



Regional assessment of cadmium pollution in agricultural lands and the potential health risk related to intensive mining activities: A case study in Chenzhou City, China

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Abstract

The purpose of this study was to assess the extent of cadmium (Cd) contamination in agricultural soil and its potential risk for people. Soils, rice, and vegetables from Chenzhou City, Southern China were sampled and analyzed. In the surface soils, the 95% confidence interval for the mean concentration of Cd varied between 2.72 and 4.83 mg/kg ($P < 0.05$) in the survey, with a geometric mean concentration of 1.45 mg/kg. Based on the GIS map, two hot spot areas of Cd in agricultural soils with high Cd concentrations were identified to be located around the Shizhuyuan, Jinshiling, and Yaogangxian mines, and the Baoshan and Huangshaping mines, in the center of the city. About 60% of the total investigated area, where the agricultural soil Cd concentration is above 1 mg/kg, is distributed in a central belt across the region. The critical distances, at which the soil Cd concentration were increased by the mining activities, from the mines of the soils were 23 km for the Baoshan mine, 46 km for the Huangshaping mine, and 63 km for the Shizhuyuan mine, respectively. These are distances calculated from models. The Cd concentrations in rice samples ranged from 0.01 to 4.43 mg/kg and the mean dietary Cd intake from rice for an adult was 191 $\mu\text{g}/\text{d}$. Results of risk indexes showed that soil Cd concentrations possessed risks to local residents whose intake of Cd from rice and vegetables grown in soils in the vicinity of the mine was 596 $\mu\text{g}/\text{d}$.

Key words: cadmium; health risk; mining activities; rice; soil contamination; vegetable

Introduction

Cadmium (Cd) is an important toxic heavy metal and the warning of health risks from Cd pollution were issued initially in the 1970s (Nordberg, 2004). The guideline for a maximum recommended Cd intake set by World Health Organization (WHO) (1993) and US Environmental Protection Agency (USEPA) (2000) is 1 μg Cd/(kg body weight·d). However, Satarug *et al.* (2003) stated that exposure levels of 30–50 μg Cd/d for an adult (about 0.6 $\mu\text{g}/(\text{kg}\cdot\text{d})$) could increase the risk of bone fracture, cancer, kidney dysfunction, and hypertension. Thus, the recommended guideline for maximum Cd intake of 1 $\mu\text{g}/(\text{kg}\cdot\text{d})$ appears to be too high to ensure against renal dysfunction resulting from dietary Cd intake.

The most severe form of chronic Cd poisoning is known as Itai-itai disease, which once developed in numerous inhabitants of the Jinzu River Basin in the Toyama Prefecture of Japan in the 1930s. The cause seemed to have been the widespread Cd contamination of rice (Ishihara *et al.*, 2001; Inaba *et al.*, 2005). Cadmium is water soluble and

can be transferred efficiently from soil to plants, which may affect human health if there is excessive intake from a contaminated food source (Satarug *et al.*, 2003).

Increased concentrations of Cd in agricultural soils are known to come from human activities (Taylor, 1997), such as the application of phosphate fertilizer, sewage sludge, wastewater, and pesticides (Chen *et al.*, 1997; Qadir *et al.*, 2000; de Meeus *et al.*, 2002; Kara *et al.*, 2004), mining and smelting of metalliferous ores with high Cd content (Tembo *et al.*, 2006; Kovacs *et al.*, 2006), and traffic (Nabulo *et al.*, 2006). Cd is a companion element in many metalliferous ores and causes serious pollution of agricultural soils in the vicinity of some mine sites in Upper Silesia of South Poland (Dudka *et al.*, 1995), in Duckum Au-Ag mine of South Korea (Kim *et al.*, 2001, 2002), and in the Sambo Pb/Zn mine of Korea (Jung and Thornton, 1997). Some researchers have stressed that lifetime exposure to low levels of soil Cd could cause renal dysfunction in residents (Nordberg *et al.*, 1997; Watanabe *et al.*, 2000).

Although there are many reports on Cd contamination in agricultural soils, most of the investigations are concentrated in the vicinity of the mine sites. Limited information

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is available on the assessment of Cd contamination in agricultural soils at a distance from the mines and on the impact of this contamination on the health of residents on a regional scale. However, other reports have shown that mining activities can cause agricultural soil contamination on a relatively large scale in hilly countryside. For example, Liao *et al.* (2005) reported that mining activities result in widespread agricultural pollution in Chenzhou City in Southern China. Cadmium is present in some local ores and, after long-range transport of mining wastes, may be widely distributed in agricultural soil. This study presents a survey of Cd levels in agricultural soils, rice, and vegetables collected from Chenzhou City, one of the oldest and largest mining cities in China, to assess the impact of mining activities on Cd contamination in agricultural soils and the potential health risk for residents on a regional scale.

