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Ecological and melioration state of irrigated sierozem soils of the territory of Nurabod district, Uzbekistan

Khusniddin N. Karimov[1], Zafar Z. Uzakov[2*], Jobir P. Khushmurodov[3], Dilafruz A. Mallaeva[4] and Nodir S. Abdurazzakov[1]

[1] *Scientific-Research Institute of Horticulture, Viticulture and Winemaking named after Academician M. Mirzaev, Tashkent, Uzbekistan*
[2] *Department of Ecology and Environmental Protection, Faculty of Irrigation melioration, Karshi State Technical University, Karshi, Uzbekistan*
[3] *Department of Agronomy and Ecology, Faculty of Geography and Agronomy, Karshi State University, Karshi, Uzbekistan*
[4] *Institute of Soil Science and Agrochemical Research, Tashkent, Uzbekistan*
[*] *Corresponding author:* uzakovzafar40@gmail.com

Abstract

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The article presents research on the study of the agrochemical and salt state of irrigated sierozem soils, the accumulation of mobile heavy metals in soil layers. The granulometric composition of the irrigated light sierozem soils was found to consist of light loam in the 50–80 cm layer, including the plow layer (Ap horizon) and underlying subsoil, while the deeper layers contained medium loam, with a pH ranging from 7.06 to 7.67. Chromium element is 40.55–12.61 mg/kg in the layer of 0–30 cm, 33.46–15.0 mg/kg in the plowed soil, it is 4.45 times higher than MPC (Maximum Permissible Concentration) in the soil layers. Copper in the soil is 6.09–4.71 mg/kg in the 0–30 cm layer, 1.57 → 1.62 → 1.77 → 1.83 → 1.94 → 1.94 → 2.03 times higher than MPC, it was found that it increased to 5.29–6.08 mg/kg in the 100–150 cm and 150–200 cm layers towards the lower layer. The third element polluting the soil composition is cadmium, which is up to 1.92 times higher than MPC in the 100 cm and 150–200 cm layers of the soil. The amount of lead is also higher towards the lower layers of the soil up to 9.62–10.71 mg/kg, which is 1.60–1.79 times higher than MPC. It was determined that the soil composition was not affected by cobalt, nickel and zinc elements.

Keywords: light sierozem soil; heavy metals; soil contamination; Maximum Permissible Concentration (MPC); accumulation; toxic elements

Introduction

In the contemporary period, anthropogenic environmental factors pose a significant threat to ecosystem stability, primarily through the degradation of soil health and the subsequent contamination of agricultural products. To address these challenges, it is essential to evaluate the ecological health of agricultural lands across the Republic, with a focus on identifying degraded zones. Creating ecological maps of areas affected by toxicants is a vital step toward restoring soil fertility and ensuring the production of safe, eco-friendly crops. These assessments must translate into practical strate-

gies that not only improve land quality but also guarantee that agricultural products consistently meet high environmental and safety standards.

Soils are crucial for human health (Zhu et al., 2019). However, population growth and rising food demand have intensified agricultural production, resulting in soil stress and greater human exposure to soil pollutants (Karimyan et al., 2020). The relationship between soil health and human health is becoming more apparent (Steffan et al., 2017), and is gaining attention in scientific research (Brevik et al., 2015). Heavy metals (HM), long-standing pollutants in agricultural soils, are of particular concern (Brevik et al., 2020). The term "heavy metals" refers to a group of metals (e.g., Cd, Co, Hg, Pb) and metalloids (e.g., Se, Sb, As) characterized by an atomic number typically greater than 20 and a density exceeding 5 g/cm³ (Duffus, 2002; Zhu et al., 2019). This term is often associated with pollution and potential toxicity or ecotoxicity (Duffus, 2002; Qin et al., 2021).

Naturally, HMs are found in low concentrations in soil, and some of them are important trace elements for plants, animals and humans (for example, Fe, Zn, Ni, Cu, Mn) (Balseiro and Baveye 2018). However, high concentrations of HM in soil as a result of various agricultural fertilization practices can lead to toxic effects. In addition, they can be inhaled along with soil particles or absorbed through the skin in certain situations or at high concentrations. There is evidence linking mutagenic, teratogenic, and carcinogenic effects in humans to exposure to HM (Demková et al., 2017; Sanaei et al., 2020).

When the total content and mobile forms of Cu, Mn, Pb, and Zn were determined in soil samples collected along the main boulevards of Plovdiv (Bulgaria), the mobile forms of magnesium were found to be 1.38–2.21% of the total content, and the mobile forms of zinc were 8.48–11.81%. Mobile form of copper and lead increased significantly, overall content (Nikolov et al., 2020).

