

# Heavy metal pollution of soils and vegetables in the midstream and downstream of the Xiangjiang River, Hunan Province

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**Abstract:** A total of 219 agricultural soil and 48 vegetable samples were collected from the midstream and downstream of the Xiangjiang River (the Hengyang–Changsha section) in Hunan Province. The accumulation characteristics, spatial distribution and potential risk of heavy metals in the agricultural soils and vegetables were depicted. There are higher accumulations of heavy metals such as As, Cd, Cu, Ni, Pb and Zn in agricultural soils, and the contents of Cd (2.44 mg kg<sup>-1</sup>), Pb (65.00 mg kg<sup>-1</sup>) and Zn (144.13 mg kg<sup>-1</sup>) are 7.97, 3.69 and 1.63 times the corresponding background contents in soils of Hunan Province, respectively. 13.2% of As, 68.5% of Cd, 2.7% of Cu, 2.7% of Ni, 8.7% of Pb and 15.1% of Zn in soil samples from the investigated sites exceeded the maximum allowable heavy metal contents in the China Environmental Quality Standard for Soils (GB15618-1995, Grade II). The pollution characteristics of multi-metals in soils are mainly due to Cd. The contents of As, Cd, Cu, Pb and Zn in vegetable soils are significantly higher than the contents in paddy soils. 95.8%, 68.8%, 10.4% and 95.8% of vegetable samples exceeded the Maximum Levels of Contaminants in Foods (GB2762-2005) for As, Cd, Ni and Pb concentrations, respectively. There are significantly positive correlations between the concentrations of Cd, Pb and Zn in vegetables and the concentrations in the corresponding vegetable soils ( $p < 0.01$ ). It is very necessary to focus on the potential risk of heavy metals for food safety and human health in agricultural soils and vegetables in the midstream and downstream of the Xiangjiang River, Hunan Province of China.

**Keywords:** Xiangjiang River; agricultural soil; vegetable; heavy metal; pollution

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## 1 Introduction

Heavy metal pollution in agriculture soils is of great concern and leads to the functional disorder of soil, interference with crop growth, and even impaired human health through a contaminated food chain. In recent years, studies on heavy metal contents in soils from industrial areas and especially in soils and crops from agricultural areas have been reported (Chen *et al.*, 1997; Lei *et al.*, 2005; Liao *et al.*, 2005; Song *et al.*, 2006). However, there is still little information on heavy metal contamination in agricultural soils and vegetables due to industrial uses of non-ferrous metals.

It is well known that there are abundant reserves of non-ferrous metals in Hunan Province, and most ores for mining, mineral processing and smelting of non-ferrous and rare metals are located in the Xiangjiang Valley (Wang *et al.*, 2004), which is a main center of industry and agriculture, a main water resource for drinking, daily life and irrigation, and a main line for transportation and fishing. With long-time mining and smelting activities of non-ferrous metals, much wastewater has been discharged to the surrounding environment, and the levels of heavy metals in the Xiangjiang River have been dramatically enhanced (Chen *et al.*, 2004). Furthermore, the surrounding soils have been contaminated by As, Cd and Pb, and other heavy metals (Guo and Zhu, 2004). In this study, agricultural soils and vegetables from the midstream and downstream of the Xiangjiang River in the Hengyang–Changsha section were investigated. The characteristics of soil contamination and heavy metal accumulation in vegetables and the spatial variations and potential risk of heavy metals in agricultural soils and vegetables were studied to evaluate the soil environmental quality.

