Evaluation of Heavy Metal Level in Soil of Typical Alpine Grassland Communities

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Abstract. Objective: Through the investigation, determination and analysis of heavy metals in the soil of typical alpine grassland community, five kinds of alpine grasslands with different degeneration degree of Maduo County in Alpine area, two kinds of alpine grassland with high Maqu County, high Alpine desert along the coast of Qinghai Lake, alpine thickets in the yellow South region, Alpine wetlands, The condition of soil heavy metals in alpine meadow and other communities is analyzed, which provides scientific guidance for the ecological protection measures of typical alpine grassland communities, and provides a basis for the sustainable utilization of Alpine grassland. Methods: The content of various kinds of heavy metals in soil samples was determined by ICP-MS, and the pollution status of heavy metals was analyzed by means of single factor pollution index method, Nemero comprehensive pollution index method and potential ecological risk index method by using Excel. Results: (1) The content of Cd in Maduo, Maqu, Qinghai Lake and Huangnan was 1.74, 0.97, 1.84 and 1.06 times times the soil environment background respectively, and the content of Hg in Maqu was 1.36 times times that of soil environmental background value. The variation coefficient of Hg and Pb in Maqu and the coefficient of variation of Cd in Qinghai Lake are more than 100%, which is in the degree of high variation, which is greatly influenced by man. (2) The highest total pollution index in the 4 sample places was in the area of MA diversity, at 1.33. The second is the Huangnan sample, with an exponential value of 0.86. The Nemero comprehensive pollution Index of the Maqu sample is 0.77. The index value of Qinghai Lake sample is the lowest, at 0.61. (3) The highest potential ecological hazard index is the most diverse, in 0-10, 10-20, 20-30cm three soil layers are 96.96, 103.58, 102.46, Maqu in 0-10, 10-20cm soil, the potential ecological hazard index is 65.70, 71.01, the potential ecological hazard index of Huangnan in three soil layer is 78.23, 73.42 and 72.84 respectively, which refers to the smallest value of Qinghai Lake sample, three, 51.07 and 51.72 in 51.48 soil layer respectively. Conclusion: The Nemero comprehensive pollution Index of Qinghai Lake sample is less than 0.7, at the level of cleanliness, the exponential value of Huangnan and Maqu two samples is between 0.7~1, at the level of cordon, and the exponential value of ma variety is between 1~2, at the level of mild pollution. The comprehensive potential ecological hazard index of 80~160 has the potential ecological risk of strength, and the exponential value of the other three samples is between 40~80, which has medium potential ecological risk. Generally, the pollution degree of heavy metals is small in the whole alpine grassland area.

1 INTRODUCTION

The heavy metals are environmental pollutants and potential toxic pollutants, which are featured by long-lasting harm, difficult degradation, amplification effect of food chain enrichment, etc. [1]. With the serious environmental disruption in the industrialization development, the sources of heavy metals in the contaminated soil have become the important research direction. The soil heavy metals may vary a lot with the soil formation process, and the atmospheric deposition, sewage irrigation, etc. are also important sources of soil heavy metals [2]. Starting from the sedimentology, Hakanson [3] proposed a method of evaluating and analyzing the heavy metal pollution and ecological risks in soil and sediments in 1980. Pastor J [4] believed that the heavy metal pollutions obviously impacted the species diversity of plant communities. Liu Y et al. [5] pointed out the differences in the toxicity coefficients between different heavy metal elements. As indicated by Chen W [6], the physiological activities of different grassland plants were influenced by the heavy metal stress.

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2 RESEARCH METHODOLOGY

2.1 The information of the Study area and the plots

The typical Alpine grassland plant communities were taken as the study objects to analyze the status, sources, and the distribution characteristics and main components of soil heavy metal lever. The followings were selected: the five Alpine steppe plant communities with different degrees of degradation in Maduo County, Guoluo Prefecture, Qinghai Province in the Sanjiangyuan area, eight typical Alpine grassland plant communities in Henan County, Huangnan Prefecture, Qinghai Province, three desert plant communities in Qinghai Lake Natural Reserve, and three Alpine grassland plant communities in Maqu County, Tibetan Autonomous Prefecture of Gannan, Gansu Province in the Sanjiangyuan area, including 7 vegetation types—alpine steppe, Alpine desert, Alpine grassland, Alpine meadow, Alpine artificial grassland, Alpine shrub, and Alpine wetland—and 19 types of plant communities.