In 90%, 28%, 83%, and 63% of the samples, the concentrations of Ni, Pb, Cd, and Cr in the edible parts exceeded the safe limits, respectively. The levels of heavy metals in the edible parts were found in the following order: Cr > Zn > Ni > Cd > Mn > Pb > Cu > Fe. The Health Risk Index (HRI) greater than 1 indicates a potential health hazard (Balkhair and Ashraf, 2016).

Research on the processes involving the transport and redistribution of heavy metals (Page and Feller, 2015) in plants, as well as the input and output of heavy metals (Shi et al., 2018) to agricultural soils, smart sensing for monitoring heavy metals (Hejna et al., 2019) in agricultural soils, and the toxicity of heavy metals (Alengebawy et al., 2021) in agricultural soils, along with the assessment of heavy metal levels (Xiao et al., 2021) in agricultural lands, is underway by Page and colleagues. To prevent the accumulation of heavy metals in plants, efforts should focus on agrotechnological approaches, such as selectively planting species inversely proportional to the prevalence of toxic elements (Uzakov et al., 2023).

As a result of selective planting of plants in contaminated soils, it is possible to reduce heavy metal bioaccumulation and prevent poisoning from agricultural products. This situation was considered by scientists in the scientific research conducted on leguminous crops (Khushmurodov and Karimov, 2024).

It was established that in the variants where agricultural measures were carried out, according to the serial number of sowing, the element chromium was removed in the amount of 25.7 → 29.4 → 28.6 mg/kg. In the initial soil variant, the Ni content was 29.0 mg/kg, however, in variant 2, where agrotechnical measures were carried out, it was found that the most accumulated heavy metal in the plant is Ni. 29.7 mg/kg during the first sowing period, 35.6 mg/kg during the second sowing period and an increase to 39.3 mg/kg during the third sowing period shows that this element participates in soil cleansing more positively than from all other toxicants (Uzakov et al., 2024).

Light sierozem soils of "Sirojiddin dalasidagi chorvo" farm located in Nurabad district of Samarkand region was selected as an object, and a total number of 7 main and 12 additional samples were taken. During the process, average chemical analyses were conducted on layers up to 100 cm deep in both the main and additional samples. Throughout the study, toxic elements such as chromium (Cr), nickel (Ni), cadmium (Cd), cobalt (Co), lead (Pb), zinc (Zn), and copper (Cu) were identified.

Materials and Methods

Researches were conducted in field and laboratory conditions. Soil samples were taken from layers 0–30, 30–50, 50–80, 80–100, 100–150, 150–200 cm using the methodological manual "Methodological recommendations for the reclamation of solonetz soils and the recording of saline soils" (Pankova, 1970; Ministry of Agriculture, 1985). Additionally, the methodological manual "Agrochemical methods of studying soils, plants and fertilizers" (Spirina and Solovyova, 2014) was used. The content of humus was determined by Tyurin's method (GOST 26213-91), total nitrogen by the Kjeldahl method (GOST 26107-84), and total phosphorus and potassium by Ginzburg's and Smith's methods (GOST 26261-84). Ammonium nitrogen was measured photometrically with Nessler's reagent (PND F 14.1:2:3.1-95), while

available phosphorus and potassium were determined by the Machigin method (GOST 26205-91). The evaluation of soil fertility indicators was performed according to the regional guidelines by Toshkuziyev (2006). Potassium was analyzed using flame photometric chromatography, while macro- and microelements were extracted from 5 grams of soil, left overnight in 50 ml of 1N nitric acid (Kuznetsov et al., 1992). The prepared aqueous extract was tested on the AVIO-200. The statistical analysis of the received data was performed using the STDEV.S function in Microsoft Excel, which estimates the standard deviation of the sample. The standard deviation serves as a measure of how widely spread the data points are in relation to the mean.

Results and Discussion

The mechanical composition of the studied soils consists of light and medium loams, with a physical clay content ranging from 20.9% to 43.3% (< 0.01 mm). These soils are characterized by a higher proportion of coarse clay fractions (0.05–0.01 mm) (Table 1).

Their composition (excluding individual horizons) ranges from 50.0–55.8% to 61.2–69.9% in the upper two-meter soil layer. The medium dust fraction (0.01–0.005 mm) ranks second in abundance, comprising 10.1–32.4%.

The soils in the studied samples consist of light and medium loams with a uniform lithological structure (sample 19) in terms of mechanical composition. The proportion of physical clay particles (< 0.01 mm) ranges from 28.9% to 39.0%.

Soils vary in their silt particle content (< 0.001 mm), which generally ranges from 11.45% to 25.7%. In certain sections, a higher concentration of clay particles (1.0–2.7%) is observed, while in others, the content is as low as 0.1–0.2%, and in some cases, clay particles are entirely absent.

