SPATIAL DISTRIBUTION OF ELEMENTS, ENVIRONMENTAL EFFECTS, AND ECONOMIC POTENTIAL OF TECHNOGENIC WASTE MATERIALS OF CHROMITE SLAG FROM DUMPS OF DON MINING AND PROCESSING PLANT

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ABSTRACT

The effective utilization and secondary application of technogenic waste pose significant challenges within the present-day economy. In order to evaluate the environmental impact and economic viability, it is imperative to examine the elemental composition of technogenic materials and unveil the spatial distribution patterns of elements, components, and indices, such as the pollution coefficient. In this research endeavor, we conducted an elemental analysis and calculated various parameters, including the average overall content, hazard quotients, metal concentration coefficients, and comprehensive pollution coefficients. The ground samples collected from the chromite slag dumps at the Don mining and processing plant (located in Khromtau, Aktobe region, Kazakhstan) were subjected to this elemental analysis, which was carried out utilizing an XRF analyzer. Additionally, we employed GIS technology to create maps illustrating the spatial distribution of element concentrations and the total pollution coefficients. Based on the observed extent of soil contamination, it is evident that the area encompassing the studied slag dumps should be deemed an environmental disaster zone.

The studied ground was of cobalt-chromium-nickel geochemical specialization. The calculated approximated volume of the accumulated waste mass was 227 974 266.54 m^3. The calculated approximate weight of the accumulated waste was 229 897 484.97 tons, including 73 744 676.05 tons of iron, 1 227 882.47 tons of manganese, and 403 470.09 tons of chromium. The approximated cost of the waste based on the market prices of components can reach up to 2.8 trillion USD. The considerable concentration of valuable components in the waste mass suggests that the studied technogenic unit has potential as a secondary resource for the production of various technological goods. In addition, the recovery of valuable metals in the form of metal concentrates is also conceivable.

Keywords: Don mining and processing plant, chromite slag, spatial distribution, elemental content, economic potential, environmental effects, technogenic waste.

INTRODUCTION

The Khromtau-Don industrial hub refines deposits of chromium, copper, and nickel. Ore mining is carried out both by mine and quarry methods. The Don Mining and Processing Plant (MPP) is the most important industrial power plant in the region and plays a crucial role in shaping the cityscape [1]. The plant specialises in the extraction and refining of chrome ore and is solely responsible for the majority of Kazakhstan's chrome ore production. The importance of the plant goes beyond its economic significance, as nearly one-third of the city's households are directly linked to this facility. An impressive 68.4% of Khromtau's working population is employed at MPP Don, further cementing its position as a major contributor to the local labour force [2].

The ecological state of Khromtau is considered unfavorable because the city is surrounded by chrome deposits on all sides [3]. There are three large deposits near the city's border, shown in Fig. 1. One is located in the southern part of the city, 300 meters from the residential area and 50 meters from the abandoned sector. The size is 900 x 500 m and the depth is 150 meters. In the southwestern part, 800 meters from the city, there are two more huge quarries, the dimensions of which reach 800 - 900 x 400 - 500 m, with a depth of 100 - 150 meters. In the north-eastern part of the city, 3 km away, there are two more large quarries, the dimensions of which are also impressive: from 900 and more than 1 km long and 500 to 900 m wide. Artificial lakes ranging in size from 300 - 500 x 150 - 200 m were formed at the bottom of all the quarries.

The slopes of the quarries are very steep, and have a conical, elongated shape, in many places gravity-landslide processes are developed. Near the quarries, artificial mountains (elevations) are formed from treated rock and soil (slag dumps) removed during the quarry development. The height of the elevations reaches from 50 to 100 m in different quarries, the length from 60 to 150 m.

The huge amounts of accumulated waste collected in dumps contain a significant number of valuable components. The secondary use, utilization, and deep refinement of the waste from dumps are relevant issues for technology [4, 5]. The knowledge about content, the spatial distribution of elements-pollutants, and environmental and economic potentials gives a meaningful contribution to the development of knowledge about the geography of the Aktobe region in Kazakhstan.

Thus, the objects of this research are the waste from three slag dumps of the quarry placed in the northeastern part of Khromtau. The research aims to reveal the elemental content of ground samples taken from different locations of the slag dumps, study the spatial distribution of the elements on the territory of the storage, calculate the average elemental content, as well the total pollution coefficient Zc [6 - 9], to calculate the approximate volume of waste which has been accumulated in the storage and to calculate the approximate amounts of the element reserves deposited in the studied technogenic object. Hereinafter, using

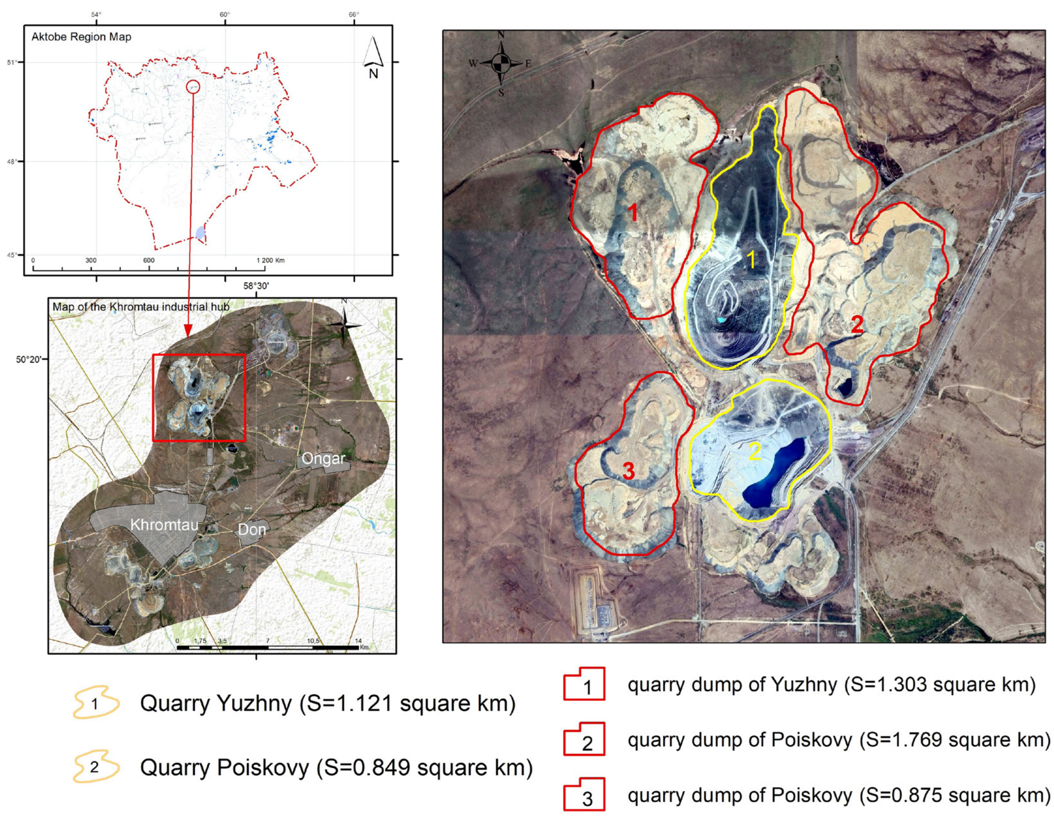

Fig. 1. Studied technogenic objects of industrial hub: 1 yellow bordered - quarry Yuzhny (S=1.121 sq. km); 2 yellow bordered - quarry Poiskovy (S=0.849 sq. km); 1 red bordered - quarry dump of Yuzhny (S=1.303 sq. km); 2 red bordered - quarry dump of Poiskovy (S=1.769 sq. km); 3 red bordered - quarry dump of Poiskovy (S=0.875 sq. km).

local prices for some valuable metals to calculate the average economic potential of the waste utilization.