## 2 Materials and methods

### 2.1 Description of the study area and sampling site

Hunan Province is located in the central south of China, where the climatology is subject to the sub-tropic monsoon climate belt. The zonal soils are mostly acidic ferrisols, which are mainly derived from shale, sandstone, purple sandstone and laterite, and the pH of the soils is acidic or strongly acidic. The annual mean air temperature is 15.5–25°C, the accumulated temperature (>10°C) is 5000–9500°C, and the annual mean precipitation is 1250–1500 mm (Guo and Zhu, 2004), which is mainly composed of acidic deposition. Hunan Province is a basin with some hillocks in central areas, enclosed by huge mountains to the east, south and west. The altitude to the south is higher than that to the north, characterized by multi-terraces and valley landforms. The monsoon travelling from north to south is greatly affected by the physical geography which leads to the weakening of self-purification ability. The Xiangjiang River is the main river in Hunan Province and originates from the Longmenjie district in Lingui County of Guangxi Zhuang Autonomous Region. The sink of the Xiangjiang River is the East Dongting Lake in the north of Hunan Province. The trunk stream of the Xiangjiang River, lying between 110°30'–114°E and 24°31'–28°45'N, is 856 km long. The drainage basin covers an area of  $9.46 \times 10^4$  km<sup>2</sup> and about 1300 branches, big or small, flowing into it. The annual mean discharge is  $7.22 \times 10^{10}$  m<sup>3</sup>/a with significant seasonal variations. According to the characteristics of riverway hydrology and terrain physiognomy, the section from the headstream to Pingdao Island of Lingling district is the upstream of the Xiangjiang River, which is determined from the calcareous soils. The midstream of the

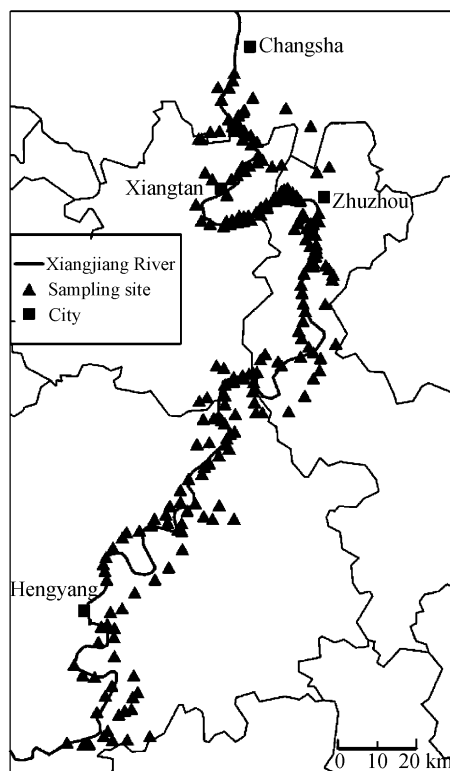
Xiangjiang River is from Pingdao Island of Lingling district to Hengyang district, with the river width ranging from 250 m to 1000 m. The midstream passes through a laterite zone with rolling terrain on both banks. The width range of the downstream of the Xiangjiang River is from 500 m to 1000 m and the length is about 326 km. The study area, including the cities of Changsha, Zhuzhou, Xiangtan and Hengyang located on either side of the midstream and downstream of the Xiangjiang River, constitutes the well developed political, economic and cultural areas in Hunan Province. Industrial contamination is very serious in these areas. Qingshitang district of Zhuzhou serves as an old industrial base of smelting, chemical engineering, building materials and energy supply. Hengyang is a medium-sized industrial city is very close to Shuikoushan district with dense Pb/Zn mining, processing and smelting activities.

A total of 219 agricultural soil samples (0–20 cm) and 48 vegetable samples were collected from the midstream and downstream of the Xiangjiang River (the Hengyang–Changsha section), including Changsha, Xiangtan, Zhuzhou and Hengyang, which are 1 km to 5 km from the river and hence easily affect its water quality. The horizontal distance between two sampling sites was about 1.5 km and the samples were taken during the period from October to December, 2005 (Figure 1). The vegetable samples were mostly the edible parts of cabbage (*Brassica chinensis L.*), Chinese cabbage (*Brassica pekinensis (Lour.) Rupr.*) and radish (*Raphanussativus*).

## 2.2 Sample analysis

Soil samples were air-dried and sieved to 0.25  $\mu\text{m}$ . Vegetable samples were washed carefully with tap-water and deionized-water. After washing, the samples were placed in an oven at 105°C for about 30 minutes and then dried at 60°C until a constant weight was achieved and ground to a fine powder.