In deeply plowed horizons (0–30 cm) within a two-meter soil profile, the physical clay fraction (< 0.01 mm) content ranges from 4.7% to 9.4%. However, in samples 22, 19, 23, and 21, it varies between 12.9% and 15.1%.

The data in the table below indicate that the water-soluble salt content in the upper plow horizon of the described light sierozem soils is significantly lower than in unsaline (leached) soils. The easily water-soluble salt content in dry matter ranges from 0.160% to 0.290%, classifying the soils as slightly saline (0.308–0.370%). In some cases, particularly in samples 25, 19, and 20, salinity reaches 0.754–1.265% in the 150–200 cm layer (Table 2).

Weakly saline and non-saline soils are generally rare and are mainly found at a depth of 200 cm in sample 19. This indicates that the entire soil profile is practically non-saline, as the dry residue does not exceed 0.105–0.185%, including 0.007–0.014% chloride content in the analyzed sections (Table 2).

The studied soils are predominantly sulfate and chloride-sulfate in terms of salinity composition. There are no significant differences in the salinity characteristics of these soils, despite their formation in different geomorphological regions and parent materials. The chloride-sulfate salinity type, typically associated with slightly saline soils, remains unchanged even at moderate salinity levels.

Table 1. Mechanical composition of light sierozem soils

Sample	Depth, cm	Particle size in mm, %							Physical clay (<0.01 mm)	Soil name by mechanical composition
		Sand			Dust			Clay		
		>0.25	0.25–0.1	0.1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001		
19	0–30	0.8	0.2	17.3	50.0	11.3	5.3	15.1	31.7	Medium loam
	30–50	1.2	0.3	3.7	60.9	12.9	8.5	12.5	33.9	Medium loam
	50–80	0.8	0.2	12.8	57.3	10.1	6.9	11.9	28.9	Light loam
	80–100	0.4	0.1	13.7	46.8	32.4	4.9	1.7	39.0	Medium loam
	100–150	2.8	0.4	9.9	55.8	24.9	4.0	1.9	30.8	Medium loam
	150–200	0.8	0.2	14.7	47.6	34.2	2.3	0.2	36.7	Medium loam
20	0–30	0.4	0.1	8.5	58.5	20.5	7.65	4.35	32.5	Medium loam
	30–50	0.6	0.15	8.25	57.85	25.45	5.2	2.5	33.15	Medium loam
	50–80	2.4	0.6	10.8	53.0	27.8	3.2	2.2	33.2	Medium loam
	80–100	1.6	0.4	41.8	21.5	32.7	2.0	0.2	34.9	Medium loam
	100–150	0.8	0.2	13.8	57.8	25.1	2.2	0.1	27.4	Light loam
	150–200	0.4	0.1	17.7	45.7	33.8	1.3	1.0	36.1	Medium loam

Source: Authors' own elaboration

For a more comprehensive quantitative assessment of soil salinity, which serves as a key indicator in land reclamation, we calculated the reserves of water-soluble salts for individual soil horizons and the entire studied soil profile, based on water extract analysis. Due to the deep groundwater table, the total reserves of water-soluble salts remain relatively low, with the dry residue in the two-meter soil profile reaching 189.22 t/ha in sample 20 (Table 3).

The soils in the selected area are naturally affected by salinity, with weak to moderate salinity levels observed in sections 19–25. The total salt content in the soil profile ranges from 0.105–0.160% to 0.765–0.830%, with chloride ions comprising 0.007–0.017% and sulfates accounting for 0.064–0.360%. The dominant salinity type is sulfate, while in some samples (19–19A), it is chloride-sulfate.

The salt reserves in the upper soil layer are the lowest, comprising 30–45% of the total dry residue. Among the water-soluble salts, chlorides make up only 1.65–4.09 t/ha, while sulfates constitute the majority of the total salt content.

In some soil samples (19 and 20), the content of easily soluble salts in water ranges from 0.160% to 2.655% within the soil profile. In the lower layers (150–200 cm), the dry residue salt content is 1.470–1.365%, with chloride ions comprising 0.052–0.059% and sulfates accounting for 0.443–0.813%.

The pH values, which indicate the alkalinity of the soils, range from 7.05 to 7.80. The most practical and widely used method for calculating salt reserves in soils by designated layers involves expressing the average salt content (determined by soil horizons) in tons per hectare (t/ha). This is achieved by multiplying the measured salt concentration by the thickness of the calculated layer (0–30, 0–50, 0–100, 0–200 cm) and the bulk density (g/cm³). Accurately assessing the soil reclamation status of agricultural lands based on salt reserves is crucial for developing effective strategies and recommendations to improve soil conditions.

