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Original article

PCA analysis of soil geochemical data and environmental assessment of the pre-mining Shuteen area, South Mongolia

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ABSTRACT

There are widespread mineralized systems, occurrences, deposits that occurred in the South Gobi, Mongolia, where many of them already undergone mining activity. However, not all of them have a pre-mining environmental assessment. The Shuteen area is one of these highly prospective areas for mining; due to the porphyry copper system observed, prospecting and exploration projects have been carried out since 1980. Numerous prospecting and exploration works have been done during 1997–2007 and suspended last decade because of economic and political reasons. The area is located in a Gobi-desert environment and wind plays a main role in the transport and mobility of the elements. This research was conducted to assess the environmental condition of the area, based on soil, dry river sediment, and drinking water geochemistry. We are expecting the area has a naturally high concentration of some heavy metals in soil, concerning the geology and mineralization. The results show that the heavy metal content in the soil does not exceed the permissible limit of the Mongolian National standard on soil quality. Whereas, the water samples contain F^- above the permissible limit guided in the Mongolian National Standard on drinking water quality. The unusual chemical composition of the water is related to the soil composition characteristic of the Gobi region. They are characterized by low alkali, high salinity and mineral/water ratios are high. Environmental assessment surveys determine the characterization of an areal geochemical base prior the development of later exploration or mining project, might have affect it and establish the initial environmental status.

Keywords: *Geoenvironment, Geology, Mineralization, Natural baseline*

INTRODUCTION

Environmental assessment of mining area is a benefit to avoid the danger for human, animal, and natural environment from the heavy metal pollution. A few numbers of studies related to mining impact on the environment have been done at the Erdenet Mine including the preliminary result of previous research (Munkhtsengel, 2007; Namkhai, 2000; Bolor-Erdene et al., 2001; Jachek, 2005; Jachek et al., 2005; Batbold et al., 2014). Moreover, the pollution of river systems in Mongolia has been considered in several studies, which mentioned that there are several pollution sources including mining sites (Altansukh, 2008; Byambaa and Todo, 2011; Batbold et al., 2014).

South Gobi is an important mining district in Mongolia, comprising several active explorations, such as the well-known Oyutolgoi, Tsagaan Suvarga and Kharmagtai porphyry copper deposits. However, there are no pre-mining environmental assessments of copper mineralized deposits in southern Mongolia, including the study area. Our study is based on geochemical analysis of soil and water at the pre-mining Shuteen copper porphyry mineralized area, in the South Gobi, aiming to assess the current environmental situation and compare to the adjacent areas information (Batkhishig et al., 2017a,b). During 2008–2012, the China

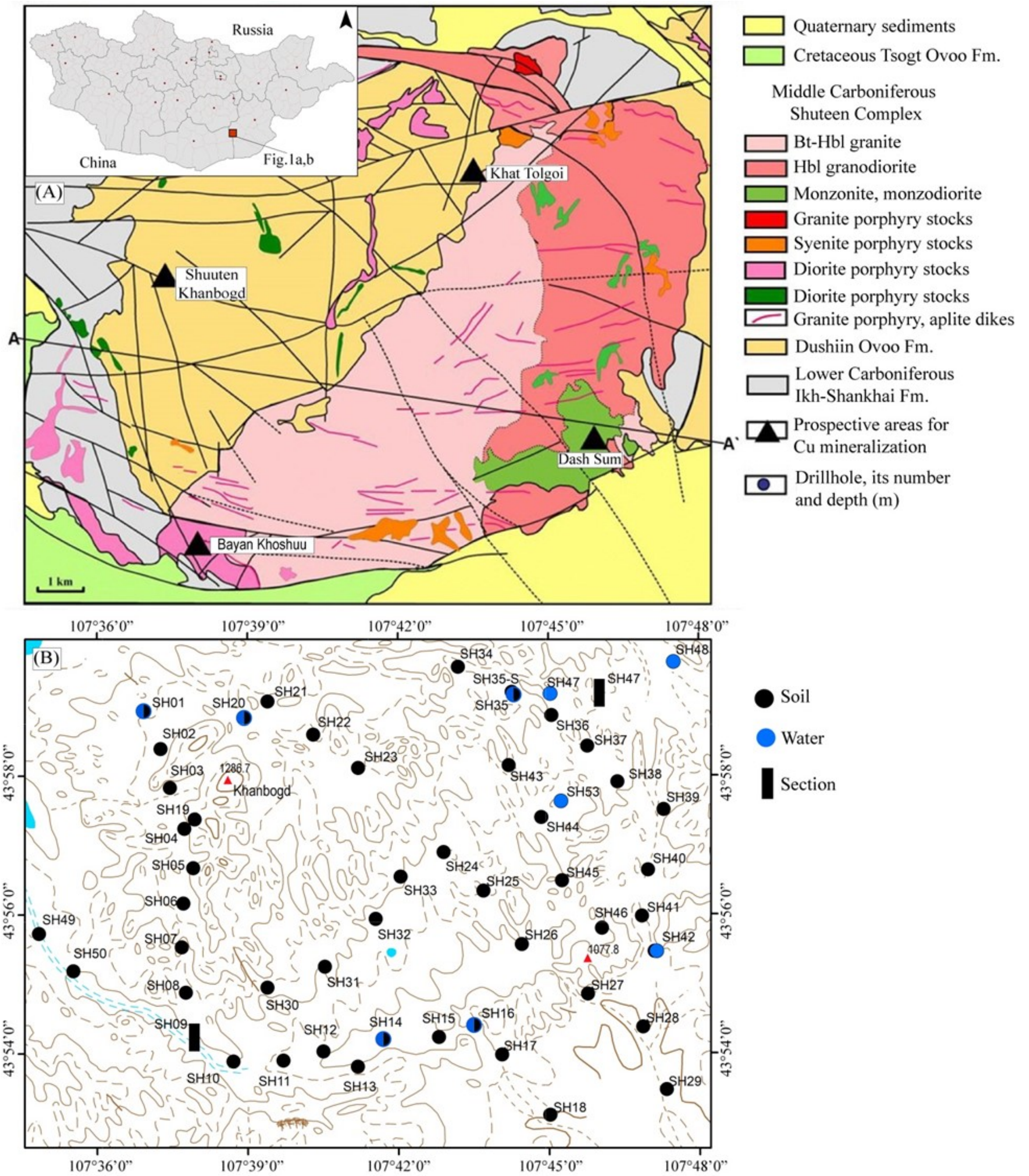


Fig. 1. (A) Geologic map of the Shuteen area. The main copper prospects are denoted by triangles: Shuteen Khanbogd lithocap, Khar Tolgoi, Bayan Khoshuu, and Dash Sum (Batkhishig et al., 2014). (B) Soil and water sampling points and their location for the environmental assessment (Batkhishig et al., 2017b).

Mongolian joint project conducted the 1:1 000 000 scale geochemical mapping along China–Mongolian Boundary. They have taken soil samples by 1:100 000 scale network (1:1000000 geochemical, 2012). Our soil data results are compared to the results of this project.

Shuteen has a semi-arid climate with average annual precipitation of 105.7 mm and wind 3.5-4.0 m/sec average wind speed (IRIMHE, 2008), without vegetation cover on the surface. A sampling campaign was carried out in May 2016, and a total of 25 rock samples, 57 soil samples and 9 water samples were taken from the Shuteen copper porphyry mineralized area to examine their geochemical composition concerning geological background and impact of mining activity on heavy metal accumulation (Fig 1).

MATERIALS AND METHODS

Samples

Soil samples were taken from the wide dry stream and downstream sediments (Fig. 1) and dried well bottom soil to investigate accumulation and transportation of the contaminants originated from the geological

Fig. 2. Water sampling in the Shuteen area. A and B. drinking water well, C. livestock watering well, D. natural spring.

background. Besides, we selected 2 places to take soil samples by cross-section to check vertical evaluation. The cross-section ranges from 2–7 m and each different soil layer sampled separately, sample intervals are approximately 10–20 cm. Soil samples were taken from 10–20 cm depth and avoided the input of ground organic materials and placed in a clean plastic bag (MNS 3298:90). After complete drying, the soil samples were sieved by 2 mm mesh, then fine particles about 100 gr used for further sample processing. The prepared 100 gr soil samples grinded using vibration sample mill Heiko Tl-100 for 20 minutes until the grain size suited for routine analysis. After that, without any additional binders, we prepared pellets with an inner diameter of 25 mm, under hydraulic pressure of up to 20 tons using Model N3124, NPa System Co., Ltd., Tokyo, Japan equipment.

Water samples were taken from drinking water wells (Fig. 2A, B), livestock watering wells (Fig. 2C), and natural spring water (Fig. 2D) in the area. Physiochemical parameters of water were measured at the sites. Temperature, pH, and electric conductivity (EC) were measured in the field using a portable Horiba U-23 combined instrument. Water samples were collected by the two-step extraction method. 10 ml samples filtered by an inorganic paper filter and directly bottled in polyethylene bottles and the other 10 ml is filtered and acidified to 0.2% HNO_3 (0.03 ml HNO_3+9.97 ml water) for heavy metal analysis. All samples were stored at a temperature below +4°C until analysis.

LABORATORY ANALYSIS

Energy dispersive X-ray fluorescence spectrometry (EDXRF)

Major elements SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5 and S and trace element V, Cr, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Sn, Cs, Ba, La, Ce, Pr, Nd, Pb and Th abundances in the sediments were determined by X-ray fluorescence in the Graduate School of Environmental Studies, Tohoku University using a PANanalytical, Epsilon 5. The instrument was equipped with a Sc/W anode X-ray tube, with the goal of increased sensitivity for lighter as well as heavier elements. The instrument has a series of user-selectable secondary targets and is equipped with a liquid-nitrogen-cooled Ge solid-state high-resolution detector with a Be (8 μm) window. A three-dimensional design (or Cartesian geometry) was adopted for the instrument to eliminate the X-ray tube spectrum by polarization. Consequently, the background can be an order of magnitude lower than the traditional two-dimensional optics, resulting in much lower detection limits. The overlapping of the characteristic L lines of heavier elements with the K lines of lighter elements (a typical example is the overlap of Cd L lines on K lines) has been known as one of the major drawbacks in determining heavy elements with the EDXRF method. However, since the instrument used in this study is equipped with a 100 kV Sc/W tube, even heavy rare earth elements (from Eu to Lu) can be analyzed using the more sensitive K lines and hence is less susceptible to spectral overlapping with the K lines of lighter elements. The instrument was calibrated with 26 geological and environmental standard reference materials (Matsunami et al., 2010; Yamasaki et al., 2011; Yamasaki, 2018).