EXPERIMENTAL

Study area

The Khromtau-Don industrial hub is located in a dry steppe zone of chestnut-brown soils, which contain sand and sandy parts of rocks. The territory of the object is located in a subzone of dark chestnut soils.

The climate of the territory is sharply continental. In winter the climate of the area is affected by the passing Siberian anticyclone, in summer the subtropical desert air freely reaches. In winter, the temperature reaches -20°C - 22°C, and in summer up to +20°C - +25°C. The average annual precipitation ranges from 350 - 450 mm. The average wind speed reaches up to 8 m/sec.

The map of studied technogenic objects is shown in Fig. 1.

Sampling

A total of 99 soil samples were collected, with 33 samples obtained from different layers from the surface to a depth of about 50 cm. Each sample had a minimum weight of 1 kg. Sampling was performed using plastic equipment, and the sampling points are shown in Fig. 2. The distance between each sampling point was at least 200 m. To ensure preservation and protection from direct sunlight, samples were transported and stored in plastic containers. Prior to analysis, the waste samples were subjected to air drying.

Elemental analysis

We performed elemental composition analysis of the samples using a BRA -18 X-Ray Fluorescent (XRF) analyzer (Russian Federation). This advanced analyzer allowed us to accurately determine the presence and amount of several chemical elements, including Cl, K, Ca, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, and Pb. Some of these elements fall into the heavy metal category. The XRF method offers significant advantages, especially when working with large numbers of samples, as it eliminates the need for labour-intensive sample preparation in solid, powder, and liquid forms [10]. This method is based on the measurement of the wavelength and intensity of fluorescence radiation emitted by the excited atoms in the sample and enables precise and efficient analysis [11].

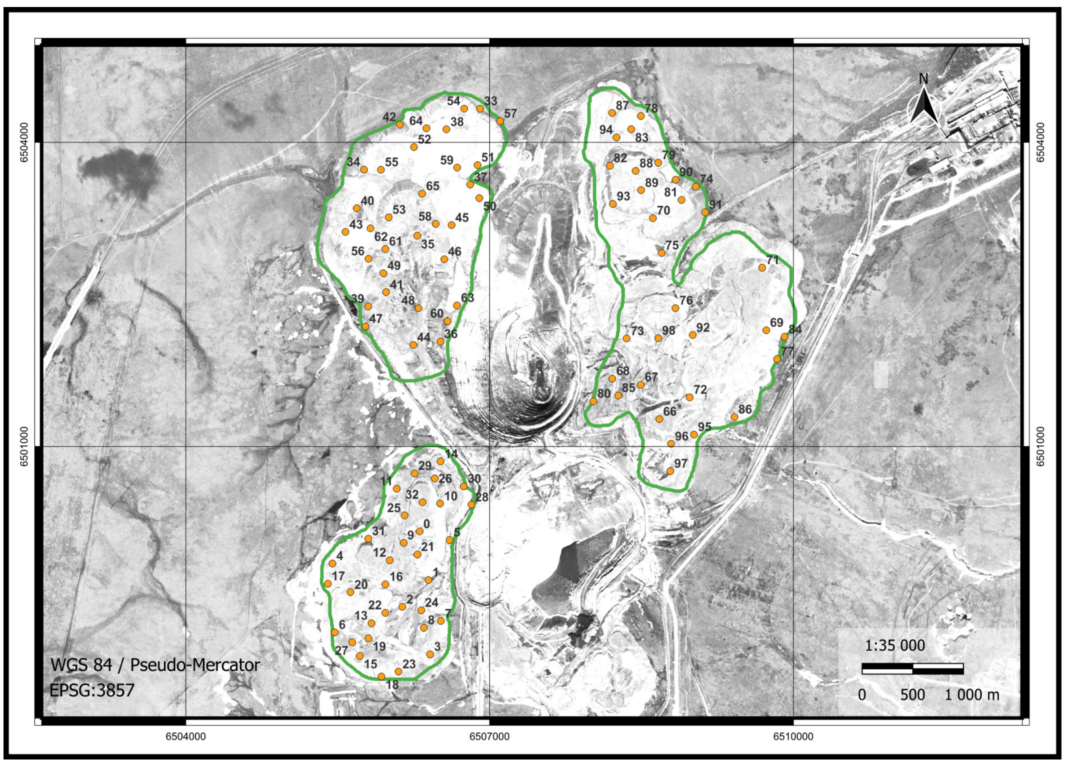

Fig. 2. Sampling map.

RESULTS AND DISCUSSION

The results of the elemental analysis are presented in Tables 1 - 3. The detected elements included heavy metals - Mn, Ni, Cu, Zn, and Cr as well as valuable components like V, Fe, and Co. Aluminum was not detected, however, it can be referred to as the undefined part of the content. The combined contents of the identified elements ranged from about 31 % to 50 %. The highest content was found to be 40.788 wt. % for Fe, followed by 6.7968 wt. % for Ca and 1.9246 wt. % for Ti (Table 4). Overall, the results show that the Cr content is not higher than 0.2927 wt. %, Ni varies in the range of 0.1363 - 0.0298 wt. %, and contents of V, Cu, and Zn are even and are approximately 0.0241, 0.0059, and 0.0117 wt. % respectively. The significant

Table 1. Elemental content of ground samples from slag dump No1 of the Don MPP.