According to the data on the reserves of total salts, chloride ions, and toxic salts in the calculated layers (0–100 cm and 0–200 cm) of the irrigated soils in the studied area, the quantitative indicators of salt reserves do not show significant variation. However, slight differences are observed due to the influence of various environmental and soil-forming factors.

Table 2. The amount of salts soluble in water and the salinity system (S – sulphate, CH-chloride)

Sample No.	Depth, cm.	Dry residue	HCO_3^-	Cl–	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	Anions and cations	SO_4 / Cl	Salinity		pH
											Type	Level	
19	0–30	0.16	0.043	0.008	0.064	0.028	0.003	0.010	2.31	6.31	S	Non–saline	7.06
			0.7	0.22	1.39	1.39	0.24	0.68	1.63				
	30–50	0.215	0.04	0.007	0.104	0.02	0.006	0.03	3.01	10.8	S	Non–saline	7.11
			0.65	0.2	2.16	1	0.49	1.52	1.49				
	50–80	0.22	0.037	0.021	0.093	0.02	0.003	0.043	3.12	3.27	CH–S	Slightly saline	7.2
			0.6	0.59	1.93	1	0.25	1.87	1.25				
	80–100	0.305	0.037	0.007	0.158	0.025	0.003	0.06	4.1	16.5	S	Slightly saline	7.27
			0.6	0.2	3.3	1.25	0.25	2.6	1.5				
	100–150	0.26	0.033	0.073	0.072	0.04	0.024	0.003	4.11	0.72	S–CH	Slightly saline	7.25
			0.54	2.07	1.5	2	1.97	0.14	3.97				
	150–200	1.47	0.024	0.059	0.443	0.155	0.039	0.009	11.31	5.49	S	Moderately saline	7.67
			0.4	1.68	9.23	7.73	3.21	0.37	10.94				
20	0–30	0.37	0.046	0.012	0.19	0.025	0.005	0.078	5.04	11.62	S	Slightly saline	7.29
			0.75	0.34	3.95	1.24	0.41	3.39	1.65				
	30–50	0.238	0.045	0.012	0.11	0.032	0.005	0.031	3.36	6.73	S	Non–saline	7.3
			0.73	0.34	2.29	1.6	0.41	1.36	2.0				
	50–80	0.615	0.04	0.024	0.329	0.015	0.009	0.154	8.19	9.92	S	Slightly saline	7.41
			0.65	0.69	6.85	0.75	0.74	6.7	1.49				
	80–100	0.655	0.043	0.077	0.296	0.03	0.009	0.156	9.04	2.84	CH–S	Moderately saline	7.45
			0.7	2.17	6.17	1.5	0.74	6.8	2.24				
	100–150	0.49	0.024	0.049	0.247	0.05	0.024	0.056	6.92	3.72	CH–S	Moderately saline	7.33
			0.4	1.38	5.14	2.5	1.97	2.45	4.47				
	150–200	1.365	0.021	0.052	0.813	0.245	0.051	0.054	18.75	11.43	S	Moderately saline	7.8
			0.35	1.48	16.92	12.23	4.19	2.33	16.42				

Source: Authors' own elaboration

The range and average values of total salts fluctuated between 30.52–66.37 t/ha at 0–1 m and 68.85–189.22 t/ha at 0–2 m, with an average of 44.16 t/ha and 119.41 t/ha, respectively. Chloride ion reserves varied from 1.62–4.09 t/ha at 0–1 m and 4.80–12.91 t/ha at 0–2 m, with average values of 2.72 t/ha and 8.08 t/ha, respectively. The toxic salt content ranged from 15.52–46.03 t/ha at 0–1 m and 32.88–104.09 t/ha at 0–2 m, with average values of 28.35 t/ha and 69.35 t/ha, respectively (Table 4).

In irrigated agricultural areas, typical sierozem soils account for 47.0%, light sierozem soils for 50.0%, meadow-sierozem soils for 2.0%, and meadow soils for 1.0%. Typical sierozem soils, which are extensively irrigated for crop cultivation, represent one of the most productive and widely utilized soil groups (Tursunov and Ismonov, 2018). In the Samarkand region, erosion-prone typical sierozem soils are characterized by a light to medium sandy texture. The groundwater table is located at a depth of 12–15 m. The humus content in the plow layer (0–30 cm) ranges from 0.800–0.900%, while total nitrogen is 0.07–0.09%, phosphorus is 0.11–0.14%, and potassium varies between 1.96–2.13% (Muminova and Muminov, 2016).

