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Soil Heavy Metal Pollution Around Iron Tailing Areas at Different Using Status

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Abstract: Heavy metal pollution was a dynamic changing process for a long period and on large spatial scale. The heavy metal content in tailing soil varied with time changing. The distribution and cumulative characteristics of heavy metals in different time and surrounding soil caused by ore dressing and smelting activities were different. The aim of this study was to assess the geochemical characteristics and pollution status of heavy metals in soil around 2 iron tailing areas at different using status. Samples were collected around the 2 different iron tailing and sieved through nylon sieves. Metals were measured in digested solutions by a atomic emission spectrometer. The concentration of all heavy metals (Fe, Mn, V, Cu, Ni) in the soil around using M tailing area exceeded local soil background value; however, the content of all metals except Fe in soil around closed W tailing areas were lower than background value. BCR results showed that average exchangeable fraction of Mn in soil around W and M accounted for 11.87%, 11.78% of the total concentration, respectively; average exchangeable and reducible fractions of Ni accounted for 26.97% and 13.59%, respectively; average oxidizable fraction of Cu accounted for 18.6%, 31.63% in soil around W and M, respectively, which were higher than other metals; residual fraction of Fe, V accounted for more than 80% of the total concentration. The results indicate the soil was moderately contaminated by heavy metal around M and unpolluted around W. However, the risk assessment results performed that Mn showed moderate potential ecological risk and other metals showed low potential risk.

Keywords: Iron tailing, soil heavy metal pollution, geo accumulation index, risk assessment.

1. INTRODUCTION

Mineral processing activity and tailing dump caused serious pollution to the surrounding soil and water which posed a threat to the ecosystem and human health [1, 2]. Tailings not only take up a lot of land but also become the potential sources of heavy metal contamination [3]. There were about 8×108 t/a tailings in China, among which the amount of iron tailing was over 6×10^8t [4]. The migration and transfer of heavy metal in environment around tailings resulted in both of changing soil properties and producing biological accumulation effect. What's more, heavy metal endanger human's health severely through food chain [5-8]. Most of the present studies paid attention to the heavy metal pollution of non-ferrous metal mine (Cu or Pb-Zn mine) [9-11], but few study focused on ferrous metal mine (Fe mine) especially deuterogenic environment effect of oxidizing iron mine tailings. Xu zhengqi [12], YANG Jinyan [13] analyzed the environment influence caused by mining V-Ti-Mn in Panzhihua. Gao yanxin [14], Huang xingxin [15]. analyzed the soil heavy metal pollution around the iron mine exploration area in upper basin of Beijing Miyun reservoir. Xing Yi [16] studied the influence to the change of soil microbial community by heavy metal pollution of iron mining. These researches suggested that the oxidizing mine already has significant influence on environment. Substantial accumulation of iron tailings through various channels exerted an influence on soil, rivers, atmosphere and groundwater. The oxidizing iron tailings mostly contained high content of Fe, Mn and V. Although some of these heavy metals was trace elements for constituting organisms, high content of these heavy metals did harm to animals, plants and human health, bringing trouble to human's life and reproduction. For example, high content of Mn and Fe resulted in red water and black water.

Heavy metal pollution was a dynamic changing process for a long period and on large spatial scale [17]. The heavy metal content in tailing soil varied with time changing. The following aspects should be made clear during the process. The 1st, how heavy metal migration in tailing area influenced the surrounding soil. The 2nd, whether there were differences to the soil pollution around tailings caused by different storage time. The 3rd, whether the differences would affect the geochemistry characteristics of heavy metals in mining area. These were worthwhile researching thor-

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oughly. The evaluation to heavy metal pollution of soil around the tailings could help to understand the geochemical behavior of soil heavy metals, revealing the regional ecosystem health [18] and bio-availability [19]. Therefore, this paper studied soil heavy metal pollution around 2 oxidizing iron tailing at different using status in Lueyang county, Shaanxi province, China. The distribution of 5 heavy metals in soil, accumulation characteristics and contamination level were researched. The results could provide reference for the local soil environment management and prevention and control on soil heavy metal pollution.