Located at the northwest of Guoluo Tibetan Autonomous Prefecture at 96°55′-99°20′E and 33°50′-35°40′N, Maduo County belongs to alpine steppe climate [7]. The study objects were five alpine grasslands with different degrees of degradation, namely, *Festuca rubra*-type slightly degraded steppe, *Leymus secalinus*-type moderately degraded steppe, *Thermopsis lanceolata* -type moderately degraded grassland, *Leymus secalinus*-type severely degraded steppe, and *Leymus secalinus* -type severely degraded control grassland. Under the jurisdiction of Gannan Prefecture, Gansu Province, Maqu County is located at the southwest of Tibetan Autonomous Prefecture of Gannan, Gansu Province, and east end of Qinghai-Tibet Plateau, with longitude and latitude of E100°45′-102°29′ and N33°06′-34°30′, and it belongs to alpine wet climate [8], where *Elymus nutans* artificial grassland, and degraded *Kobresia humips* meadow were selected in this study. Located at the northeast of Qinghai-Tibet Plateau in the territory of Qinghai Province, China (latitude: N36°37′-37°5′, longitude: E 100°25′-100°55′), Qinghai Lake has plateau continental climate [9]. The deserts and steppes with serious desertification along the Qinghai Lake were selected as the study objects. Huangnan Tibetan Autonomous Prefecture is located at the southeast of Qinghai Province (longitude: E34°75', latitude: N101°62'), and it belongs to plateau continental climate, where *Potentilla fruticosa* shrub, *Elymus nutans* grassland, *Kobrbresia pygmaea* meadow, and *Kobresia tibetica* marsh meadow were chosen as the study objects.

2.2 Collection and pretreatment of soil samples

In order to explore the distribution characteristics of heavy metal pollutions in the selected typical alpine grassland soils, the sample plots were divided according to their different environments and terrains, and then the soil samples were collected from the three soil layers—0-10, 10-20, and 20-30 cm. The sundries were removed after the samples were dried naturally at indoor shade place, a certain amount of soil sample was taken through the quartering method and grinded, passed the 100-mesh nylon sieve, and was finally put into a sealing bag to determine the soil heavy metal contents.

2.3 determination method of heavy metal elements in soil

0.1000 g of soil sample was weighed, 7 mL of HNO_3, 1 mL of HF, and 0.5 mL of $HClO_4$ were added, followed by the microwave digestion [10] under the working conditions in Table 1, and a reagent blank was made; after the digestion was completed, the sample was transferred to a crucible, the acids were caught on an electric heating plate at 100℃, and after the sample was completely cooled, its volume was made constant at 50 mL using ultrapure water. The contents of heavy metals such as Cr, Ni, Cu, Zn, As, Cd, Hg and Pb were determined through the inductively coupled plasma mass spectrometry (ICP-MS) method [11].

Table 1 Working Conditions of Microwave Digestion

Steps	Power/W	%	temperature control/℃	time/min	hold/min
1	800	100	120	8	4
2	800	100	150	7	7
3	800	100	180	7	30

2.4 Analytical method

2.4.1 Evaluation method for heavy metal contents

The soil heavy metal contents were evaluated by comparing the determined soil heavy metal contents with the soil environmental background values in Qinghai Province, along with the coefficients of variation of the soil heavy metals.

2.4.2 Evaluation method for heavy metal pollution

The single-factor pollution index is the basis for other environmental quality grading, environmental quality indexes, and comprehensive environmental assessment [12], however, being only applicable to the assessment of environmental pollution caused by single factors, it can only reflect the pollution degree of a single factor [13]. Its calculation formula is as follow:

$$P_i=C_i/S_i \tag{1}$$

(1) where P_i, C_i and S_i are pollution index, measured concentration, and standard value of pollution factor i, respectively [15]. The grading standards [13] are seen in Table 2:

Table 2 Classification Standard of Single Factor Pollution Index Method

Grade division	Pi	Pollution grade
I	$P_i \leq 1$	clean
II	$1<P_i \leq 2$	Slight pollution
III	$2<P_i \leq 3$	Moderate pollution
IV	$P_i>3$	Intensity pollution

The Nemerow index method is a weight calculation-type multi-factor environmental quality assessment index, which takes full consideration of the extreme values of various polluting elements, and can comprehensively reflect the combined action of the heavy metals on the soil [13]. It is only capable of reflecting the heavy metal pollution degree in the soil, but cannot embody the qualitative change characteristics of contaminated soil [13]. Its calculation formula is as below:

$$P_{comprehensive}=[(P_{average}+Pi_{max}) / 2]1/2 \quad (2)$$

(2) where $P_{comprehensive}$ is Nemerow comprehensive pollution index; $P_{average}$ is average value of all single pollution indexes; $P\ i_{max}$ is the maximum value among all single pollution indexes. The grading standards [13] of the Nemerow comprehensive pollution index method are seen in Table 3:

