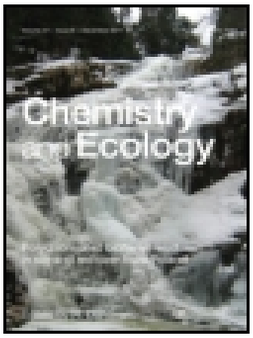

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RESEARCH ARTICLE

Trace elements in Gobi soils of the northeastern Qinghai-Tibet Plateau

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ABSTRACT
This study investigated the pollution, potential ecological risks, and possible sources of trace elements in Gobi soils of the northeastern Qinghai-Tibet Plateau. Contents of Hg in soils were below the detection limit. The average contents of the remaining trace elements in soils ranged from 0.21 (Cd) to 2360.82 (As) mg/kg. Multiple methods were used to evaluate the soil pollution of the study area. Pb posed the most serious pollution based on geo-accumulation index evaluation. As showed the strongest enrichment feature according to enrichment factor method. Compared with pollution load index and modified contamination degree, Nemerow pollution index results obtained the most serious evaluation on pollution that 10% and 40% of sampling sites possessed moderate and high pollution, respectively. Trace elements in soils posed high ecological risks in 20% of sampling sites. Pearson's correlation matrix and principal component analysis were used to determine that anthropogenic activities such as industrial and mining activities might be the main source for several trace elements. This study will provide important information on soil quality control in the northeastern Qinghai-Tibet Plateau, especially the area with little vegetations.

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KEYWORDS
Trace element; soil pollution; ecological risk; source apportionment; the Qinghai-Tibet Plateau

Introduction

The Qinghai-Tibet Plateau is vulnerable due to high elevation [1]. Soil pollution frequently occurred in this plateau with in-depth development of the western China [2–4]. Gobi is an important geographical unit of the Qinghai-Tibet Plateau and Gobi areas possess abundant mineral and energy resources [5]. Therefore, Gobi soil quality will affect the ecological stability of the Qinghai-Tibet Plateau to a great extent.

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Trace elements in soils show persistence, toxicity, and bioaccumulation [6–9]. Therefore, the excessive trace elements in soils possibly change soil compositions and inhibit soil functions [10–14]. Anthropogenic activities will significantly increase the contents of trace elements in soil [15]. Previous studies have also exhibited that the soil quality of the Qinghai-Tibet Plateau is drastically influenced by human disturbance [2–4]. However, the information on Gobi soil quality in the Qinghai-Tibet Plateau is still limited. It is necessary to investigate the pollution and possible sources of Gobi soils in the Qinghai-Tibet Plateau since some energy facilities have been established in these regions. Various methods have been developed to evaluate pollution, sources, and risks of trace elements in soils [4,16–18]. Therefore, this study used different methods to investigate pollution, potential ecological risks, and possible sources of trace elements in soils of the Gobi areas in the northeastern Qinghai-Tibet Plateau. The final aim of this study is to provide useful information on soil quality of Gobi areas of the northeastern Qinghai-Tibet Plateau.

Materials and methods

Sample collection and analysis

Sampling and analysis method referred to the Technical Specification for Soil Environmental Monitoring (HJ/T 166-2004). Total 20 topsoil (0–20 cm) samples were collected during 14th June to 29th June 2017 (Figure 1). Soil samples were prepared by naturally drying, grinding, and passing through 0.074 mm nylon sieve. Soil pH was determined by measuring pH of supernatant with soil–water ratio of 1:2.5 using a pH meter (Shanghai

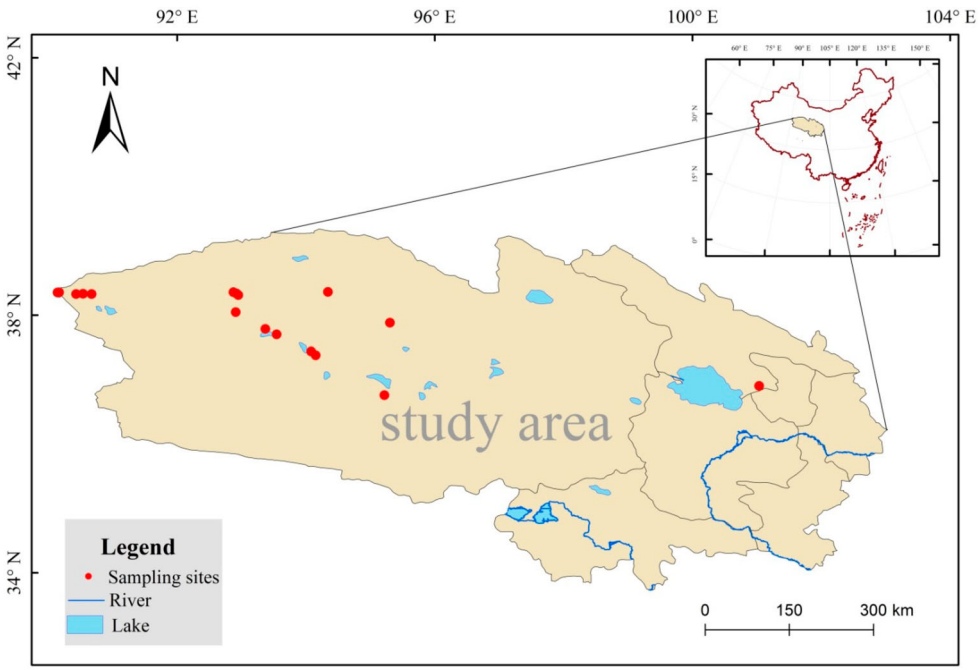

Figure 1. The sampling sites from the Gobi area of the northeastern Qinghai-Tibet Plateau.