2. MATERIALS AND METHODS

2.1. Study Area

This study was conducted in Lveyang county, located in southwest of Shaanxi province, China. Lveyang county lied in the south piedmont of QinLing Mountain, belonged to the north subtropical northern mountain warm temperate zone with moist monsoon climate. The annual average temperature was 13.2 ^{o}C and annual average rainfall was 860 mm. Lveyang is rich in iron mine. In 1980s & 1990s, disorderly and wasteful mining of iron was serious. A lot of small and medium-sized tailings took natural valley as dam. Without the manually scale of reclamation to the slope and dam surface of these tailings, dust and rain infiltration could take the heavy metals into around environment. This study selected 2 typical tailing areas at different using status. Wang Jiagou tailing area (abbr. as W), a rank-4 tailing, had been closed for 10 years (usage period: 1994 – 2004). The other one was Mi Jiangou tailing area (abbr. as M), a rank-2 tailing, which has been used for nearly 30 years and was still in use. The 2 tailings all belonged to ditch dam type with mountains surrounding and streams around the tailing areas.

2.2. Soil Sampling and Sample Preparation

2.2.1. Soil Sampling

In March 2013, 42 soil samples were collected around M and W. Sampling sites were shown in Fig. (**1**). Soil sample was collected at a depth of (0~20cm) by random sampling. Soils at 3 points within 5 meters around one sampling site were mixed as one soil sample for this site. Soil samples which were sealed in plastic bags were immediately taken to the laboratory. The soil was putted on plastic board indoor for air-drying after removing stones and plant fragments. The dried soil was crushed, homogenized and sieved through 0.149 μm nylon sieve. 2 ore samples from tailings in W and M were also collected and prepared as above. All prepared samples were stored in plastic containers for use.

2.2.2. Analysis of Sample

Mineral phase of tailing ore was analyzed by X-ray diffractometer (D/MAX-2600pc, Rigaka, Japan).

The soil pH in a suspension of 1:2.5 ((sample: water ratio, w/v) suspension was determined by a pH meter [20].

The organic matter content was analyzed through the oxidation of organic matter by dichromate in an acid medium [21].

The concentrations of heavy metal was measured by ICP-AES (SP8000, Beijing) after digestion (Q/GD001-2002).

Modified BCR sequential extraction was performed on the soil for understanding speciation of metals [22-24]. 4 fractions of heavy metals were determined. *Fraction 1* (F1), acid soluble, bound to carbonate and cation exchange site; *Fraction 2*, reducible, bound to the Fe-Mn oxide; *Fraction 3*, oxidizable, bound to organic matter and sulphides; *Fraction 4*, remaining residue, bound to mineral matrix [25]. The analyses procedures were as follows:

Fraction 1: All soil samples were dried at 105 ^{o}C for 2 h. 0.800 g dried soil sample was putted in a centrifuge tube. 32 mL of acetic acid solution with concentration of 0.11 mol/L was added to the centrifuge tube. The tubes were shaken in an automatic shaker at 180 rpm for 16 h. Later, the shaken samples were centrifuged at 10,000 rpm for 20 min for the separation of solid and liquid phase. The samples were filtered with Whatman-42 filter paper to a polyethylene storage

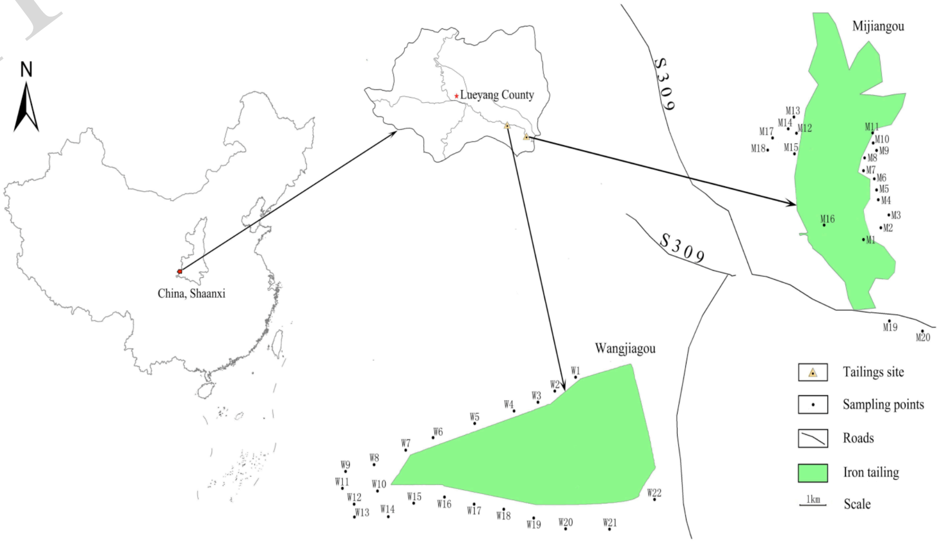

Fig. (1). Diagram of sampling sites around M and W tailing areas.

container. 16 mL of deionized water was added to the solid phase in the centrifuge tube for washing, and shaken for 20 min. The mixture was centrifuged for 20 min and then discharged the liquid phase.