Table 3 Classification Standard of Nemerow Comprehensive Pollution Index Method

Grade division	Nemero Comprehensive Pollution Index	Pollution grade
I	$P_{comprehensive} \leq 0.7$	clean
II	$0.7<P_{comprehensive} \leq 1.0$	cordon
III	$1.0<P_{comprehensive} \leq 2.0$	Slight pollution
IV	$2.0<P_{comprehensive} \leq 3.0$	Moderate pollution
V	$P_{comprehensive}>3.0$	Intensity pollution

Established by the Swiss scientist Hakanson in 1980, the potential ecological risk index method is applicable to the assessment of hazard levels of sediments or soil heavy metals as well as ecological risks [12]. This method can realize the quantitative division [14] of hazard levels of the heavy metals, its grading standards [13] are seen in Table 4, and its calculation formula is as follow:

Single heavy metal pollution coefficient: $C^i_f=C^i/C^i_n$ (3)

Heavy metal pollution degree: $C_d=C_f^1+C_f^2+...+C^i_f$ (i=1,2...n) (4)

In formulas (3) and (4), C^i_f is single heavy metal pollution coefficient; C^i is measured value of pollutant i; C^i_n is the corresponding reference value [15] for the assessment of the heavy metal i.

Potential ecological hazard coefficient of single heavy metal: $E_r^i=T_r^i \times C_f^i$ (5)

Comprehensive potential risk index of multiple heavy metals: $RI=E_r^i+E_r^2+...+E_r^i$ (i=1, 2...n) (6)

In formulas (5) and (6), E_r^i is potential ecological hazard index of heavy metal i; T_r^i is toxicity coefficient of heavy metal i [15].

Table 4 Classification Criteria of Potential Ecological Risk Index Method

Pollution level	C^i_f	C_d	Potential ecological risk degree	E_r^i	RI
Low	Cif<1	Cd<8	Slight	Eri<10	RI<40
Moderate pollution	1~3	8~16	Moderate pollution	10~20	40~80
High pollution	3~6	16~32	Intensity pollution	20~40	80~160
Maximum pollution	6~9	Cd≥32	Serious pollution	40~80	RI≥160
	≥9		Extremely	≥80	

2.5 Data processing

The data processing of soil heavy metal contents was conducted via Excel, followed by the Origin plotting. SPSS25 was utilized to perform one-way analysis of variance, and LSD multiple comparisons for the data ($p<0.05$).

3 RESULTS

3.1 Analysis of soil heavy metal contents in typical alpine grasslands in different areas

As seen in Table 5, the heavy metal Zn had the maximum content in soil in Maduo County, being 81.68 mg/kg, while Hg presented the minimum content, being 0.09 mg/kg. The average values of other heavy metal elements did not exceed the soil environmental background values.

In Maqu County, Zn had the maximum content (0.16 mg/kg) in soil, and Cd had the minimum content (0.19 mg/kg). Moreover, the content of heavy metal Hg exceeded the standard, and reached 1.36 times of the background value. The average values of other elements did not exceed the soil environmental background values. The elements presenting great inhomogeneity were Hg and Pb, the coefficients of variation of which were 108.04% and 110.31%, respectively.

In Qinghai Lake, the heavy metal Zn had the maximum content (36.05 mg/kg) in soil, and Hg had the minimum content (0.05 mg/kg). The average content of Cd exceeded the standard, and reached 1.84 times of the background value. The average values of other elements did not exceed the soil environmental background values. The heavy metal element with the maximum inhomogeneity was Cd, the coefficient of variation of which was 109.79%.

Zn presented the maximum content in soils of Huangnan alpine wetland, shrub, and meadow, reaching 61.25 mg/kg. Hg had the minimum content (0.08 mg/kg). The average content of Cd in soil exceeded the standard, and reached 1.06 times of the background value. The average values of other elements did not exceed the soil environmental background values. The heavy metal element under inhomogeneous distribution was Hg, the coefficient of variation of which was 22.68%.

Table 5 Statistics of Soil Metal Element Content and Soil Background Value in Alpine Grassland