INESA Scientific Instrument Co., China). Soil total organic carbon (TOC) was determined by a multi N/C 3100 analyzer (Analytik Jena AG, Germany). Soil samples were digested by microwave and analysed by an Agilent7900 inductively coupled plasma mass spectrometry (ICP-MS, Agilent Inc, USA). The target elements included As, Pb, Cd, Cr, Ni, Zn, Mo, Cu, Sn, Hg, Co, Sb, V, and rare earth elements (REEs). REEs consisted of Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sc, Sm, Tb, Tm, Y, and Yb.

Pollution and ecological risks of trace elements in soil

Geo-accumulation index (I_{geo}) and enrichment factor (*EF*) were used to evaluate the contamination status and enrichment degree of individual trace element, respectively [2–4,19]. The I_{geo} and *EF* were calculated respectively as follows:

$$I_{geo} = \log_2 \frac{C_m^i}{1.5 \times C_b^i} \tag{1}$$

$$EF = \frac{(C_m^i/R_{sm})}{(C_b^i/R_b)} \tag{2}$$

where C_m^i and C_b^i are the measured concentration and background concentration of the *i*th target trace element in soils, respectively; R_{sm} and R_b are the measured concentration of reference element in soil sample and background concentration of reference element in soil, respectively. The background concentrations of trace elements in Gobi soils of this study were obtained by checking MEPC [20]. Fe was chosen as reference element by this study to calculate *EF* because it is an important soil major element [2,21]. Values of I_{geo}, classes and their interpretation referred to previous reports [22,23]: uncontaminated (≤0); uncontaminated to moderate (0–1), moderate (1–2), moderate to strong (2–3), strong (3–4), strong to extremely strong (4–5), and extreme (>5). Degrees of enrichment were typically divided into seven classifications based on *EF* values [2,4]: no enrichment (<1), minor (1–3), moderate (3–5), moderately severe (5–10), severe (10–25), very severe (25–50), and extremely severe (>50).

The comprehensive indices including pollution load index (*PLI*), modified degree of contamination (mC_d), and Nemerow pollution index (*PN*) were used to determine pollution degree of all target trace elements[2–4,19]. The calculations of these indices are briefly shown below

$$PLI = \left(\frac{C_m^1}{C_b^1} \times \frac{C_m^2}{C_b^2} \times \ldots \times \frac{C_m^n}{C_b^n}\right)^{1/n} \tag{3}$$

$$mC_d = \frac{\sum_{i=1}^{n} C_m^i/C_b^i}{n} \tag{4}$$

$$PN = \sqrt{\frac{(C_m^i/C_b^i)_{max}^2 + (C_m^i/C_b^i)_{mean}^2}{2}} \tag{5}$$

where *n* is the number of the target trace elements; $(C_m^i/C_b^i)_{max}^2$ and $(C_m^i/C_b^i)_{mean}^2$ are the maximal value and average value of (C_m^i/C_b^i) among all target trace elements. The *PLI* is classified into a low level (≤1), moderate level (1–2), high level (2–5), or extremely high

level (>5) [15,24]. The mC_d has five categories [3,25]: nil to very low (<1.5), low (1.5–2), moderate (2–4), high (4–8), very high (8–16), extremely high (16–32), and ultra high (≥32). The *PN* evaluation results are divided into five grades [26]: safety (≤0.7), precaution (0.7–1.0), slightly polluted (1.0–2.0), moderately polluted (2.0–3.0), and severely polluted (>3.0).

The potential ecological risk index (*RI*) was adopted to evaluate the potential ecological risks posed by target trace elements in soils [27]. The *RI* can be defined as

$$RI = \sum_{i=1}^{n} T_m^i \times \frac{C_m^i}{C_b^i} \tag{6}$$

where T_m^i means the biological toxicity factor of an individual trace element; the toxic response factor refers to previous studies [2,19,27,28]. The evaluation criteria for low, moderate, considerable, and very high ecological risk were <150, 150–300, 300–600, and >600 [29,30].

Statistical analysis

Pearson's correlation matrix (PCM) was adopted to discuss the relationship among trace elements. Moreover, principal component analysis (PCA) using factor extraction with an eigenvalue >1was employed to explore the possible sources of the trace elements in soil [17]. PCM and PCA were performed by SPSS 22.0 (IBM, New York, USA).