The humus content in the profile of irrigated light sierozem soils (samples 19–25) at the "Sirojiddin Dalasidagi Chorva" farm in Nurabad district ranges from 0.141–0.191% to 0.539–0.911%. These soils fall into the category of poorly humus-supplied soils (0.5–1.0%). The measured humus content at different depths, from the subsurface of the plowed horizon to the deeper layers, is as follows: 0.341–0.661%, 0.251–0.401%, 0.241–0.375%, 0.191–0.330%, 0.141–0.308% (Table 5).

During the study, in order to provide a comprehensive assessment of the agrochemical state of the soil, special attention should be given to ensuring an adequate number of soil samples and conducting a representative average analysis of their key indicators.

The average humus content in the soil layers of the main samples, where samples were collected up to a depth of 200 cm, gradually decreased from 0.735% in the 0–30 cm layer to 0.204% in the deeper layers.

Table 3. The amount and reserves of total and toxic salts, as well as chloride ions and sulfates in the calculated layers of irrigated soils

Sample No.	Depth, cm	Dry residue		Cl^-		SO_4^{2-}		Toxic salts	
		%	t/ha	%	t/ha	%	t/ha	%	t/ha
19	0–30	0.160	6.720	0.008	0.34	0.064	2.680	0.061	2.580
	30–50	0.215	6.020	0.007	0.20	0.104	2.910	0.134	3.750
	50–80	0.220	9.240	0.021	0.88	0.093	3.910	0.141	5.940
	80–100	0.305	8.540	0.007	0.20	0.158	4.420	0.190	5.320
	100–150	0.260	18.200	0.073	5.11	0.072	5.040	0.141	9.850
	150–200	0.754	52.780	0.059	4.13	0.443	31.01	0.305	21.37
	0–100	0.218	30.520	0.012	1.62	0.099	13.91	0.126	17.59
	0–200	0.363	101.500	0.039	10.9	0.178	49.97	0.174	48.81
20	0–30	0.370	15.540	0.012	0.50	0.190	7.980	0.253	10.64
	30–50	0.238	6.660	0.012	0.34	0.110	3.080	0.118	3.300
	50–80	0.615	25.830	0.024	1.01	0.329	13.82	0.429	18.03
	80–100	0.655	18.340	0.077	2.16	0.296	8.290	0.502	14.06
	100–150	0.490	34.300	0.049	3.43	0.247	17.29	0.295	20.63
	150–200	1.265	88.550	0.052	3.64	0.813	56.91	0.535	37.43
	0–100	0.474	66.370	0.029	4.01	0.237	33.17	0.328	46.03
	0–200	0.675	189.220	0.040	11.1	0.383	107.4	0.371	104.1

Source: Authors' own elaboration

Table 4. Variation range and average values of total and toxic salts, and chloride ion reserves in irrigated soils

District's, estate's farm	Number of samples	Variation range of total salts, t/ha		Variation range of chloride ions, t/ha		Variation range of toxic salts, t/ha	
		0–1 m	0–2 m	0–1 m	0–2 m	0–1 m	0–2 m
"Sirojiddin dalasidagi chorva" farm of Nurabad district	7	30.52–66.37	68.85–189.22	1.62–4.09	4.80–12.91	15.52–46.03	32.88–104.09
		44.16	119.41	2.72	8.08	28.35	69.35

Source: Authors' own elaboration

Table 5. Humus and nutrient content of irrigated light sierozem soils

Sample No.	Depth, cm	Humus, %	Total, %			C:N	Mobile mg/kg		CO_2 (carbonates)
			N	P_2O_5	K_2O		P_2O_5	K_2O	
19	0–30	0.539	0.038	0.187	1.48	8.2	22.22	259	8.0
	30–50	0.341	0.026	0.173	1.40	7.6	19.17	221	8.1
	50–80	0.282	0.025	0.153	1.30	6.5	11.11	145	7.8
	80–100	0.275	0.024	0.134	1.36	6.6	11.67	103	7.8
	100–150	0.264	0.023	0.112	1.33	6.7	9.17	92	7.7
	150–200	0.247	0.021	0.067	0.90	6.8	9.10	85	7.5
20	0–30	0.649	0.052	0.126	1.97	7.2	18.94	257	8.1
	30–50	0.385	0.031	0.162	1.83	7.2	16.11	203	8.0
	50–80	0.380	0.030	0.210	1.80	7.3	13.89	162	7.5
	80–100	0.375	0.031	0.134	1.18	7.0	10.28	122	7.3
	100–150	0.330	0.030	0.061	1.10	6.4	9.44	101	7.2
	150–200	0.308	0.030	0.054	1.05	6.0	8.61	82	7.1

Source: Authors' own elaboration

Analysis of the humus supply indicators in the 0–30 cm plow layer of irrigated soils, based on the data of Toshkuziyev (2006), shows that the average humus content in the 0–30 cm layer of both main and additional samples ranges from 0.539–0.649%. According to classification limits (0.5–1.0%), this corresponds to a low humus supply level, while in the deeper layers, the humus content decreases further, falling into the very low category (< 0.5%).