Point id	Elemental content, wt. %										Sum	Other
	Ca	Ti	V	Mn	Fe	Co	Ni	Cu	Zn	Cr		
0	6.5857	1.7208	0.025	0.4202	31.8707	0.0784	0.116	0.0074	0.0136	0.213	41.0508	58.9492
1	6.597	1.7377	0.0252	0.4792	33.5283	0.0844	0.1135	0.0073	0.0134	0.2073	42.7933	57.2067
2	6.5985	1.6538	0.0243	0.4837	33.2376	0.0832	0.1265	0.0075	0.0146	0.2649	42.4946	57.5054
3	6.568	1.5535	0.0232	0.3907	27.2973	0.0636	0.0967	0.0069	0.0133	0.1954	36.2086	63.7914
4	6.5965	1.6377	0.0247	0.5044	33.8059	0.0858	0.1304	0.0075	0.0141	0.2394	43.0464	56.9536
5	6.5994	1.5927	0.0243	0.4247	32.9631	0.0823	0.1139	0.0074	0.0142	0.2376	42.0596	57.9404
6	6.6049	1.7449	0.0244	0.4821	33.4675	0.0845	0.1285	0.0076	0.0145	0.2698	42.8287	57.1713
7	6.6182	1.5913	0.0245	0.3796	31.8999	0.0777	0.1183	0.0074	0.0136	0.2133	40.9438	59.0562
8	6.62	1.6799	0.0252	0.4462	32.8598	0.0815	0.1319	0.0076	0.0145	0.2675	42.1341	57.8659
9	6.6482	1.6924	0.0245	0.5165	33.8406	0.0858	0.1325	0.0076	0.0148	0.268	43.2309	56.7691
10	6.5967	1.5925	0.0246	0.454	31.5267	0.0785	0.1187	0.0075	0.0144	0.2367	40.6503	59.3497
11	6.6266	1.7066	0.0251	0.5102	34.3123	0.0879	0.1279	0.0075	0.015	0.2868	43.7059	56.2941
12	6.6217	1.7567	0.0251	0.4629	34.1749	0.0875	0.1303	0.0073	0.0151	0.2786	43.5601	56.4399
13	6.6102	1.648	0.0246	0.5156	33.5775	0.0848	0.1363	0.0077	0.0155	0.2853	42.9055	57.0945
14	6.5861	1.6661	0.0249	0.4325	31.3793	0.076	0.1152	0.0072	0.014	0.2114	40.5127	59.4873
15	6.5984	1.7608	0.0242	0.4683	33.4608	0.0834	0.1176	0.0074	0.0139	0.211	42.7458	57.2542
16	6.5915	1.7277	0.0248	0.4872	33.4656	0.0851	0.1267	0.0074	0.0141	0.2684	42.7985	57.2015
17	6.5619	1.5653	0.0231	0.3816	27.3977	0.0632	0.0987	0.007	0.0128	0.1954	36.3067	63.6933
18	6.6067	1.7023	0.0249	0.5225	33.9964	0.0857	0.1305	0.0075	0.0148	0.2419	43.3332	56.6668
19	6.5728	1.5986	0.0244	0.4578	33.4588	0.0833	0.114	0.0074	0.0137	0.242	42.5728	57.4272
20	6.617	1.7835	0.0247	0.4913	33.7206	0.0841	0.1272	0.0076	0.0148	0.2756	43.1464	56.8536
21	6.6224	1.5398	0.0247	0.3852	32.1923	0.0788	0.1207	0.0074	0.0137	0.2178	41.2028	58.7972
22	6.6219	1.6435	0.025	0.4541	33.0175	0.082	0.1283	0.0075	0.0151	0.2674	42.2623	57.7377
23	6.6237	1.6778	0.0247	0.4961	33.7326	0.0862	0.1322	0.0075	0.0154	0.2731	43.0693	56.9307
24	6.5941	1.5871	0.0246	0.4474	31.3566	0.0764	0.1193	0.0073	0.015	0.2363	40.4641	59.5359
25	6.6418	1.6903	0.0249	0.5204	34.3365	0.0883	0.1327	0.0076	0.0153	0.2879	43.7457	56.2543
26	6.6135	1.7456	0.0251	0.4642	34.3297	0.0884	0.1309	0.0073	0.0144	0.2803	43.6994	56.3006
27	6.594	1.7067	0.0251	0.5142	33.8485	0.0859	0.1356	0.0074	0.0152	0.2927	43.2253	56.7747
28	6.7357	1.4696	0.0229	0.3256	25.5159	0.0557	0.054	0.0053	0.0103	0.0888	34.2838	65.7162
29	6.7519	1.4437	0.0225	0.4106	27.2252	0.0623	0.0753	0.0053	0.0109	0.0801	36.0878	63.9122
30	6.7641	1.5507	0.0232	0.4104	28.6702	0.0676	0.0623	0.0053	0.0109	0.1196	37.6843	62.3157
31	6.7953	1.4422	0.0225	0.3871	26.5026	0.0593	0.0753	0.0055	0.0108	0.0865	35.3871	64.6129
32	6.6878	1.515	0.0229	0.3375	26.557	0.0599	0.0628	0.0056	0.0109	0.0992	35.3586	64.6414

occurrence of valuable metals, including Fe, Ti, Mn, and Cr, in the studied waste material offers promising prospects for its use in the manufacture of new products or in the recovery of metal concentrates.

Based on the average gross content values, the elements studied can be arranged in descending order as follows: Fe > Ca > Ti > Mn > Cr > Co > Ni > V > Zn > Cu. The variation coefficient allows us to compare the uniformity of the values, even with different scales of data. The variation coefficient (%) is calculated by the equation 1:

$$c = D\frac{100}{\bar{x}} \quad (1)$$

where D is the standard deviation and $\overline{x}$ is the medium value [12].

Table 2. Elemental content of ground samples from slag dump No 2 of the Don MPP.