	Heavy metal	Statistical value of heavy metals in alpine grassland soil of Maduo（mg/kg）						
		Minimum value	Maximum value	Average value	Standard deviation	Coefficient of variation	Background value	Average value to background value
Maduo	Cr	14.25	19.64	16.5	1.96	11.86%	90	0.18
	Ni	19.04	21.03	19.83	0.65	3.27%	40	0.5
	Cu	14.31	17.37	15.45	0.72	4.64%	35	0.44
	Zn	60.48	100.35	81.68	12.39	15.17%	100	0.82
	As	10.35	17.13	14.29	1.63	11.39%	15	0.95
	Cd	0.22	0.72	0.35	0.16	45.73%	0.2	1.74
	Hg	0.08	0.13	0.09	0.01	15.49%	0.15	0.63
	Pb	16.5	26.26	23.34	3.18	13.64%	35	0.67
Maqu	Cr	9.93	16.69	11.26	1.95	17.32%	90	0.13
	Ni	12.81	14.55	13.92	0.43	3.12%	40	0.35
	Cu	9.11	10.83	10.25	0.43	4.19%	35	0.29
	Zn	53.49	72.96	60.16	6.58	10.94%	100	0.6
	As	4.99	10.32	8.67	1.39	16.00%	15	0.58
	Cd	0.17	0.23	0.19	0.02	10.44%	0.2	0.97
	Hg	0.06	0.22	0.2	0.22	108.04%	0.15	1.36
	Pb	16.83	19.06	12.48	13.77	110.31%	35	0.36
Qinghai Lake	Cr	6.39	12.35	9.38	2.19	23.36%	90	0.1
	Ni	6.93	14.81	11.08	3.06	27.61%	40	0.28
	Cu	4.52	10.17	7.57	2.31	30.56%	35	0.22
	Zn	23.29	45.9	36.05	6.74	18.70%	100	0.36
	As	5.88	10.78	8.06	6.23	77.23%	15	0.54
	Cd	0.11	0.19	0.37	0.4	109.79%	0.2	1.84
	Hg	0.04	0.08	0.05	0.01	23.11%	0.15	0.36
	Pb	12.43	18.13	15.57	2.14	13.74%	35	0.44
Huangnan	Cr	9.98	18.14	14.02	1.81	12.90%	90	0.16
	Ni	15.35	20.59	18.38	1.4	7.61%	40	0.46
	Cu	11.78	15.08	13.52	0.86	6.34%	35	0.39
	Zn	43.37	76.99	61.25	9.19	15.00%	100	0.61
	As	7.68	16.08	13.44	1.72	12.81%	15	0.9
	Cd	0.17	0.27	0.21	0.03	11.98%	0.2	1.06
	Hg	0.05	0.11	0.08	0.02	22.68%	0.15	0.52
	Pb	19.09	25	22.45	1.61	7.15%	35	0.64

Note: Soil environmental background values [16] in Qinghai Province are used, similarly hereinafter.

The soil heavy metal contents at different soil layers in the four sample plots are listed in Table 6. In the 4 sample plots, the contents of the eight heavy metals at soil layers of 0-10 and 10-20 cm are ranked as Maduo> Huangnan> Maqu> Qinghai Lake.

Table 6 Soil Heavy Metals in Different Soil Layers in Four Sample Lands

Heavy metal	Solum/cm	Contents of Heavy Metals in Different Soil Layers in Four Sample Lands（mg/kg）			
		Maduo	Maqu	Qinghai Lake	Huangnan
Cr	0-10	16.97±0.89 aA	11.64±1.05 aBC	9.20±1.43 aC	13.41±0.61 aB
	10-20	16.23±1.06 aA	10.88±0.49 aB	8.83±0.89 aB	14.67±0.59 aA
Ni	0-10	19.52±0.19 bA	14.04±0.14 aC	11.61±2.10 aD	17.3±0.49 bB
	10-20	19.66±0.26 abA	13.79±0.21 aB	9.99±1.60 aC	18.76±0.30 aA
Cu	0-10	15.39±0.13 aA	10.28±0.12 aC	7.95±1.59 aD	13.42±0.40 aB
	10-20	15.48±0.31 aA	10.21±0.23 aC	6.93±1.24 aD	13.65±0.24 aB
Zn	0-10	83.59±6.29 aA	59.68±2.80 aB	33.29±5.38 aC	64.62±3.44 aB
	10-20	73.67±5.35 aA	60.63±2.82 aB	35.45±3.38 aC	62.35±2.71 aB
As	0-10	14.39±0.66 aA	9.05±0.36 aB	8.12±1.18 aB	13.73±0.37 aA
	10-20	15.08±0.61 aA	8.30±0.72 aB	7.69±0.66 aB	13.67±0.63 aA
Cd	0-10	0.32±0.05 aA	0.19±0.01 aB	0.16±0.02 aB	0.23±0.01 aB

	10-20	0.35±0.09 aA	0.20±0.01 aB	0.16±0.02 aB	0.21±0.00 bB
Hg	0-10	0.09±0.01 aA	0.08±0.02 aAB	0.05±0.01 aB	0.08±0.01 aAB
	10-20	0.10±0.01 aA	0.10±0.03 aA	0.06±0.01 aA	0.08±0.01 aAB
Pb	0-10	24.79±0.68 aA	18.49±0.19 aC	16.27±1.42 aD	22.53±0.47 aB
	10-20	21.72±1.51 aB	18.27±0.31 aC	15.21±1.41 aD	21.87±0.70 aA

Note: The data in the above table are expressed by mean ± standard deviation. The same lowercase represents no significant differences of heavy metal contents at different soil layers in the same sample plot (p>0.05). The same uppercase indicates no significant differences of heavy metals at the same soil layer in different sample plots (p>0.01).