The highest total nitrogen content in the plow layer was recorded at 0.052% in both sections, gradually decreasing to 0.021% in the deeper layers. The carbon-to-nitrogen (C/N) ratio was 8.2 in the upper layer and showed a decreasing trend, reaching 6.8 in the lower layers.

The mobile phosphorus content in the 0–30 cm layer of the soil ranges from 18.94 to 22.22 mg/kg, indicating that the soils are poorly supplied with phosphorus, while the deeper layers fall into the very poorly supplied category. The exchangeable potassium content in the same layer ranges from 257 to 259 mg/kg, classifying the soils as moderately to well-supplied. The CO_2 carbonates are distributed uniformly across the profile, ranging from 6% to 8%.

In conclusion, the agrochemical status of the irrigated light sierozem soils was found to be low to very low in all essential nutrients and humus, except for mobile potassium, which was present at a moderate to sufficient level.

The maximum permissible concentration (MPC) for the mobile form of chromium in soil is 6 mg/kg (Kuznetsov et al., 1992), the highest contamination was determined in the plowed layer of 0–30 cm of samples 19–26, which was 12.61–40.55 mg/kg, 2.10–6.76 times more than MPC. Chromium in the sublayers of plowed soils is about 33.46–15.00 mg/kg, 5.58–2.50 times more than MPC, and it is about 49.42–95.19 mg/kg in 30–50 cm samples, and it is 8.24–15.87 times higher than MPC, respectively (Table 6).

In conclusion, it was determined that soil contamination with chromium is on average 4.45 times higher than MPC. A large amount of chromium in these soils causes contamination of the trophic chain, first of all, in the plant world, but also in the composition of the cultivated products.

MPC in the mobile form of copper in the soil is 3 mg/kg (Kuznetsov et al., 1992), in the soils of the selected object, high amounts of the copper were found along the layers. The amounts of copper elements in the plowed layers of 0–30 cm were 6.09–5.31–5.48–5.81–4.71–4.87–5.82 mg/kg and were

Table 6. The average amount of chromium in the 0–200 cm layers of the soil

Layers	Sample 19		Sample 20		Sample 21		Sample 22		Sample 23		Sample 24		Sample 25	
	MPC 6 mg/kg													
0–30	21.62	3.60	40.55	6.76	18.85	3.14	22.70	3.78	12.61	2.10	31.84	5.31	13.01	2.17
30–50	33.46	5.58	15.19	2.53	28.88	4.81	24.71	4.12	25.21	4.20	32.29	5.38	15.00	2.50
50–80	36.96	6.16	13.89	2.31	34.50	5.75	23.31	3.88	34.72	5.79	13.75	2.29	13.33	2.22
80–100	19.42	3.24	27.61	4.60	14.54	2.42	19.83	3.31	25.05	4.18	29.08	4.85	17.89	2.98
100–150	21.09	3.52	40.03	6.67	43.52	7.25	19.17	3.20	10.68	1.78	21.76	3.63	8.48	1.41
150–200	11.08	1.85	6.77	1.13	19.34	3.22	13.92	2.320	31.04	5.17	15.66	2.611	40.24	6.71

Source: Authors' own elaboration

1.57 → 1.62 → 1.77 → 1.83 → 1.94 → 1.94 → 2.03 times (layers are located accordingly; (23, 24, 20, 21, 22, 25, 19) higher than MPC (Table 7). 1.60–2.10 times higher amounts of copper in soil layers than MPCs were detected in all samples. In the 100–150 cm and 150–200 cm layers of samples 19 and 25, it was found that it increased to 5.29–6.08 mg/kg. In table 2, it can be seen that the contamination with the element is uniform in the soil layers up to 100 cm. The pollution in this state of the element can be said to be natural, because the pollution is uniform throughout the soil layers.

Soil contamination with cadmium is one of the most dangerous environmental phenomena, to reduce its mobility, it is necessary to increase soil pH value with the help of lime (CaO) (Babenko and Safronova, 2020).

MPC of cadmium in the soil is 0.5 mg/kg (Kuznetsov et al., 1992), it was observed that the element in the mobile form is distributed differently in the soil layers according to the mechanical composition of the soil.