Soil samples were digested with a mixture of  $\text{HNO}_3\text{--H}_2\text{O}_2$  (EPA, 1996), and vegetable samples were digested with a solution of  $\text{HNO}_3\text{--HClO}_4$  (Song *et al.*, 2006). Arsenic content was analyzed with a hydrogen generation-atomic fluorescence spectrometer (HG-AFS) (AFS-2202, Beijing Haiguang Instrumental Co., China), Cd content was determined with a graphite furnace atomic



**Figure 1** Sampling sites in the midstream and downstream of the Xiangjiang River

absorption spectrophotometer, and Cr, Cu, Ni, Pb and Zn contents were determined with an atomic absorption spectrophotometer (Vario 6, Analytic Jena, Germany). Blank and standard reference materials for plant (GBW-08513) and soil (GBW-08303) samples, obtained from the China National Center for Standard Reference Materials, were included for quality assurance. The concentrations of heavy metals in vegetable samples were based on the weight

of fresh vegetables.

### 2.3 Risk evaluation

To quantify the pollution risk, the Nemero synthesis index evaluation method was performed. The synthesis index can be computed with

$$P = \sqrt{\frac{\left(\frac{C_i}{S_i}\right)_{\max}^2 + \left(\frac{1}{n} \sum_{i=1}^n \frac{C_i}{S_i}\right)^2}{2}}$$

where  $P$  is the synthesis evaluation score,  $C_i$  is the measured content of a certain element at a sampling point,  $i$  denotes the element, and  $S_i$  is the evaluation criterion of the  $i$ -th element. In this study, the evaluation criterion is based on the China Environmental Quality Standard for soil metals (GB15618-1995, Grade II) (pH 6.5–7.5) (SEPAC, 1995). A result of  $P \leq 1$  means the soil is clean,  $1 < P \leq 2$  means the soil is slightly polluted, and  $2 < P \leq 3$  means the soil is heavily polluted with heavy metals.

### 2.4 Statistical analysis

Values for the contents of As, Cd, Cr, Cu, Ni, Pb and Zn in soils were transformed into logarithmic values to elucidate the normal distribution characteristics and avoid result distortions and low levels of significance (Shapiro-Wilk determination,  $p < 0.05$ ) by software of Origin 7.5. A map was generated using ArcGIS 9.0. All statistical analyses were performed using Microsoft Excel 2003 and SPSS 13.0. Analysis of variance (ANOVA) was used to examine statistically significant differences in the mean concentrations of heavy metals among groups of soils and vegetables. A probability level of  $p < 0.05$  was considered significant.

## 3 Results and discussion

### 3.1 Spatial distributions of heavy metals in agricultural soils

The contents of Cd, Cu, Pb and Zn in soils from the investigated sites varied greatly, ranging 0.05–107.14, 9.85–1067.04, 11.89–2730.04 and 54.98–2828.70 mg kg<sup>-1</sup>, respectively (Table 1). This implies that the main contamination sources may be external inputs. The geometric mean concentrations of As, Cd, Ni, Pb and Zn in the soils significantly exceeded background levels for soils in Hunan Province (CNEMC, 1990). The mean contents of Cd, Pb and Zn in agricultural soils were 2.44, 65.00 and 144.13 mg kg<sup>-1</sup>, respectively, which were 7.97, 3.69 and 1.63 times the background levels. The results show the main contribution to metal contamination of agricultural soils in the Hengyang–Changsha section of the Xiangjiang River is that of Cd, and significant increases in Pb and Zn contents in soils were also found.

According to the Nemero synthesis index based on the geometric mean concentrations of heavy metals in soils,  $P$  reached 1.72. The China Environmental Quality Standard for Soil Metals (GB15618-1995, Grade II) (SEPAC, 1995) was exceeded by 13.2% of As, 68.5% of Cd, 2.7% of Cu, 2.7% of Ni, 8.7% of Pb and 15.1% of Zn in soil samples collected from the investigation sites. Table 1 shows there are multiple metal contaminations, and contamination by Cd is especially high. In the midstream and downstream of the Xiangjiang Valley, the