Point id	Elemental content, wt. %										Sum	Other
	Ca	Ti	V	Mn	Fe	Co	Ni	Cu	Zn	Cr		
33	6.7475	1.3558	0.0226	0.3285	25.5263	0.0562	0.0549	0.0054	0.0107	0.0858	34.1937	65.8063
34	6.7968	1.4089	0.0224	0.4103	27.045	0.0626	0.0742	0.0055	0.0109	0.0796	35.9162	64.0838
35	6.7475	1.4774	0.0228	0.4193	28.3795	0.066	0.062	0.0054	0.0108	0.1153	37.306	62.694
36	6.7627	1.4687	0.0227	0.3964	26.2586	0.06	0.0735	0.0056	0.0109	0.086	35.1451	64.8549
37	6.7318	1.4657	0.0229	0.3292	25.7118	0.0572	0.0618	0.0054	0.0111	0.0945	34.4914	65.5086
38	6.7234	1.3512	0.0217	0.3315	26.0205	0.0581	0.0613	0.0055	0.0108	0.091	34.675	65.325
39	6.7533	1.4276	0.0225	0.375	27.3362	0.0629	0.0686	0.0055	0.0111	0.0873	36.15	63.85
40	6.7495	1.3964	0.0223	0.3795	27.4202	0.0645	0.0803	0.0054	0.0111	0.0989	36.2281	63.7719
41	6.7745	1.372	0.0217	0.3217	25.098	0.054	0.0741	0.0054	0.0107	0.0844	33.8165	66.1835
42	6.7199	1.3669	0.0221	0.3115	22.5529	0.0452	0.0649	0.0052	0.0104	0.0722	31.1712	68.8288
43	6.7781	1.4532	0.0227	0.4357	27.2388	0.0621	0.0828	0.0055	0.0109	0.0948	36.1846	63.8154
44	6.736	1.4177	0.0226	0.3593	24.6646	0.0531	0.0621	0.0053	0.0113	0.1201	33.4521	66.5479
45	6.7294	1.3714	0.0222	0.4028	24.153	0.0538	0.0649	0.0054	0.0109	0.0819	32.8957	67.1043
46	6.7244	1.3914	0.0226	0.3277	25.342	0.0554	0.0624	0.0053	0.0105	0.0953	34.037	65.963
47	6.7258	1.3625	0.0224	0.322	25.645	0.0564	0.0543	0.0054	0.0106	0.0858	34.2902	65.7098
48	6.7465	1.4637	0.0223	0.4124	27.009	0.0629	0.0746	0.0055	0.011	0.0808	35.8887	64.1113
49	6.7151	1.4883	0.0239	0.4078	28.3045	0.0674	0.0621	0.0054	0.0111	0.117	37.2026	62.7974
50	6.7862	1.44	0.0233	0.382	26.365	0.0597	0.0762	0.0055	0.0111	0.0863	35.2353	64.7647
51	6.7243	1.4835	0.0228	0.3307	25.8719	0.0587	0.0627	0.0055	0.0107	0.0945	34.6653	65.3347
52	6.7217	1.3076	0.0218	0.316	25.9649	0.0578	0.0657	0.0055	0.0106	0.0882	34.5598	65.4402
53	6.7599	1.4326	0.0228	0.3859	27.3528	0.0624	0.0703	0.0054	0.011	0.0884	36.1915	63.8085
54	6.7644	1.4416	0.0221	0.3704	27.4929	0.0632	0.0824	0.0055	0.0113	0.0973	36.3511	63.6489
55	6.771	1.3933	0.0226	0.3202	25.2936	0.055	0.0735	0.0055	0.0113	0.0897	34.0357	65.9643
56	6.7179	1.3431	0.0217	0.3198	22.5804	0.046	0.0623	0.0054	0.0108	0.0737	31.1811	68.8189
57	6.7812	1.4741	0.0224	0.43	27.3077	0.0626	0.0835	0.0055	0.0112	0.0925	36.2707	63.7293
58	6.7603	1.4394	0.0228	0.3612	24.6797	0.0532	0.0606	0.0054	0.0112	0.1227	33.5165	66.4835
59	6.7285	1.4013	0.023	0.3877	23.7479	0.0518	0.062	0.0055	0.011	0.0828	32.5015	67.4985
60	6.7189	1.4058	0.0225	0.3354	25.5603	0.0576	0.0638	0.0054	0.0108	0.0953	34.2758	65.7242
61	6.7357	1.4696	0.0229	0.3256	25.5159	0.0557	0.054	0.0053	0.0103	0.0888	34.2838	65.7162
62	6.7519	1.4437	0.0225	0.4106	27.2252	0.0623	0.0753	0.0053	0.0109	0.0801	36.0878	63.9122
63	6.7641	1.5507	0.0232	0.4104	28.6702	0.0676	0.0623	0.0053	0.0109	0.1196	37.6843	62.3157
64	6.7953	1.4422	0.0225	0.3871	26.5026	0.0593	0.0753	0.0055	0.0108	0.0865	35.3871	64.6129
65	6.6878	1.515	0.0229	0.3375	26.557	0.0599	0.0628	0.0056	0.0109	0.0992	35.3586	64.6414

Table 3. Elemental content of ground samples from slag dump No 3 of the Don MPP.

Point id	Elemental content, wt. %										Sum	Other
	Ca	Ti	V	Mn	Fe	Co	Ni	Cu	Zn	Cr		
66	6.7079	1.7777	0.0249	0.6883	34.6241	0.0842	0.0326	0.0053	0.0103	0.191	44.1463	55.8537
67	6.7774	1.8141	0.0252	0.7682	37.7508	0.0945	0.0364	0.0052	0.0103	0.2087	47.4908	52.5092
68	6.7609	1.8111	0.0251	0.7607	37.3583	0.0923	0.0375	0.0053	0.0105	0.1954	47.0571	52.9429
69	6.7696	1.7691	0.0248	0.8034	38.1993	0.0959	0.0382	0.0053	0.0103	0.2096	47.9255	52.0745
70	6.73	1.8033	0.0252	0.7806	38.3691	0.0964	0.038	0.0053	0.0103	0.2034	48.0616	51.9384
71	6.7596	1.7751	0.0247	0.8242	39.6622	0.1003	0.0409	0.0053	0.0105	0.2253	49.4281	50.5719
72	6.7664	1.7893	0.0253	0.8123	38.4708	0.097	0.0349	0.0052	0.0105	0.2153	48.227	51.773
73	6.7599	1.7043	0.0252	0.8301	39.9425	0.1022	0.0371	0.0052	0.0103	0.2275	49.6443	50.3557
74	6.7173	1.7904	0.0256	0.7673	38.2419	0.096	0.032	0.0053	0.0103	0.1941	47.8802	52.1198
75	6.7499	1.7567	0.0251	0.7695	38.0056	0.0958	0.0353	0.0053	0.01	0.1985	47.6517	52.3483
76	6.7756	1.7614	0.0253	0.7906	38.5179	0.0973	0.0337	0.0053	0.0101	0.2162	48.2334	51.7666
77	6.7295	1.786	0.0246	0.7512	38.5612	0.097	0.036	0.0053	0.0103	0.2076	48.2087	51.7913
78	6.7139	1.7431	0.0249	0.8107	37.4006	0.093	0.0298	0.0052	0.01	0.1887	47.0199	52.9801
79	6.7601	1.7945	0.0249	0.8192	38.9968	0.0978	0.0378	0.0052	0.0103	0.2137	48.7603	51.2397
80	6.7079	1.8413	0.0246	0.6837	34.8523	0.0837	0.0342	0.0053	0.0102	0.1885	44.4317	55.5683
81	6.788	1.8465	0.0254	0.7915	38.318	0.0968	0.0368	0.0053	0.0103	0.2104	48.129	51.871
82	6.7923	1.7269	0.0245	0.7766	37.6845	0.0924	0.0371	0.0052	0.0103	0.2006	47.3504	52.6496
83	6.7608	1.78	0.0253	0.8103	38.5643	0.0964	0.0387	0.0053	0.0104	0.2113	48.3028	51.6972
84	6.7558	1.7761	0.0257	0.789	38.5168	0.0955	0.0365	0.0054	0.01	0.2075	48.2183	51.7817
85	6.7539	1.7544	0.0249	0.823	39.4753	0.0982	0.04	0.0053	0.0103	0.2235	49.2088	50.7912
86	6.7499	1.9246	0.0257	0.8227	39.1716	0.0989	0.0369	0.0053	0.0106	0.2189	49.0651	50.9349
87	6.7889	1.7711	0.0253	0.8321	40.788	0.1028	0.039	0.0053	0.0102	0.235	50.5977	49.4023
88	6.7423	1.7726	0.025	0.7631	38.3307	0.0948	0.0325	0.0053	0.0103	0.2009	47.9775	52.0225
89	6.7366	1.817	0.0258	0.7921	38.5997	0.0957	0.0372	0.0052	0.0102	0.2126	48.3321	51.6679
90	6.7478	1.7647	0.0253	0.7994	38.8014	0.0966	0.0339	0.0052	0.0099	0.2174	48.5016	51.4984
91	6.7685	1.8792	0.0252	0.7549	39.0697	0.0961	0.0344	0.0053	0.0099	0.2127	48.8559	51.1441
92	6.7069	1.7917	0.0257	0.7861	37.5489	0.0926	0.0307	0.0053	0.0103	0.1922	47.1904	52.8096
93	6.779	1.8702	0.0255	0.8392	39.4964	0.0981	0.0369	0.0052	0.0103	0.2147	49.3755	50.6245
94	6.7112	1.8713	0.0255	0.6989	35.105	0.0844	0.0349	0.0052	0.0103	0.1914	44.7381	55.2619
95	6.7423	1.8299	0.0252	0.7968	38.1622	0.0947	0.0361	0.0053	0.0103	0.2143	47.9171	52.0829
96	6.7614	1.8121	0.0253	0.7794	37.7951	0.0938	0.0373	0.0053	0.0106	0.2005	47.5208	52.4792
97	6.7812	1.8827	0.0262	0.8342	39.2868	0.0981	0.0391	0.0054	0.0102	0.2185	49.1824	50.8176
98	6.7601	1.8515	0.0263	0.7808	39.0561	0.0969	0.0384	0.0054	0.0105	0.2102	48.8362	51.1638