It was found to be 0.53–0.22 mg/kg along the 19th sample layers, and 1.06–0.24 times higher than MPC. It was observed that in plowed layers of 19–25 samples, it is in the range of 1.06–1.24–0.62–1.56–1.20–0.46–0.74 times compared to MPC. 0.87 mg/kg cadmium was measured in the 50–80 cm layer of sample 25, which was found to be 1.74 times higher than MPC (Table 8).

The highest contamination was detected in sample 20, 1.24 times higher in the 0–30 cm layer and 1.92 times higher than the MPC in the 150–200 cm layer.

MPC of cobalt in the soil is 5 mg/kg (Kuznetsov et al., 1992), MPC was found to be low in these soils. It can be seen that it is 1.0–1.48 mg/kg throughout the lower layers of the soil, which is 0.2–0.3 below the MPC. Cobalt was found in soil samples in the layers of 0–30 cm and 80–100 cm in the maximum amount of 1.46 and 1.48 mg/kg, lower values than MPC were determined, and the conclusion is that this element is affected by the mobile form of the element (Table 9).

Nickel is a silver-white heavy metal, very resistant to air and water. An increase in the concentration of Ni in the soil leads to endemic diseases (in plants – bad forms, in animals – eye diseases). The average daily MPC in air is 0.003 mg/m^3. MPC for nickel in mobile form in the soil is 4 mg/kg (Kuznetsov et al., 1992). It can be seen that the amount of Ni is less than MPCs in selected samples soils. According to average calculations, it can be seen that the highest index is 3.90–3.82 mg/kg in the 50–80 cm layers of 19 and 24 samples, that is, it is close to MPC. It was found that the mobile form of nickel is low in all the sample soils (Table 10).

Table 7. Indicators of copper in mobile form in soil layers

Layers	Sample 19		Sample 20		Sample 21		Sample 22		Sample 23		Sample 24		Sample 25	
	MPC 3 mg/kg													
0–30	6.09	2.03	5.31	1.77	5.48	1.83	5.81	1.94	4.71	1.57	4.87	1.62	5.82	1.94
30–50	4.83	1.61	4.71	1.57	4.23	1.41	4.48	1.49	3.79	1.26	3.89	1.30	4.89	1.63
50–80	4.54	1.51	4.02	1.34	4.63	1.54	3.58	1.19	3.95	1.32	3.74	1.25	4.98	1.66
80–100	4.23	1.41	3.92	1.31	3.84	1.28	3.71	1.24	3.51	1.17	3.89	1.30	4.64	1.55

Source: Authors' own elaboration

Table 8. Mobile form of cadmium in soil layers

Layers	Sample 19		Sample 20		Sample 21		Sample 22		Sample 23		Sample 24		Sample 25	
	MPC 0.5 mg/kg													
0–30	0.53	1.06	0.62	1.24	0.312	0.62	0.78	1.56	0.6	1.20	0.23	0.46	0.37	0.74
30–50	0.39	0.78	0.29	0.59	0.29	0.59	0.69	1.38	0.47	0.94	0.50	1.00	0.70	1.40
50–80	0.12	0.24	0.56	1.13	0.19	0.38	0.63	1.26	0.65	1.30	0.17	0.34	0.87	1.74
80–100	0.31	0.626	0.96	1.92	0.64	1.27	0.49	0.98	0.30	0.60	0.01	0.02	0.63	1.26

Source: Authors' own elaboration

Table 9. Dispersion of cobalt in mobile form in soil layers

Layers	Sample 19		Sample 20		Sample 21		Sample 22		Sample 23		Sample 24		Sample 25	
	MPC 5 mg/kg													
0–30	1.46	0.29	1.14	0.23	0.55	0.11	1.36	0.27	0.93	0.19	0.85	0.17	0.80	0.16
30–50	1.00	0.20	0.97	0.19	1.15	0.23	0.90	0.18	0.95	0.19	0.80	0.16	0.70	0.14
50–80	1.23	0.25	1.44	0.29	0.84	0.17	0.90	0.18	1.03	0.21	0.97	0.19	0.77	0.15
80–100	1.48	0.30	1.19	0.24	0.86	0.17	1.19	0.24	0.85	0.17	0.89	0.18	0.56	0.11

Source: Authors' own elaboration

Table 10. Amounts of nickel in mobile form in soil layers

Layers	Sample 19		Sample 20		Sample 21		Sample 22		Sample 23		Sample 24		Sample 25	
	MPC 4 mg/kg													
0–30	2.21	0.55	1.90	0.48	1.48	0.37	1.59	0.40	2.86	0.72	1.39	0.35	0.63	0.16
30–50	3.24	0.81	3.08	0.77	2.63	0.66	1.91	0.48	2.43	0.61	0.54	0.14	0.12	0.03
50–80	3.90	0.98	2.42	0.61	2.52	0.63	2.25	0.56	0.96	0.24	3.82	0.96	1.37	0.34
80–100	3.11	0.78	2.14	0.54	3.34	0.84	1.86	0.47	2.45	0.61	1.83	0.46	1.77	0.44