Results and discussion

Distribution of heavy metals in topsoils of Gobi area

Table 1 shows the statistical information on the concentrations of soil trace elements, pH, and TOC. Soil pH of Gobi areas varied from 6.15 to 9.13. The pH values of soil samples

Table 1. Statistical summary of pH, TOC, and concentrations of trace element soil samples, background value and world soil average ($n = 20$, mg/kg for all trace elements, g/kg for TOC).

Element	Mean	SE	Minimum	Median	Maximum	Background value [20]	World soil average [35]
V	64.44	13.75	35.83	64.55	95.03	71.8	–
Cr	199.61	347.44	35.88	55.43	1409.29	70.1	59.5
Co	16.02	18.55	5.33	9.65	79.77	10.1	11.3
Ni	175.78	419.04	12.57	24.12	1640.17	29.6	29
Cu	38.59	20.42	15.85	31.89	93.72	22.2	38.9
Zn	68.60	28.00	37.72	63.43	144.65	80.3	70
As	2360.82	10381.04	10.04	18.21	46463.74	14.0	6.83
Mo	1.52	1.45	0.28	1.19	7.20	0.9	1.1
Cd	0.21	0.09	0.08	0.20	0.49	0.137	0.41
Sn	3.12	1.12	1.10	3.04	6.92	2.0	2.5
Sb	2.53	4.29	0.83	1.27	20.15	1.47	0.67
Hg	BDL	BDL	BDL	BDL	BDL	0.02	0.07
Pb	20.52	15.72	6.58	17.05	72.68	20.9	27
REEs	154.70	49.85	28.42	156.85	252.81	159.6	171.79
LREEs	118.18	39.3	16.68	119.62	196.54	124.49	122.7
HREEs	36.52	9.86	11.14	36.41	56.27	35.54	49.09
LREEs/HREEs	3.15	0.54	1.42	3.69	4.28	3.50	2.50
pH	8.30	0.64	6.15	8.44	9.13	–	–
TOC	0.79	1.69	0.11	0.33	7.84	–	–

Note: SE means standard error; BDL refers to below the detection limit.

collected from 95% of sampling sites were above 7.0, indicating that Gobi soils of the northeastern Qinghai-Tibet Plateau were predominantly alkaline. TOC contents showed drastic variation with a mean value of 0.79 g/kg. The infrared peaks of Gobi soils were all around 3600, 3400, 1400, 1000 and 800 cm^{-1} with slight differences, indicating the Gobi soil samples had the same functional groups. XRD patterns showed that the soils were mainly composed of quartz, calcite, albite, clinochlore, plagioclase, dolomite and muscovite. Some soil samples contained certain quantities of chrysotile.

Contents of Hg in Gobi soils were below the detection limit (BDL), significantly different from those reported previously [2,4]. The average contents of the remaining trace elements in soils ranged from 0.21 (Cd) to 2360.82 (As) mg/kg. The average contents of V, Zn, and Pb were lower than their corresponding background values (Table 1). The average contents of Co, Cu, Mo, Cd, Sn and Sb in Gobi soils were slightly higher than their background values. The average contents of Cu, Zn, Cd and Pb were lower than their world soil average values (Table 1). The average contents of Co, Mo, Sn and Sb in Gobi soils were slightly higher than world soil average values. The mean concentration of As reached 2360.82 mg/kg, almost 169 times its background value and 346 times its world soil average value. The average contents of Cr and Ni were 199.61 and 175.78 mg/kg, respectively. Contents of As, Cr, and Ni showed significant site-variations, similar with those previously reported [2,4]. Site S-9 located near a discarded oil well possessed the highest concentration of As in soil while site S-13 located at a chemical factory exhibited the maximal concentrations of Ni and Cr. Interestingly, the contents of As near discarded oil well of Gobi soils were much higher than those in Lhasa–Shigatse–Nam Co region of Qinghai-Tibet Plateau [31], showing potential As pollution of soils in Gobi areas. However, XRD patterns showed that S-9 was not composed of As-containing minerals with high levels. The average contents of Cr and Cu in soils of Gobi areas were slightly lower than those in watershed soils of the eastern Qinghai-Tibet Plateau [32] while the average contents of Cd, Pb, and Zn in soils of the study area were higher than those in watershed soils. The contents of Cr in Gobi soils were similar with those in Tibetan topsoils [33].

Soil quality of approximately 30% of sampling sites was ranked as Level III or worse based on As thresholds of Environmental Quality Standard Soil of China (GB15618-1995). Soil quality of Gobi areas was at acceptable levels by comparing contents of Cr, Ni, Cu, Cd, Zn and Pb with their thresholds of Environmental Quality Standard Soil of China.

Distribution of rare earth elements (REEs) in topsoils of Gobi area

Contents of REEs in soil samples collected from Gobi areas ranged from 28.42 to 252.81 mg/kg, with an average value of 154.70 mg/kg (Table 1). The average content of REEs in Gobi soils was slightly lower than the background value (159.6 mg/kg), but higher than that of the upper continental crust (146.4 mg/kg) [34]. Concentrations of individual REE in soils were shown in Figure 2. The average concentrations of individual REEs followed the order of Ce > La > Nd > Y > Sc > Pr > Sm > Gd > Dy > Er > Yb > Eu > Ho > Tb > Lu > Tm. Elements including Ce, La, and Nd were the most abundant REEs, accounting for 36%, 17% and 15% of the total REEs, respectively.