**Table 1** Contents of heavy metals in soils from the midstream and downstream of the Xiangjiang River

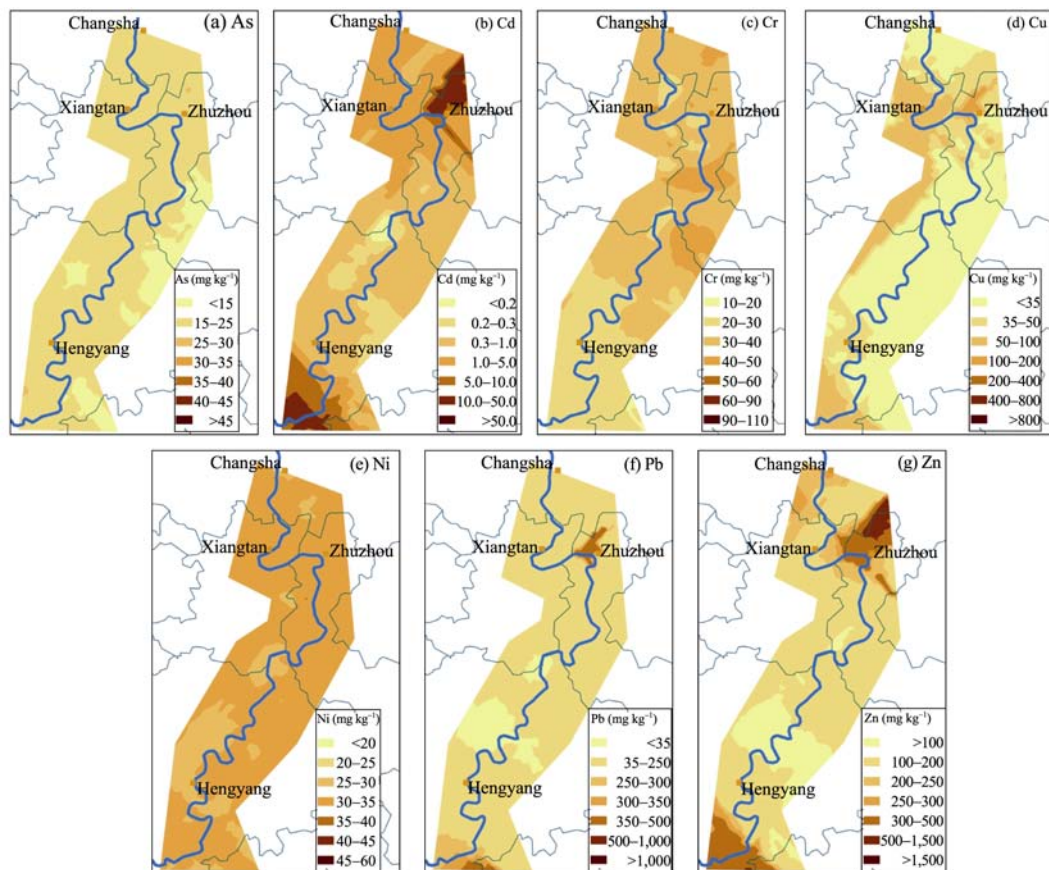
Element	Content of heavy metals (mg kg <sup>-1</sup> ) (n=219)						Ratio of overrunning (%) <sup>b</sup>
	Range	Median	Arithmetical mean (SD)	Geometric mean (SD)	Background value <sup>a</sup>	China Environmental Quality Standard for Soil Metals <sup>b</sup>	
As	4.90–72.41	17.16	18.35 (7.80)	17.00 (1.48)	13.60	25 (paddy soil)	13.2
Cd	0.05–107.14	0.50	2.50 (8.60)	0.63 (3.78)	0.079	0.3	68.5
Cr	10.45–108.13	29.20	31.19 (12.91)	29.30 (1.41)	64.9	300 (paddy soil)	0
Cu	9.85–1067.04	31.70	44.79 (79.90)	34.60 (1.70)	25.4	100 (agricultural soil)	2.7
Ni	16.37–58.29	30.45	31.21 (7.53)	30.40 (1.26)	29.4	50	2.7
Pb	11.89–2730.04	48.51	121.54 (234.17)	65.00 (2.64)	27.3	300	8.7
Zn	54.98–2827.70	122.69	196.77 (264.68)	144.13 (1.93)	88.6	250	15.1

Note: SD is the standard deviation; <sup>a</sup> soil trace element background for Hunan Province (CNEMC, 1990); <sup>b</sup> compared to the metal standard of China Soil Environmental Quality (GB15618-1995, Grade II).

activities of non-ferrous metal mining, processing and smelting are mostly for the sulfur-containing ores of Pb/Zn, and are associated with elements such as As, Cd, Cr, Cu and Ni. During the period of the 9th Five-Year Plan of China (1996–2000), a great quantity of industrial wastewater with toxic elements including As, Cd and Pb, which accounted for 91.1%, 79.6% and 90.1% of the total element quantity, was discharged into the Xiangjiang River (Chen *et al.*, 2000). Therefore, it is concluded that the heavy metal contamination of agricultural soils significantly correlates with the non-ferrous industrial activities in the midstream and downstream of the Xiangjiang River.