1 Materials and methods

1.1 Study area

The study area, Chenzhou City of Southern China, located between 24°53'N and 26°50'N latitudes, and between 112°13'E and 114°14'E longitudes, is a city with a 1,000-year history of metal-mining activities and is characterized as hilly and upland landscape. The total area of the city is about 19,400 km², of which 2,415 km² are covered by paddy soil, 2,964 km² by dry land, and about 10,542 km² are hilly or mountainous. The climate is subtropical and the average annual rainfall is about 1,500 mm. Rice is the main crop and a staple food, and water spinach, eggplant, pumpkin, shallot, capsicum, towel gourd, and kidney bean serve as the main kinds of vegetables in the diets of the local residents.

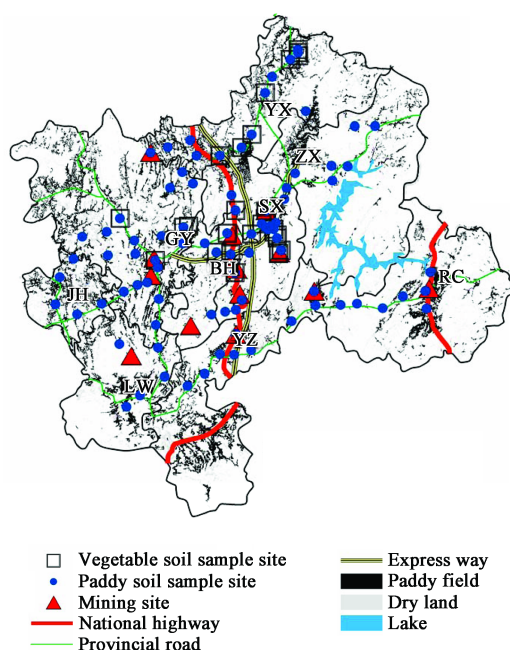


Fig. 1 Sampling locations in the investigated area of Chenzhou City, a metalliferous mining city, with a long history of mining in China.

The investigated area comprises two districts and nine counties as shown in the sampling map (Fig.1). Suxian District (SX) and Guiyang County (GY) had more mining activities than the other areas, such as, Beihu District (BH), Yongxing County (YX), Zixing County (ZX), Jiahe County (JH), Linwu County (LW), Yizhang County (YZ), and Rucheng County (RC). Most of the largest mines in the city, such as, Shizhuyuan, Baoshan, Huangshaping, Xianghualing, Jinshiling, Jinchuantang, Anyuan, Yaogang, Rucheng, Jiepailing, and Dashunlong are concentrated in the central belt of the city, where the main crops are grown. The Shizhuyuan mine where Pb, Zn, W, and Mo ores are mined and smelted is known as one of the largest metal mines in the world and covers a total area of 35 km². Baoshan and Huangshaping mines in GY are known for their long history of exploitation and large production of Cu, Pb, Zn, and Ag ores in China.

1.2 Sampling and analysis

Soils and corresponding vegetables and rice were collected from agricultural lands every 0.5–2 km in the mining area and every 3–5 km in control area (area with fewer mining activities). Selected agricultural soils, rice, and vegetables were sampled at the same site where both crops were grown in very close proximity (< 20 m). The soil samples were taken from surface, 0–20 cm in depth. The distribution of sampling sites is shown in Fig.1. The total numbers of soil samples, rice samples, and vegetable samples were 155, 97, and 70, respectively. The soils were air-dried and ground to pass through a 100-micron mesh screen. The samples of rice and vegetables were washed with tap water to remove adhering soil, rinsed with deionized water, dried at 60°C for 48 h in an oven, and ground to fine powder. The soils were digested using HNO₃-H₂O₂ (Chen *et al.*, 2002). The plants were digested using HNO₃-HClO₄ (Liao *et al.*, 2004). Concentrations of Cd in the soil and plant digestions were determined using graphite furnace atomic absorption spectrometry (Vario 6, Jena Co. Ltd., Germany). Standard reference materials for soil (GBW-07401) and plant (GBW-07602) obtained from the China National Center for Standard Reference Materials were digested along with the samples and used for the Quality Assurance/Quality Control program.