Fraction 2: 32 mL of hydroxylamine hydrochloride solution with 0.1 mol/L concentration was added to the residue in the centrifuge tubes from the first step. The tubes were shaken for 16 h and centrifuged for 20 min as described in Fraction 1. The filtrate was stored in the container after filtration with Whatman-42 filter paper. Repeated the washing process that had been performed at the end of the first step.

Fraction 3: 8 mL H_2O_2 solution with 8.8 mol/L concentration was added to the residue in the centrifuge tubes from the second step. The tubes were shaken at room temperature for 1 h. Then, the sample was evaporated to near dryness at 85 ^oC. When the samples had cooled, 8 mL H_2O_2 solution was added to the residue. 40 mL of ammonium acetate solution was added to the samples after the samples had cooled again. The samples were shaken for 16 h and then centrifuged for 20 min.

Fraction 4: Calculated by the subtraction of Fraction 1-3 from total concentration.

Quality control was conducted using blank sample and reference standard sample (GBW0704). The relative standard deviation was less than 10%.

2.3. Statistical Analysis

Excel 2013 and Minitab 16 were used for statistical analysis. The level of heavy metal pollution and the potential ecological risk level were determined by heavy metal content correlation analysis, geoaccumulation index and risk assessment code.

2.3.1. Geo Accumulation Index

Geo accumulation index was used to evaluate the soil heavy metal pollution, considered both of the impact from the change in background value caused by natural factor and the influence of human activity [26, 27]. The formula is expressed as follows:

$$I_{geo} = \log_2(\frac{c_n}{k \times B_n}) \qquad (1)$$

Where, I_{geo} is the geo-accumulation index; c_n is the measured concentration of each element (n); B_n is the geochemical background value of corresponding element. The data in this study were from the Background Value of Shaanxi Yellow Brown Soil [28]; k is the background matrix correction factor due to lithgenic effects, it is 1.5 here.

According to I_{geo}, the pollution level could be classified into 7 grades, they were: $I_{\text{geo}} < 0$, unpolluted; $0 \leq I_{\text{geo}} < 1$, unpolluted to moderately polluted; $1 \leq I_{\text{geo}} < 2$, moderately polluted; $2 \leq I_{\text{geo}} < 3$, moderately to strongly polluted; $3 \leq I_{\text{geo}} < 4$, strongly polluted; $4 \leq I_{\text{geo}} < 5$, strongly to extremely strongly polluted; $I_{\text{geo}} \geq 5$, extremely strongly polluted, respectively.

2.3.2. Risk Assessment Code and Risk Level

The potential environment risk of heavy metal pollution was determined based on the risk assessment code (RAC) of speciation, mainly bio-utilization fraction of metal (*i.e.* exchangeable fraction). The risk level could be classified into 5 grades based on exchangeable fraction (F1) content according to Perin [29]. F1< 1%, no potential risk; 1% <F1< 10%, low potential risk; 11%<F1<30%, moderate potential risk; 30% <F1<50%, high potential risk; F1>50%, extremely high potential risk which means that the metal was very dangerous and easy to enter food chain.

3. RESULTS AND DISCUSSION

3.1. Mineral Composition of Tailing Sample

Table **1** showed the matrix composition of tailing ore. The biggest difference in ore mineral composition was that the main components were quartz and dolomite in W and M, respectively.

3.2. Heavy Metal Concentration and Soil Physicochemical Properties

3.2.1 Content of Heavy Metal

Fe, Mn, V, Cu and Ni were detected in soils around the 2 tailing areas according to the detection limit of ICP-AES; thus, the 5 heavy metals were discussed in this study. The concentrations, pH and organic matter content in each sample were presented in Table **2**. In the soil around W tailing, the concentration of Fe in 13 sampling sites slightly exceeded the background value, and the mean value basically equaled to the background value. The concentration of Mn in 2 sampling sites exceeded background value. V, Cu and Ni were less than soil background value in all sampling sites. In the soil around the M, the average values of 5 heavy metals all exceeded background value. The mean values of Ni and Cu were 11.1 times and 3.7 times as bigger as the local background value, respectively, suggesting high accumulation of Ni and Cu and Ni was more serious.