The spatial variations for contents of As, Cd, Cr, Cu, Ni, Pb and Zn in agricultural soils mapped by a GIS system are shown in Figure 2. Significant accumulation has occurred for As, Cd, Cu, Pb and Zn. Cd is distributed far from the city and industrial areas in the midstream of the Xiangjiang River (the Hengyang–Zhuzhou section) and has a relatively low content. However, Cd, Cu, Pb and Zn have significantly accumulated in the agricultural soils in the downstream of the Xiangjiang River (the Zhuzhou–Changsha section) due to intense anthropogenic activities such as agriculture, industry, mining and mineral processing of metallic ores in the triangle belt of Changsha, Zhuzhou and Xiangtan. The contents of Cd, Cr, Pb and Zn increase from the upper to lower Xiangjiang River.

Pollution of Cd in agricultural soils from the midstream and downstream of the Xiangjiang River is serious (Figure 2), especially in the Shuikoushan area of Hengyang district and the Qingshuitang area of Zhuzhou district, suggesting that the main contamination source of Cd is due to the large-scale mining activities of non-ferrous metal industry. The Cd content in agricultural soils was greater than 10 mg kg<sup>-1</sup> within 10 km of a point source of the pollutant and decreased with increasing distance. The spatial variations of the contents of Pb and Zn in agricultural soils were similar to those of Cd, especially in the Shuikoushan area of Hengyang district and the Qingshuitang area of Zhuzhou district. The contents of Cd, Pb and Zn in the soils from the triangle belt of Changsha, Zhuzhou and Xiangtan were significantly higher than those from the countryside in the midstream of the Xiangjiang River, which implies that these heavy metals in agricultural soils are also affected by other anthropogenic activities. The spatial distribution for Cu is also significantly affected by point sources of pollutants, and the soil Cu content from Xiangtan and Zhuzhou districts has reached or exceeded the Standard of China Soil Environmental Quality for Cu (100 mg kg<sup>-1</sup>)



**Figure 2** Spatial variation maps of the heavy metal distributions in the soils from the midstream and downstream of the Xiangjiang River

(SEPA, 1995). The contents of As, Cr and Ni increase with the flow of the Xiangjiang River, and range from 30 to 40  $\text{mg kg}^{-1}$ , from 40 to 100  $\text{mg kg}^{-1}$  and from 30 to 45  $\text{mg kg}^{-1}$ , respectively. The As content in agricultural soils exceeds the Standard of China Soil Environmental Quality while the contents of Cr and Ni do not.

The geometric mean of Cd, Pb and Zn contents in agricultural soils from Zhuzhou district were 3.16, 104.31, 183.25  $\text{mg kg}^{-1}$ , respectively, which were higher than the contents in the districts of Changsha, Xiangtan and Hengyang (Table 2). The soil Pb content from Zhuzhou district was significantly higher than contents from the other three districts ( $p < 0.01$ ), and the contents of Cr and Zn were significantly higher than those from Hengyang district ( $p < 0.01$ ). The results show the contamination of heavy metals in agricultural soils from Zhuzhou district is the heaviest among the study areas. Some studies have reported that the heavy metals released from the 36 main industrial enterprises in Zhuzhou district account for 46% of the total heavy metal discharge from 146 enterprises in the Xiangjiang Valley (Wang *et al.*, 2004), showing the contamination of heavy metals in soils in Zhuzhou district significantly correlates with the industrial activities of non-ferrous metals.