Contents of LREEs (light REEs) ranged from 16.68 to 196.54 mg/kg with an average of 118.18 mg/kg. LREEs averagely contributed to 76% of total REEs in Gobi soils. The mean content of LREEs in Gobi soils was lower than the background value of the study area

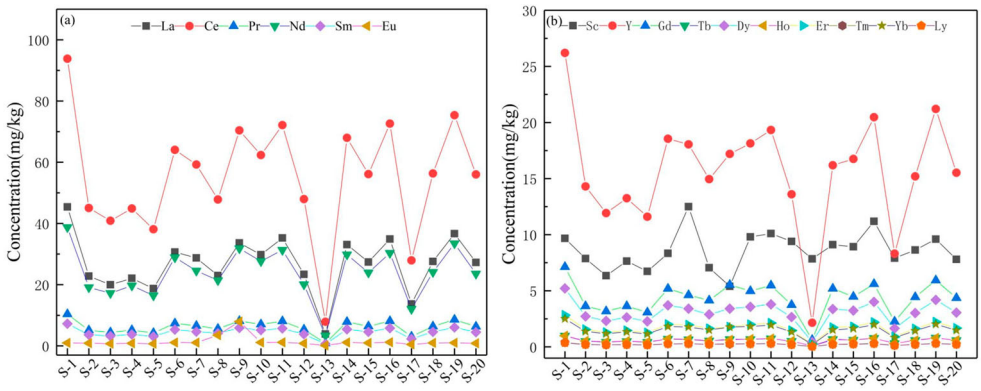

Figure 2. Concentration of light rare earth elements (a) and heavy rare earth elements (b) in soil samples.

and world soil average [20,35]. Contents of HREEs (heavy REEs) ranged from 11.14 to 56.27 mg/kg with the average of 36.52 mg/kg. The average content of HREEs was slightly high than the background value of the study area (35.54 mg/kg) and lower than world soil average (49.09 mg/kg) [20,35]. LREEs were the predominant REEs for all soil samples with LREEs/HREEs ratios ranging from 1.42 to 4.28. The average LREEs/HREEs value of Gobi soils reached 3.15, lower than that of soil samples collected from Nam Co Basin of Tibetan Plateau [36].

Soil pollution by trace elements

The mean I_{geo} values for the trace elements were generally in the order of Pb > As > Cu > Sn > Cd > Mo/Ni > Cr > Co > Sb > REEs > V > Zn(Table 2). The average I_{geo} value for Pb was 2.44, indicating that Pb in soils of Gobi areas was in moderately to heavily contaminated status based on the ranking criteria [37]. As averagely posed uncontamination or moderate contamination. However, As in S-8 and S-9 near a discarded oil well exerted heavy to extremely heavy contamination and extremely heavy contamination, respectively. Sb also posed heavy contamination in Site S-9. I_{geo} values of Cr, Co, and Ni in soil samples collected near an asbestos mining area were almost greater than 2, indicating that soils of S-12 and S-13 were heavily contaminated by Cr, Co and Ni. Mo posed moderate-to-heavy contamination in soil sample collected from Site S-1 which was near a chemical factory. In summary, Pb should be selected as priority control trace elements through the whole study area while other elements including As, Cr, Co, Ni, Mo and Sb should be also paid much attention in some sites especially in mining and industrial areas.

EF values of target trace elements in soils could reflect the influences of anthropogenic activities on soil quality [9]. The average *EF* values of heavy metals ranged from 0.75 (Zn) to 39.65 (As) while the mean *EF* value of REEs was 0.92 (Table 3). The *EF* values of As significantly varied at different sites. High average *EF* value of As illustrated high enrichment feature of As in Gobi soils of the northeastern Qinghai-Tibet Plateau. Ni in Gobi soils was moderately enriched to reflect possible influences of anthropogenic activities. Average *EF* values of Cr, Mo, Cu, Sn, Cd, Co and Sb were in the range of 1.20–2.04,

Table 2. Geo-accumulation index (I_{geo}) of trace elements in soil of the study area.