Table 1. Mineral compositions of the tailing iron.

Tailing	Mineral facies				
	Calcite ($CaCO_3$)	Quartz (SiO_2)	Dolomite 〔$CaMg(CO_3)_2$〕	Clinochlore ($(Mg_5Al)(Si,Al)_4O$〕	Sodium feldspar (NaAlSiO3O8)
W	13.37	46.60	19.42	11.77	8.84
M	18.35	14.24	35.08	18.46	13.88

Table 2. Heavy metal concentrations, pH and organic matter content in soil .

Tailing	Item	Max.	Min.	Mean	Standard deviation	Variable coefficient	Background value[23]	Multiple
W 1)	Fe/(g/kg)	37.4	24.9	30.64	36.90	0.21	28.6	1.07
	Mn/(mg/kg)	949.6	258.6	557.11	210.96	0.39	684	0.81
	V/(mg/kg)	71.3	39.6	52.65	9.49	0.18	93.0	0.57
	Ni/(mg/kg)	24.9	1.3	8.86	6.79	0.77	31.5	0.28
	Cu/(mg/kg)	8.9	0.2	1.77	2.51	1.42	23.4	0.08
	pH	6.94	6.22	6.61	0.22	0.03	—	—
	w(organic matter)/%	10.42	4.21	6.50	1.66	0.26	3.29	1.98
M 2)	Fe/(g/kg)	76.6	29.9	51.60	11.60	0.22	28.6	1.80
	Mn/(mg/kg)	1917.4	506	1051.09	382.79	0.36	684	1.53
	V/(mg/kg)	201.7	60.7	122.36	43.81	0.36	93.0	1.32
	Ni/(mg/kg)	2018	18.9	350.31	300.05	0.85	31.5	11.11
	Cu/(mg/kg)	318.8	6.2	86.65	86.35	0.99	23.4	3.70
	pH	8.24	6.59	7.49	0.51	0.07	—	—
	w(organic matter)/%	9.58	1.68	3.96	2.25	0.57	3.29	1.20

Note: 1) n=22 ; 2) n=20.

Accumulation of heavy metals in soil around M demonstrated that the area suffered serious pollution. The pollution mainly caused by tail sand floating with the wind down to ground and its eluviations. The heavy metal concentration in soil around W was lower than that around M due to lots of thatch, reed and other vegetation grown on surface of the trailing storage; what's more, slope surface had a certain function of stability and adsorption after the mine has been closed for 10 years. However, M tailing had been used for 30 years and was still in use. The exposed tail sand existed almost everywhere on the surface of the trailing and slope. Natural wind blowing and surface runoff accelerated the migration of tail sand, which caused the content in these sampling sites exceeding background values seriously.

3.2.2. Correlation of Heavy Metal Content with Soil Physicochemical Properties

The source of heavy metals in soil and controlling factor could be determined through the correlation analysis between heavy metal content, pH and organic matter content as shown in Table **3**.

Organic matter affected the mobility and transfer of heavy metals in the soil through forming complex with heavy metal [30]. Organic matter content and the concentration of heavy metals presented negative linear correlation. Low negative correlation was presented in Fe and V around W (R_{Fe}= - 0.422 , R_V= - 0.440 , $P<0.05$). Moderate negative correlation with Fe and V around M (R_{Fe}= - 0.527 , P<0.05 ; R_V= - 0.623 , P<0.01) suggested that organic matter had important influence on heavy metal content. It was mainly because that Humus would adsorb and fix heavy metal. Thus the process affected the migration and transfer of heavy metal in soil. Soil pH had negligible relationship with heavy metal content.

Significant positive correlation was presented between Fe and V (R_W=0.780 , R_M=0.568 , P<0.01), indicating that V generated from iron mine and Fe in soil particles could adsorb other metallic to form insoluble compounds [31]. Significant positive correlation with Mn and Ni, Cu in the soil around W (R_{Ni}=0.644 , R_{Cu}=0.624 , P<0.01) were also presented. The significantly positive correlation between Ni and Cu (R=0.568 , $P<0.01$) showed that Mn, Ni and Cu had the same artificial and natural source. However, there was negligible relationship between Mn, Ni and Cu in the soil around M.