1.3 Calculation and statistic analysis

The daily dietary intake of Cd through consumption of crop food was calculated by following method (Tripathi *et al.*, 1997):

$$\text{DIM} = \text{DCCF} \times \text{CCF} \quad (1)$$

where, DIM means daily intake of metal; DCCF means daily consumption of crop food; CCF means Cd concentration in food. The average quantity of crop consumed by a person (70 kg in body weight) was chosen as 652 and 300 g/d for rice and vegetables, respectively, in China (Feng and Shi, 2006).

The risk index in the study is defined as the ratio of the estimated exposure from the daily Cd intake (DIM) from soil through the food chain and the oral reference dose

(RfDo) for Cd (WHO, 1993; USEPA, 2000).

$$\text{Risk index} = \frac{\text{DIM}}{\text{RfDo}} \quad (2)$$

where, RfDo represents safe level of exposure orally over a lifetime. Thus, an index < 1 is assumed to be safe during a lifetime. The health risks as a result of the intake of Cd from consumption of rice and vegetables by the local residents were assessed based on the index.

The enrichment concentration (C_e) of a plant was calculated using the following equation:

$$C_e = \frac{C_{\text{Cd-E}}}{C_{\text{Cd-C}}} \quad (3)$$

where, $C_{\text{Cd-E}}$ is Cd concentration in edible parts of plants, $C_{\text{Cd-C}}$ is Cd concentration in contaminated soil.

The maps of Cd distribution in soil and rice were generated using ArcGIS V9.0 (ESRI Corporation, American). The data were statistically analyzed using a statistical package, SPSS 13.0. The level of significance was set at $P < 0.05$ (two-tailed).

2 Results

2.1 Concentrations of Cd in soils

The histograms of Cd concentrations for the 155 soil samples and their logarithmic-transformed values are shown in Fig.2. The concentration of Cd is remarkably skewed to the right, showing a departure from the symmetrical shape of the normal distribution. The 9% confidence interval for the mean soil Cd concentrations varied from 2.72 to 4.83 mg/kg ($P < 0.05$), with a geometric mean of 1.45 mg/kg. The highest Cd concentration of 48.33 mg/kg was found to occur near Huangshaping mine in GY and the maximum geometric mean of soil Cd concentrations, 3.90 mg/kg, was found in SX (Table 1).

The maximum permit levels (MPL) of soil Cd are generally used to assess the pollution level of Cd in agricultural soils. About 81% of the soil samples were found to contain higher Cd than China's MPL, 0.6 mg/kg (SEPAC, 1995). When the MPLs of the Netherlands (1 mg/kg) (VROM, 1983), Canada (1.4 mg/kg) (Canadian, 1999), and Australian (3 mg/kg) (NEPC, 1999) are applied, 61.9%, 69.7%, and 30%, respectively, of the soil samples exceeded the levels.

On the basis of the geographic information system (GIS) map of Cd spatial distribution in agricultural soils (Fig.3),

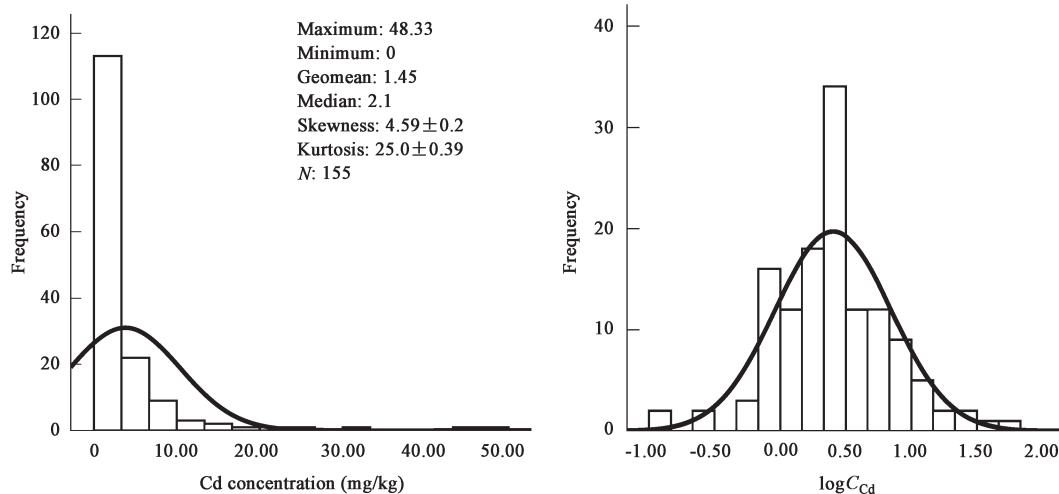


Fig. 2 Distributions of Cd in agricultural soil sampled from rice and vegetable soils in Chenzhou, South China.