I_{geo}	V	Cr	Co	Ni	Cu	Zn	As	Mo	Cd	Sn	Sb	Pb	REEs
S-1	−0.59	−0.92	−0.66	−0.89	0.06	−0.68	1.61	2.41	0.23	1.21	1.40	4.53	0.11
S-2	−0.81	−1.26	−0.97	−1.10	1.06	−0.94	−0.38	0.15	0.56	0.05	−0.74	2.23	−0.86
S-3	−1.13	−1.55	−1.18	−1.33	1.06	−1.45	−0.58	0.83	−0.71	−0.30	−0.92	1.16	−1.04
S-4	−0.92	−1.32	−1.07	−1.08	−0.06	−1.20	−0.52	0.03	−0.16	−0.18	−1.00	2.33	−0.87
S-5	−1.02	−1.48	−1.12	−1.19	0.32	−0.88	−0.71	0.26	−0.22	−0.20	−0.97	1.94	−1.11
S-6	−0.66	−1.26	−1.16	−1.34	−0.11	−1.40	−1.06	−0.21	−0.10	−0.26	−1.17	2.25	−0.39
S-7	−0.18	−0.70	−0.15	−0.49	1.49	−0.69	0.01	0.77	0.09	0.24	−0.50	1.37	−0.47
S-8	−1.03	−1.19	−1.27	−1.42	0.66	−1.43	4.11	−0.04	−0.51	−0.26	−0.77	2.03	−0.75
S-9	−0.85	−0.25	−1.51	−1.82	0.30	0.26	11.11	0.04	1.26	−0.04	3.19	4.06	−0.27
S-10	−0.50	−1.02	−0.65	−0.84	−0.20	−0.81	0.18	0.59	0.43	0.09	−0.52	2.87	−0.42
S-11	−0.38	−0.85	−0.57	−0.74	−0.37	−0.91	−0.24	−0.74	0.12	0.03	−0.97	2.71	−0.24
S-12	−0.61	2.00	0.90	3.37	−0.13	0.24	0.34	−0.23	−0.04	−0.04	−0.16	2.67	−0.80
S-13	−1.59	3.74	2.40	5.21	−1.07	−1.67	0.88	−2.25	−1.31	−1.45	0.02	1.07	−3.04
S-14	−0.65	−0.93	−0.65	−0.69	−0.56	−0.99	−0.45	−0.71	−0.11	0.08	−1.30	2.74	−0.35
S-15	−0.72	−0.94	−0.50	−0.60	0.09	−0.95	−0.33	−0.18	−0.02	0.14	−0.93	2.55	−0.57
S-16	−0.36	−0.69	−0.37	−0.37	−0.06	−0.66	−0.17	−0.19	0.34	0.53	−0.82	3.18	−0.22
S-17	−1.14	3.03	1.83	4.52	−0.77	−1.37	0.60	−1.26	−0.73	−0.53	0.06	2.07	−1.51
S-18	−0.69	−1.15	−0.76	−0.97	0.79	−0.75	−0.18	−0.46	−0.48	0.01	−0.31	1.83	−0.59
S-19	−0.76	0.74	−0.05	−0.90	−1.00	−0.77	−0.63	−1.24	0.03	0.36	−1.41	2.62	−0.17
S-20	−0.91	1.68	−0.26	−0.87	−0.62	−0.94	−0.56	−1.23	−0.39	0.13	−1.24	2.59	−0.61

Table 3. Enrichment factor (*EF*) of trace elements in soil of the study area.

EF	V	Cr	Co	Ni	Cu	Zn	As	Mo	Cd	Sn	Sb	Pb	REEs
S-1	1.32	1.05	1.26	1.07	2.07	1.23	6.07	10.57	2.32	4.57	5.24	4.60	2.14
S-2	0.96	0.70	0.86	0.78	3.50	0.87	1.29	1.86	2.47	1.73	1.00	0.79	0.93
S-3	1.07	0.80	1.03	0.93	4.87	0.85	1.56	4.17	1.43	1.90	1.24	0.52	1.14
S-4	0.98	0.74	0.88	0.87	1.77	0.80	1.29	1.88	1.65	1.63	0.93	0.92	1.01
S-5	0.92	0.67	0.86	0.82	2.33	1.02	1.14	2.23	1.60	1.62	0.95	0.71	0.86
S-6	1.12	0.74	0.79	0.70	1.64	0.67	0.84	1.52	1.65	1.47	0.78	0.84	1.35
S-7	0.96	0.67	0.98	0.78	3.07	0.67	1.10	1.86	1.16	1.29	0.77	0.28	0.79
S-8	0.94	0.84	0.80	0.72	3.03	0.71	33.16	1.86	1.35	1.60	1.13	0.78	1.14
S-9	0.18	0.28	0.12	0.09	0.41	0.40	732.78	0.34	0.79	0.32	3.03	0.55	0.28
S-10	1.13	0.79	1.02	0.90	1.39	0.91	1.82	2.42	2.15	1.71	1.12	1.17	1.20
S-11	1.13	0.82	0.99	0.88	1.14	0.78	1.25	0.88	1.61	1.51	0.76	0.97	1.25
S-12	0.85	5.14	2.41	13.32	1.18	1.51	1.63	1.09	1.25	1.25	1.15	0.82	0.74
S-13	0.27	10.69	4.20	29.45	0.38	0.25	1.47	0.17	0.32	0.29	0.81	0.17	0.10
S-14	0.87	0.72	0.87	0.85	0.93	0.69	1.00	0.83	1.27	1.44	0.56	0.91	1.08
S-15	0.86	0.73	1.00	0.93	1.50	0.73	1.13	1.25	1.39	1.56	0.74	0.83	0.95
S-16	0.98	0.78	0.98	0.98	1.21	0.80	1.13	1.11	1.60	1.82	0.71	1.14	1.08
S-17	0.63	11.38	4.95	32.00	0.81	0.54	2.10	0.58	0.84	0.96	1.45	0.59	0.49
S-18	0.99	0.72	0.94	0.81	2.76	0.95	1.41	1.16	1.14	1.60	1.29	0.57	1.06
S-19	0.41	1.16	0.67	0.37	0.35	0.41	0.45	0.29	0.71	0.89	0.26	0.43	0.62
S-20	0.22	1.34	0.35	0.23	0.27	0.22	0.28	0.18	0.32	0.46	0.18	0.25	0.28

illustrating that these heavy metals partly originated from anthropogenic sources. Average *EF* values of REEs, Pb, V and Zn were less than 1, indicating these elements mainly originated from natural sources.

