Comparison of heavy metal accumulation capacity of some indigenous mosses in Southwest China cities: a case study in Chengdu city

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ABSTRACT

In order to evaluate the accumulation capacity of heavy metals in mosses, the total contents of eight elements (Cu, Zn, Fe, Mn, Ni, Pb, Cd, Cr) determined by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) and Atomic Absorption Spectrophotometry (AAS) methods were compared in four types of indigenous mosses (*Brachythecium plumosum*, *Eurhynchium laxirete*, *Taxiphyllum taxirameum*, *Haplocladium strictulum*), which were collected from different sampling sites in the Chengdu city, China. The study found that heavy metal concentrations showed significant differences in interspecies and intraspecies comparison, while the accumulation capacity of *T. taxirameum* was higher than others. ANOVA analysis indicated that the atmospheric pollution of heavy metals in Wangjiang Park was relatively more serious than that of Ta Zishan Park and Cultural Park. The data also showed that the concentrations of heavy metals in the Chengdu city were higher compared to some foreign cities. The results are coincident with the previous conclusions that the difference of heavy metal depositions in mosses was not only related to environment, but also to their biological features.

Keywords: moss; accumulation capacity; interspecies; intraspecies; heavy metals

Due to the lack of real root and vascular system, mosses obtain nutrients through the entire plant surface from atmosphere and precipitation. Since Ruhling and Tyler (1968) had taken advantage of mosses as sensitive bioindicators of heavy metal contamination, the utilization of terrestrial mosses for biomonitoring of atmospheric pollution was widely applied in the last thirty years (Grodzinska et al. 1990, Thoni et al. 1996, Otvos et al. 2003). So far, *Hylocomium splendens*, *Pleurozium schreberi* and *Hypnum cupressiforme* were commonly employed as bioindicators of atmospheric pollution in Europe and the North America (Ross 1990, Bargagli et al. 1995, Poikolainen et al. 2004). However, due to their limited distribution, some other mosses were selected for the investigation, such as *Bryum radiculosum*, *Aloina aloides*, *Tortella flavovirens*, *Scleropodium purum* and *Polytrichum formosum* in the Czech and Slovak Republics (Markert et al. 1996). Moreover, it was obvious that the heavy metal depositions in mosses varied greatly, even in the same species or biotope (Steinnes 1993). Only a few detailed interspecies and intraspecies comparisons were carried out in mosses except for the common mosses mentioned above (Ruhling 1994, Wolterbeek et al. 1995, Zechmeister et al. 2003).

The Chengdu city, which lies in the Sichuan basin, is the political, economic and cultural center of Southwest China, as well as one of the famous historical and tourist cities in the world. In recent years, with an increase of the city development and human activities, the environmental problem is getting more and more serious. However, few works

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were reported with regard to the biomonitoring of atmospheric pollution in Chengdu city.

In the present study, the contents of eight metal elements (Cu, Zn, Fe, Mn, Ni, Pb, Cd, Cr) in four moss species from different sampling sites in the Chengdu city were determined by Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) and Graphite Furnace-Atomic Absorption Spectrophotometry (GF-AAS) methods, and then were compared among interspecies and intraspecies. The main aims of this investigation were as follows: (1) to find out the difference of heavy metal accumulation capacity of mosses; (2) to evaluate the degree of atmospheric pollution in the Chengdu city; (3) to identify some mosses suitable for biomonitoring in Chengdu and to establish good methods for monitoring atmospheric and water pollution in the world.

MATERIAL AND METHODS

Collection of mosses and sampling sites. Many mosses only lay in some gardens of urban areas. Therefore, the sampling sites were mainly located at these gardens between the first-ring and the third-ring road of Chengdu (Figure 1). Sampling was carried out in autumn. These sampling sites were at least 300 m away from the main roads. Finally, four moss species (*Brachythecium plumosum* (Hedw.) B.S.G., *Eurhynchium laxirete* Broth., *Taxiphyllum taxirameum* (Mitt.) Fleisch, *Haplocladium strictulum* (Card.) Reim) were collected with a plastic shovel from three sampling sites (Wangjiang Park, Cultural Park, Ta Zishan Park,) and brought back to laboratory.

