Evaluation of the Potential Ecological Risk of Heavy Metal Pollution in Soil and Bioaccumulation Characteristics of Dominant Plants in Siding Pb-Zn Mineland

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Abstract*—Soils and dominant plants were surveyed in the Siding mineland area. Based on the determination of heavy metal concentration of soil from 8 sections and 14 dominant plant species in different parts, the potential ecological risk was assessed using the Hakanson Index Method. The results indicated that the soil of Siding mineland area was seriously contaminated by Pb and Zn. The risk index values of Pb and Zn were higher than 320, and the degree of ecological hazard was extremely high. While the risk index values of Cu and Cr were lower than 40, and the degree of ecological hazard was low. Statistical analyses showed that mining and smelt activities had a great influence on the concentration and distribution of heavy metals. Pb-Zn and Pb-Cu were likely from a same source, while Cr had a different cumulating character. Furthermore, Pb, Zn, Fe, Mn, Cu and Cr in 14 dominant plant species were at different levels. But the heavy metal concentrations of aboveground part had not reached the level for hyperaccumulators. Among all the dominant plants, Phragmites australis (Cav) Trin.ex Steud., Imperata cylindrical (Linn.) Beauv., Herba taraxaci and Peris vittata L. appeared to have good accumulation of Pb and Zn, and would be very useful in the restoration of Pb and Zn contaminated areas.

Keywords-heavy metal pollution;ecological risk; hyperaccumulator; Siding Pb-Zn mineland area insert

I. INTRODUCTION

There is a dense distribution of non-ferrous metal minelands in south China. The mining activities started long time ago and were intensive. As the mineral resources can't be removed, it brought about a series of social economic and ecological problems, such as long time of occupying, destroying and polluting lands (Luo, et al., 2007). These all changed the aqueous and thermal structures and destroyed the areas and systems for animals and plants. Heavy metal pollution exists universally and is most series (Pen, et al., 2005). It not only limited the development of the mine, but also influenced the agricultural production and inhabitant health around minelands. Siding is the large-scale of state multi-metal mine in China, with the area of 13.64 km^2. It was finished and put into production in February 1960. Until now, the heartland of the mine had been mining up, left only sporadic mine operating around it.

This work investigated and analyzed the heavy metal concentrations in soils and dominant plant accumulation in Siding minelands. Using the Hakanson Index Method, the potential ecological risk of heavy metal pollution was also evaluated. The understanding of bioaccumulation characteristics of dominant plants will be useful for heavy metal pollution, scientific management, phytoremediation and ecological restoration.

II. MATERIALS AND METHODS

A. The survey site

The geography coordinate center of Siding Pb-Zn mineland is longitude 109° 31′ 12″ E, latitude 25° 00′ 13″ N, located at Guangxi Rong-an County, China. The landform there is external ring protuberant with the height more than 400m, and internal billabong with the height about 320m. The soil is subacidity (pH≈6.0). The good condition of aqueous and thermal structures is propitious to plant growing, which provides advantageous climate and geological condition for reclamation and environmental improvement.

B. Sample collection

Soil sampling and vegetation investigation in Siding Pb-Zn mineland were carried out in March 2006. The mineland was divided into 8 areas in terms of mining and vegetation coverage (Fig.1). A area was unquarried; B area was located in sewage outfall of refinery, where there was a small river 10m away. Sewage from the refinery was discharged into the river; C area was located in 50m downstream of the sewage outfall; D area was located in sewage outfall of Laqiong village. Sewage from contaminated area flowed down hillside so that formed a contaminated area of black silt pulpy (about 300m^2). There was no plant in the center of the contaminated area; E area was a flat of sewage outfall at the foot of the hill; F area was a tailing dam; G area was a pithead tailing dam; H area have been used for reclamation for 5 years. For each area,

Figure 1. Positions of sampling sites

3 samples were collected randomly (3-5 subsamples were merged into one single sample with the sampling depth of 20cm). There were 24 soil samples in all. According to the growing situation, the dominant plants were sampled. All soil and plant samples were sealed with polythene bags and transported into laboratory.