Table 4. The general elemental content of ground samples from slag dumps of the Don MPP.

	Elemental content, wt. %									
	Ca	Ti	V	Mn	Fe	Co	Ni	Cu	Zn	Cr
Max	6.7968	1.9246	0.0263	0.8392	40.788	0.1028	0.1363	0.0077	0.0155	0.2927
Min	6.5619	1.3076	0.0217	0.3115	22.5529	0.0452	0.0298	0.0052	0.0099	0.0722
Average	6.7082	1.6221	0.0241	0.5341	32.0772	0.0775	0.0728	0.0059	0.0117	0.1755

The coefficient of variation of the average gross contents of the studied elements ranged from 1.04 wt. % (Ca) to 48.57 wt. % (Ni). Thus, the distribution of Co, Fe, Cu, Zn, Ti, V, and Ca is more or less uniform, and the distribution of Mn, Cr, and Ni is more random. The increased non-uniformity is the consequence of the fact that the origin of the waste is ore from quarries without any scaled processing. A complect of maps was created to demonstrate the distribution character of detected elements (Figs. 3 - 7).

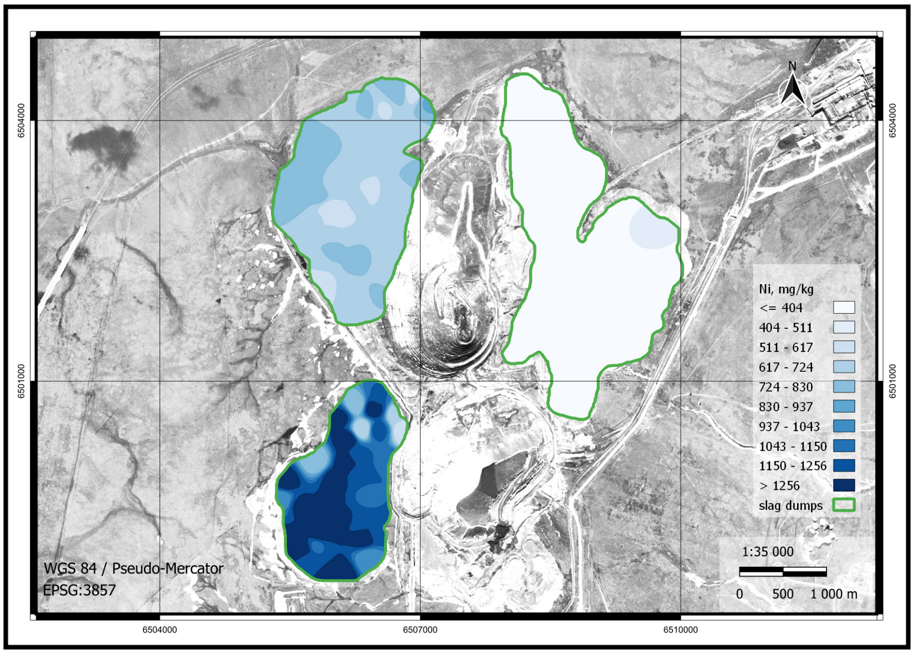

Fig. 3. Spatial distribution of Ni on the slag dumps of the Don MPP. (Coordinate system: WGS 84 : Pseudo-Mercator EPSG:3857, satellite map: ESRI Satellite (ArcGIS/World_Imagery), scale: 1:35 000, method of interpolation: QGIS IDW, distance coefficient = 5.0, pixel size = 1.0).

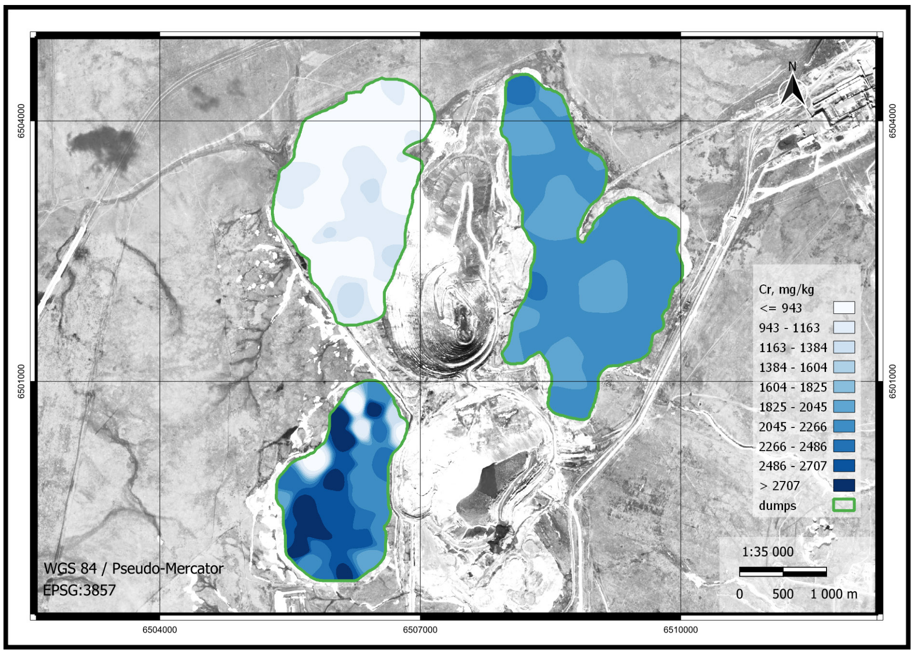

Fig. 4. Spatial distribution of Cr on the slag dumps of the Don MPP. (Coordinate system: WGS 84 : Pseudo-Mercator EPSG:3857, satellite map: ESRI Satellite (ArcGIS/World_Imagery), scale: 1:35 000, method of interpolation: QGIS IDW, distance coefficient = 5.0, pixel size = 1.0).