Disposal of samples. After removal of all other debris (plant remains, soil particles, other mosses etc.), the moss shoots were cut into the length of 3–4 cm to get apical green segments. The samples were first thoroughly washed with tap water, and then with double-distilled water for 3 times. The washed samples were then dried to constant weight in a forced-air oven at 60–80°C for 2–3 days, and were subsequently ground in an agate pot to obtain fine particles (< 200 μm). The moss samples were stored in polyethylene bags in desiccators.

Measure of samples. For analysis, approximately 500 mg of homogenized moss tissue and the standard reference material were weighed and digested with 8 ml HNO_3 and 2 ml H_2O_2 in Teflon bombs in a microwave oven. After complete digestion, the solutions were diluted with bi-distilled water to the volume of 100 ml. At the same time, the procedural blanks (1 every 10 samples) and 10 replicates in all samples were made. The concentrations of Cu, Zn, Fe, Mn, Ni, Cr, and Pb in the digested solutions of mosses were surveyed by ICP-AES, and the Cd concentration was determined by GF-AAS because of the low detection threshold. The quality control of the results was ensured by the use of the total of ten replicates in all samples and a parallel analysis of the standard reference material (tea plant leaves GBW08513).

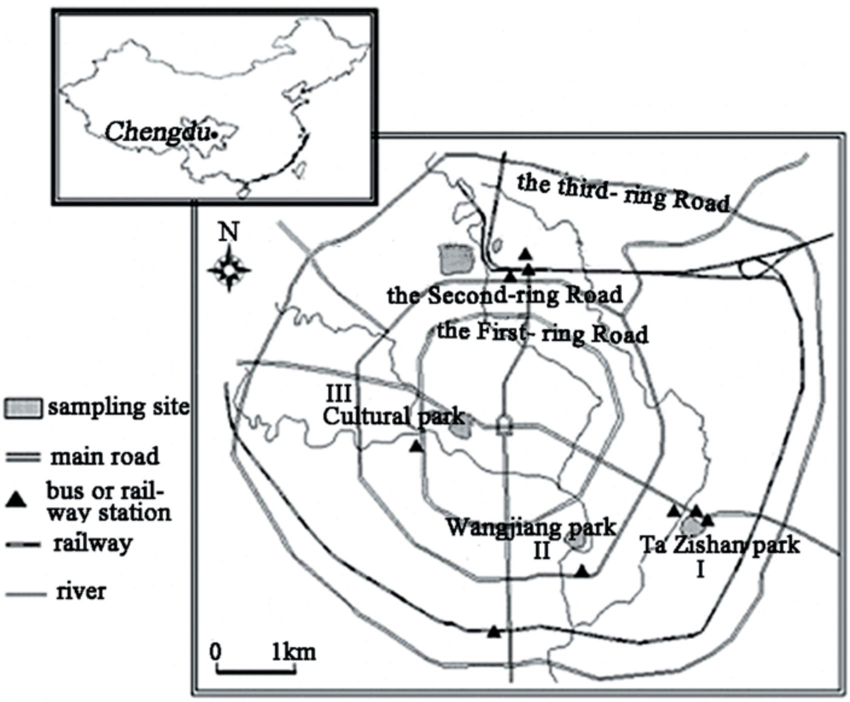

Figure 1. The location of the sampling sites in the Chengdu city

Statistical analysis. The heavy metal concentrations in moss samples were shown as mean values. The survey also made a value of each sampling site (I, II, III) by using four mosses (n = 4) and the total mean of 8 heavy metal contents in all mosses. One-way analysis of variance (ANOVA) was used to analyze the difference of elemental concentrations of 8 moss species in the different sampling sites (P < 0.05).