3.2 Comparison of soil heavy metal contents in different grasslands

Table 7 Contents of Heavy Metals in Soils of Different Grassland Types

Grassland type	Heavy metal content[mg/kg]							
	Cr	Ni	Cu	Zn	As	**Cd**	**Hg**	Pb
Alpine steppe A	16.50	19.83	15.45	81.68	14.29	0.35	0.09	23.34
Alpine Grassland B	11.26	13.92	10.25	60.16	8.67	0.19	**0.20**	12.48
Alpine desert C	9.38	11.08	7.57	36.05	8.06	0.37	0.05	15.57
Alpine swamp D	11.63	17.34	13.86	62.28	14.42	0.22	0.06	21.47
Alpine shrub E	13.59	19.38	13.71	68.77	14.23	0.22	0.09	24.05
Alpine meadow F	15.08	18.18	13.37	60.93	13.24	0.20	0.09	21.71
Background value of soil environment	90.00	40.00	35.00	100.00	15.00	0.20	0.15	35.00

The alpine steppe, alpine grassland, alpine desert, alpine wetland, alpine shrub, and alpine meadow were respectively set as A, B, C, D, E and F. It could be seen that the Cr contents in different grasslands were ranked as C<B<D<E<F<A, the Ni contents as C<B<D<F<E<A, the Cu contents as C<B<F<E<D<A, the Zn contents as C<B<F<D<E<A, the As contents as C<B<F<E<A<D, and the Pb contents as B<C<D<F<A<E, and none of the above elements exceeded the soil environmental background values (Table 7). The Cd contents in different grasslands were ranked as B<F<D<E<A<C, and except for the alpine grassland B, the Cd contents in other grasslands exceeded the soil environmental background value of Cd. The Hg contents were ranked as C<D<F<E<A<B, where the Hg content in alpine grassland was 0.20 mg/kg, exceeding the soil environmental background value.

3.3 Assessment of soil heavy metal pollutions in typical alpine grasslands in different areas

3.3.1 Pollution assessment based on single-factor pollution index

Table 8 Single Factor Pollution Index and Nemerow Comprehensive Pollution Index of Soil Heavy Metals in Four Sample Lands

Sample plot	Solum/cm	Single factor pollution index								Nemerow Composite Pollution Index
		Cr	Ni	Cu	Zn	As	Cd	Hg	Pb	
Maduo	0-10	0.19	0.49	0.44	0.84	0.96	1.60	0.62	0.71	1.24
	10-20	0.18	0.49	0.44	0.74	1.01	1.76	0.67	0.62	1.35
	20-30	0.18	0.51	0.44	0.88	0.89	1.84	0.59	0.67	1.41
Qinghai Lake	0-10	0.10	0.29	0.23	0.33	0.54	0.79	0.33	0.46	0.62
	10-20	0.10	0.25	0.20	0.35	0.51	0.78	0.39	0.43	0.61
	20-30	0.11	0.29	0.22	0.39	0.57	0.76	0.36	0.44	0.61
Huangnan	0-10	0.15	0.43	0.38	0.65	0.91	1.17	0.53	0.64	0.93
	10-20	0.16	0.47	0.39	0.62	0.91	1.04	0.50	0.62	0.84
	20-30	0.16	0.48	0.39	0.57	0.86	0.98	0.54	0.66	0.81
Maqu	0-10	0.13	0.35	0.29	0.60	0.60	0.97	0.51	0.53	0.77
	10-20	0.12	0.34	0.29	0.61	0.55	0.98	0.65	0.52	0.78

The single-factor pollution indexes and Nemerow comprehensive pollution indexes of soil heavy metals in the four sample plots are seen in Table 8. The single-factor pollution indexes of heavy metals in Maduo were ranked as Cd>As>Zn>Pb>Hg>Ni>Cu>Cr. The Cd contents at all soil layers exceeded the primary standard, and the As content at soil layer of 10-20 cm exceeded the primary standard, being at light pollution level. The other heavy metals did not exceed the primary standard at all soil layers, so they were at clean level. The single-factor pollution indexes of different heavy metals at different soil layers in Maduo sample plot were insignificantly different (p>0.05).

In Maqu, the single-factor pollution index of Cd was the maximum, followed by Zn, As, Hg, Pb, Ni, Cu and Cr. None of the heavy metals at all soil layers exceeded the primary standard, so they were at clean level. The single-factor pollution indexes of different heavy metals at different soil layers in Maqu sample plot were not significantly different (p>0.05).