In a word, the sources and natural distribution of heavy metal in soil around 2 tailing areas were different. W tailing area, had been closed for years with no new tailing injection, made the heavy metal in the surrounding soil migration and transfer under natural conditions. M tailing area, still in use with continued new tailings injection, showed more complicated function to the content of heavy metal in the surrounding soil and its migration and transfer.

3.3. Speciation of Heavy Metal in Soil

The distribution and speciation characteristics of heavy metal in soil around the 2 tailing area were important to reveal the heavy metal pollution level. The speciation of heavy metal significantly influenced its migration and transfer in soil [32], Although 2 tailing areas were all iron mine tail stock and had similarities in speciation characteristics of heavy metal in soil, different usage status resulted in some difference in the speciation characteristics as shown in Table **4**.

Table 3. Correlation of heavy metal contents, pH with organic matter content in soil.

Item	**W $^{1)}$**						
	***w*(Fe)**	***w*(Mn)**	***w*(V)**	***w*(Ni)**	***w*(Cu)**	**pH**	***w*(organic matter)**
w(Fe)	1						
w(Mn)	0.148	1					
w(V)	0.780^{**}	-0.335	1				
w(Ni)	0.156	0.664^{**}	-0.186	1			
w(Cu)	0.250	0.624^{**}	-0.191	0.568^{**}	1		
pH	-0.138	-0.062	-0.147	0.130	-0.014	1	
w(organic matter)	-0.422^{*}	-0.215	-0.440^{*}	-0.071	-0.174	-0.153	1
Item	M $^{2)}$						
	w(Fe)	*w*(Mn)	*w*(V)	*w*(Ni)	*w*(Cu)	pH	*w*(organic matter)
w(Fe)	1						
w(Mn)	0.802^{**}	1					
w(V)	0.568^{**}	0.314	1				
w(Ni)	-0.002	0.065	0.551^{*}	1			
w(Cu)	0.321	0.032	0.25	-0.380	1		
pH	0.109	-0.074	0.435	0.312	0.008	1	
w(organic matter)	-0.527^{*}	-0.317	-0.623^{**}	-0.323	-0.162	-0.392	1

note：** represents $P<0.01$，and there was significantly obvious difference；* represents $P<0.05$，and there was obvious difference. 1) $n=22$；2) $n=20$.

Table 4. Speciation of heavy metals in soil.

Tailing	**Heavy metal**	***w*/(mg/kg)**				**Proportion/%**			
		Exchangeable	**Reducible**	**Oxidizable**	**Residual**	**Exchangeable**	**Reducible**	**Oxidizable**	**Residual**
W $^{1)}$	Fe	4.09	923.57	999.98	2866.4	0.004	3.04	3.22	93.74
	Mn	64.55	188.33	23.33	276.8	11.78	30.03	4.24	53.95
	V	—	2.91	4.72	44.8	—	5.73	8.32	84.95
	Ni	0.17	2.28	2.1	3.92	2.58	24.39	28.11	44.92
	Cu	—	0.05	0.28	1.2	—	0.1	18.6	81.3
M $^{2)}$	Fe	62.04	1112.56	1705.99	50742.4	0.07	2.31	2.72	94.90
	Mn	181.42	464.13	140.94	317.4	11.87	34.97	13.23	39.93
	V	1.70	5.13	21.05	88.2	0.15	0.84	8.55	93.88
	Ni	12.15	51.94	63.80	296.4	2.09	11.50	15.68	70.73
	Cu	1.33	2.09	11.33	48.00	2.08	2.69	31.03	64.21

Note: 1) $n=22$；2) $n=20$. — represents it was below detectable limit.

The mineral composition of ore particles in 2 tailing area was similar, but speciation of heavy metals showed different in some degree. The average concentration of 5 heavy metals and average content of 4 fractions of each metal in soil around M were higher than that around W.