Inductively coupled plasma mass spectrometry (ICP-MS)

Trace and rare elements (Li, B, Al, Sc, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Mo, Cd, Sb, Cs, Ba, Pb, and U) in water and soil samples were carried out using an ICP-MS PerkinElmer, ELAN 9000 equipment, in the laboratory of the Graduate School of Environmental Studies, Tohoku University. Sample preparation was performed by acid-leaching method. Half a gram of each finely ground soil sample was treated with 4 ml of perchloric acid ($HClO_4$) and hydrofluoric acid (HF) (1:1 mixture) in a closed polytetrafluoroethylene (PTFE) vial. The sample was dissolved with 6 ml of (HNO_3) and water (2:4 mixture) and then was treated with 8 ml of hydrochloric acid (HCl) and water (2:6 mixture). Each treatment for the sample was performed in the closed vials on a hot plate for 1 night at 140^0C. After cooling, the vials were opened and then heated at 210^0C until completely dry. Finally, the residue was heated with 25 ml of nitric acid (HNO_3) and water (1:10 mixture) and dissolved by the addition of 25 ml of H_2O and made up to 50 ml. The final solutions were stored in plastic bottles until measurement. After a 100-fold dilution of the final solution, the acid digests were analyzed by ICP–MS for trace elements. Indium (In) was used as an internal standard (Yamasaki 1996; 2000). For the determination of In, however, rhodium (Rh) was used as an internal standard. The working standards were prepared from a series of SPEX Multi-Element Plasma Standards (XSTC-1, XSTC-7, XSTC-8, and XSTC-13 and XSTC-331) supplied by SPEX Industries (New Jersey, USA).

Ion chromatography

Major anions (F^- Cl^-, NO_2^- Br, NO_3^- PO_4 and SO_4^{2-}) were determined using an ion-chromatography 881 Compact IC pro, Metrohm with 1% accuracy at the Graduate School of Environmental Studies, Tohoku University, Japan. The analytical error for the measurement of major ions was determined by calculating the ionic charge balance, which was within ± 5% for all samples.

Data analysis

Principal compound analysis (PCA) this method aid in reducing the complexity of large-scale data sets and are currently broadly used in environmental impact (Candeias et al., 2011) studies elucidate relations among variables by identifying common underlying processes (Davis, 1986; Webster and Oliver 1990; Wackernagel 1998). PCA, was performed, using JMP 12.0.1 statistical software.

GEOLOGY AND MINERALIZATION AT THE SHUTEEN AREA

The Shuteen area contains intermediate volcanic rocks of the Dushiin-Ovoo Formation and plutonic rocks of Shuteen pluton (also called Shuteen Complex) were emplaced over and into the Lower Carboniferous Ikh Shankhai Formation, respectively (Fig. 1). Quaternary sediments are located in the topographic lower areas. The Shuteen Complex is approximately 15x13 km in size (Fig. 1) and is characterized by co-magmatic andesitic, dacitic, and rhyolitic volcanic rocks, diorite, and granodiorite (Batkhishig, 2005; Batkhishig et al., 2010). The Shuteen pluton has a well-defined isochron age of 321 ± 9 Ma, whereas the Shuteen andesites yielded a 336 ± 24 Ma Rb–Sr whole-rock isochron age (Iizumi and Batkhishig, 2000; Batkhishig et al., 2010). A 325.5 ± 1 Ma U-Pb zircon age was obtained from the Shuteen quartz monzonite, and microgranite dikes that crosscut the intrusion have been dated at 325.4 ± 1 Ma (Blight et al., 2010). The Shuteen Complex contains local silicic, potassic, advanced argillic, and propylitic alteration assemblages, and weakly developed porphyry-style copper mineralization is associated with small porphyritic intrusions. Gold-bearing quartz and quartz–tourmaline veins and domains of intense alunite alteration have been found on the periphery of the main Shuteen alteration zone. (Hovan et al., 1982, 1983; Batkhishig et al., 2014). Geologic, surface geochemical, and geophysical data have revealed intensely developed hydrothermal alteration zones and weak copper porphyry mineralization locally associated with porphyritic intrusions. Several prospects of copper mineralization are recognized within the complex, including Shuteen-Khanbogd, Khar Tolgoi, Bayan Khoshuu, and Dash Sum (Fig. 1). Currently, it is concluded that the Carboniferous Shuteen Complex hosts one or more fossil magmatic-hydrothermal systems. During the early stages of magmatic-hydrothermal fluid activity, weak copper porphyry mineralization associated with potassic and propylitic alteration formed in association with the emplacement of porphyry intrusions into the Shuteen Complex. Extensive exploration activity at Shuteen has not yet identified any economic resource, only large-scale geochemical anomalies and hydrothermal alteration zones have been identified. The copper porphyry style mineralization remains to be discovered in the Shuteen area and it is likely to be concealed beneath the Shuteen lithocap (Batkhishig, 2005; Batkhishig et al., 2014).

RESULTS

Soil geochemistry

Results of geochemical analysis of the soil samples are shown in Table 1. Average contents of heavy metals in the Shuteen soil are Cu ~35

Table 1. Major and trace element composition of the soil samples from the Shuteen area

%	SH01	SH02	SH03	SH04	SH05	SH06	SH07	SH08	SH09	SH10	SH11	SH12	SH13	SH14	SH15	SH16	SH17	SH18	SH19	SH20	SH21	SH22	SH23	SH24	SH25
SiO_2	64.8	67.4	74.1	76.4	79.5	71.5	75.1	71.6	69.6	70.3	74.5	74.6	69.3	75.7	72.2	75.2	74.4	73.1	68.2	75.4	67.9	65.2	67.5	70.1	71.4
TiO_2	0.57	0.47	0.51	0.42	0.36	0.63	0.47	0.50	0.52	0.50	0.44	0.43	0.53	0.43	0.47	0.43	0.42	0.45	0.58	0.43	0.49	0.51	0.52	0.49	0.47
Al_2O_3	14.3	13.3	13.1	12.2	10.2	12.9	12.1	13.6	12.6	12.9	11.8	12.2	12.8	11.9	12.3	11.0	11.9	12.4	13.6	11.0	13.6	13.3	13.5	12.8	12.7
MnO	0.079	0.06	0.057	0.057	0.035	0.08	0.061	0.08	0.07	0.064	0.058	0.055	0.06	0.055	0.054	0.049	0.045	0.053	0.072	0.061	0.069	0.066	0.071	0.066	0.059
MgO	3.13	2.55	1.67	1.73	1.08	2.26	1.83	2.17	2.33	2.39	1.88	1.83	2.14	1.73	1.78	1.54	1.64	1.79	2.85	2.28	2.82	2.91	2.77	2.44	2.44
CaO	3.21	2.23	1.75	1.54	1.20	1.70	1.47	1.92	2.48	2.39	2.22	2.24	2.57	1.91	2.07	2.02	2.10	2.29	3.09	1.92	2.88	3.05	3.76	2.92	2.74
Na_2O	2.46	2.62	2.23	2.44	2.43	2.25	2.31	2.22	2.68	2.56	2.63	2.75	2.32	2.65	2.66	2.87	2.74	2.70	2.24	2.37	2.61	2.25	2.55	2.47	2.47
K_2O	2.71	2.93	2.50	2.59	2.67	2.72	2.48	2.70	2.93	2.78	2.76	2.90	3.13	2.77	2.99	2.78	2.98	3.10	2.45	1.95	2.86	2.89	2.59	2.60	2.55
P_2O_5	0.16	0.09	nd	0.01	nd	0.10	0.01	0.07	0.12	0.11	0.09	0.11	0.11	0.01	0.09	-	0.11	0.08	0.07	0.06	0.14	0.15	0.11	0.08	0.15
Fe_2O_3	5.02	3.55	3.78	3.20	2.32	4.28	3.53	3.79	3.55	3.73	3.23	3.28	3.49	3.27	3.09	2.82	2.62	3.18	4.65	3.76	3.72	3.60	4.06	3.73	3.52
Trace elements (ppm)																									
As	12.8	10.4	18.9	16.7	13.4	16.8	20.6	48.3	17.7	22.6	18.6	19.7	13.3	20.7	14.2	14.5	12.3	14.4	15.1	15.2	10.2	10.0	10.2	11.6	10.2
Ba	620	675	585	567	580	578	549	560	604	591	596	633	610	584	626	587	622	621	571	471	638	643	596	583	564
Br	nd	0.34	0.26	nd	nd	nd	0.27	0.99	nd	0.39	nd	0.32	nd	0.32	nd	0.29	nd	nd	nd	nd	nd	nd	nd	nd	nd
Cd	0.04	0.15	nd	0.11	nd	0.05	0.10	0.16	nd	0.07	0.02	0.02	0.04	0.07	nd	0.06	0.03	nd	0.08	nd	nd	nd	nd	nd	nd
Ce	25.7	19.9	23.0	18.5	18.5	33.3	23.3	22.3	23.7	21.5	20.8	21.1	31.0	20.9	20.1	20.8	24.5	25.0	23.3	20.3	22.3	26.7	25.5	24.3	25.1
Co	11.7	7.33	8.23	6.89	4.65	9.65	7.69	8.06	7.47	7.92	6.95	7.22	7.41	7.48	6.44	6.20	5.30	6.84	10.5	7.95	8.18	7.52	8.92	8.30	7.62
Cr	41.4	32.6	54.3	40.0	32.6	80.3	47.8	61.9	52.0	47.0	61.4	44.2	70.3	44.1	56.7	47.1	35.2	48.3	44.7	41.0	79.6	54.3	52.5	70.9	51.9
Cs	4.55	3.64	2.66	2.59	2.84	2.15	2.34	2.85	3.10	3.07	3.50	3.20	3.57	2.99	3.16	2.51	3.35	3.28	2.88	2.05	3.35	3.99	2.79	2.65	2.38
Cu	47.1	32.1	33.0	30.3	18.9	30.8	29.6	37.0	33.0	35.1	37.4	33.9	45.9	34.9	29.1	26.2	26.3	27.5	43.0	38.5	36.1	31.9	37.3	36.9	33.3
I	1.58	1.55	1.47	1.50	1.41	1.17	1.45	1.35	1.56	1.25	1.47	1.47	1.67	1.39	1.38	1.18	1.22	1.55	1.75	1.06	1.18	1.50	1.36	1.14	1.23
La	12.5	8.52	11.0	8.87	7.28	15.3	10.7	10.3	12.2	11.8	10.6	11.2	14.6	10.2	11.5	10.4	12.6	12.1	10.1	10.7	11.0	12.5	11.5	11.7	13.2
Mo	0.71	0.62	2.43	1.31	1.51	3.97	2.00	1.60	1.20	0.91	1.24	1.25	1.97	1.40	1.16	1.84	1.12	1.47	1.42	1.41	0.92	0.90	1.27	1.34	0.94
Nb	4.13	4.23	5.37	4.51	5.06	7.18	5.40	4.15	4.78	4.35	3.98	4.23	5.60	4.25	4.45	4.82	4.70	4.91	4.49	3.91	4.24	4.67	4.93	4.75	4.56
Nd	14.5	12.2	13.0	10.6	10.9	17.0	13.2	12.3	13.1	13.2	13.1	11.5	16.2	12.3	12.0	12.1	13.0	12.6	14.1	11.8	13.1	15.9	13.8	13.2	13.7
Ni	22.3	20.6	22.0	19.8	17.4	22.5	21.7	28.6	26.4	26.4	24.2	26.1	24.2	24.1	25.0	21.8	22.1	23.7	19.4	23.1	26.4	24.1	23.1	23.7	24.1
Pb	13.3	16.0	16.8	14.0	15.9	19.9	18.8	21.1	15.0	14.1	14.0	14.4	16.9	12.7	14.8	12.8	15.0	14.8	15.3	13.6	14.7	16.7	14.4	15.1	14.0
Pr	1.39	0.80	0.80	0.80	0.80	2.00	1.51	1.35	0.80	1.74	0.80	0.80	2.11	1.24	0.80	0.80	0.80	0.80	0.80	1.16	0.80	1.34	1.14	0.80	0.80
Rb	65.9	78.7	65.7	68.0	73.6	72.6	63.9	70.1	76.0	68.8	70.7	73.2	86.3	68.2	78.8	71.5	77.5	81.4	62.3	48.1	74.8	84.7	66.9	69.4	66.0
S	nd	0.09	0.02	2.22	nd	nd	1.66	0.12	0.19	0.03	0.11	0.04	0.11	1.39	3.30	nd	0.03	0.23	0.01	2.06	0.10	0.09	0.16	0.09	0.16
Sb	0.58	0.62	0.75	0.62	1.14	1.28	1.19	1.42	0.98	0.67	0.71	1.08	0.61	0.80	0.63	0.75	0.99	0.75	0.53	0.59	0.36	0.33	0.49	0.38	0.67
Sn	1.01	0.97	2.11	1.17	1.41	3.61	1.14	1.11	1.36	0.85	1.10	0.72	0.97	0.91	0.91	1.11	1.75	1.08	0.57	1.27	0.91	0.80	0.93	3.62	1.71
Sr	427	342	307	280	252	287	276	318	311	340	319	348	314	339	326	314	322	332	352	291	371	362	383	355	353
Th	4.30	4.29	4.23	4.38	4.33	4.80	3.75	3.34	5.18	4.24	4.85	4.78	7.16	4.44	4.93	4.87	6.26	5.73	3.84	3.71	4.36	4.71	4.00	4.54	5.21
V	123	81.3	87.2	75.4	57.0	105	80.2	84.1	82.1	85.2	78.1	83.2	81.0	77.4	81.2	67.4	63.9	77.0	111	86.8	83.8	83.9	93.1	85.5	84.0
Y	13.7	11.9	12.5	11.4	8.62	15.4	11.7	12.3	12.5	12.4	11.6	11.8	13.2	11.4	10.6	10.2	10.7	11.8	12.9	10.8	11.9	12.5	13.3	13.2	11.8
Zn	61.6	48.0	46.1	48.4	31.8	61.1	54.7	111	51.3	58.5	50.6	50.8	46.8	49.0	44.6	45.3	41.4	45.0	54.7	48.5	48.5	48.0	51.6	47.8	45.5
Zr	116	121	176	123	137	323	149	131	158	106	131	116	195	118	122	118	138	144	126	103	121	125	157	165	145