In Qinghai Lake sample plot, the single-factor pollution index of Cd was the maximum, followed by As, Pb, Hg, Zn, Ni, Cu and Cr. None of the heavy metals at all soil layers exceeded the primary standard, so they were at clean level. No significant differences were manifested in the single-factor pollution indexes of different heavy metals at different soil layers in Qinghai Lake sample plot (p>0.05).

In Huangnan sample plot, the single-factor pollution index of Cd was the maximum, followed by As, Pb, Zn, Hg, Ni, Cu and Cr. The Cd contents at soil layers of 0-10 and 10-20 cm exceeded the primary level, being at light pollution level. None of the other heavy metals exceeded the primary level at all soil layers, so they were at clean level. No significant differences existed in the single-factor pollution indexes of different heavy metals at different soil layers in Huangnan sample plot (p>0.05).

3.3.2 Pollution assessment based on Nemerow comprehensive pollution index

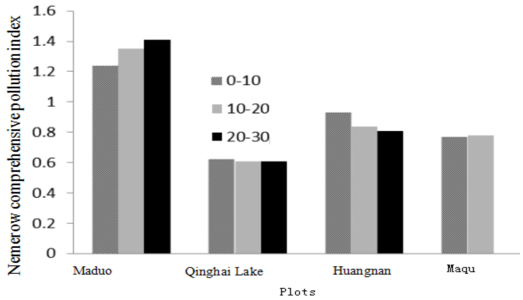

Fig.1 Nemerow comprehensive pollution index of soil heavy metals in four sample plots

As shown in Table 8 and Figure 1, the Nemerow comprehensive pollution index in Maduo among the four sample plots was the maximum, being 1.33, followed by Huangnan (0.86), Maqu (0.77), and Qinghai Lake (0.61), successively. According to the grading standard, the Nemerow comprehensive pollution index of Qinghai Lake sample plot was smaller than 0.7, being at clean level, those of Huangnan and Maqu were within 0.7-1, approaching the warning line, and that of Maduo sample plot was 1-2, being at light pollution level.

3.3.3 Pollution assessment based on potential ecological hazard index

Table 9 Potential Ecological Hazard Indexes of Heavy Metals in Different Soil Layers of Four Sample Lands

Sample plot	Solum/cm	Potential Ecological Hazard Coefficient of Single Heavy Metal								RI
		Cr	Ni	Cu	Zn	As	Cd	Hg	Pb	
Maduo	0-10	0.48	3.30	3.19	1.04	10.28	48.02	24.70	5.93	96.96
	10-20	0.46	3.32	3.21	0.92	10.77	52.84	26.86	5.20	103.58
	20-30	0.46	3.43	3.21	1.09	9.57	55.28	23.78	5.62	102.46
Qinghai Lake	0-10	0.26	1.96	1.65	0.41	5.80	23.74	13.36	3.89	51.07
	10-20	0.25	1.69	1.44	0.44	5.49	23.28	15.49	3.64	51.72
	20-30	0.29	1.97	1.62	0.49	6.10	22.80	14.57	3.65	51.48
Huangnan	0-10	0.38	2.92	2.78	0.80	9.80	34.98	21.18	5.39	78.23
	10-20	0.42	3.17	2.83	0.78	9.77	31.07	20.15	5.23	73.42
	20-30	0.40	3.22	2.80	0.71	9.24	29.45	21.53	5.49	72.84
Maqu	0-10	0.33	2.37	2.13	0.74	6.46	28.95	20.28	4.42	65.70
	10-20	0.31	2.33	2.12	0.76	5.93	29.34	25.86	4.37	71.01

The potential ecological hazard indexes of heavy metals at different soil layers in the four sample plots are seen in Table 9. In Maduo sample plot, the potential ecological hazard indexes of Cd at soil layers of 0-10, 10-20 and 20-30 cm were the maximum, being 48.02, 52.84 and 55.28, respectively, followed by those (34.97, 31.07 and 29.45) in Huangnan sample plot, and those in Qinghai Lake sample plot. It could be seen that the potential ecological hazard indexes of Cd in Maqu and Huangnan were not significantly different, while those in other sample plots were significantly different. The potential ecological hazard index of Cd in Maduo was within 20-40, which indicated extremely strong potential ecological risk, and those in the other three sample plots were 0-20, manifesting strong potential ecological risk. The single-factor potential ecological hazard indexes of Cd at different soil layers in the same sample plot were not significantly different. The potential ecological hazard indexes of Cr, Ni, Cu, Zn, As, Cd, Hg and Pb were the maximum in Maduo sample plot, and the minimum in Qinghai Lake sample plot. The potential ecological hazard index of Hg in Maqu was not significantly different from those in Maduo and Huangnan, but significant differences were found between other sample plots. The potential ecological hazard index of As was insignificant different between Maduo and Huangnan, and between Maqu and Qinghai Lake, while significant differences were manifested between other sample plots. The potential ecological hazard index of Pb in Maduo was insignificantly different from that in Huangnan, while significant differences were found between other sample plots. The potential ecological hazard indexes of Hg in Maduo, Maqu and Huangnan were within 20-40, indicating strong potential ecological risks, but it was smaller than 10 in Qinghai Lake, manifesting slight potential ecological risk. The potential ecological hazard indexes of As at soil layers of 0-10 and 10-20 cm in Maduo were within 10-200, meaning moderate potential ecological risk, but those in other sample plots were lower than 10, indicating slight potential ecological risk. The potential ecological hazard indexes of other heavy metals at all soil layers in the four sample plots were smaller than 10, with slight potential ecological risk.