RESULTS

The heavy metal concentrations of all mosses. A summary of eight heavy metal concentrations in all mosses was given in μg/g dry weight in following tables and figures. We found that the contents of most heavy metal elements varied significantly in inter- and intraspecies analyses. For example, Cu ranged from 16.5 to 337 μg/g, with the total mean value of 51.7 μg/g. The concentration of Zn was from 101 to 385 μg/g and its total mean value was 163 μg/g, while that of Fe ranged from 2248 to 9546 μg/g, with the highest mean of 5401 μg/g. In general, the content of Fe was the highest, the next element was Zn, while Cd (1.31 μg/g) was the lowest among the eight heavy metal elements. The total average abundance of each element was in the following order: Fe > Zn > Mn > Cu > Pb > Cr > Ni > Cd.

The interspecies comparison of the heavy metal concentrations. In order to analyze the interspecies differences of moss heavy metal accumulation capacity, the comparison of the elemental mean concentrations between four mosses was showed in Table 1. The concentrations of over 2/3 elements in *B. plumosum* and *T. taxirameum* were higher than other species (Table 1). However, contents of all eight elements in *E. laxirete* were lower than the average levels (all with significance levels > 0.05).

Furthermore, the interspecies comparison of elemental concentrations was also carried out to see their uptake efficiency of the heavy metal elements in similar ecological environment (Figure 2). In sampling site I, *H. strictulum* had the highest Cu content, while *T. taxirameum* had the highest contents of Fe, Mn, Ni and Cr and a lower Cd content. At the same time, *E. laxirete* had lower concentrations of Cu, Zn, Mn, Pb, Cd. In sampling site II, *T. taxirameum* had the highest concentrations of all the eight heavy metals and other mosses had lower element contents. However, in the sampling site III, the elemental contents in *T. taxirameum* were not significantly higher except for Cu, Zn (P > 0.05); other six elemental concentrations were higher in *B. plumosum*.

The intraspecies comparison of the heavy metal concentrations. In *B. plumosum*, the concentrations of Cu, Zn, Pb, Cr and Cd in sampling site II were lower than I and III, and Fe, Mn, Ni were higher than I and III. Sampling site II had the highest contents of Fe and Ni of all three sampling sites (Figure 3). The analytical data showed that the intraspecies concentrations of most elements were significantly different except for the contents of Pb (P = 0.058), Cr (P = 0.136) in I/III and Ni (P = 0.063) in II/III. As for *E. laxirete*, the eight heavy metal contents were always significantly higher in sampling site II than I and III, except for Cd (P values for Cd at I, II, III sites were 0.204, 0.305, 0.0834 respectively).

For *T. taxirameum*, the highest concentrations of Cu and Zn were in sampling site III, but Fe, Ni, Pb, Cd and Cr were highest at II, and Mn was highest at I. With the one-way ANOVA analysis, all the mean concentrations of the elements had a significant difference except for Cd in I/III. However, in *H. strictulum,* the highest contents of Cu, Fe, Ni, Cr, Cd were in sampling site II. In the whole, the eight elemental concentrations however did not show an obvious trend.

DISCUSSION

The heavy metal contents of four mosses can be expressed in the following order: Fe > Zn > Mn >

Table 1. The elemental mean values in four moss species (μg/g). Standard deviations (S.D.) are indicated following the mean values (n = 4)

	Moss species	Cu	Zn	Fe	Mn	Ni	Pb	Cd	Cr
A	*B. plumosum*	36.6 ± 4.2	169 ± 34	6159 ± 1240	156 ± 27	15.4 ± 6.4	42.0 ± 5.5	1.44 ± 0.3	19.4 ± 4.0
B	*E. laxirete*	19.5 ± 3.6	114 ± 21	4648 ± 937	111 ± 19	11.9 ± 2.8	23.9 ± 3.1	0.97 ± 0.2	14.8 ± 2.8
C	*T. taxirameum*	139 ± 27	229 ± 33	7590 ± 1788	170 ± 33	16.4 ± 5.4	30.7 ± 2.6	1.21 ± 0.3	19.1 ± 3.9
D	*H. strictulum*	34.9 ± 5.2	124 ± 47	4088 ± 651	109 ± 26	11.5 ± 4.3	43.3 ± 3.3	1.22 ± 0.4	14.4 ± 3.2
Mean		57.5 ± 11	159 ± 26	5621 ± 882	137 ± 25	13.8 ± 4.7	35.0 ± 3.3	1.21 ± 0.3	16.9 ± 3.3