C. Soil and plant analysis

Soil samples were air-dried, ground and passed through a 100 mesh plastic sieve. Plant samples were gently washed with tap water and then rinsed with deionized water. Than they were put into an oven with 105℃ for 30min and 70℃ for 24 hours. Dried plant tissues were ground into fine powder. Soil samples were digested with concentrated HCl + concentrated HNO_3 + HF + $HClO_4$ (10:5:5:3, v/v) and plant tissues were digested with concentrated HNO_3. The total metal concentrations (Pb, Zn, Mn, Cu and Cr) in digestates were then determined by a atomic absorption spectrometer (AA-700). The quality control was made by parallel samples and recovery of standard substance (GBW08303) in order to ensure the accuracy and precision.

D. Evaluation method and standard of heavy metal pollution

The potential ecological risk index was used for evaluation of heavy metal contamination in soil, which was suggested by Hakanson (1980) basing of heavy metal's characteristic and environmental action (Liu, et al., 2007). This method associated with heavy metal concentration, ecological effect, environmental effect and toxicology to evaluate single element or multiple elements quantitatively. This method was also used to evaluate heavy metal pollution of sedimentation (Jia, et al., 1997; Li, et al., 2007; Ma, et al., 2003; Liu, et al., 2007; Xiang, et al., 2006). The calculation formulas are as follows:

$$C_f^i = C_f^n / C_n^i, \quad E_r^i = T_r^i \times C_f^i$$

$$RI = \sum_{i=1}^{n} E_r^i = \sum_{i=1}^{n} T_r^i \times C_f^i = \sum_{i=1}^{n} T_r^i \times C_f^m / C_n^i$$

where C_f^i is a parameter of metal pollution; C_f^n is actually testing concentration of heavy metal in sedimentation; C_n^i is a reference value in calculation; E_r^i is a parameter of potential ecological risk; and T_r^i is a parameter of toxic response by single pollutant, which can display relationships of heavy metal among aqueous phase, solid phase of sedimentation and organisms.. There were great differences in the selection of reference value among the previous works. Most of them prefer to choose average background value of heavy metal in sedimentation (Wang, et al., 2005), or background value of local soil (Wu, et al., 2007), or background value of sampling (Liu, et al., 1999). In order to evaluate the heavy metal pollution more objectively, the present work chose the background value of local soil as the reference value. The standard parameter of toxic response made by Hakanson is: Zn(1) < Cr(2) < Cu(5) = Ni(5) = Pb(5) < As(10) < Cd(30) < Hg(40) (Lars Hakanson, 1980). As lacking of the parameter of toxic response of Mn, this study had not evaluated of its potential ecological risk. The grading standard of coefficients and indices of heavy metals' ecological risks was showed in table 1.

TABLE I. GRADING STANDARD OF COEFFICIENTS AND INDICES OF POTENTIAL ECOLOGICAL RISK OF HEAVY METALS

Changes of E_r^i	**Levels of ecological risks of single factor**	**Changes of indices of potential ecological risks(*RI*)**	**Levels of overall potential ecological risks**
E_r^i<40	Slight	*RI*<150	slight
40≤E_r^i<80	medium	150≤*RI*<300	medium
80≤E_r^i<160	strong	300≤*RI*<600	strong
160≤E_r^i<320	very strong	*RI*≥600	very strong
E_r^i≥320	extremely strong		

III. RESULTS

A. Heavy metals in soil

The concentrations of Pb, Zn, Mn, Cu and Cr in the soils were 5934.2, 23285.3, 447.0, 78.8 and 51.7 mg/kg (Table 2). The order of metal concentration was Zn>Pb>Mn>Cu>Cr. The concentrations of Pb, Zn, Mn, Cu in the 8 sampling areas were much higher than soil background values in both Guangxi and China, with the concentrations of Pb, Zn higher than the Grade III of Environmental Quality Standard for soils. The concentration of Pb was 18212.0mg/kg, which was

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36 times to the value of Grade III of Environmental Quality Standard for soils. The highest concentration of Zn with 75300.9mg/kg of tailing dam was 150 times to the value of Grade III of Environmental Quality Standard for soil. The highest concentrations of Cu and Cr (146.0mg/kg and 101.0mg/kg) were from the sewage outfall of refinery. They were both lower than Grade II of Environmental Quality Standard for soils. As regard Mn, the highest concentration (846.0mg/kg) appeared in the flat of the sewage outfall at the foot of the hill， which was 5-folds of soil background values in Guangxi and 1.7-folds of soil background values in China. The variation coefficients of Pb, Zn were high, which indicated the distribution of Pb, Zn in different sampling points was greatly different and the mining activity significantly influence the concentration and distribution of heavy metals.