Table 1. Major and trace element composition of the soil samples from the Shuteen area (continued)

%	SH26	SH27	SH28	SH29	SH30	SH31	SH32	SH33	SH34	SH35	H35W	SH36	SH37	SH38	SH39	SH40	SH41	SH42	SH43	SH44	SH45	SH46	SH47	SH48	SH49	SH50
SiO_2	72.1	71.8	69.3	69.3	72.8	74.1	68.2	72.5	69.8	73.3	70.8	71.9	70.8	68.8	74.3	70.7	68.5	68.6	71.6	68.9	71.3	57.7	71.7	70.2	69.2	73.4
TiO_2	0.40	0.39	0.44	0.43	0.65	0.52	0.64	0.64	0.54	0.46	0.43	0.49	0.49	0.51	0.38	0.41	0.44	0.44	0.46	0.50	0.42	0.78	0.45	0.48	0.49	0.47
Al_2O_3	12.4	13.3	13.3	13.2	14.8	12.3	14.5	12.1	12.9	11.7	11.4	12.0	12.4	12.8	10.8	12.8	13.3	12.7	12.1	12.9	12.6	16.0	12.0	11.9	13.2	12.6
MnO	0.050	0.048	0.056	0.053	0.076	0.057	0.092	0.116	0.078	0.079	0.055	0.064	0.064	0.062	0.055	0.058	0.059	0.056	0.075	0.065	0.053	0.140	0.054	0.057	0.063	0.059
MgO	2.00	1.93	2.15	2.07	1.33	1.89	2.55	2.35	3.25	2.73	2.29	2.68	2.71	2.70	2.19	2.27	2.36	2.25	2.69	2.54	2.18	4.05	2.24	2.48	2.06	1.87
CaO	2.64	3.18	3.62	3.48	1.47	1.82	2.93	2.47	3.00	2.33	3.01	2.56	2.81	2.87	2.52	3.00	3.26	3.72	3.21	3.03	2.60	4.67	2.44	2.61	2.23	1.91
Na_2O	2.78	2.99	2.98	3.02	1.86	2.17	2.30	2.17	2.35	2.28	2.49	2.45	2.61	2.36	2.40	2.83	2.83	2.65	2.34	2.52	2.57	1.01	2.67	2.21	2.48	2.79
K_2O	2.62	2.54	2.51	2.64	2.30	2.61	2.68	2.23	2.33	2.32	2.70	2.36	2.49	2.70	2.30	2.80	2.71	2.66	2.16	2.59	2.58	3.13	2.72	2.64	3.21	3.23
P_2O_5	0.17	0.13	0.18	0.12	nd	0.01	0.17	0.10	0.15	0.09	nd	0.17	0.17	0.18	0.12	0.13	0.13	0.10	0.13	0.12	0.11	0.16	0.12	0.10	0.11	0.16
Fe_2O_3	3.07	2.95	3.51	3.08	5.46	3.59	4.68	5.80	4.45	3.89	3.08	4.09	4.03	3.72	3.08	3.19	3.31	3.38	4.25	3.72	3.11	6.76	3.24	3.38	2.86	2.83
Trace elements (ppm)																										
As	10.4	12.2	13.2	11.9	19.7	14.4	16.1	15.3	21.1	18.1	12.0	13.5	14.3	12.3	11.9	9.61	11.4	13.1	34.9	19.2	13.8	22.5	12.8	10.2	12.6	12.0
Ba	590	602	607	640	581	581	627	558	517	511	579	517	559	615	526	637	664	641	518	586	556	581	604	570	641	641
Br	nd	nd	nd	0.25	nd	nd	nd	0.37	0.27	1.59	nd	nd	0.57	nd	0.26	nd	-	0.67	0.26	-	4.81	-	-	0.42	-	-
Cd	nd	nd	nd	nd	nd	0.00	0.03	0.08	nd	0.09	nd	nd	nd	nd	nd	nd	-	0.06	0.13	-	-	0.18	-	-	-	-
Ce	22.7	21.5	25.8	22.3	24.6	26.9	32.2	26.3	23.0	21.1	26.0	24.6	22.5	26.6	17.9	21.8	22.4	21.4	23.5	26.6	21.3	56.4	21.5	23.6	27.8	28.4
Co	6.62	6.24	7.61	6.27	13.1	7.89	10.8	15.3	10.1	8.54	6.61	9.21	9.22	8.24	6.62	7.06	6.86	7.17	10.0	7.93	6.42	16.7	7.22	7.19	5.66	6.19
Cr	56.6	47.6	59.3	47.8	65.3	58.2	128	119	81.7	119	67.6	81.5	72.7	73.4	70.4	43.7	46.8	53.5	87.5	55.5	46.5	95.4	56.1	44.1	44.0	54.9
Cs	2.45	2.79	2.86	2.92	2.12	3.49	2.73	1.96	2.41	2.26	3.75	3.10	1.81	2.97	2.03	3.14	2.81	2.51	2.34	3.01	2.22	6.71	2.65	3.16	3.92	4.49
Cu	29.3	31.0	33.1	30.0	42.7	32.1	42.5	45.4	40.5	34.8	29.4	39.1	36.9	35.2	37.5	30.0	31.2	34.3	42.9	37.8	32.0	63.8	30.6	29.1	23.5	22.5
I	1.16	1.51	1.17	1.09	2.08	1.64	1.65	1.26	1.04	0.81	1.52	1.04	1.13	1.18	1.15	1.32	1.53	1.21	1.28	1.24	1.34	3.41	1.22	1.24	1.88	1.51
La	11.6	10.5	13.0	11.3	10.5	13.6	14.7	12.1	10.9	10.0	13.1	12.4	10.6	12.3	8.10	10.3	10.6	9.71	12.3	12.9	9.63	28.4	9.63	11.9	14.2	14.6
Mo	0.82	0.81	1.20	0.79	3.13	2.05	2.82	2.97	1.55	1.16	1.62	1.53	1.62	1.69	0.50	0.67	0.83	0.67	1.10	1.33	1.14	1.77	1.08	1.21	0.98	1.25
Nb	3.58	3.54	4.03	3.60	5.57	5.34	5.94	4.77	4.22	4.06	5.17	4.20	4.26	4.85	3.51	4.03	3.66	3.93	3.66	4.02	3.91	8.47	4.39	5.08	5.25	5.76
Nd	12.8	12.5	13.9	13.4	13.8	13.9	17.3	14.3	12.7	12.3	12.1	12.3	13.5	14.5	10.4	12.4	14.7	13.3	14.1	14.5	12.2	26.4	13.2	13.7	14.2	15.0
Ni	23.0	23.4	23.2	23.0	23.4	26.0	26.6	28.7	26.1	25.2	23.3	24.3	26.5	25.7	23.1	24.7	25.1	23.2	25.5	24.6	22.6	42.2	22.3	24.2	23.7	24.6
Pb	12.6	12.2	11.9	13.2	13.4	14.5	17.0	14.8	12.4	12.9	14.4	12.6	11.7	12.7	11.5	12.8	12.7	12.5	12.9	12.7	11.6	19.1	14.1	14.4	14.9	14.7
Pr	0.80	1.11	0.80	0.80	2.38	1.46	1.86	1.36	0.80	1.97	0.80	0.80	1.83	2.70	2.07	0.80	0.80	0.80	2.27	0.80	0.80	3.09	0.80	0.80	0.80	0.80
Rb	65.1	63.4	61.8	64.4	60.0	68.4	71.5	56.4	54.9	57.8	72.0	61.0	59.9	69.8	56.1	65.9	65.0	67.0	55.2	69.3	66.5	96.3	72.1	69.8	89.8	87.8
S	0.06	0.25	0.00	0.38	0.01	0.07	0.12	0.10	0.26	0.01	nd	0.05	0.05	0.01	0.39	0.03	0.24	0.05	-	0.10	0.03	0.00	0.37	0.10	0.07	0.14
Sb	0.69	0.71	0.94	0.77	0.85	0.96	0.89	0.55	0.81	0.78	0.83	0.39	0.79	0.38	0.75	0.46	0.30	0.53	1.08	0.64	0.91	1.20	0.40	0.18	0.28	0.71
Sn	0.96	0.80	1.39	0.86	2.92	1.44	0.76	1.52	0.84	0.50	1.53	1.31	1.20	1.53	0.79	0.77	0.42	0.83	0.79	0.97	0.93	2.78	1.94	0.78	1.34	1.19
Sr	399	500	478	470	391	303	426	382	324	283	311	321	368	369	318	421	471	455	397	386	380	319	319	299	281	292
Th	4.62	4.00	3.94	3.62	2.86	4.93	4.26	3.13	2.91	3.35	4.81	3.92	4.37	4.23	4.17	4.65	4.58	4.33	3.66	4.98	4.27	8.12	4.46	5.23	5.62	5.68
V	74.1	71.2	92.8	74.3	127	78.5	105	138	109	84.0	58.7	97.6	101	88.2	70.3	81.4	82.5	88.6	97.5	86.5	72.3	119	70.7	74.5	61.1	59.5
Y	10.6	9.52	10.1	9.93	12.5	11.2	14.0	14.8	14.0	11.1	11.8	14.0	11.1	11.7	9.18	10.0	10.6	10.0	12.6	12.3	9.88	24.1	11.4	12.1	14.6	14.7
Zn	43.0	39.8	42.6	41.3	52.1	47.4	63.4	53.0	56.8	46.8	43.4	46.4	44.6	43.2	41.2	44.2	44.0	41.6	51.7	48.4	40.3	87.9	42.0	44.2	41.1	41.5
Zr	127	107	132	112	155	191	237	137	135	109	147	158	155	163	88.9	107	111	102	110	132	124	186	138	145	145	200