The geometric mean contents of As, Cd, Cu, Pb and Zn in vegetable soils were 1.16, 1.95, 1.47, 2.28 and 1.81 times those in paddy soils, respectively (Table 3). In particular, the contents of As, Cu, Pb and Zn in vegetable soils were significantly higher than those in paddy

soils ( $p < 0.05$ ). Similar results have been obtained in an investigation of Beijing City, where the contents of Cd, Cr, Ni and Pb in vegetable soils were higher than those in paddy soils (Zheng *et al.*, 2005a, 2005c). However, the contents of As and Zn in paddy soils were higher than those in vegetable soils (Zheng *et al.*, 2005b; Chen *et al.*, 2005; Zheng *et al.*, 2006). The results indicate that the contamination of heavy metals in soils is significantly affected by land use.

The relationships between the contents of As and Cd, Cu, Ni, Cr, Pb and Zn, of Cd and Cu, Pb and Zn, of Cu and the other heavy metals, of Cr and Ni and Zn, of Ni and Zn, of Pb and Zn in soils are significant (Table 4). The seven contaminating metals in agricultural soils can

**Table 2** Geometric mean for metals contents in the soils from different areas of the midstream and downstream of the Xiangjiang River

Element	Content of heavy metals ( $\text{mg kg}^{-1}$ )				Values of F
	Changsha (n=18)	Xiangtan (n=40)	Zhuzhou (n=75)	Hengyang (n=86)	
As	17.30 (1.53) a	17.01 (1.52) a	18.04 (1.26) a	16.14 (1.53) a	1.50
Cd	0.54 (2.53)	0.75 (3.36)	1.04 (2.48)	0.39 (3.73)	NA
Cr	32.92 (1.21) a	29.43 (1.34) ab	31.50 (1.40) a	26.70 (1.41) b	4.40**
Cu	35.12 (1.30) ab	41.53(1.86) a	35.61 (1.31) ab	31.02 (1.60) b	3.80*
Ni	31.10 (1.16) a	31.02 (1.28) a	30.62 (1.24) a	29.74 (1.26) a	0.50
Pb	55.14 (1.77) b	66.60 (2.37) b	104.31 (2.05) a	44.41 (2.44) b	14.6**
Zn	153.41 (1.62) a	158.04 (1.78) a	183.25 (1.58) a	110.11 (1.85) b	17.0**

Note: \*,  $p < 0.05$ ; \*\*,  $p < 0.01$ ; the different letters in the same line show differences among the contents of heavy metals in soils from different areas; NA means the data belong to a non-normal distribution; the data in brackets are the geometric standard deviations.

**Table 3** Contents of heavy metals in the paddy soils and vegetable soils from the midstream and downstream of the Xiangjiang River

Element	Content of heavy metals ( $\text{mg kg}^{-1}$ )						Values of F
	Paddy soil (n=179)			Vegetable soil (n=40)			
	Range	Arithmetical mean (SD)	Geometric mean (SD)	Range	Arithmetical mean (SD)	Geometric mean (SD)	
As	4.91–72.41	17.8 (7.76)	16.5 (1.48)	8.90–36.10	20.74 (7.62)	19.30 (1.48)	4.70*
Cd	0.09–42.61	1.74 (5.00)	0.52 (3.39)	0.33–107.14	5.95 (17.12)	1.49 (4.43)	NA
Cr	10.53–108.13	31.34 (13.01)	29.42 (1.41)	12.61–84.92	30.82 (12.70)	28.93 (1.43)	0.10
Cu	9.85–341.32	36.81 (34.32)	32.11 (1.55)	16.4–1067.04	58.41 (169.30)	48.62 (2.11)	19.90**
Ni	16.37–58.29	31.41 (7.70)	30.61 (1.26)	16.81–47.83	30.34 (6.71)	29.50 (1.25)	0.70
Pb	11.89–1114	93.92 (149.44)	56.02 (2.41)	26.13–2730.04	238.43 (432.32)	127.42 (2.97)	21.13**
Zn	55.03–1610	166.41 (192.23)	129.30(1.80)	83.14–2827.70	331.41 (444.31)	233.01 (2.09)	32.0**

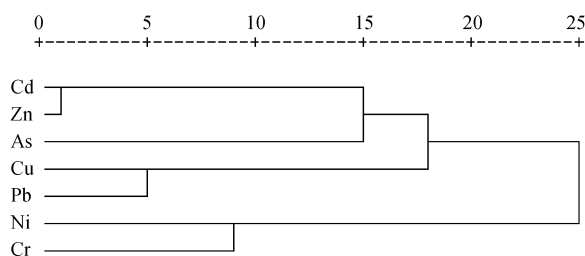
Note: \*,  $p < 0.05$ ; \*\*,  $p < 0.01$ ; SD is the standard deviation; NA means the data of Cd has a non-normal distribution.