Soil pollution of the study area comprehensively evaluated by all target elements was shown in Figure 3. The *PLI* values at sites S-1, S-7, S-9, S-10, S-12, S-16 and S-19 were greater than 1, indicating that these sites were polluted. Elements including Cr, Ni and As were the main pollution contributors for these sites. *PLI* values at the remaining sites were less than 1 to show that soil quality of these sites was classified as non-polluted [11,38]. The mC_d values at 14 sampling sites were lower than 1.5, indicating that soil pollution of 14 sampling sites was at nil to very low level [4]. The mC_d values of sampling sites including S-1, S-8 and S-12 were between 1.5 and 2 to show soil pollution of these sites was at low level. The mC_d values of sampling sites S-13 and S-17 were between 2 and 4 to show moderate pollution of these sites. The mC_d value of S-9 was greater than 32, indicating ultra-high contamination at this site. *PN* values of all the sampling sites ranged from 1.20 to 2348.32 with the average of 123.69. According to ranking criterion of *PN* [39], 8 sampling sites including S-1, S-7, S-8, S-9, S-12, S-13, S-17 and S-20 showed high pollution while the other 12 sites caused low or moderate pollution. In summary, *PN* method obtained the most serious pollution evaluation results that approximately 10% and 40% of sampling sites showed respectively moderate and high pollution, similar with the previous report [2].

Ecological risks posed by trace elements in soil

RI is an important index to evaluate the potential ecological risks by comprehensively considering both contents and toxicity of target trace elements [19]. *RI* values were less than 150 for 60% of the sampling sites, indicating that trace elements in soils exerted low potential ecological risks for the main part of the study area. Only 10% of sampling sites were at moderate potential ecological risk. In contrast, high *RI* values ($RI > 300$)