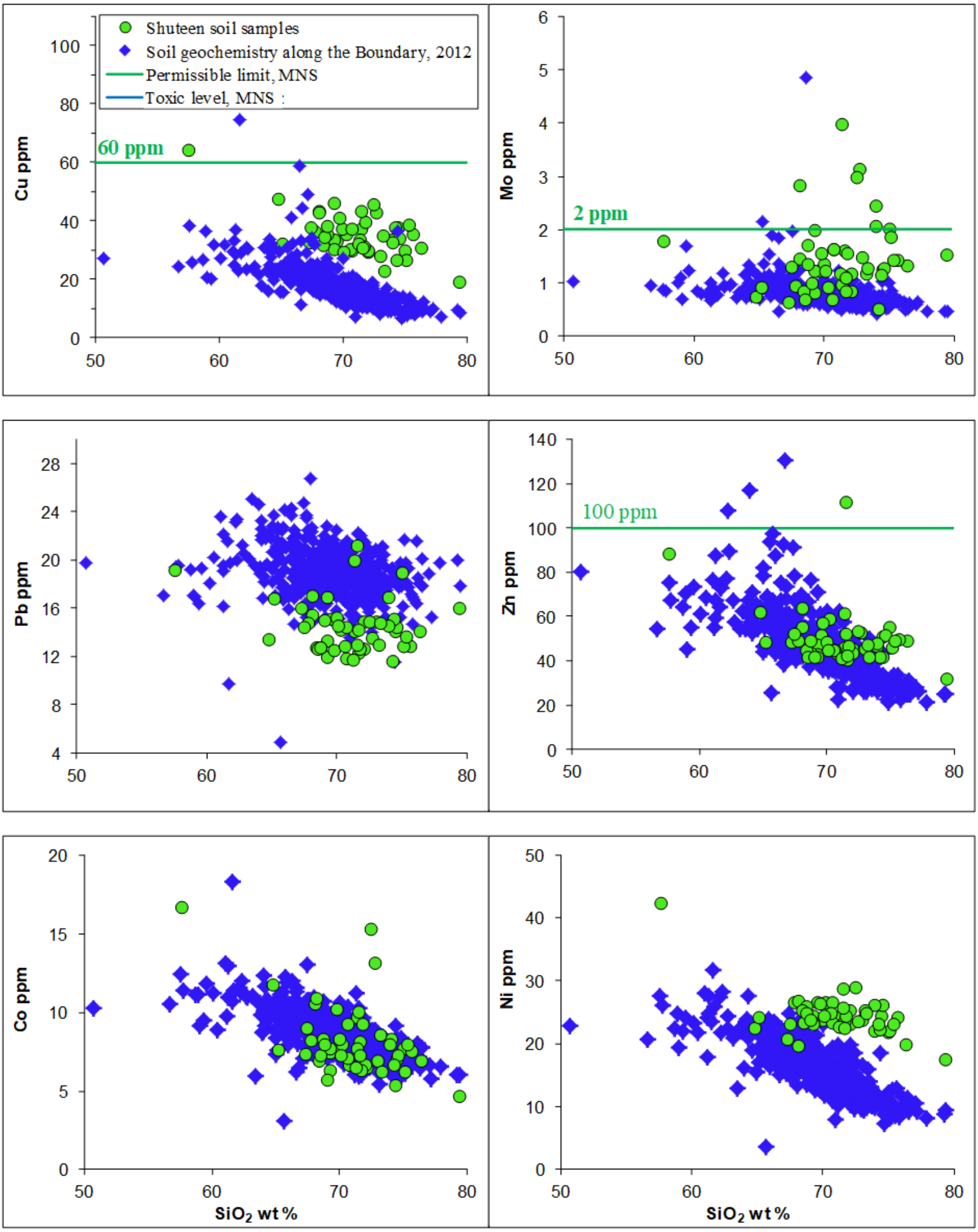


Fig. 4. Heavy metal contents vs SiO_2 diagram for the Shuteen area.

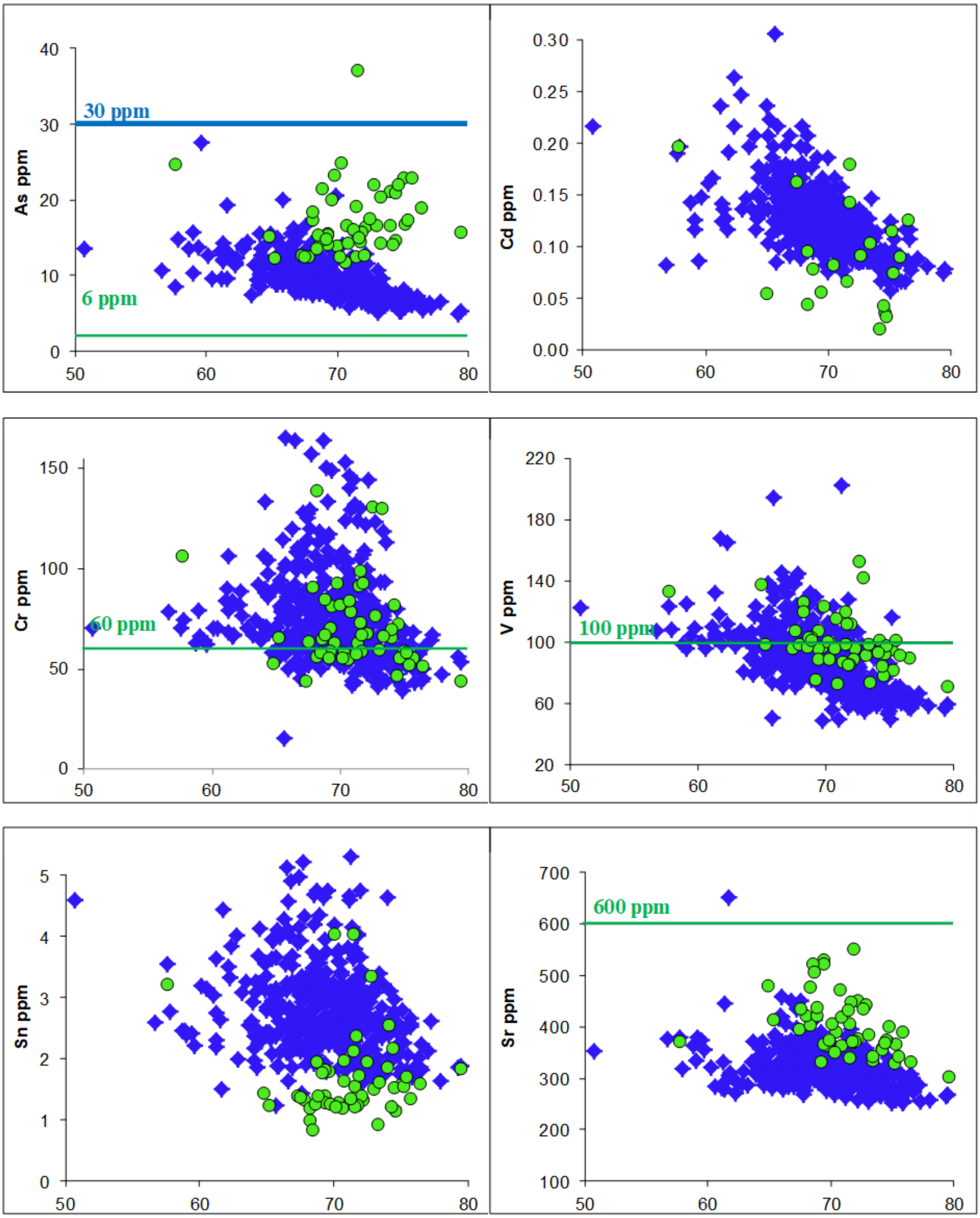


Fig. 4. Heavy metal contents vs SiO_2 diagram for the Shuteen area (continued).