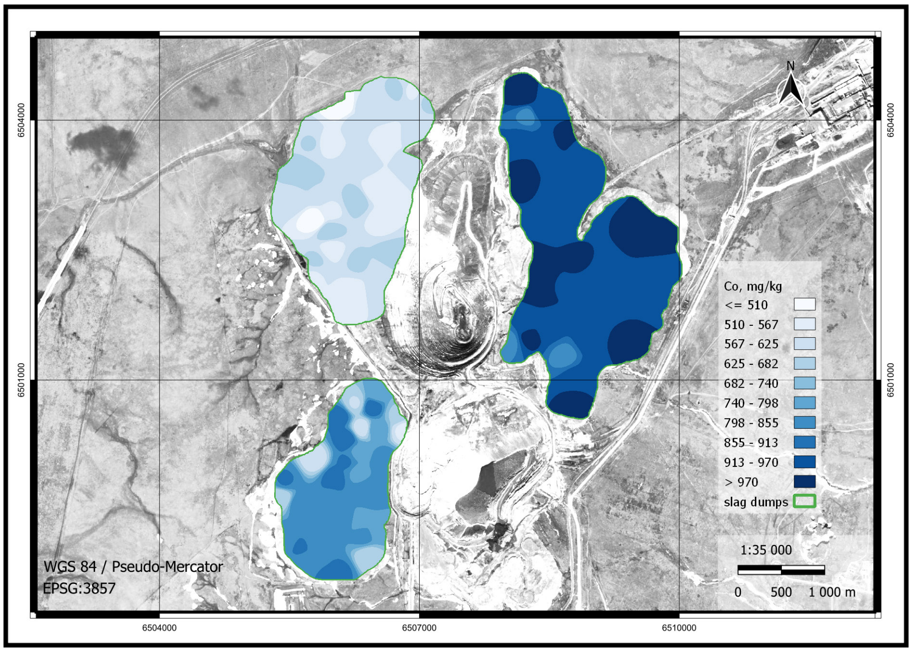

Fig. 5. Spatial distribution of Co on the slag dumps of the Don MPP. (Coordinate system: WGS 84 : Pseudo-Mercator EPSG:3857, satellite map: ESRI Satellite (ArcGIS/World_Imagery), scale: 1:35 000, method of interpolation: QGIS IDW, distance coefficient = 5.0, pixel size = 1.0).

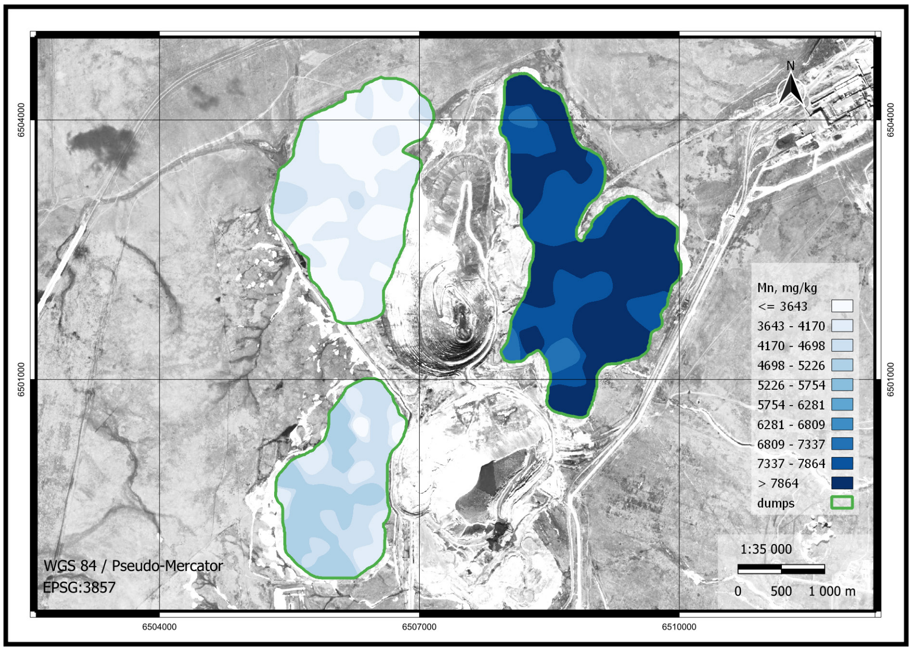

Fig. 6. Spatial distribution of Mn on the slag dumps of the Don MPP. (Coordinate system: WGS 84 : Pseudo-Mercator EPSG:3857, satellite map: ESRI Satellite (ArcGIS/World_Imagery), scale: 1:35 000, method of interpolation: QGIS IDW, distance coefficient = 5.0, pixel size = 1.0).

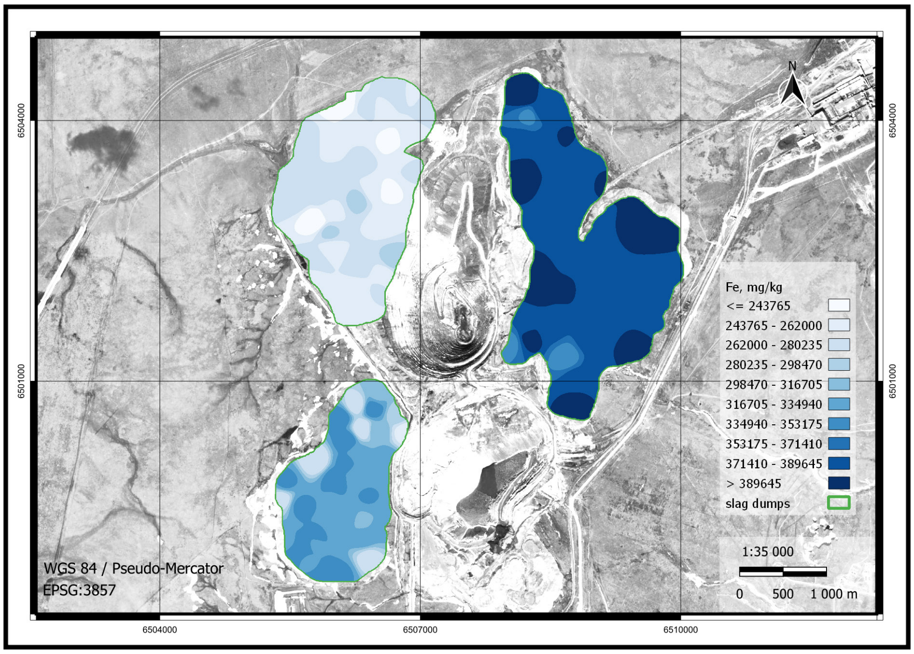

Fig. 7. Spatial distribution of Fe on the slag dumps of the Don MPP. (Coordinate system: WGS 84 : Pseudo-Mercator EPSG:3857, satellite map: ESRI Satellite (ArcGIS/World_Imagery), scale: 1:35 000, method of interpolation: QGIS IDW, distance coefficient = 5.0, pixel size = 1.0).

