I. (1989). *Terrain geochemistry*. Moscow: Higher school, 419 p.
- Sajjad, I.M., Hussain, Ds., Tasneem, A., Ahmad, M., Akram, W. and Khan, I.H. (1993). Isotopic evidence of the source of groundwater salinity in the Indus Basin, Pakistan. *Science of the Total Environment*, 129(3), 311–318.
- Smalley, I.J., Mavlyanova, N.G., Rakhmatullaev, Kh.L., Sher-matov, M.Sh., Machalett, B., Dhand, K. O'Hara and Jef-ferson I.F. (2006). The formation of loess deposits in the Tashkent region and parts of Central Asia; and problems with irrigation, hydrocollapse, and soil erosion. *Quater-nary International*, 152–153, 59–69. DOI:10.1016/j.quaint.2005.12.002.
- Stringer, C.E., Rains, M.C., Kruse, S. and Whigham, D. (2010). Controls on water levels and salinity in a barrier island mangrove, Indian River Lagoon, Florida. *Wetlands*, 30(4), 725–734.
- Stulina, G., Cameira, M.R. and Pereira L.S. (2005). Using RZWQM to search improved practices for irrigated maize in Fergana, Uzbekistan. *Agricultural Water Management*, 77 (1–3), 263–281. DOI: 10.1016/j.agwat.2004.09.040.
- Turdaliev, A.T. and Askarov, K.A. (2019). Energy characteris-tics of trace elements in saline soils of Central Fergana. *Ac-tual Problems of Modern Science*, no. 6, pp. 83–87. DOI: 10.25633/APS.N.2019.06.04.
- Turdaliev, A.T., Askarov, K.A. and Mirzaev, F.A. (2019a). Mor-phological features of irrigated soils in Central Fergana. *Soils and Environment*, 2(3), 56–61. DOI:10.31251/pos.v2i3.71.
- Turdaliev, A.T., Askarov, K.A., Zhalilova, Sh.A., Gulomova, Z.A. and Musaev, I.I. (2019b). Physicochemical, geochemi-cal features and their influence on the soil-ecological state of hydromorphic soils. *Scientific Review. Biological Sciences*, 4, 44–49. DOI:10.17513/srbs.1171.
- Turdaliev, A.T. and Yuldashev, G. (2015). *Geochemistry of Pe-dolithic Soils*. Tashkent: FAN, 200 p.
- Turdaliev, A.T. and Yuldashev, G. (2016). Morphological fea-tures of pedolytical soils in Central Ferghana. *European Science Review*, no. 5–6, 14–15.
- Umali, D.L. (1993). Irrigation-induced salinity: a growing problem for development and the environment. *World Bank Technical Paper*, 215, pp. 78.
- IUSS Working Group WRB (2015). *World Reference Base for Soil Resources 2014, update 2015: International soil clas-sification system for naming soils and creating legends for soil maps*. World Soil Resources Reports, No. 106, FAO: Rome.
- Yuldashev, G., Kholdarova, M., Isagaliev, M., Turdaliev, A. and Sotiboldieva, G. 2013. Agrochemical properties of dif-ficult-to-reclaim soils in Fergana. *Agrarian Bulletin of the Urals*, 3(109), 16–17.

Received: November 3, 2020

Accepted: April 20, 2021