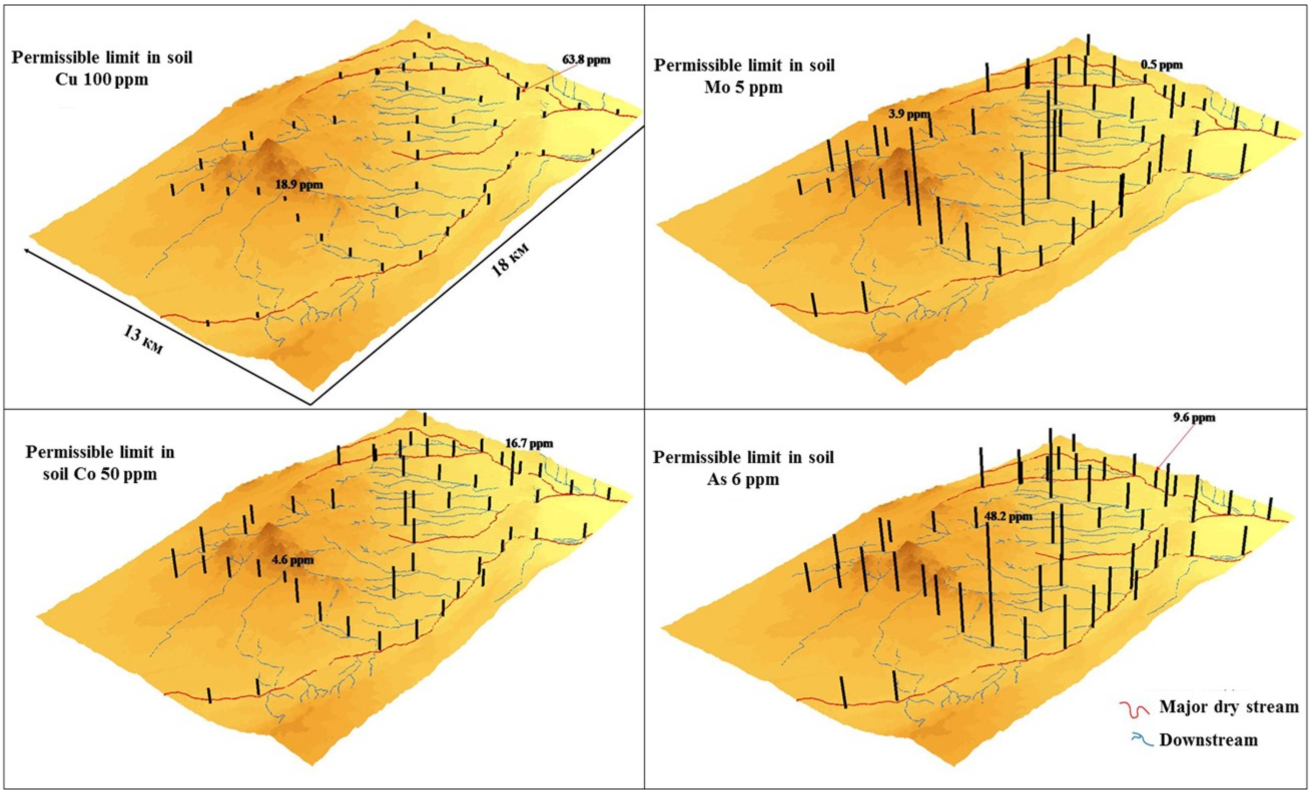


Fig. 5. Distribution of selected heavy elements in the soil of the Shuteen area by 3D images (Batkhishig et al., 2017b).

ppm, Mo ~1 ppm, As ~16 ppm, Co ~8 ppm, Ni ~24 ppm, Pb ~14 ppm, V ~86 ppm, Zn ~50 ppm, Cd ~0.1 ppm, Sn ~1 ppm, Sr ~351 ppm and Cr ~60 ppm, which are usually causing major pollution in soil. Diagrams comparing the heavy metal content of a soil sample with silica (silica is resistant to weathering and erosion) are presented in Fig. 4. The diagram shows that the arsenic (As) content of the soil in the Shuteen area is higher than the permissible limit of the Mongolian National standard on soil quality (Fig. 4). As for other elements, they do not exceed the soil standard permitted (MNS 5850:2008; Batkhishig et al., 2017a,b).

3D images were created to visualize the differences in the distribution of heavy elements in the soil over distinct lithology, geomorphology, location features, mineralization, and other natural factors. For 3D images, Cu and Mo are selected concerning the major mineralization of the area, whereas As and Co are due to the most higher content, compared to the other elements. The results show that there are no distribution differences in relation to wind direction, water flow factors, geomorphology and geological structure, lithology and mineralization. The geochemical composition of the soil is uniform throughout the area (Fig. 5).

Moreover, the Shuteen soil geochemical results are compared to the results of the 1:1000000 geochemical mapping project's data (1:1000000 Geochemical, 2012). It is the geographically closest and comparable data in the South Gobi region; the Shuteen area is located in the northern edge of their study area. We have selected data from the geochemical mapping project which are the closest to our study area, but not completely covered the same area.

Basically, results do not show much difference, but our data is higher in Cu, Mo, As, Ni and Sr, the same in Zn, Cd, Co, Cr and V contents and Pb and Sn are lower than Geochemical mapping data (Fig. 4; Batkhishig et al., 2017b; 1:1000000 Geochemical, 2012).

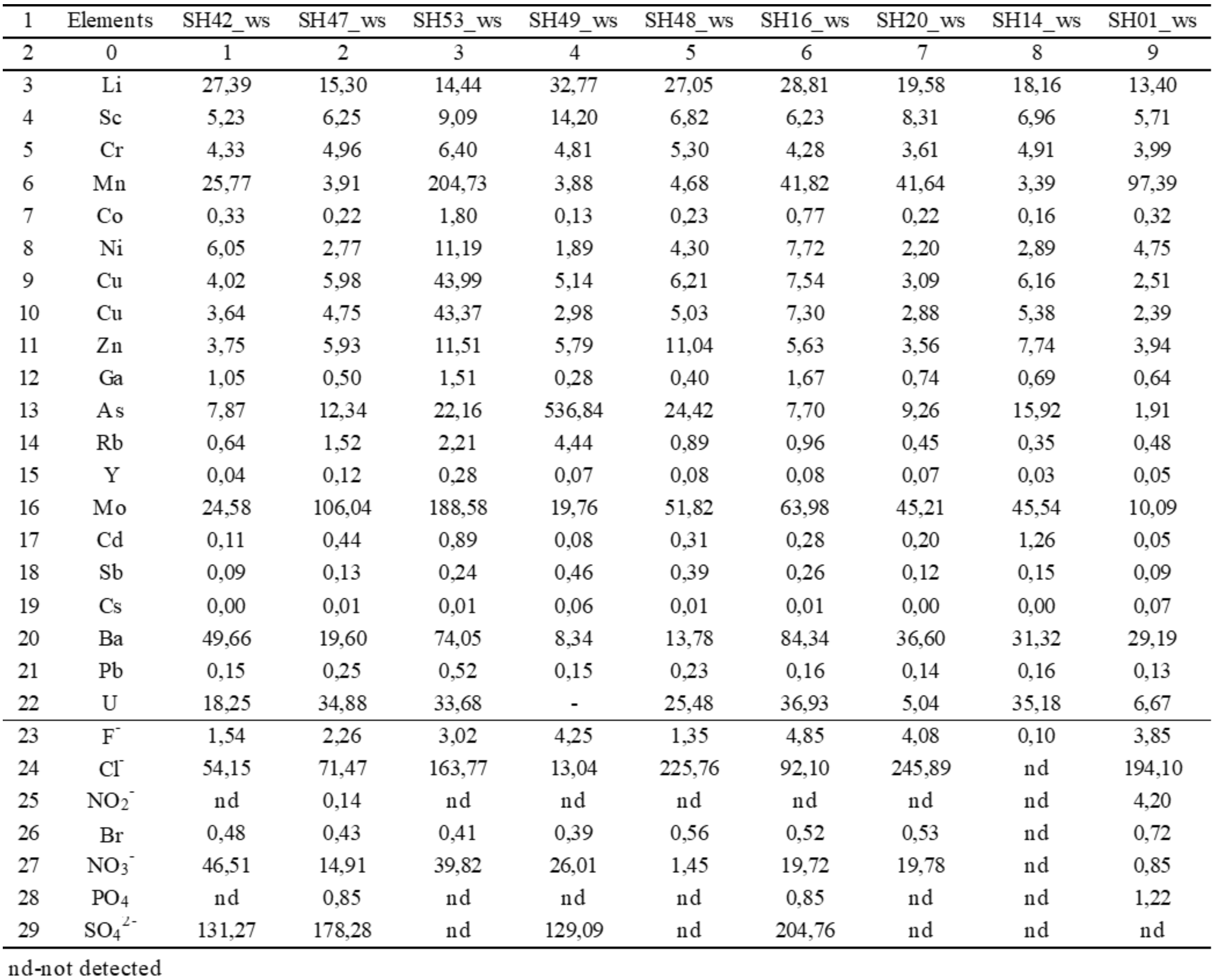
Water geochemistry

Table 2 shows the general characteristics of drinking and livestock water wells and natural springs located in the Shuteen area. The heavy

Table 2. General characteristics of river water in Shuteen area, 2016

Sample numbers	Water temperature at sampling (T°C)	Alkaline properties (pH)	Electrical conductivity (EC)	Note
SH01_ws	25.4	9.05	0.44	An old well for watering livestock. Not used for drinking water
SH20_ws	23.9	9.02	0.09	Old abandoned well. Not used for drinking water
SH49_ws	13.7	9.17	0.31	Motor well for drinking water
SH47_ws		9.07	0	Zuun Khujirtiin Shand well, depth is 1.5 m
SH48_ws		9.04	0.03	Livestock well, depth is 2 m
SH42_ws		9.85	0.05	Hand motor drinking well
SH16_ws		9.07	0.2	Small natural springs
SH14_ws		8.99	0.02	Newly developed drinking well
SH53_ws	17.8	9.01	0.01	Winter camp drinking well depth of the well is 1.5 m
Average	**20.2**	**9.14**	**0.13**	