B. Correlations of heavy metals

In order to realize the correlations of heavy metals, the Spearman Ranking Correlation Coefficient and Kendall ζ Correlation Coefficient were calculated（Table 3）. The correlation between heavy metals could estimate whether they came from the same source. In natural world, heavy metal pollution is complex with several metals compound. If they significantly correlated, the possibility of homeology is grate. The source may come from natural (source of geochemistry), or compound pollution resulted from human activities (Yang, et al., 2007). The two correlation coefficients both showed that there was a significant correlation between Pb and Zn, or Pb and Cu (table 3). Therefore, there was great possibility of their homeology, and in accordance with reality. In addition, the Spearman Ranking Correlation Coefficient showed that there was a very significantly correlation between Cu and Zn, while the Kendall ζ Correlation Coefficient also displayed significant correlation. The results showed that the two calculating methods were consistent. The correlation between Cr and other heavy metals was low, indicating special accumulation of Cr.

TABLE II. HEAVY METAL CONCENTRATIONS IN SOIL AND SLAG OF SIDING PB-ZN MINELAND

Sampling points	Pb	Zn	Mn	Cu	Cr
A	1420.0±104.6	3236.0±283.1	214.0±21.4	36.0±4.6	50.0±3.0
B	18212.0±2121.6	32375.0±3410.8	310.0±45.2	146.0±22.5	101.0±14.3
C	3021.8±132.3	26889.9±244.3	313.9±19.0	82.6±7.3	16.1±1.1
D	5138.0±341.7	14041.0±2953.0	596.0±33.9	109.0±27.2	67.0±13.3
E	1746.0±87.2	4500.0±144.3	846.0±26.0	48.0±8.6	59.0±6.5
F	9821.5±128.8	75300.9±1636.6	838.0±56.7	119.8±14.3	29.6±5.1
G	6614.0±175.2	26500.0±1232.0	246.0±23.1	56.0±11.7	46.0±5.5
H	1500.0±181.8	3440.0±263.2	212.0±22.4	33.0±5.7	45.0±9.3
Average value	5934.2	23285.3	447.0	78.8	51.7
Standard deviation	5769.6	24040.8	272.7	42.3	25.5
Variation coefficient (%)	97.2	103.2	61.0	53.7	49.3
Soil background values in Guangxi	18.82	46.43	172.57	20.79	56.25
Soil background values in China	24.00	67.40	482.00	20.00	54.10
Grade II of Environmental Quality Standard for soil	250	200	-	150	150
Grade III of Environmental Quality Standard for soil	500	500	-	400	300

TABLE III. SPEARMAN AND KENDALL Z CORRELATION COEFFICIENTS OF HEAVY METALS

	Coefficients	Pb	Zn	Mn	Cu
Zn	Spearman	0.905(**)			
	Kendallζ	0.786(**)			
Mn	Spearman	0.357	0.452		
	Kendallζ	0.214	0.286		
Cu	Spearman	0.905(**)	0.881(**)	0.500	
	Kendallζ	0.786(**)	0.714(*)	0.429	
Cr	Spearman	0.190	-0.167	0.095	0.238
	Kendallζ	0.143	-0.071	0.071	0.214

** means very significant correlation ($p<0.01$), * means significant correlation ($p<0.05$).

C. Evalution of the potential ecological risk of heavy metal pollution

Potential ecological risk indexes of single (E_r^i) and multiple (*RI*) heavy metals of Siding Pb-Zn mineland were in table 4. The potential ecological risk indexes ranged from 377.3 to 4838.5 for Pb, from 69.7 to 1621.6 for Zn, from 7.9 to 35.1 for Cu, and from 0.6 to 2.4 for Cr. So the corresponding potential ecological risk levels were: very strong of Pb、Zn, slight of Cu、Cr. The trend of potential ecological risk of this 4 heavy metals was: E_r^i (Pb)> E_r^i (Zn)> E_r^i (Cu)> E_r^i (Cr).