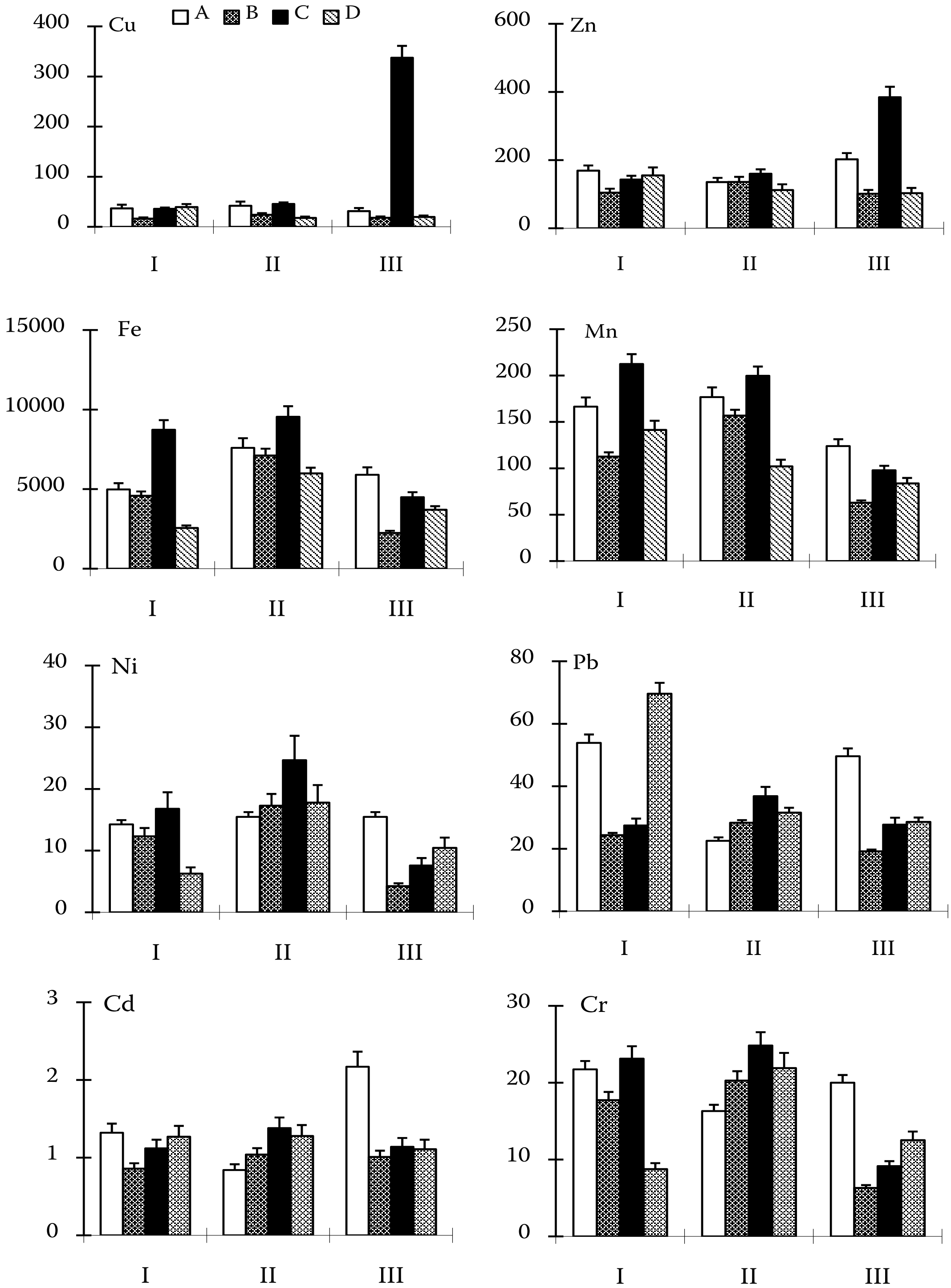

Figure 2. Comparison of Cu, Zn, Fe, Mn, Ni, Pb, Cd, Cr concentrations (μg/g) of different moss species in three sampling sites (I, II, III)