Table 3. Heavy metals (ug/L) and anion contents (ppm) of the water samples, Shuteen area



1	Elements	SH42_ws	SH47_ws	SH53_ws	SH49_ws	SH48_ws	SH16_ws	SH20_ws	SH14_ws	SH01_ws
2	0	1	2	3	4	5	6	7	8	9
3	Li	27,39	15,30	14,44	32,77	27,05	28,81	19,58	18,16	13,40
4	Sc	5,23	6,25	9,09	14,20	6,82	6,23	8,31	6,96	5,71
5	Cr	4,33	4,96	6,40	4,81	5,30	4,28	3,61	4,91	3,99
6	Mn	25,77	3,91	204,73	3,88	4,68	41,82	41,64	3,39	97,39
7	Co	0,33	0,22	1,80	0,13	0,23	0,77	0,22	0,16	0,32
8	Ni	6,05	2,77	11,19	1,89	4,30	7,72	2,20	2,89	4,75
9	Cu	4,02	5,98	43,99	5,14	6,21	7,54	3,09	6,16	2,51
10	Cu	3,64	4,75	43,37	2,98	5,03	7,30	2,88	5,38	2,39
11	Zn	3,75	5,93	11,51	5,79	11,04	5,63	3,56	7,74	3,94
12	Ga	1,05	0,50	1,51	0,28	0,40	1,67	0,74	0,69	0,64
13	As	7,87	12,34	22,16	536,84	24,42	7,70	9,26	15,92	1,91
14	Rb	0,64	1,52	2,21	4,44	0,89	0,96	0,45	0,35	0,48
15	Y	0,04	0,12	0,28	0,07	0,08	0,08	0,07	0,03	0,05
16	Mo	24,58	106,04	188,58	19,76	51,82	63,98	45,21	45,54	10,09
17	Cd	0,11	0,44	0,89	0,08	0,31	0,28	0,20	1,26	0,05
18	Sb	0,09	0,13	0,24	0,46	0,39	0,26	0,12	0,15	0,09
19	Cs	0,00	0,01	0,01	0,06	0,01	0,01	0,00	0,00	0,07
20	Ba	49,66	19,60	74,05	8,34	13,78	84,34	36,60	31,32	29,19
21	Pb	0,15	0,25	0,52	0,15	0,23	0,16	0,14	0,16	0,13
22	U	18,25	34,88	33,68	-	25,48	36,93	5,04	35,18	6,67
23	F^-	1,54	2,26	3,02	4,25	1,35	4,85	4,08	0,10	3,85
24	Cl^-	54,15	71,47	163,77	13,04	225,76	92,10	245,89	nd	194,10
25	NO_2^-	nd	0,14	nd	nd	nd	nd	nd	nd	4,20
26	Br	0,48	0,43	0,41	0,39	0,56	0,52	0,53	nd	0,72
27	NO_3^-	46,51	14,91	39,82	26,01	1,45	19,72	19,78	nd	0,85
28	PO_4	nd	0,85	nd	nd	nd	0,85	nd	nd	1,22
29	SO_4^{2-}	131,27	178,28	nd	129,09	nd	204,76	nd	nd	nd

nd-not detected

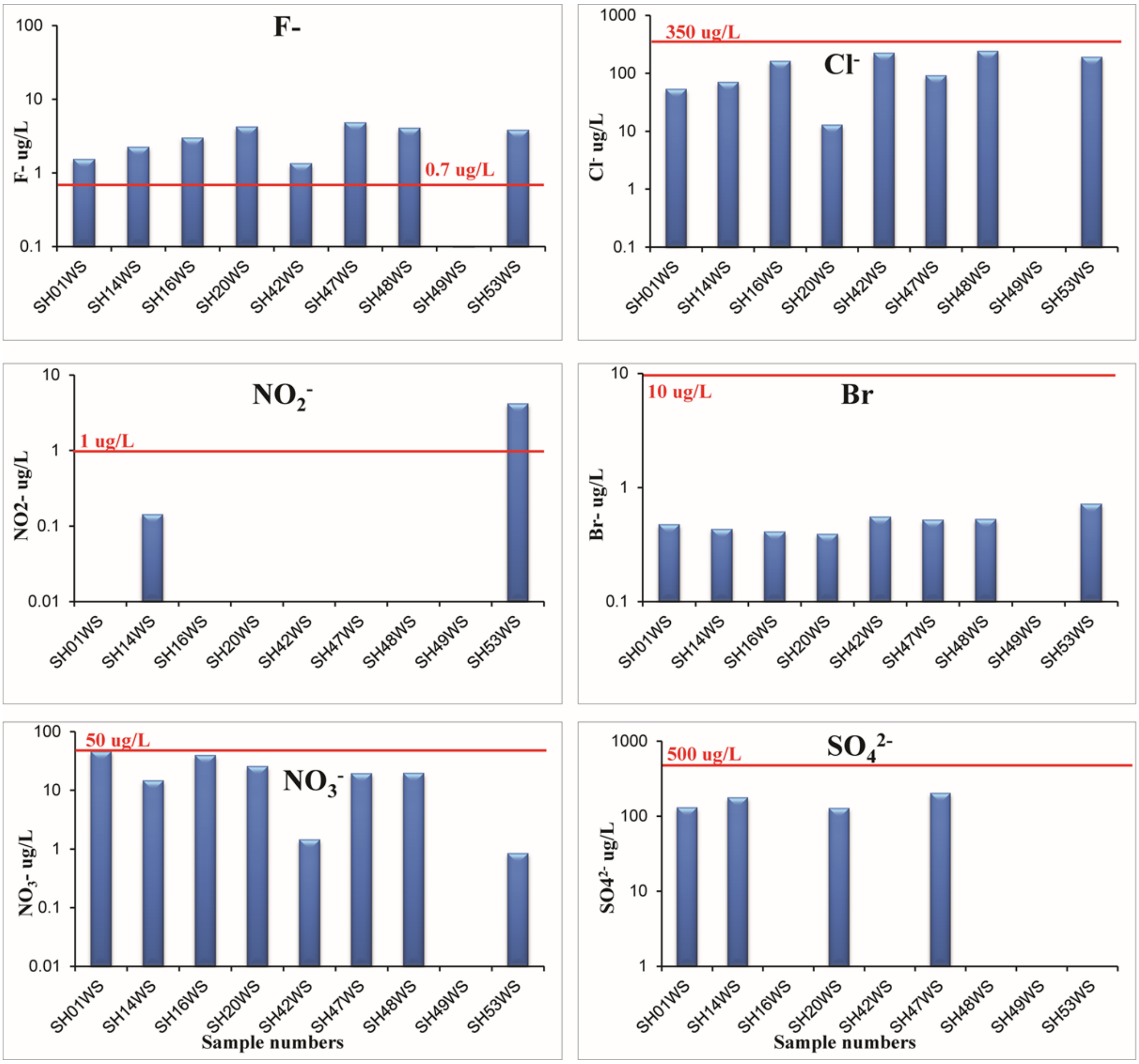


Fig. 6. Comparison of the drinking water standard of Mongolia with anion content of water samples from the wells in the Shuteen area. The red line shows the permissible limit of drinking water (Batkhishig et al., 2017b).

metals and anion contents of the water samples are summarized in Table 3.

Fig. 6 shows a diagram comparing the content of F^-, Cl^-, NO^{2-}, Br^-, NO^{3-}, PO_4^{3-}, SO_4^{2-} with the Mongolian drinking water quality and safety assessment standard (MNS 0900: 2005; MNS, 1992). Water samples from the Shuteen area show an average temperature of 20.2°C, pH 9.14, and electric conductivity 0.13. Generally, the water samples contain F^- above the permissible limit guided in Mongolian National Standard (MNS) on drinking water quality (MNS 5850:2008). However, Cl^-, NO_2^-, Br^-, NO_3^-, PO_4^{3-}, SO_4^{2-} are within the permissible value (Batkhishig et al., 2017a,b).

Mongolia has a harsh continental climate, with four seasons that make differences in water quality. As well, the water compositions different due to geographic locality, especially in the Gobi region, low alkalinity and high saline water are due to the high carbonate content of the soil. Although only 2-3 wells of regularly used drinking water have been surveyed, the sample number SH49_ws from a