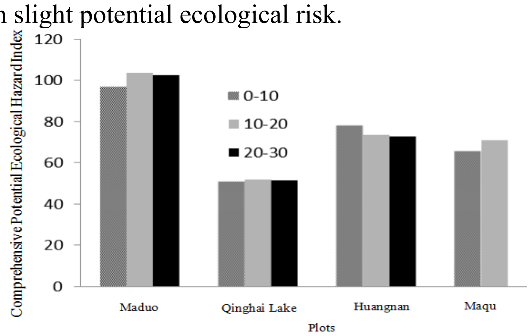

Fig. 2 Comprehensive Potential Ecological Hazard Index of Heavy Metals in Soil

Among the four sample plots, the comprehensive potential ecological hazard index in Maduo was the maximum, and those at three soil layers of 0-10, 10-20 and 20-30 cm were 96.96, 103.58 and 102.46, respectively, and the sample plot with the minimum comprehensive potential ecological hazard index was Qinghai Lake sample plot. The comprehensive potential ecological hazard index in Maduo was within 80-160, indicating strong potential ecological risk, and those in other three sample plots were within 40-80, manifesting moderate potential ecological risk (Figure 2). Given this, no significant differences were found in the comprehensive potential ecological hazard indexes at different soil layers in the same sample plot.

4 DISCUSSION

4.1 Over-standard status and analysis of soil heavy metals in different areas

In the alpine grassland, the heavy metal Zn had the maximum content, which exceeded 70.00 mg/kg, but did not exceed the soil environmental background value. The content of heavy metal Cd exceeded the soil environmental background value in Qinghai Lake sample plot and Huangnan sample plot, and it was Hg content that exceeded the background value in Maqu, which was consistent with the research conducted by Li R Q et al. on the soil heavy metal pollution in plateau of Gansu Province, and moreover, the Hg content was higher than other heavy metals. It could be seen that the Cd content nearly on the whole alpine grassland exceeded the soil environmental background value, while the other six heavy metals did not, so the overall soil quality in the alpine grassland was good.

The coefficient of variation (CV) can be divided into 3 levels [17], respectively being high degree of variation (CV>36%), moderate degree of variation (16%<CV<36%), and low degree of variation (CV<16%). In Maduo sample plot, the CV of Cd was 45.73%, which indicated high degree of variation, but other heavy metals were under low degree of variation. In Maqu sample plot, the CVs of Hg and Pb were 108.04% and 110.31%, respectively, which indicated high degree of variation, while other heavy metals had low CVs. In Qinghai Lake sample plot, the CVs of As and Cd were 77.23% and 109.79%, respectively, manifesting high degree of variation, those of Cr, Ni, Cu, Zn and Hg were within 16%-36%, belonging to moderate degree of variation, and the heavy metal Pb was under low degree of variation. In Huangnan sample plot, the CV of Hg was 22.86%, belonging to moderate degree of variation, and other heavy metals were under low degree of variation. It is generally accepted that the greater the CV of soil heavy metal, the more greatly this area will be influenced by human activities [19]. The CVs of some soil heavy metals in Maqu and Qinghai Lake exceeded 100%, so the two sample plots suffered from considerable man-made disturbance [19,20], and this was identical with the human factor analysis (Wei H L et al.) for the grassland vegetations in Maqu, and the ecological status and cause analysis of Qinghai Lake grassland (Zhang B C et al.).