RI of 8 sampling areas were all above 300 (table 4), which indicated that potential ecological risk in each area was strong. The order of the ecological risk level was: B > F > G > D > C > E > H > A. It meaned: sewage outfall of refinery>tailing dam>pithead tailing dam>sewage outfall of Laqiong village>50 meters downstream of the sewage outfall>reclaimed area>unquarried area. The result showed that waste water and residue from smelting were main pollution sources in Siding mineland. The potential ecological risk of surrounding area of sewage outfall even exceeded that of tailing dam. Therefore, management must be strict and audit to cleaning production of processing heavy metals ought to be strengthened.

D. Community analyze of dominant plants

In Siding mineland, 14 species of higher plants that belonged to 11 families, including 3 gramineae and 2 euphorbiaceae, had been investigated. The main artificial cultivated plants were fruit trees, vegetables and cash crops. Dominant species were almost herbaceous plant and mainly belonged to gramineae, which due to their abundant species, fast growing, widely distribution and resistant of arid and dry.

TABLE IV. POTENTIAL ECOLOGICAL RISK FACTOR (E_r^i) AND POTENTIAL ECOLOGICAL RISK INDEX (*RI*) OF HEAVY METALS IN SIDING PB-ZN MINELAND

Areas	E_r^i				*RI*
	Pb	***Zn***	***Cu***	***Cr***	
A	377.3	69.7	8.7	1.8	457.4
B	4838.5	697.3	35.1	3.6	5574.5
C	802.8	579.1	19.9	0.6	1402.4
D	1365.0	302.4	26.2	2.4	1696.0
E	463.9	96.9	11.5	2.1	574.4
F	2609.3	1621.8	28.8	1.1	4261.0
G	1757.2	570.8	13.5	1.6	2343.0
H	398.5	74.1	7.9	1.6	482.1
Average values (E_r^i ***)***	1448.2	471.7	25.6	1.7	

TABLE V. DOMINANT SPECIES OF PLANTS IN SIDING PB-ZN MINELAND

Families	Species	Abundance	Life form
Gramineae	Imperata cylindrica （Linn.）Beauv.	F	Perennial herb
Gramineae	Phragmites australis （Cav.）Trin. ex Steud.	D	Perennial herb
Moraceae	Ficus tikoua	F	Prostrate woody vine
Labiatae	Dysophylla EI－Gazzar et L. Wats. ex Airy shaw	F	Annual forb

Pteridacea	Pteris vittata L.	F	Perennial herb
Rosaceae	Rosa laevigata Michx.	F	Shrub
Euphorbiaceae	Alchornea trewioides（Benth.） Muell. Arg.	F	Shrub
Equisetaceae	Equisctum ramosissimum Desf.	D	Perennial herb
Euphorbiaceae	Drypetes cumingii（Baill.） Pax et Hoffm	F	Shrub
Compositae	Herba Taraxaci	F	Perennial herb
Gramineae	Miscanthus floridulus	D	Perennial herb
Compositae	Ageratum conyzoides L.	F	Annual forb
Loganiaceae	Flos Buddlejae	O	Sheepberry
Cruciferae	Beassica pekinensis （Lour.）Rupr.	F	Annual forb

Abundance class: D-Dominant, F-Frequent, O-Occasional.

E. Concentrations of heavy metals in dominant plants

In order to study the absorption and accumulation to Pb, Zn, Mn, Cu and Cr by dominant plants quantitatively and to find accumulators with heavy metal resistance, the concentrations of heavy metals in dominant plants were analyzed. The accumulated ability of plants is depended on biological features of the plants, soil types, nutrient elements and heavy metal availability. Table 6 presented the accumulation of heavy metals by 14 dominant plants, with the concentration range was: Pb 15.24~1496.0mg/kg, Zn 110. 20~20425.3mg/kg, Mn 4.6~282.9mg/kg, Cu 1.6~285.9mg/kg, Cr 1.0~152.3mg/kg. Compared with the normal concentration in plant, only the concentration of Mn was in normal range.