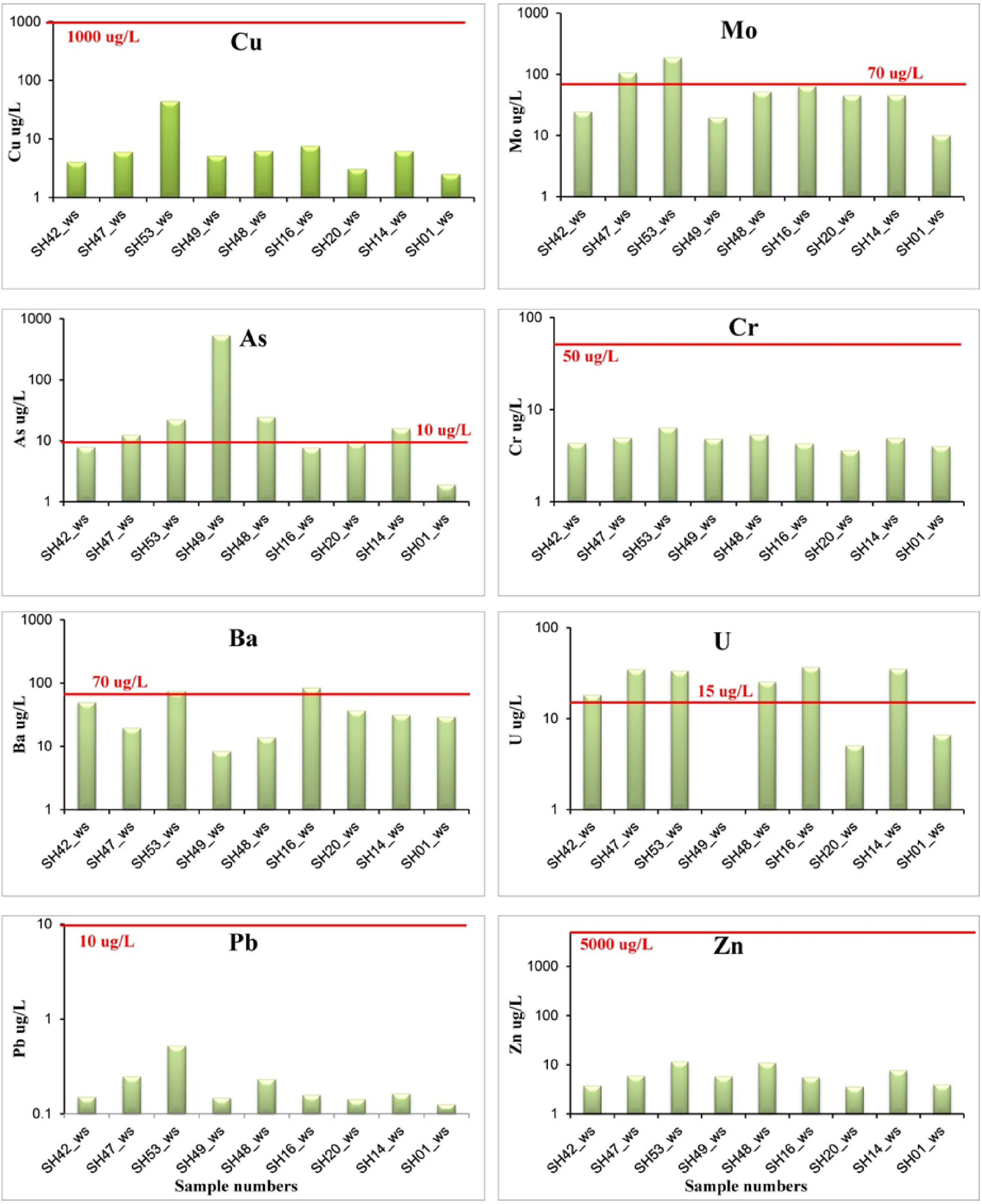


Fig. 7. Comparison of the drinking water standard of Mongolia with a heavy metal content of water samples from the wells in the Shuteen area. The red line shows the permissible limit of drinking water (Batkhishig et al., 2017b).

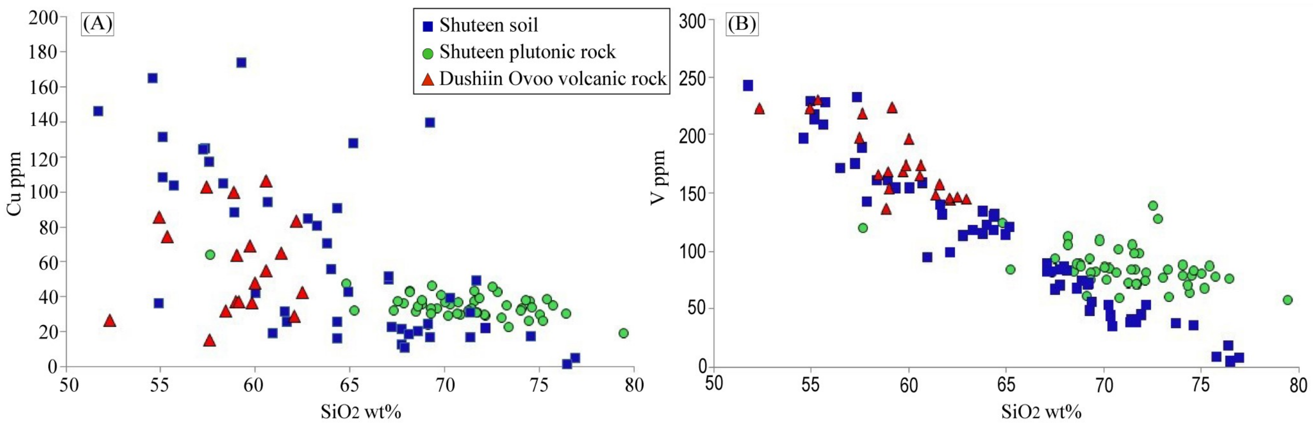


Fig. 8. Correlation of selected heavy metals (Cu and V) concentration between rock and soil, in the Shuteen area

motor drinking water well show relatively standard composition.

Fig. 7 shows the content of some heavy metals in the drinking and livestock wells water in the Shuteen area. Heavy metal contents of Cu, Cr, Pb and Zn are much lower, and Mo and Ba are close to the permissible limit, whereas As and U are higher than the guided limit of Mongolian National standard (MNS 5850:2008). Those higher concentrations of U, As, and F in water samples may have related to the South and Eastern Mongolian U, Pb-Zn and CaF_2 metallogenic belts. The water quality concern is the salinity with the occasional occurrence of trace elements like As, and F (Batkhishig et al., 2017a,b).

DISCUSSION

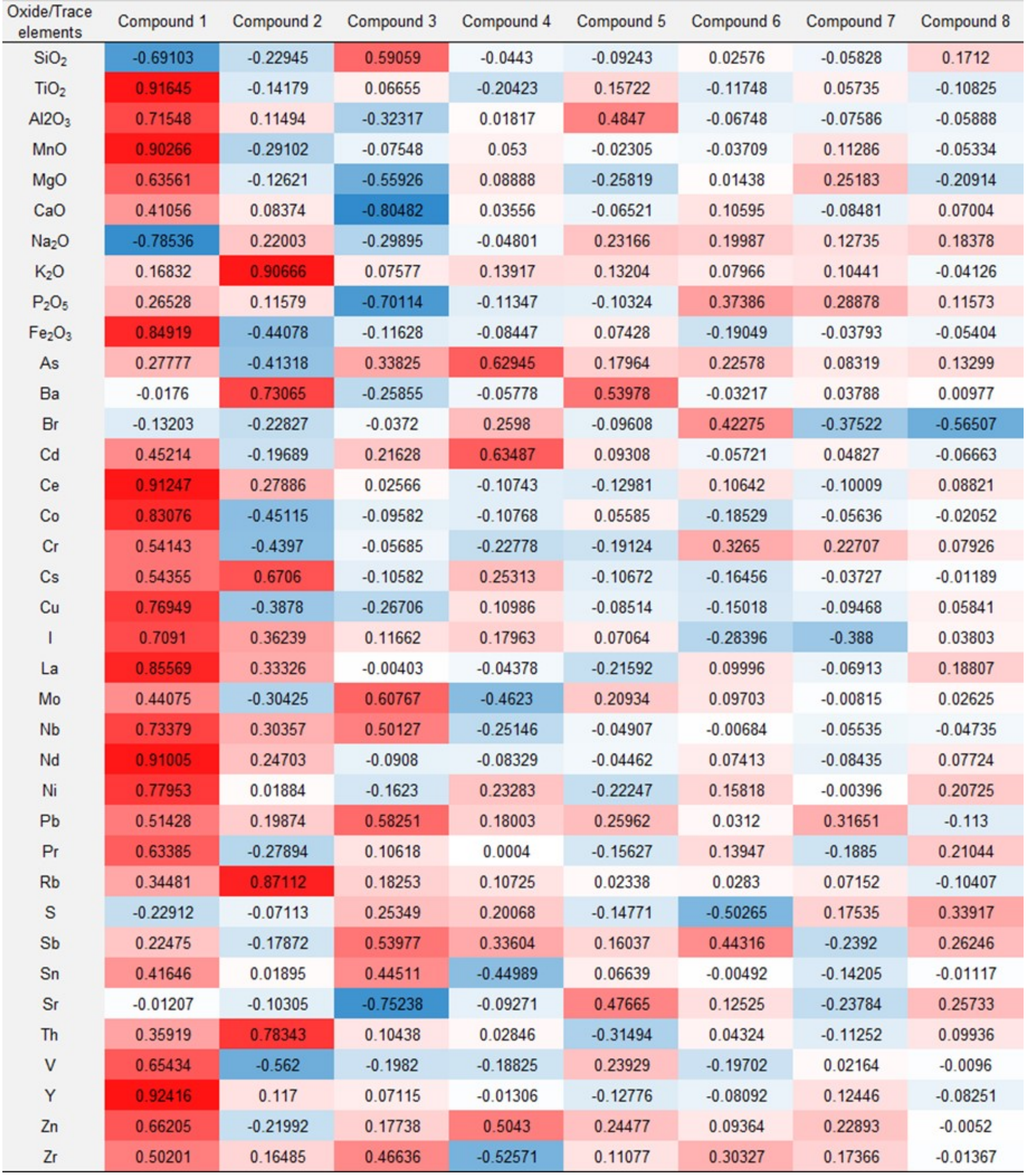
Heavy metal concentration correlation between rock and soil

According to Hovan et al., lithogeochemical (rock chips) anomalies of <100–200 ppm Cu and <10-20 ppm Mo are considered at the Shuteen area (Hovan et al., 1982; 1983; Batkhishig et al., 2014), whereas ongoing project of 1:50000 scale geological mapping work used geochemical baseline limit of soil as Cu is ~70 ppm and V is ~95 ppm in the Manlai area, including Shuteen (unpublished data). The Cu content of the soil compared with the Cu content of the volcanic and plutonic rocks in the area, where yielded similar content between them (Fig. 8A). It indicates there is no late enrichment of heavy metals in soil associated with mineralization. The basic and intermediate composition rocks (diorite, granodiorite, and andesite) in the Shuteen area are mostly affected by hydrothermal alteration and associated with mineralization. Although vanadium (V) content is not directly related to the copper mineralization of the Shuteen, it is considered that the high content of V in the soil than guided standard limit, can be explained by basic and ultrabasic rocks in the Manlai region (Fig. 8B).

Soil natural geochemical baseline

A multivariable analysis and factor analysis are useful to understand the nature of the background of heavy metals. To understand a natural background of heavy metals, especially Cu and Mo (or V) related to mineralization of the area is described using principal compound analysis (PCA) of major and trace element composition of soil in Shuteen area is described below. There were 8 principal compounds obtained by PCA statistical analysis using the element concentrations of the soil samples (Table 4). Three principal compounds were considered for discussion (Fig. 9). Principal compound 1 (PC1), explaining 38.4% of the total variance, defines two groups of variables: Sn, Pb, Nb, As, positively related, in opposition to Al_2O_3 CaO, Cu and Sr variables, with high negative SiO_2 and Na_2O loadings. Principal compound 2 (PC2), explaining 15.1% of the total variance, defines variables: K_2O, Rb, Th Cs positively related, in opposition to As, MnO and Mo variables. Principal compound 3 (PC3), explaining 13% of the total variance, defines variables: positively related Pb, Zn, Sb, and Sn elements (Fig. 9).