**Table 4** Relationship among the contents of heavy metals in the soils from the midstream and downstream of the Xiangjiang River

Element	As	Cd	Cr	Cu	Ni	Pb	Zn
As	1	0.417**	0.156*	0.499**	0.142*	0.401**	0.503**
Cd		1	0.100	0.470**	0.129	0.885**	0.944**
Cr			1	0.205**	0.626**	0.080	0.166*
Cu				1	0.251**	0.424**	0.528**
Ni					1	0.063	0.217**
Pb						1	0.861**

Note: \*\*,  $p < 0.01$ ; \*,  $p < 0.05$ .

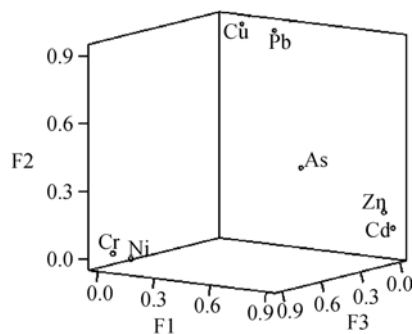
be classified into three types based on the correlation coefficients using the furthest neighbor linkage method (Figure 3). Group I comprises As, Cd and Zn, Group II comprises Cu and Pb, and Group III comprises Cr and Ni. The metals in each group have similar source or releasing principles in soils. Based on the principal component analysis, the relationships are more easily seen with Factor 1 giving the similarity of As, Cd and Zn with loadings of 0.527, 0.928 and 0.944, respectively, Factor 2 giving the similarity of Cu and Pb, and Factor 3 giving the similarity of Cr and Ni (Figure 4).



**Figure 3** Clustering tree of heavy metals in agricultural soils from the midstream and downstream of the Xiangjiang River based on correlation coefficients using the furthest neighbor linkage method

### 3.2 Concentrations of heavy metals in vegetables

Concentrations of Cd, Pb and Zn in fresh vegetables ranged from 0.07 to 3.55, 0 to 29.50 and 2.48 to 166.21 mg kg<sup>-1</sup>, respectively (Table 5). The As, Cd, Ni and Pb concentrations in vegetable samples exceeded the Maximum Levels of Contaminants in Foods (GB2762-2005) (Ministry of Health, 1991, 1994, 2003, 2005) for 95.8%, 68.8%, 10.4% and 95.8% of the samples, respectively, implying that contamination by heavy metals in vegetables is very serious. Furthermore, the relationship between concentrations of Cd, Pb and Zn in vegetables and corresponding vegetable soils is significant ( $p < 0.01$ ). The arithmetic mean content of As, Cd, Pb and Zn in Zhuzhou district is



**Figure 4** Matrix of principal component analysis loadings of heavy metals in agricultural soils from the midstream and downstream of the Xiangjiang River

**Table 5** Content and accumulation of heavy metals in the vegetables from the midstream and downstream of the Xiangjiang River

Element	Concentrations of heavy metals (mg kg <sup>-1</sup> ) (n=48)					Ratio of overrunning (%)	BF (SD)
	Range	Median	Arithmetical mean (SD)	Geometric mean (SD)	China Food Quality Standard		
As	0.03–0.75	0.14	0.19 (0.16)	0.15 (2.01)	0.06 <sup>1)</sup>	95.8	0.008 (2.05)
Cd	0.07–3.55	0.29	0.65 (0.80)	0.37 (2.84)	0.2	68.8	0.265 (3.78)
Cr	0.04–0.46	0.16	0.18 (0.10)	0.15 (1.85)	0.5	0	0.006 (2.04)
Cu	0.28–2.42	0.94	0.99 (0.46)	0.85 (1.78)	10.0	0	0.022 (2.09)
Ni	0.3–1.46	0.73	0.76 (0.24)	0.73 (1.37)	1.0	10.4	0.025 (1.51)
Pb	0.00–29.50	1.47	3.82 (5.92)	1.73 (3.56)	0.3	95.8	0.019 (2.44)
Zn	2.8–166.21	16.80	31.21 (34.9)	19.8 (2.53)	20	0	0.091 (2.18)

Note: SD is the standard deviation; BF is the bio-concentration factor, which is the ratio of the element concentration in vegetables to that in soil.

significantly higher than arithmetic mean contents in the other districts, including Changsha, Xiangtan and Hengyang (Table 6), which further supports the result that the contents of Cd, Pb and Zn in soils from Zhuzhou district are higher than the contents in the other study areas (Table 3).