Concentrations of Pb, Zn in all plants were in the normal level. But they unreached to the critical concentrations (1000mg/kg and 10000mg/kg) (Baker, et al., 1983) of the hyperaccumulator. Concentrations of Pb, Zn in root of Pteris vittata L. were 467.93mg/kg and 20425.31mg/kg. Meanwhile, concentrations in its stem and leaf were 536.62mg/kg and 2537.56mg/kg. It proved that Pteris vittata L. had a good toxic resistance of Pb, Zn, that was accordance with the study by An et al (2007). Ageratum conyzoides L. had a concentration of 703.14mg/kg of Pb in the stem and leaf, which closed to 1000mg/kg. Further research could be carried out to study its potential accumulation.

As to Cu, concentrations with 285.91mg/kg and 47.07mg/kg in root and leaf of Pteris vittata L. in the sewage outfall of Laqiong village exceeded the normal level. And concentrations of other plants were all in normal level.

To Cr, only concentration of Drypetes cumingii (Baill.) Pax et Hoffm which grew in downstream of the sewage outfall of Laqiong village was in normal level, while others' all exceeded. But they were below the critical concentration of hyperaccumulator (1000mg/kg).

F. Accumulation and transfer characteristics by different plants

The concept of hyperaccumulator was proposed by Brooks in 1977 (Brooks, et al., 1977). Plants ideal for phytoremediation should posses multiple traits. They must have short growing period, resistance of plant diseases and insect pests, large biomass of aboveground part, and accumulate more than two heavy metals simultaneously.

To known the accumulation ability of plants further, Biological Accumulation Coefficient (BAC) and Biological Transfer Coefficient (BTC) were calculated (Table 7). BAC represents accumulation of one heavy metal (Salt, et al., 1995). As easy to collect, the aboveground part of plant is important in actual soil heavy metal remediation. It is that, larger the BAC, stronger the ability of accumulating heavy metals. BAC of aboveground part of plant larger than 1 is a prominent feature that to distinct the hyperaccumulator from other plants. BTC can reflect the plant ability of transferring heavy metals from root to their aboveground part. Heavy metal concentration in root is usually much higher than that in stem and leaf. But in hyperaccumulator, situation can be opposite. Generally, there should be more ionic transfer or channel protein to promote heavy metals loading to xylem (Wu, et al., 2007). As presented in table 7, BAC of Pteris vittata L. for Cr was 2.27. However, Pteris vittata L. was not a hyperaccumulator for Cr due to the Cr concentration (141.7 mg/kg) in the plant could not meet the critical level of 1000mg/kg. Plants with stronger ability of Pb accumulation were Phragmites australis (Cav.) Trin. Ex Steud. (BAC=0.4) and Ageratum conyzoides L. (BAC=0.37). Plants with stronger ability of Zn accumulation was Imperata cylindrica (Linn.) Beauv. (BAC=0.47). Plants with stronger ability of Cu accumulation were Pteris vittata L. (BAC=0.43) and Herba Taraxaci (BAC=0.46). Plants with stronger ability of Cr accumulation were Pteris vittata L. (BAC=2.27) and Ficus tikoua (BAC=0.54). Plants with stronger ability of Mn accumulation was Phragmites australis (Cav.) Trin. Ex Steud. (BAC=0.47).

TABLE VI. HEAVY METAL CONCENTRATIONS OF THE DOMINANT SPECIES IN SIDING PB-ZN MINELAND (MG/KG)