Exchangeable fraction (F1), bounded to the particle surface mainly through ion exchange and adsorption, was easy to migrate, transfer and be absorbed by plants; therefore, it had the strongest bioavailability resulting in biggest harm to environment and biology [33]. The exchangeable fraction of

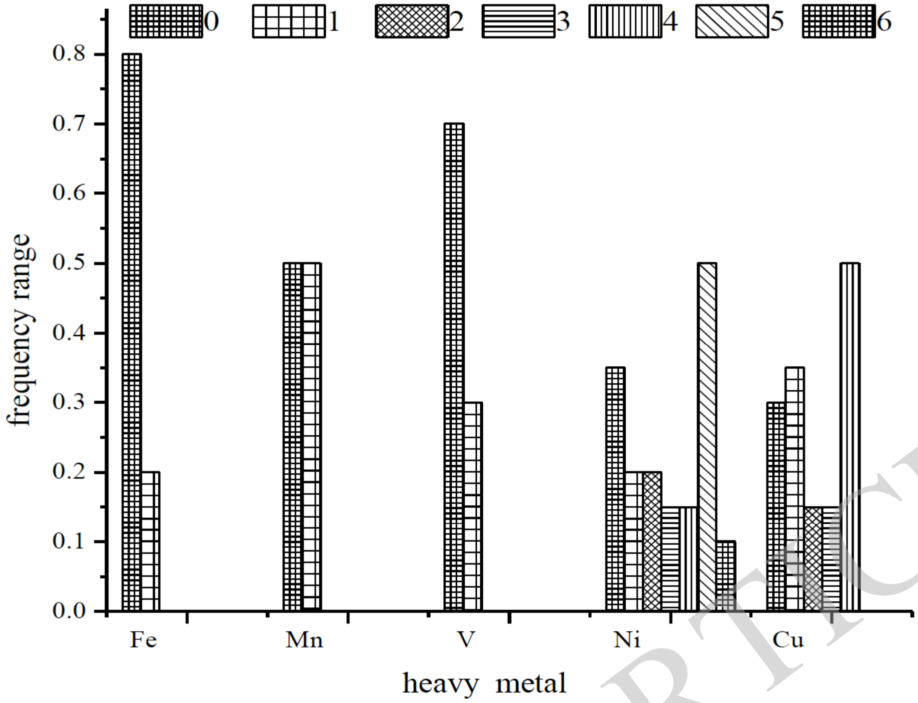

Fig. (2). Frequency distribution of Geo accumulation index of heavy metals in soil samples around M tailing area.

Mn in the soil was highest. Thus Mn was easy to migrate and transfer and influence the water quality around the tailing. This was agreement with the drinking water quality monitoring results in this region (the concentration of Mn in the drinking water nearly exceeded 2 times of the detection limit [34].

Reducible fraction (F2), the strong ionic bond combination form, could be revivified to exchangeable fraction when Eh reducing, pH decreasing or anoxic condition which increased the soil heavy metal pollution. The reducible fraction of Mn in soil was the highest (30.03% in soil around M and 34.87% around W. respectively), followed by Ni (24.39% around M and 11.50% around W, respectively), indicating that Mn and Ni were potential soil pollution metals.

Oxidizable fraction (F3) of metals formed sulfides by complexation or chelation with organic matter in soil. It was usually relatively stable and uneasy to be absorbed by biology, but it could turn to exchangeable form in the presence of alkaline or oxidation condition.

The content of Cu in soil around W was low. The exchangeable fraction (F1) of Cu was below the detection limit and reducible fraction (F2) accounted for 18.6%. However, the average content of Cu in soil around M was 3.6 times as bigger as background value. Oxidizable fraction (F3) of Cu accounted for 31.03%, suggesting that Cu was easier to form organic copper compounds or sulfide with high stability. This was similar with the speciation of Cu in the soil of Miyun reservoir upstream iron mining area [15]. Oxidizable fraction of metal was still unstable. The oxide might decomposed once condition change resulting in release of heavy metals [35]. Thus Cu presented certain potential risk around 2 tailings and the risk of Cu was more serious in soil around M.

The speciation of Fe and V was roughly similar around 2 tailing areas. The remaining residue fraction (F4) of Fe and V was high; especially exchangeable fraction of V (F1) around W was below the detection limit. The remaining residue fraction usually existed in the primary mineral crystal lattice, so it was relatively stable in natural environment. The metal could not be absorbed by vegetable and hard to migrate and transfer; therefore, the metals with high F4 content were not easy to cause environment pollution in mine area.