Table 5. Assessment of gross content of heavy metals in waste samples regarding MPC (n = 99).

Metal	Average gross content, wt. %	Average gross content, mg kg^{-1}	Range of gross content (Lim), mg kg^{-1}	Variation Coefficient, %	MPC, mg kg^{-1}	Average HQ	Share of samples where HQ > 1, %
Ca	6.7082	67082.45	65619-67968	0.0104	-	-	-
Fe	32.0772	320772.09	225529-407880	0.1672	-	-	-
Cr	0.1755	1754.69	722-2927	0.3996	6	292.45	100
Ti	1.6221	16220.91	13076-19246	0.1043	-	-	-
Mn	0.5341	5340.93	3115-8392	0.351	1500	3.56	100
V	0.0241	240.53	217-263	0.053	150	1.6	100
Zn	0.0117	116.7	99-155	0.1527	23	5.07	100
Cu	0.0059	59.4	52-77	0.1585	33	1.8	100
Ni	0.0728	727.58	298-1363	0.4857	4	181.89	100
Co	0.0775	775.18	452-1028	0.2141	5	155.04	100

The assessment of the environmental impact

To assess the environmental impact, we performed an evaluation by calculating the total pollution coefficients (Zc) both in terms of average values and in terms of specific values for each point studied. In this way, we were able to create a map of the spatial distribution showing the Zc values. We also made a comparison with the maximum permissible concentrations (MPC, mg kg^{-1}) established for the soil. During the analysis (Table 5), it was found that all waste samples exceeded the MPC values set by the Kazakh regulations for heavy metal content.

The extent of value excess was quantified by using hazard quotients (HQ) [13 - 15], where

$$HQ = \frac{actual\ gross\ content\ (\mathrm{mg\ kg^{-1}})}{MPC\,(\mathrm{mg\ kg^{-1}})} \quad (2)$$

This measurement allowed us to assess the magnitude of the potential risk or hazard posed by the observed excess values. By calculating the hazard quotients, we gained valuable insight into the extent of deviation from expected or allowable levels and were able to make a more accurate assessment of the potential hazards. The HQ levels were extremely high and achieve 292.45 in the case of chromium, 181.89 for nickel, and 155.04 for cobalt. The content of all detected heavy metals exceeded the MPC level in 100 % of the samples.

The extent of the impact of technogenesis can be assessed by comparison with indices representing the typical elemental content of the soil. This comparison can be made using indicators such as the maximum permissible concentrations (MPCs) established by Kloke for soil and by Clarke for both soil and lithosphere. (Table 6) [16]. The analysis showed extremal exceeding in the content of elements-pollutants. The most level of exceeding was observed for Cr, Fe, Co, Ni. Thus, Cr was exceeding the MPC by Kloke by 17.55 times, Co - 15.50 times, and Ni - by 14.55 times. Fe is exceeding the MPC by Vinogradov by 6.89 times, when comparing to Clarke in soil by Alekseenko the indicator of exceeding is increased to 14.38.

The total pollution indicator (Zc) is calculated as a comprehensive measure of pollution. It represents the cumulative excess coefficients of concentrations of chemical elements found in technogenic anomalies. The calculation of Zc is based on the Saeta index formula [9], which takes into account the deviations from normal or expected values of various elements. Using this formula, we can quantitatively assess the extent of pollution and better understand the overall environmental impact of the technogenic objects studied. Typical soils for the Aktobe region were taken as background samples from a pollution-free territory.

Based on the studied elemental impurities found in the soil of the Don MPP, we calculated the geochemical specialization formula [20-22], which is $Co_{107.66}Cr_{47.55}Ni_{25.26}Fe_{16.64}Mn_{10.16}V_{5.03}Cu_{3.32}Zn_{2.75}$. On average, the studied ground is of cobalt-chromium-nickel geochemical specialization.

For calculation of the Zc level, values of Kc by metals Cu, Fe, Zn, Cr, Mn, V, Co, and Ni were used.

The assessment scale is created by studying population health indicators in areas with different levels of pollution. The gradations within this scale allow for a comprehensive assessment of the health status in different areas. In the case of the Don MPP, the Zc indicator, calculated using the average metal concentrations in soil samples from three slag dumps, yielded a value of 209.37. According to the established

Table 6. Values of average gross content of heavy metals in waste samples in comparison with conventional indicators (n = 99).

Metal	Average gross content, mg kg^{-1}	MPC by Kloke, mg kg^{-1} [17]	Clarke in soil, mg kg^{-1} [18]	Clarke of the earth's crust, mg kg^{-1} by P. Vinogradov (1962) [19]	Background, mg kg^{-1}	Kc
Cu	59.4	100	39	47	17.9	3.32
Fe	320772.09	-	22300	46500	19274	16.64
Zn	116.7	300	158	83	42.4	2.75
Cr	1754.69	100	80	83	36.9	47.55
Mn	5340.93	-	729	1000	525.8	10.16
V	240.53	50	104.9	90	47.8	5.03
Co	775.18	50	14.1	18	7.2	107.66
Ni	727.58	50	33	58	28.8	25.26

criteria for evaluating environmental conditions and identifying areas of environmental emergency and disaster, the studied area exceeded the threshold of 128 for Zc, indicating significant soil contamination. Therefore, the studied area should be classified as an environmental disaster area due to the exceptionally high contamination. However, it should be taken into account, that the Zc indicator was calculated by the defined list of elements and the normal parameters of soils (the salt content, the content of organic mass in soil, pH, the content of nutrients, soil humidity and microbial activity) haven't been considered.

The Zc indicator was calculated for every sample point. The obtained spatial data were input as a layer into a map (Fig. 8).

The metals Co and Cr give the highest contribution in Zc level. Therefore, the spatial distribution of these metals correlates with the spatial distribution of the Zc indicator. The most polluted dumps are numbers 3 and 2 (Fig. 8).

The average coefficient of variation for the Zc index was calculated to be 23.04 %, indicating moderate uniformity of the index in the samples studied. This value indicates that the distribution of the Zc index follows an established statistical pattern and exhibits a moderate degree of variability among the observed values [23, 24]. Along with that, Zc in every point exceeded 128. Consequently, each dump can exert an extremal influence on the environment.