Species	areas	Tissue	Pb	Zn	Cu	Cr	Mn
Imperata cylindrica （Linn.） Beauv.	A	Root	758.60	3989.00	44.32	32.33	50.06
		Stem	189.64	1516.05	12.41	24.25	33.54
Phragmites australis （Cav.） Trin. Ex Steud.	B	Root	148.45	1310.91	23.13	8.47	8.23
		Stem	93.12	1462.53	17.05	9.10	7.06
		Leaf	578.10	500.00	17.64	14.25	10.02
Ficus tikoua	B	Root	562.96	1549.90	19.52	59.80	179.46
		Stem	523.29	1063.16	19.54	41.51	123.45
		Leaf	438.32	1112.62	11.94	40.07	120.49
Dysophylla	B	Root	513.15	1988.97	63.76	57.44	282.89
		Stem	112.71	303.10	4.74	29.95	80.18
Pteris vittata L.	D	Root	467.93	20425.31	285.91	141.71	160.52
		Stem and leaf	536.62	2537.56	47.07	152.32	56.49
Rosa laevigata Michx.	D	Root	1285.35	13400.11	26.13	4.18	23.64
		Stem	256.07	587.54	16.46	14.78	18.05
		Leaf	126.54	550.20	13.37	26.54	41.04
Alchornea trewioides （Benth.） Muell. Arg.	D	Root	378.17	637.55	15.64	8.52	29.93
		Stem	340.06	562.52	18.65	6.33	25.37
		Leaf	164.00	662.50	12.30	20.30	30.60
Equisctum ramosissimum Desf.	D	Root	151.60	1250.0	18.49	33.32	53.09
		Stem and leaf	103.10	575.00	8.32	9.33	27.61
Drypetes cumingii （Baill.） Pax et Hoffm	D	Root	959.50	2325.0	12.91	140.31	59.07
		Stem	110.71	300.00	7.64	7.15	17.15
Herba Taraxaci	F	Root	23.22	125.00	8.98	4.41	4.67
		Stem	35.84	263.94	21.84	36.84	10.64
		Leaf	86.03	875.03	13.18	15.68	15.84
Miscanthus floridulus	F	Root	217.46	1230.85	16.22	30.81	33.93
		Stem	342.52	1162.57	7.14	51.45	33.66
Ageratum conyzoides L.	F	Root	1496.0	4079.0	23.96	32.60	51.22
		Stem and leaf	703.14	1550.04	11.50	21.84	39.95
Flos Buddlejae	G	Root	792.81	2500.0	17.46	9.94	30.33
		Stem	495.02	1437.52	14.05	4.42	20.03

		Leaf	305.30	1300.02	15.83	23.10	30.52
Beassica pekinensis （Lour.） Rupr.	H	Root	54.42	343.80	5.64	3.78	23.77
		Stem and leaf	15.24	110.20	1.58	1.02	5.23
Normal concentration			0.1~41.7	1~160	0.4~45.8	0~8.4	1~700

TABLE VII. THE BIOLOGICAL ACCUMULATION COEFFICIENT (BAC) AND BIOLOGICAL TRANSFER COEFFICIENT (BTC) OF THE DOMINANT SPECIES IN SIDING PB-ZN MINELAND

Species	**Sampling area**	**Pb**		**Zn**		**Cu**		**Cr**		**Mn**	
		BAC	***BTC***	***BAC***	***BTC***	***BAC***	***BTC***	***BAC***	***BTC***	***BAC***	***BTC***
Imperata cylindrica （Linn.） Beauv.	A	0.13	0.25	0.47	0.38	0.34	0.28	0.49	0.75	0.16	0.67
Ficus tikoua	B	0.10	0.85	0.06	0.70	0.10	0.81	0.54	0.68	0.11	0.68
Dysophylla	B	0.32	0.22	0.01	0.15	0.02	0.07	0.01	0.52	0.15	0.28
Phragmites australis （Cav.） Trin. Ex Steud.	B	0.40	0.22	0.40	0.50	0.07	0.44	0.01	0.86	0.47	0.15
Pteris vittata L.	D	0.10	1.15	0.18	0.12	0.43	0.16	2.27	1.07	0.09	0.35
Rosa laevigata Michx.	D	0.04	0.15	0.04	0.04	0.14	0.57	0.31	4.94	0.05	1.25
Alchornea trewioides （Benth.） Muell. Arg.	D	0.05	0.67	0.04	0.96	0.14	0.99	0.20	1.56	0.05	0.94
Equisctum ramosissimum Desf.	D	0.06	0.68	0.13	0.46	0.17	0.45	0.16	0.28	0.03	0.52
Drypetes cumingii （Baill.） Pax et Hoffm	D	0.06	0.12	0.07	0.13	0.16	0.59	0.12	0.05	0.02	0.29
Herba Taraxaci	F	0.03	2.62	0.06	4.56	0.46	1.95	0.24	5.95	0.02	2.84
Ficus tikoua	F	0.06	0.21	0.05	0.25	0.10	0.28	0.04	0.15	0.04	0.64
Miscanthus floridulus	F	0.17	1.49	0.12	0.94	0.19	0.44	0.46	1.67	0.05	0.99
Ageratum conyzoides L.	F	0.37	0.47	0.17	0.38	0.30	0.48	0.20	0.67	0.06	0.78
Flos Buddlejae	G	0.06	0.50	0.05	0.55	0.27	0.86	0.30	1.38	0.10	0.83
Pteris vittata L.	G	0.11	2.63	0.10	0.16	0.25	0.31	0.18	0.10	0.17	0.41
Chinese cabbage	H	0.01	0.28	0.03	0.32	0.05	0.28	0.02	0.27	0.02	0.22