4.2 Discussion about the difference significance of soil heavy metals at different soil layers in different sample plots

The contents of eight heavy metals in the four sample plots were ranked as Maduo> Huangnan> Maqu> Qinghai Lake. The Cr content at soil layer of 0-10 cm in Maqu was insignificantly different from those in Qinghai Lake and Huangnan, and its content at soil layer of 10-20 cm in Maduo was insignificantly different from those in the other three sample plots. The Ni contents at soil layers of 10-20 and 20-30 cm in Maduo were insignificantly different those in Huangnan. Significant differences were found in the Cu contents at soil layers of 0-10, 10-20, and 20-30 cm in the four sample plots. The differences between Maqu and Huangnan in the aspect of Zn contents at soil layers of 0-10 and 10-20 cm were not significant. The As contents at soil layers of 0-10 and 10-20 cm in Maduo were not significantly different from those in the other three sample plots. Maduo presented significant differences from the other three sample plots in the Cd contents at soil layers of 0-10 and 10-20 cm, and Qinghai Lake was insignificant different from Huangnan in the Cd contents at soil layer of 20-30 cm. Insignificant differences were manifested between Maduo and Huangnan in the Hg content at soil layer of 0-10 cm, the Hg content at soil layer of 10-20 cm in Qinghai Lake was significantly different from those in Maduo and Maqu, and Maduo presented insignificant difference from Huangnan in the Hg content at soil layer of 20-30 cm. Insignificant difference was found between Maduo and Huangnan in the Pb content at soil layer of 20-30 cm. The overall differences of the heavy metal contents at the same soil layer in the four sample plots were significant.

The vertical distributions of heavy metals in the four sample plots basically presented a gradual declining trend with the increase of depth, and no significant differences existed under most circumstances, which was consistent with the conclusion drawn by related scholars [21-24], namely, the heavy metal contents on the soil profile basically presented downward gradual declining trend from the surface layer. The Ni contents at soil layer of 0-10 cm in Maduo and Huangnan were significantly different from those at soil layers of 10-20 and 20-30 cm, the Ni content in topsoil was remarkably lower than that in undersoil, and this was consistent with the research conducted by Zhang A X et al. [25] regarding the vertical distribution of soil heavy metals in Wanzhuang gold field, which might be ascribed to differences in man-made influence and vegetations. The Cd content at soil layer of 0-10 cm in Huangnan was significantly different from those at soil layers of 10-20 and 20-30 cm, and the Cd content in topsoil was evidently higher than that in undersoil, which was consistent with the heavy metal distribution characteristics in Nantai soil on Mount Wutai (Zheng H X et al. [26]).

4.3 Comparison of soil heavy metal contents in different grasslands

The contents of Cr, Ni, Cu, Zn, As and Hg were the minimum in alpine desert soil among the six grasslands, while the Cd content was the maximum. The heavy metals Cr, Ni, Cu, Zn and As had the minimum contents in alpine grassland soil, the Cd and Pb were also at low content levels, but the Hg content was the maximum among the six grasslands. The Cr, Ni, Cu and Zn contents were the highest in alpine steppe soil, and the As, Hg, Cd and Pb contents were also at high levels. The heavy metal contents were not significantly different in three grasslands: alpine wetland, alpine shrub, and alpine meadow, where the Pb content was the maximum in alpine shrub, and this might be related to the different effects of different soil-forming parent materials, human activities, and vegetation types on the enrichment of heavy metals.

5 CONCLUSION

Through field investigation and sampling in the study areas, the four sample plots—Maduo, Maqu, Qinghai Lake, and Huangnan—were selected as the study objects, the contents of heavy metals such as Cr, Ni, Cu, Zn, As, Cd, Hg and Pb in soil were determined through the ICP-MS method, and the relationship between soil heavy metal contents and soil environmental background values, and the significance levels of the differences of heavy metal contents at the same soil layer in different sample plots, and those at different soil layers in the same sample plot were analyzed. In the end, the heavy metal pollution degrees, and potential ecological risks in the four sample plots were evaluated by combining the Nemerow comprehensive pollution index method and potential ecological hazard index method, and the following conclusions were drawn: The Cd content was high in the whole alpine grassland, and exceeded the soil environmental background value, and the Hg content was high in Maqu; through the CV calculation, the CVs of Hg and Pb in Maqu, and that of Cd in Qinghai Lake all exceeded 100% (high degree of variation), indicating that they were under great man-made influence; the contents of the eight heavy metals were ranked as Maduo> Huangnan> Maqu> Qinghai Lake. The significant differences were found in the contents of most heavy metals at the same soil layer in different sample plots, but not in the contents of most heavy metals at different soil layers in the sample plot; the contents of eight heavy metals in alpine steppe soil were at high levels, and except for Cd in alpine desert soil and Hg in alpine grassland, the other heavy metals were at low levels, and the contents of most heavy metals were at intermediate levels in alpine meadow, alpine wetland, and alpine shrub, without significant differences; according to the Nemerow comprehensive pollution index and potential ecological hazard index, the pollution degree was the maximum in Maduo at slight pollution level, indicating strong potential ecological risks. The pollution degrees of other three sample plots were at or below the warning line, with moderate potential ecological risks. The overall heavy metal pollution degree is low in alpine grasslands, but it is still especially important to protect the soil from heavy metal pollution.

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