3.4. Risk Assessment of Polluted Soil

Geo-accumulation index and risk assessment code were used to analyze and compare the level of heavy metal pollution in soil around 2 tailing areas. The I_{geo} of 5 metals in all sampling sites around W was <0, indicating no pollution in soil. The frequency distribution of I_{geo} of 5 heavy metals in the sampling sites around M was shown in Fig. (**2**). I_V(I_V represents the I_{geo} of V) of 6 sites was in 0 - 1, 14 sites were < 0; I_{Cu},7 sites were in 0 - 1, 3 sites in 1 - 2, 3 sites in 2 - 3, 1 sites in 3 - 4, other 6 sites were < 0; I_{Fe}, 16 sites were in 0 - 1, 4 sites were < 0; I_{Ni}, 4 sites were in 0 - 1, 4 sites were in 1 - 2, 1 sites were in 2 - 3, 1 sites were in 3 - 4, 1 sites were in 4 - 5, 2 sites were > 5, 7 sites were < 0; I_{Mn}, 10 sites were in 0 - 1. 10 sites were < 0.

The average I_{geo} of 5 metals presented the following order: $I_{Ni}(1.33) > I_{Cu}(0.63) > I_V(0.28) > I_{Fe}(0.23) > I_{Mn}(0.10)$. The soil around M was seriously contaminated by Ni. 2 sampling sites showed extremely strong polluted level. 5 sites were on moderate to strong polluted level. V, Fe, Cu and Mn were on moderately polluted to unpolluted level. Ni was on the moderately polluted level. The reasons remained to be further studied. Overall, the heavy metal pollution in soil around M was on moderately polluted level.

The evaluation to speciation of heavy metal could better predict the potential ecological risk. The exchangeable fraction (F1) of Mn around W accounted for 4.03 - 20.55% of the total content with average value of 11.78%, suggesting moderate potential risk level. However, exchangeable fraction (F1) of Mn around M accounted for 4.67 - 45.26% of the total content with average value of 11.87%, suggesting high potential risk level. It should be noted that the exchangeable fraction (F1) in 3 sampling sites around M were in the range of 30 - 50%, which means high potential risk. Fe and V around 2 tailing areas belonged to the metal without potential risk; Ni belonged to low risk metal; Cu was non-risk metal around W but low risk metal around M.

The order of potential risk of 5 metals followed as: Mn>Ni>Cu>V>Fe, which had some differences with I_{geo} result. The differences and reasons would be expressed as following. Firstly, I_{geo} showed that there were no heavy metal pollution in soil around W. However, potential ecological risk assessment showed that Mn around W had moderate potential risk and Ni performed low potential risk. Secondly, the pollution intensity reflected by I_{geo} around M was: Ni>Cu>V>Fe>Mn. The pollution level of Mn was the lowest, but the potential risk of Mn in potential ecological risk assessment was the highest. This result indicated different results might come out using different evaluation criterions. Geo-accumulation index placed emphasis on analyzing the anthropogenic source and natural background value of heavy metal, aimed to reflect the degree of exogenous heavy metal accumulation. Risk assessment code placed emphasis on the bioavailability of heavy metal through the exchangeable fraction of heavy metal to represent its bioavailability and further explain the potential ecological risk of heavy metal. If comprehensive assessment was conducted through the total content and speciation characteristic of heavy metal, the following aspects could be avoided. The situation of extremely low total content of heavy metal and very high bioavailability would not cause too much attention. When the total content of heavy metal was high and the bioavailability was low, the serious pollution caused by heavy metal would not be ignored.

4. CONCLUSION

In the soil around W tailing area that had been closed for nearly 10 years, the content of Ni, Mn, Cu and V were lower than local soil background value. In the soil around M tailing area still in use, the content of Ni, Mn, Cu, V and Fe exceeded the local background value, indicating obvious accumulation. There was a negative correlation between the organic matter and the concentration of 5 heavy metals, and the organic matter influenced the migration and speciation of heavy metal. Fe and V had same source in soil around W and M. In the soil around W, Mn, Cu and Ni had same source, but there was no obvious correlation in soil around M and the sources were not necessarily same. The soil around W was not polluted by the 5 metals; however, the soil around M was moderately polluted, and 5 metals followed the order: Ni > Cu > V > Fe > Mn. Ni was on moderately polluted level and other metals were on strongly polluted to unpolluted level. The potential ecological risk order of the 5 metals followed as: Mn>Ni>Cu>V>Fe. Mn and Ni was on the moderate and low potential pollution risk level, respectively; in addition, Mn in the soil around M was on the high potential risk level. Cu was on no risk level around W but low risk level around M. Fe and V were on no risk level.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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