BAC= (heavy metal concentration in aboveground part of plant)/(heavy metal concentration of soil), BTC= (heavy metal concentration in aboveground part of plant)/(heavy metal concentration in root of plant).

When BTC was concerned, it seemed that Pteris vittata L. and Herba Taraxaci had a higher Pb transfer rate. Rosa laevigata Michx. and Phragmites australis (Cav.) Trin. Ex Steud. had a higher Cr transfer rate. And Rosa laevigata Michx. also had good Mn transfer ability. Herba Taraxaci showed good relocation abilities of Pb, Zn, Cu, Cr, Mn with BTCs larger than 1.

In all investigated plants, no hyperaccumulators had been find. However, some dominant plants in mineland such as Pteris vittata L., Imperata cylindrical (Linn.) Beauv., Ageratum conyzoides L., Herba Taraxaci) displayed good resistance to heavy metals. These species can be uesed as the pioneers for ecological restoration of mineland in early period, which can not only promote the vegetation coverage rate quickly and conserve water and soil, but also accumulate some of heavy metals.

IV. CONCLUSIONS

The heavy metal concentrations were very high in mineland siol. Most of them were exceeded the soil critical concentration for agricultural and forestry production and plant normal growth. There were significant differences among heavy metal concentrations. Heavy metal pollution in Pb mineland soil was serious, with the major pollution factors of Pb and Zn. Significant correlations between Pb-Zn, Pb-Cu and Cu-Zn illustrated their possibility of homology. This was accordance with the conclusion of Baoshan Pb-Zn mineland studied by Yue (2004). There was significant positive correlation between Pb-Cu, and very significant positive correlation among Cu, Pb, Zn (Yue, 2004). The correlation between Cr and other heavy metals was not obvious. This was a proof of the special accumulation of Cr.

Evaluation of the potential ecological risk of heavy metal pollution showed that pollution of Pb, Zn was serious in Siding mineland. The trend of pollution situation followed the order: sewage outfall of refinery>tailing dam>pithead tailing dam>sewage outfall of Laqiong village>50 meters downstream of the sewage outfall>reclaimed area>unquarried area. Pollution in sewage outfall of refinery was the most seriously because the sewage discharged into rivers nearby. Therefore, the government department should control more strictly in order to make sewage discharge meet the standard. The ecological risk of reclaimed area was light. In other words, after reclamation, the heavy metal pollution situation in mineland was a bit abated.

Investigation of dominant plants in mineland indicated that different plants had significant differences of the same heavy metal absorption. And different parts of one plant also had differences to heavy metal absorption, with root>stem>leaf usually. Although concentrations of Pb, Zn were high in mineland, plant accumulation was not ideal, with BACs lower than 0.5 on the whole. This was in accordance with the study of Pb-Zn mineland in Zhejiang by Bi De (Bi, et al., 2006). That was to say, plants in Pb-Zn mineland surely had some resistance to Pb. Even though, accumulation of all investigated plants did not meet the critical concentrations of hyperaccumulator, they were all dominant plants in local with large biomass and heavy metal resistance. Phragmites australis (Cav.) Trin. Ex Steud., Imperata cylindrica （Linn. ） Beauv., Herba Taraxaci and Pteris vittata L. had obvious Pb and Zn accumulation, and can be used as pioneer plants for ecological restoration in Pb-Zn mineland.

REFERENCES

[1] LUO Ya-ping, WU Xiao-fu, LI Ming-shun, et al. Investigation of main plant species and assessment of soil heavy metal pollutions in manganese mine wastelands in north Guangxi[J]. Ecology and Environment, 2007, 16（4）：1149-1153.