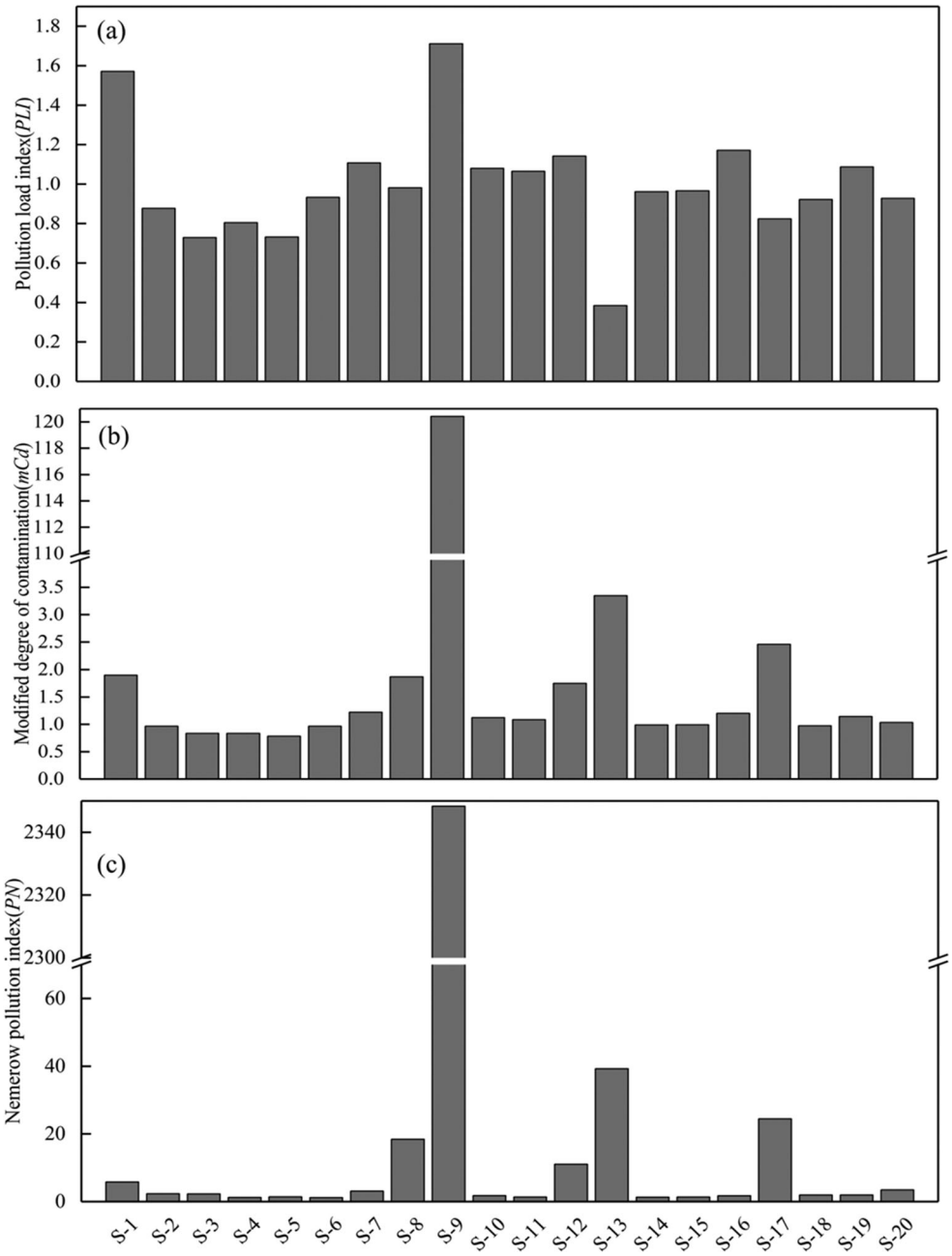

Figure 3. Pollution load index (*PLI*), modified contamination degree (mC_d), and Nemerow pollution index (*PN*) of trace elements in soils of the sampling sites.

were observed at sampling sites (S-8, S-9, S-13 and S-17) near discarded oil well or asbestos mining area (Figure 4). Metalloid As accounted for over 75% of total ecological risks at S-8 and S-9 while Ni contributed to over 50% of ecological risks at S-13 and S-17. REEs exhibited very low ecological risks, similar with the previous report [2,19].

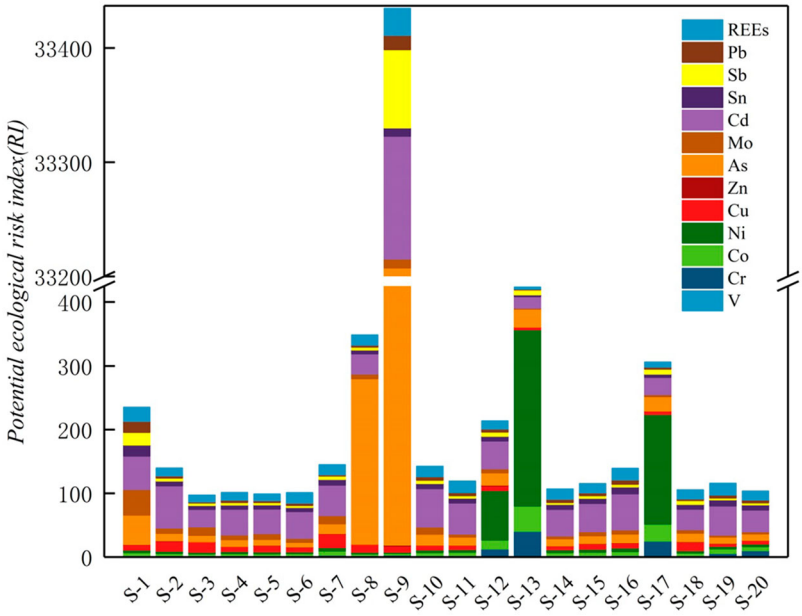

Figure 4. Potential ecological risks posed by trace elements in soils of the sampling sites.

Possible sources of trace elements in topsoils

Pearson's correlation coefficients were used to identify the possible relationship among the trace elements, pH, and TOC (Table 4). V was negatively correlated with Co, Co, Ni at significance level of $P < 0.05$ while it was positively correlated with Sn at $P < 0.05$. Cr was significantly positively correlated with Co and Ni at $P < 0.01$ while it was negatively correlated with Sn at $P < 0.05$. Positive correlation existed in Zn–As, Zn–Cd, Zn–Sb, As–Cd, As–Sb, Mo–Sn, Mo–-Pb, Cd–Sb, Cd–Pb, Sn–Pb, and Sb–Pb at significance level of $P < 0.01$ while negative correlation existed in Co–Cd and Ni–Sn at $P < 0.05$. REEs were positively correlated with V, Cd, Sn, and Pb at $P < 0.01$ while they were negatively correlated with Cr, Co, and Ni at $P < 0.01$. Cu was not correlated with other trace elements, TOC, and pH to show that Cu might originate from a different source. Soil TOC was only positively correlated with Mo, Sn, and REEs at $P < 0.01$ while pH was not correlated with trace elements in soil. In summary, Cr, Co, and Ni might originate from the same or similar source while Zn, As, Mo, and Sb might originate from the other same or similar source. Moreover, trace elements including REEs, Cd, Sn, and Pb might originate from the same or similar source that might negatively contribute to Cr, Co, and Ni.