**Table 6** Arithmetic mean for metal contents in the vegetables from different areas of the midstream and downstream of the Xiangjiang River

Element	Concentrations of heavy metals (mg kg <sup>-1</sup> )			
	Changsha (n=11)	Zhuzhou (n=19)	Xiangtan (n=9)	Hengyang (n=9)
As	0.09 (0.03) b	0.30 (0.20) a	0.10 (0.04) b	0.19 (0.07) b
Cd	0.21 (0.11) b	1.10 (1.06) a	0.42 (0.31) b	0.47 (0.58) b
Cr	0.15 (0.09) a	0.19 (0.11) a	0.16 (0.07) a	0.22 (0.12) a
Cu	1.00 (0.39) a	1.01 (0.58) a	0.95 (0.47) a	0.91 (0.44) a
Ni	0.61 (0.16) b	0.78 (0.23) ab	0.75 (0.19) ab	0.95 (0.30) a
Pb	0.83 (0.67) b	7.83 (7.89) a	1.07 (0.53) b	1.81 (1.38) b
Zn	11.80 (6.30) b	51.50 (45.80) a	19.10 (10.76) b	24.50 (23.90) b

Note: The different letters in the same line show the significant differences among the contents of heavy metals in soils from different areas ( $p < 0.05$ ); the data in brackets is the standard deviation (affiliated to the normal distribution).

The ratio of element concentration in vegetables to that in the corresponding soil is calculated to appraise the bio-accumulation effects of vegetables uptaking toxic elements from the soils. The results show that bio-concentration factors (BFs) of vegetables for these considered elements are in the order of Cd > Zn  $\approx$  Ni  $\approx$  Cu  $\approx$  Pb > As  $\approx$  Cr (Table 5), which agrees with the literature data (Cd > Zn > Cu > Pb > As) for Chenzhou district given by Liu *et al.* (2005). The other previous study has shown that BFs of vegetables from Beijing are in the order of Cd > Cu > As > Pb  $\approx$  Ni > Cr > Zn<sup>1)</sup>. These results suggest that Cd is easily transferred from soil to plants.

It is concluded that heavy metal contamination in agricultural soils and vegetables in the midstream and downstream of the Xiangjiang River is serious. It is very necessary to take measures to prevent and remediate the contaminated soil to reduce the contamination by heavy metals in soils and agricultural products.

## 4 Conclusions

We can draw major conclusions from the above analysis:

(1) As, Cd, Cr, Cu, Ni, Pb and Zn have obviously accumulated in agricultural soils from the midstream and downstream of the Xiangjiang River (from Hengyang to Changsha). There is co-contamination of heavy metals, especially for Cd in agricultural soils. In particular, the heavy metal contamination in agricultural soils from Zhuzhou district is heavier than contaminations in the other study areas. The concentrations of As, Cd, Ni and Pb in vegetables exceed the pollutant standards of edible food quality in China (GB2762-2005) for 95.8%, 68.8%, 10.4% and 95.8% of the samples taken, respectively.

(2) Significant GIS-based spatial accumulations of As, Cd, Cu, Pb and Zn in agricultural

<sup>1)</sup> Song B, 2007. GIS-based risk assessment of heavy metals in regional soils and planting regionalization of harmless vegetables: A case study in Beijing [D]. Institute of Geographic Sciences and Natural Resource Research, Chinese Academy of Sciences, Beijing, 40-83. (in Chinese)

soils were found in the Zhuzhou–Changsha section of the Xiangjiang River. The agricultural soils were heavily contaminated by Cd, Pb and Zn, and Cu pollution should be paid special attention.

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