[2] PENG Jian, JIANG Yi-jun, WU Jian-sheng, et al. Eco-environmental effects of mining and related land reclamation technologies in china[J]. Progress in Geography, 2005, 24（2）：38-48.

[3] LIU Jing, TENG Yan-guo, CUI Yan-fang, et al. Review in ecological risk assessment methods for heavy metal polluted soil[J]. The Administration and Technique of Environmental Monitoring, 2007, 19（3）：6-11.

[4] JIA Zhen-bang, LIANG Tao, LIN Jian-zhi, et al. Study on heavy metal contamination and potential ecological risk in Hong Kong rivers[J]. Universitatis Pekinensi, 1997, 33（4）：485-492.

[5] LI Gui-hai, LAN Dong-zhao, CAO Zhi-min, et al. Specificity and potential ecological risks of heavy metals in the sediments of the Xiamen sea area[J]. Journal of Marine Science Bulletin, 2007, 26（1）：67-72.

[6] MA De-yi, WANG Ju-ying. Evaluation on potential ecological risk of sediment pollution in main estuaries of China[J]. China Environmental Science, 2003, 23（5）：521-525.

[7] LIU Meng-lan, ZHENG Xi-lai, LIN Duan, et al. Enrichment of heavy metals in the surface sediments from the three regions of random dumping in South China Sea and assessment of their potential ecological risk[J]. Marine Environmental Science, 2007, 26（2）：158-165.

[8] XIANG Yong, MIAO Qi-long, FENG Jiang-fan, et al. Pollution of heavy metals in the bottom mud of lake Taihu and its assessment of potential ecological risk[J]. Journal of Nanjing Institute of Meteorology, 2006, 29（5）：700-705.

[9] WANG Sheng-qiang, SUN Jin-sheng, DING Hui, et al. Evaluation on potential ecological risk of sediment heavy metal pollution in Hai River[J].Environmental Engineering, 2005, 23（2）：62-64.

[10] WU Yong-feng, LIU Cong-qiang, TU Cheng-long, et al. The heavy metal pollution in urban soils of Guiyang City and their potential ecological hazard assessment[J]. Bulletin of Mineralogy, Petrology and Geochemistry, 2007, 3：254-257.

[11] LIU Wen-xin, LUAN Zhao-kun, TANG Hong-xiao. Environmental assessment on heavy metal pollution in the sediments of leanriver with potential ecological risk index[J]. Acta Ecologica Sinica, 1999, 19（2）：206-211.

[12] Lars Hakanson. An ecological risk index for aquatic pollution control-Asedimentological[J]. Approach Water Research, 1980, 14：975-1000.

[13] YANG Zhen, HU Ming-an, HUANG Song. Heavy metals pollution in stream sediments and potential ecological risk assessment in dabaoshan mining area[J]. Journal of Guilin University of Technology, 2007, 27（1）：44-48.

[14] Baker A J M, brooks R R, Pease A J, et al. Studies on copper and cobalt tolerance in three closey related taxa with in the genus Science from Zaire[J]. Plant and Soil, 1983, 73：377-385.

[15] AN Zhi-zhuang, CHEN Tong-bin, LEI Mei. Tolerance of Pteris vittata L. to Pb, Cu and Zn[J]. Actc Ecologica Sinica, 2007, 27（1）：44-48.

[16] Books R R, Lee J, Reeves R D, et al. Detection of nickeliferous rocks by analysis of herbarium specimens of indicator plants[J]. Journal of Geochemical Exploration. 1977, 7：49-57.

[17] Salt E D, Blaylock M B, Kumar N P B A, et al. Phytore-mediation：A novel strategy for the removal of toxic metals from the environment using plants[J]. Biotechnology, 1995, 13：468-474.

[18] WU Zhi-qiang, GU SHANG-yi, LI Hai-ying, et al. Phytoremediation of heavy metals contaminated soils and hyper-accumulator's research advance[J]. Environmental Science and Management, 2007,32（3）：67-71.

[19] YUE Qing-ling. Study on heavy metal of soils and plants in mining in Hunan[D]. 2004.

[20] BI De, WU Long-hua, LUO Yong-ming, et al. Dominant plants and their heavy metal contents in six abandoned lead-zinc mine areas in Zhejiang Province[J]. Soils, 2006, 38（5）：591-597.