PCA was performed on the normalised data to further explore the possible sources of trace elements in soils of the northeastern Qinghai-Tibet plateau (Table 5). Four components with eigenvalues >1 could explain approximately 89.13% of the total variance (Table 5). The results were consistent with those of correlation analysis. The first principal component (PC1) accounted for 44.60% of the total variance with high loadings of REEs (0.885) as well as moderate loadings of Cd (0.765), Sn (0.751), Pb (0.721), and V (0.632). Considering that the average concentrations of REEs, Cd, Sn, Pb and V were lower or slightly higher than their corresponding background levels, these elements might

Table 4. Pearson correlation coefficients of trace elements in soil of the study area.

	V	Cr	Co	Ni	Cu	Zn	As	Mo	Cd	Sn	Sb	Pb	REEs	pH	TOC
V	1														
Cr	−0.550*	1													
Co	−0.470*	**0.985****	1												
Ni	−0.530*	**0.980****	**0.992****	1											
Cu	0.269	−0.424	−0.382	−0.366	1										
Zn	0.324	−0.163	−0.182	−0.180	0.026	1									
As	−0.078	−0.076	−0.136	−0.092	0.030	**0.638****	1								
Mo	0.237	−0.311	−0.279	−0.271	0.255	0.086	−0.022	1							
Cd	0.384	−0.432	−0.449*	−0.434	0.132	**0.692****	**0.775****	0.190	1						
Sn	0.547*	−0.471*	−0.443	−0.491*	0.050	0.244	−0.045	**0.783****	0.339	1					
Sb	−0.069	−0.027	−0.077	−0.033	0.019	**0.650****	**0.968****	0.186	**0.760****	0.112	1				
Pb	0.231	−0.230	−0.246	−0.241	−0.196	0.484*	0.475*	**0.704****	**0.610****	**0.767****	**0.635****	1			
REEs	**0.711****	**−0.688****	**−0.674****	**−0.716****	−0.009	0.351	0.188	0.471*	**0.550***	**0.813****	0.238	**0.675****	1		
pH	−0.040	0.223	0.328	0.364	−0.237	−0.038	−0.079	0.045	−0.114	−0.124	−0.024	0.022	−0.138	1	
TOC	0.036	0.065	0.074	0.069	−0.117	0.075	−0.023	**0.863****	0.047	**0.730****	0.218	**0.767****	0.362	0.109	1

Note: ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

Table 5. Principal component analysis for trace elements in soil of the study area.

	Component matrix			
Trace metals	PC1	PC2	PC3	PC4
V	0.632	−0.349	0.015	−0.299
Cr	−0.786	0.478	0.322	0.001
Co	−0.783	0.423	0.351	0.011
Ni	−0.790	0.460	0.314	0.065
Cu	0.263	−0.315	−0.449	0.697
Zn	0.548	0.565	−0.150	−0.170
As	0.430	0.808	−0.343	0.074
Mo	0.558	−0.108	0.601	0.531
Cd	0.765	0.483	−0.243	−0.068
Sn	0.751	−0.194	0.592	0.032
Sb	0.475	0.835	−0.128	0.178
Pb	0.721	0.408	0.532	0.047
REEs	0.885	−0.155	0.222	−0.292
Eigenvalues	5.798	2.981	1.787	1.020
% total variance	44.603	22.929	13.746	7.847
%cumulative	44.603	67.532	81.277	89.125

Note: PC means principal component.

mainly originate from the natural source. Cr, Co, and Ni exhibited contributed high concentrations in soils and exerted negative loadings to PC1 so that these elements might originate from the industrial/mining activities. The second principal component (PC2) accounted for 22.93% of the total variance associated with As and Sb. It could be inferred that oil exploitation might contribute to high concentrations of As and Sb in soils when considering the high concentrations of As in some sites around abandoned oil well of this study area and strong correlation of As and Sb. The third principal component (PC3) and the fourth component (PC4) explained 13.75% and 7.85% of the total variance, respectively. Mo and Cu contributed the main loading to PC3 and PC4, respectively. It was hypothesised that Mo might mainly originate from natural source that was different from source of REEs, Cd, Sn, Pb and V while Cu might be mainly influenced by the agricultural activities.

Conclusions

The average concentrations of trace elements in soils of the northeastern Qinghai-Tibet Plateau ranged from BDL (Hg) to 2360.82 (As) mg/kg. Elements including As, Ni and Cr showed high concentrations in soils. Different indices were used to assess pollution of trace element in soils of study area. Pb posed the most serious pollution in the study area based on I_{geo} evaluation and selected as priority control trace element in study area. *EF* values of trace elements in soils ranged from 0.09 (Ni) to 1044.56 (Cr) with average values in the range of 0.84 (V)-39.65 (As). Gobi soils in the study area were influenced by anthropogenic activities. Among three comprehensive pollution evaluation methods, *PN* obtained the most serious pollution evaluation results that moderate and high pollution occurred at 10% and 40% of sampling sites, respectively. Trace elements exerted high ecological risks to about 20% of sampling sites based on *RI* evaluation results. The results of the PCM and PCA showed that contaminated soils in study area were influenced by anthropogenic activities such as industrial and mining effluents and the uncontaminated soils were affected by natural sources.

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