Source: Authors' own elaboration

Table 11. Amount of lead in mobile form in soil layers

Layers	Sample 19		Sample 20		Sample 21		Sample 22		Sample 23		Sample 24		Sample 25	
	MPC 6 mg/kg													
0–30	7.48	1.25	5.04	0.84	7.61	1.27	4.13	0.69	4.98	0.83	5.63	0.94	6.02	1.00
30–50	5.65	0.94	5.89	0.98	4.84	0.81	6.79	1.13	7.10	1.18	2.88	0.48	6.51	1.09
50–80	7.10	1.18	6.88	1.15	7.07	1.18	3.60	0.60	4.35	0.73	7.11	1.18	8.31	1.38
80–100	4.30	0.72	6.2	1.03	3.51	0.59	4.80	0.80	5.86	0.98	5.74	0.96	6.81	1.14

Source: Authors' own elaboration

Table 12. Amount of zinc in mobile form in soil layers

Layers	Sample 19		Sample 20		Sample 21		Sample 22		Sample 23		Sample 24		Sample 25	
	MPC 23 mg/kg													
0–30	3.63	0.16	2.22	0.10	2.18	0.09	7.51	0.33	3.02	0.13	1.72	0.07	4.39	0.19
30–50	9.50	0.41	1.82	0.08	1.12	0.05	0.67	0.03	3.08	0.13	1.06	0.05	14.48	0.63
50–80	10.81	0.47	1.92	0.08	3.77	0.16	1.16	0.05	8.18	0.36	3.18	0.14	32.68	1.42
80–100	7.10	0.31	2.68	0.12	4.09	0.18	1.69	0.07	1.79	0.08	2.94	0.13	11.76	0.51

Source: Authors' own elaboration

Lead (Pb) is a metal that has been mined by people for a long time and used in various fields of economic activity. The negative impact on human health has been known for a long time, since the II century. The MPC for the mobile form of lead in the soil is 6 mg/kg (Kuznetsov et al., 1992). The concentration was discovered to exceed the MPC, albeit by a slight margin. The increase of MPC in all sample soils indicated their accumulation in some layers. 7.48 and 7.10 mg/kg in the 0–30 and 50–80 cm layers of the 19th sample, and 7.61 and 7.07 mg/kg in the 21st sample, it was found to be 1.02→1.09→1.83→1.14 times more higher than MPC in all layers of the 25th sample (Table 11).

It was observed that lead leached towards the lower layers of the soil, and it increased in the lower 100–150 cm and 150–200 cm layers of the samples, 8.98–7.23 mg/kg in 19th sample, 6.03–8.29 mg/kg in the 21st sample, and 9.62–10.71 mg/kg in the 24th and 25th samples.

Some of the analyzed elements, such as lead, tend to be less prone to leaching and therefore accumulate in the lower soil layers. This is particularly evident in weakly saline soils with sulfate and chloride-sulfate salinity. Additionally, due to the high mobility of certain elements influenced by the elevated reserves of toxic salts, the accumulation of some toxic elements in these layers is significantly higher.

MPC for the mobile form of zinc in the soil is 23 mg/kg (Kuznetsov et al., 1992). Its quantity was found to be low in all samples. In the 25th sample, it was measured that its amount increases along the layers to the following: 4.23→14.48→32.68→11.76 mg/kg, and in the range of 0.19→0.63→1.42→0.51 times of MPC (Table 12).

Conclusion

In conclusion, the selected light sierozem soils are predominantly medium loamy in mechanical composition. They exhibit sulfate and chloride-sulfate salinity, while their agrochemical status is classified as low to very low in humus and essential nutrients. Additionally, among the macro- and microelements, the levels of chromium and copper were found to exceed the maximum permissible concentration (MPC) in the soil composition. In the 200 cm layers of all samples, mobile chromium is up to 4.45 times higher than average. Moreover, copper exceeds MPC by 1.57–2.03 times for 0–30 cm, 1.26–1.61 times 30–50 cm, 1.19–1.66 times for 50–80 cm, and 1.17–1.55 times for the 80–100 cm layer, respectively. It is related to the fact that the soil is heavily con-

taminated with chromium, and the process of initial contamination with copper is underway. In addition, it was found that cadmium in soils increases up to 1.92 times from MPC, in the layers of 100 cm of soil with lead up to 1.38 times from MPC, and towards the lower layers up to 1.78 times.

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