Cu > Pb > Cr > Ni > Cd. Fe concentration was the highest (over 9500 μg/g), which was coincident with the previous results that Fe might be the most accumulated and tolerated heavy metal in mosses (Berg and Steinnes 1997, Genoni et al. 2000). Cd was the least abundant element; the reason might be that Cd is a trace element. However, in other moss researches, the elemental concentrations do not always follow the above order. These different orders probably reflect the differences among moss species, existent environments and sampling times.

The interspecies analysis of the heavy metal concentrations. As shown in Table 1, most moss species had different accumulation capacity even for the same heavy metal element. The interspecies

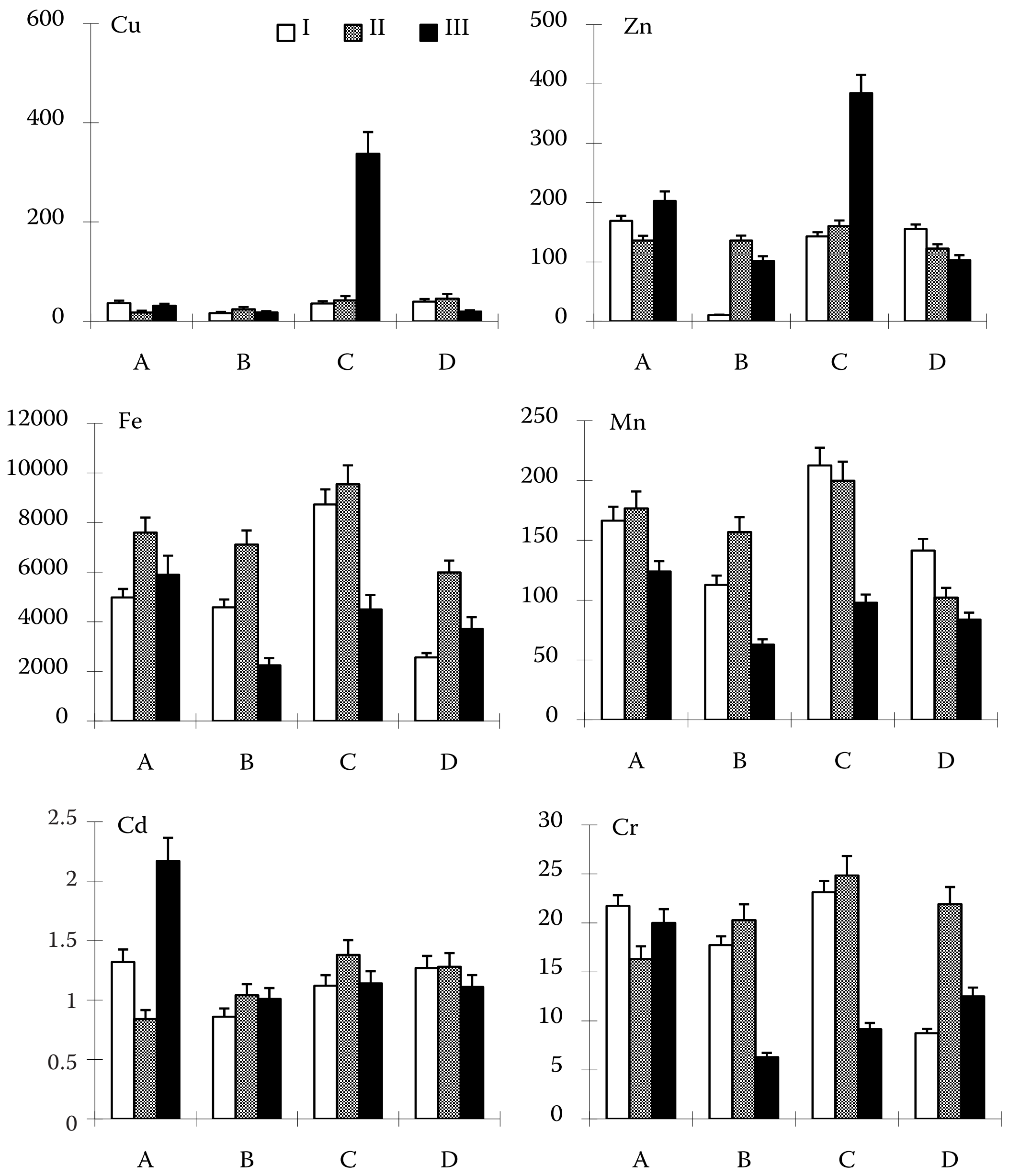

Figure 3. Comparison of Cu, Zn, Fe, Mn, Ni, Pb, Cd, Cr concentrations (μg/g) of different sampling sites (I, II, III) in *B. plumosum*, *E. laxirete*, *T. taxirameum* and *H. strictulum*

comparison of specific heavy metal content in the present study indicated that the biological characters of each species, such as living form, morpha, had a great influence on accumulative capacity of the elements in mosses, even if collected from the same biotope (Sucharova and Suchara 1998, Pacyna and Pacyna 2001). For example, higher contents of most elements in *T. taxirameum* might be due to its biologic characters. *T. taxirameum* is frond, more branched, of creeping growth and forming dense carpet. These features possibly made it absorb elements easily from environment. It was clear that *T. taxirameum* in most sampling sites had relatively higher heavy metal contents except for some elements.

The intraspecies comparison of the heavy metal concentrations. The intraspecies comparison and test of significance of the elemental concentrations in mosses indicated that in general the environment in sampling site II is worse than in I and III. However, the elemental contents of every moss species have some differences among different sampling sites. For example, *E. laxirete* and *H. strictulum* at sampling site II had high elemental concentrations, which may be result of steel industry, heavy traffic and more human activities near Wangjiang Park. Similarly, higher