Table 4. Result of correlation between major and trace elements in soil of the Shuteen area. Red color indicates positive and blue color indicates a negative correlation.



Oxide/Trace elements	Compound 1	Compound 2	Compound 3	Compound 4	Compound 5	Compound 6	Compound 7	Compound 8
SiO_2	-0.69103	-0.22945	0.59059	-0.0443	-0.09243	0.02576	-0.05828	0.1712
TiO_2	0.91645	-0.14179	0.06655	-0.20423	0.15722	-0.11748	0.05735	-0.10825
$Al2O_3$	0.71548	0.11494	-0.32317	0.01817	0.4847	-0.06748	-0.07586	-0.05888
MnO	0.90266	-0.29102	-0.07548	0.053	-0.02305	-0.03709	0.11286	-0.05334
MgO	0.63561	-0.12621	-0.55926	0.08888	-0.25819	0.01438	0.25183	-0.20914
CaO	0.41056	0.08374	-0.80482	0.03556	-0.06521	0.10595	-0.08481	0.07004
Na_2O	-0.78536	0.22003	-0.29895	-0.04801	0.23166	0.19987	0.12735	0.18378
K_2O	0.16832	0.90666	0.07577	0.13917	0.13204	0.07966	0.10441	-0.04126
P_2O_5	0.26528	0.11579	-0.70114	-0.11347	-0.10324	0.37386	0.28878	0.11573
Fe_2O_3	0.84919	-0.44078	-0.11628	-0.08447	0.07428	-0.19049	-0.03793	-0.05404
As	0.27777	-0.41318	0.33825	0.62945	0.17964	0.22578	0.08319	0.13299
Ba	-0.0176	0.73065	-0.25855	-0.05778	0.53978	-0.03217	0.03788	0.00977
Br	-0.13203	-0.22827	-0.0372	0.2598	-0.09608	0.42275	-0.37522	-0.56507
Cd	0.45214	-0.19689	0.21628	0.63487	0.09308	-0.05721	0.04827	-0.06663
Ce	0.91247	0.27886	0.02566	-0.10743	-0.12981	0.10642	-0.10009	0.08821
Co	0.83076	-0.45115	-0.09582	-0.10768	0.05585	-0.18529	-0.05636	-0.02052
Cr	0.54143	-0.4397	-0.05685	-0.22778	-0.19124	0.3265	0.22707	0.07926
Cs	0.54355	0.6706	-0.10582	0.25313	-0.10672	-0.16456	-0.03727	-0.01189
Cu	0.76949	-0.3878	-0.26706	0.10986	-0.08514	-0.15018	-0.09468	0.05841
I	0.7091	0.36239	0.11662	0.17963	0.07064	-0.28396	-0.388	0.03803
La	0.85569	0.33326	-0.00403	-0.04378	-0.21592	0.09996	-0.06913	0.18807
Mo	0.44075	-0.30425	0.60767	-0.4623	0.20934	0.09703	-0.00815	0.02625
Nb	0.73379	0.30357	0.50127	-0.25146	-0.04907	-0.00684	-0.05535	-0.04735
Nd	0.91005	0.24703	-0.0908	-0.08329	-0.04462	0.07413	-0.08435	0.07724
Ni	0.77953	0.01884	-0.1623	0.23283	-0.22247	0.15818	-0.00396	0.20725
Pb	0.51428	0.19874	0.58251	0.18003	0.25962	0.0312	0.31651	-0.113
Pr	0.63385	-0.27894	0.10618	0.0004	-0.15627	0.13947	-0.1885	0.21044
Rb	0.34481	0.87112	0.18253	0.10725	0.02338	0.0283	0.07152	-0.10407
S	-0.22912	-0.07113	0.25349	0.20068	-0.14771	-0.50265	0.17535	0.33917
Sb	0.22475	-0.17872	0.53977	0.33604	0.16037	0.44316	-0.2392	0.26246
Sn	0.41646	0.01895	0.44511	-0.44989	0.06639	-0.00492	-0.14205	-0.01117
Sr	-0.01207	-0.10305	-0.75238	-0.09271	0.47665	0.12525	-0.23784	0.25733
Th	0.35919	0.78343	0.10438	0.02846	-0.31494	0.04324	-0.11252	0.09936
V	0.65434	-0.562	-0.1982	-0.18825	0.23929	-0.19702	0.02164	-0.0096
Y	0.92416	0.117	0.07115	-0.01306	-0.12776	-0.08092	0.12446	-0.08251
Zn	0.66205	-0.21992	0.17738	0.5043	0.24477	0.09364	0.22893	-0.0052
Zr	0.50201	0.16485	0.46636	-0.52571	0.11077	0.30327	0.17366	-0.01367

PC1 is representing the host rock composition of the Shuteen area. SiO_2 and Na_2O exhibit negative (unique characteristic), whereas other elements were positive (Fig 9; Table 4). There are two possibilities to explain the negative SiO_2 and Na_2O oxides. (1) High amount of SiO_2 and Na_2O oxides suggest the host rock weathering in the area. The host rocks in the Shuteen area

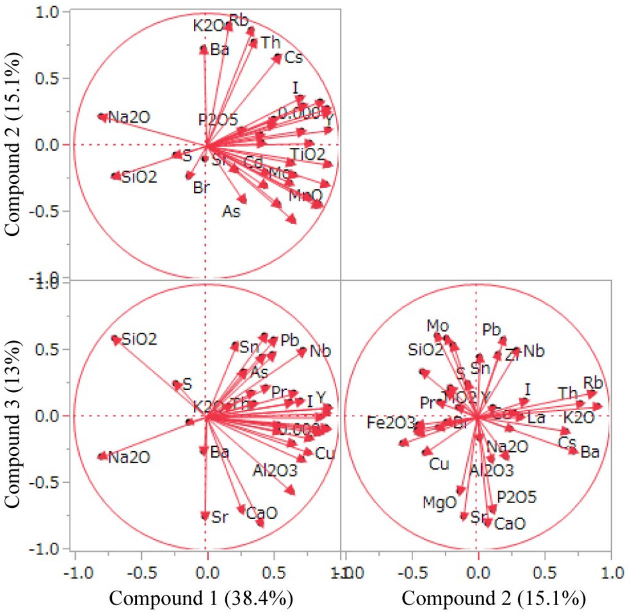


Fig. 9. Comparative diagram of the main three compounds described in the Shuteen soil geochemistry. Scatters of the representative elements contained in the soil of each Compound. Confidence coefficients: Compound 1- 38.4%, Compound 2 - 15.1%, Compound 3 - 13%.

comprised intermediate to felsic (SiO_2> 64%) volcano-plutonic rocks with adakitic affinity (mostly plagioclase porphyritic-Na feldspar), silica lithocap, quartz stockworks, and widespread quartz veins. Those rocks can be responsible for weathering soil surfaces with a high amount of SiO_2 and Na_2O. (2) The other possibility is concerning to a dry environment and climate characteristics of the Gobi region. An evaporation of NaCl and quartz vein or quartzite is unrestricted.

PC2 is may have represented hydrothermal alteration of the Shuteen area (Fig 9; Table 4). The high-temperature, magmatic alterations in the copper mineralized Shuteen Complex consist of mineral assemblages including plagioclase, biotite, and quartz. Besides, high-temperature, hydrothermal alterations are characterized by silicification, argillic, prophyllitic alteration, including quartz/ chalcedony, alunite, hematite and kaolinite. Besides, the temperature series matches field observation, for instance, at high-temperature hydrothermal alteration assemblages include quartz, alunite, andalusite, hematite and kaolinite, whilst at lower temperature chalcedony, kaolinite and pyrophyllite formed (Batkhishig, 2005). According to PC2, K, Ba and Rb and subsequent Cs and Th enriched in hydrothermal alteration may have indicated potassic alteration which is indicative of the porphyry type mineralization.

PC3 shows positive Mo, Pb, Zn, Sb and Sn elements, that are represented mineralization characteristics of the Shuteen area (Fig 9; Table 4). Mo and Sn are indicative of high-temperature mineralization, whereas Pb, Zn and Cu are for the moderate-temperature mineralization. The main mineralization type of the Shuteen is porphyry copper mineralization, however interesting that the Cu did not appear positive by the PCA. On the other hand, in Fig. 4, all data of Cu in Shuteen are higher than those of soil results of the 1:1000000 geochemical mapping project (1:1000000 Geochemical, 2012), and lithogeochemical anomalies of <100 –200 ppm Cu are distinguished (Hovan et al., 1982; 1983). Therefore, in the general meaning, a positive Cu anomaly is demonstrated in this area. Mo is generally not positive and some points show very high concentration up to 4 ppm, and Pb and Zn are also negative and As is also high in the Shuteen Complex (Fig. 4). Those geochemical anomalies indicate the following: (1) Low Pb and Zn anomalies indicate that Shuteen is a porphyry copper deposit, not a hydrothermal (or epithermal) vein-type deposit. (2) Mo is a high-temperature element than Cu, but the Mo concentration anomaly is not so clear in Fig. 4, but in the PCA, Mo shows a high value which means there are some effects of Mo in Shuteen. (3) Cu concentration associated with As is obvious and it was caused by porphyry copper mineralization (high-temperature mineralization), not epithermal (low to middle temperature) mineralization. (4) The current surface shows some effects of Cu mineralization, but the main body may be in the subsurface (relatively high concentration but PCA is negative) and Mo is a much deeper zone than Cu.

Copper mineralization can occur with all three (high, moderate and low temperature) levels of hydrothermal events. In the case of copper mineralization is associated with low-temperature mineralization, the main ore body may be weathered or in contrast, if the copper mineralization is associated with high and medium-temperature alteration, the ore body may be at significant depth. This suggestion is consistent with the previous study of the present-day erosion level at Shuteen is relatively shallow, implying that economic porphyry-style mineralization may exist at depth within or beneath the Shuteen lithocap (Batkhishig et al., 2014).

CONCLUSION

The environmental assessment results show that the heavy metal content of the soil in the Shuteen area does not exceed the permissible limit of the Mongolian National standard on soil quality. The Shuteen soil geochemistry reveals the geochemical characteristics related to the geology and mineralization of the host rocks, alteration, and mineralization widespread throughout the area, without mechanical contamination.

Whereas, the water samples contain F- above the permissible limit guided in Mongolian National Standard on drinking water quality. The chemical composition of the water (elevated content of Cl, F and As) is due to the Gobi region.

These environmental assessment surveys determine the characterization of an aerial geochemical base prior the development of later exploration or mining project, and establish the initial environmental status.

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