Technogenic resource assessment

For calculation of the approximate cost of the waste mass deposited in dumps, it is required to calculate the approximate weight of the waste mass, obtain the data on the composition, and the orienting market prices for the studied components. We can do that approximately knowing average density and volume of the waste mass. Density was calculated with the weighing a mixed sample from different parts of dumps. For calculation of the volume of dumps we used a formula of volume for of the truncated pyramid with a correlation of base and top areas as 2:1. The total area of the studied objects was used as the base area. Half of the base area was accepted as the top area. The geometry and gravimetry parameters of dumps are shown in Table 7.

Using the elemental content data, we were able to estimate the approximate occurrence of each detected element in its elemental state (Table 8). This analysis shows the significant economic potential of the dumps, with an estimated value of about $ 2.8

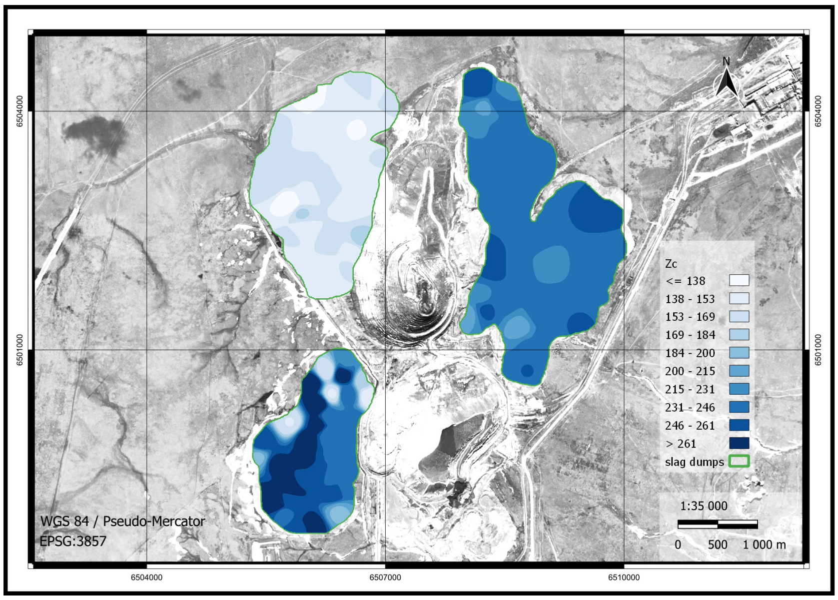

Fig. 8. Spatial distribution of Zc levels on the slag dumps of the Don MPP. (Coordinate system: WGS 84 : Pseudo-Mercator EPSG:3857, satellite map: ESRI Satellite (ArcGIS/World_Imagery), scale: 1:35 000, method of interpolation: QGIS IDW, distance coefficient = 5.0, pixel size = 1.0).

Table 7. Geometry parameters of studied storage for calculation of waste volume.

Storage	Average height, m	S_{base}, sq.m.	Bulk density, g cm^{-3}	Bulk density, kg m^{-3}	Volume, cub.m.	Weight, ton
Slag dump 1	97	1 303 000	0.99971	999.71	92 986 144.39	92 959 178.41
Slag dump 2	78	1 769 000	1.010865	1 010.87	101 513 669.29	102 616 615.31
Slag dump 3	52	875 000	1.02531	1 025.31	33 474 452.85	34 321 691.25
Total					227 974 266.54	229 897 484.97

Table 8. Economic assessment of gross content of heavy metals in waste samples regarding maximum permissible concentrations (MPC) (n = 75).

Metal	Average gross content, wt. %	Approximate content in the sludge storage, tons	Prices of metals, USD t^{-1} on 11.08.2022	Approximate cost of the deposit, USD
Ca	6.7082	15 421 983.09	-	-
Fe	32.0772	73 744 676.05	395.00 [25]	29 129 147 039.54
Ti	1.6221	3 729 167.10	-	-
Mn	0.5341	1 227 882.47 Corresponds to 1 942 286.81 of MnO_2	1 440 000.00 (MnO_2) [26]	2 796 893 009 006.22
V	0.0241	55 405.29 Corresponds to 197 720.85 of V_2O_5	16 314.19 (V_2O_5) [27]	3 225 655 557.32
Zn	0.0117	26 898.01	3 575.00 [25]	96 160 370.53
Cu	0.0059	13 563.95	7 971.00 [25]	108 118 258.31
Ni	0.0728	167 365.37	21 350.00 [25]	3 573 250 629.42
Co	0.0775	178 170.55	48 490.00 [25]	8 639 490 010.88
Cr	0.1755	403 470.09	12 456.00 [28]	5 025 623 392.79
Other	58.6909	134 928 903.01	-	-
Total	100	229 897 484.97	-	2 846 690 454 265.01

trillion. These results highlight the significant value and potential resource wealth in the area studied and underscore the importance of efficient exploitation and extraction methods to take advantage of this economic opportunity. The components Mn and V are not freely sold on the market as metal, which is why we calculated the partial cost as compounds MnO_2 and V_2O_5 freely sold on the market. It is obvious, that the product of refining has a greater cost than raw metals. However, even not considering the MnO_2 and V_2O_5 contributions the approximated cost of the waste accumulated in studied dumps will remain the great one and reach $ 41.54 billion.

CONCLUSIONS

In this study, we conducted a comprehensive investigation of waste materials found on the slag dumps of the Don Mining and Processing Plant in the Aktobe region of Kazakhstan. Our goal was to analyze the elemental composition of the waste and assess its potential environmental impact and economic value. A total of 99 sites were carefully sampled, at various depths from the surface down to about 50 cm. Each sample weighed at least 1 kg, resulting in an extensive data set for analysis.

For elemental analysis, we used an advanced X-ray fluorescence (XRF) analyzer BRA -18, which allowed us to identify and quantify the presence of specific chemical elements. Our investigation included the detection of elements such as Cl, K, Ca, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, and Pb, including several heavy metals. The XRF method proved to be extremely beneficial as it allowed the analysis of numerous samples without the need for extensive preparation procedures for solid, powder and liquid samples.

When analyzing the results, we found that the total content of the elements detected ranged from about 31% to 50 %. The highest concentrations were 40.788 wt. % for Fe, 6.7968 wt. % for Ca, and 1.9246 wt. % for Ti.

The results indicate that the wastes contain a significant number of valuable metals, especially Fe, Ti, Mn, and Cr, which offer potential opportunities for their use in various technological processes. Moreover, these metals can be extracted as metal concentrates, which further increases their economic value.

In conclusion, our study reveals the significant content of valuable metals in the studied wastes from Don mining and processing plant. The data obtained underscore the potential for using these materials in the manufacture of new technological products or in the recovery of valuable metal concentrates. Such efforts are promising for both environmental management and economic prosperity.

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