Table 2. Comparison of elemental contents in mosses between Chengdu and some other countries (μg/g)

Country	Cu	Zn	Fe	Pb	Cd	Cr
Chengdu, China	51.7	162.7	5400	33.9	1.31	17.8
Denmark	6.9	38.9	544	12.1	0.27	1.5
Great Britain	6.4	37.8	255	10.8	1.43	0.8
Italy	8.3	35.6	127	16.5	0.39	3.2
Norway	7.1	41.8	671	14.0	0.20	1.4
Portugal	9.2	39.0	1200	17.4	0.22	2.2
Switzerland	4.8	36.0	441	18.3	0.40	2.7
Canada	2.5	24.1	353	9.4	0.17	1.24
Argentina	3.0	14.2	1984	0.4	–	–
Nigeria	38.1	153	2114	6.6	0.70	–

zinc and copper contamination in *T. taxirameum* in sampling site III may be associated with intensive traffic and metal and chemical industries (Ruhling 1994, Otvos et al. 2003, Wang et al. 2009). Some researches also indicate that environmental characteristics such as climatic conditions, mineral composition of soil dust, soil water, natural element cycling process and vegetation zone may have a significant influence on uptake efficiencies of heavy metal elements in moss (Ross 1990, Zechmeister 1998, Reimann et al. 2001).

Evaluating the degree of atmospheric pollution in the Chengdu city. This study suggests that the heavy metal concentrations at sampling site II are mildly higher than those of I and III, which also reflects that atmospheric pollution of heavy metals at II is higher than that of I and III. The total mean concentrations are all higher when compared with the values reported by the Ruling in European countries in 1994 and other some countries (Percy 1983, Onianwa and Ajayi 1987, Pignata et al. 2002). Table 2 shows that the concentrations of Cu, Zn, Fe, Pb, Cd, Cr in the Chengdu city were much higher than those in European and other countries, which confirms that the atmospheric pollution in the Chengdu city is relatively serious. However, because of the limitation of sampling, it has to be confirmed further.

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