Table 1 Statistics of Cd concentrations in agricultural soils from different counties in Chenzhou City, South China

County	Soil Cd concentration (mg/kg)				CV (%)
	Minimum	Maximum	Geomean	Median	
Densely mining area					
GY ($N = 27$)	0.35	48.33	2.14	1.88	203
SX ($N = 49$)	0.18	46.38	3.90	4.59	121
BH ($N = 11$)	0.33	4.09	2.28	2.86	45
YX ($N = 28$)	0.95	7.32	2.28	2.39	46
YZ ($N = 11$)	0.01	2.02	0.22	0.5	116
LW ($N = 6$)	0.22	5.00	1.28	1.45	95
Control area					
JH ($N = 5$)	0.81	0.96	0.93	0.93	91
RC ($N = 8$)	0.14	1.06	0.4	0.51	147
ZX ($N = 10$)	0.1	3.88	0.09	0.2	263

Control area: with fewer mining activities. SX: Suxian District, GY: Guiyang County, BH: Beihu District, YX: Yongxing County, ZX: Zixing County, JH: Jiahe County, LW: Linwu County, YZ: Yizhang County, RC: Rucheng County.

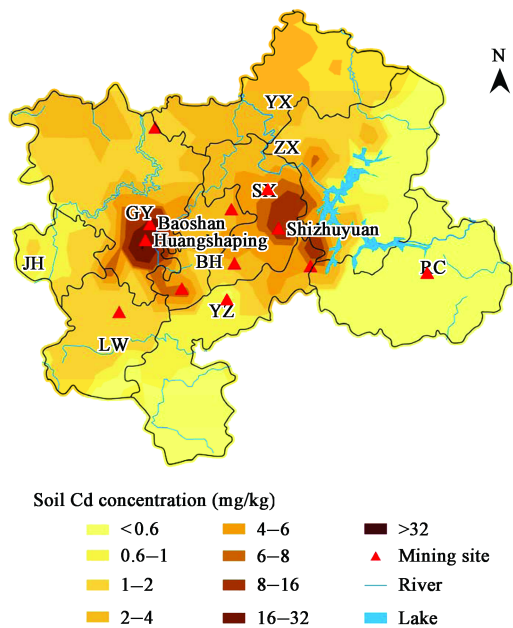


Fig. 3 Geographical distribution of Cd levels in the investigated area of Chenzhou, South China. Cd concentration in the mine wastes: (1) Shizhuyuan mining area: Caishan slag 227 mg/kg, Caishan tailing 32.1 mg/kg, Bailutang tailing 7.0 mg/kg; (2) Baoshan mining area: mine stone 293 mg/kg, tailing 28.2 mg/kg; (3) Huangshaping mining area: tailing 100.1 mg/kg; (4) Xianghualing mining area: slag 10.1 mg/kg, Tailing: 35.2 mg/kg.

two hot spot areas with high Cd concentrations were identified around the Shizhuyuan, Jinshiling, and Yaogangxian mine sites, and the Baoshan and Huangshaping mine sites. The total areas of paddy and vegetable lands with Cd levels higher than 1 mg/kg are estimated to be 320,000 km², which is about 60% of the city's cultivated lands, and are distributed primarily in the central belt (Fig.3). The Cd concentrations of paddy soils decreased as the distance from the individual mining sites increased and the resulting curvilinear relationships could be fitted by power models (Fig.4). The critical distances, calculated from the models, that the soil Cd concentration was elevated by mining activities, were 23 km from Baoshan mine site, 46 km from Huangshaping mine site, and 63 km from Shizhuyuan mine site.

Samples of paddy and vegetable soils in close proximity to one another (< 20 m) were compared using the paired-samples *T*-test and showed significant differences (*P* < 0.05) in soil Cd concentrations between the two land-use types. The Cd concentrations in paddy soils were significantly higher than those in vegetable soils in the mining area but just the reverse was true in the control area (Fig.5). The geometric mean of the Cd concentration, 5.67 mg/kg, in the paddy soil in the mining area was 2.6 times higher than in the control area. The geometric mean of the Cd concentration in vegetable soil in the mining area and the control area were 4.29 and 2.42 mg/kg, respectively.

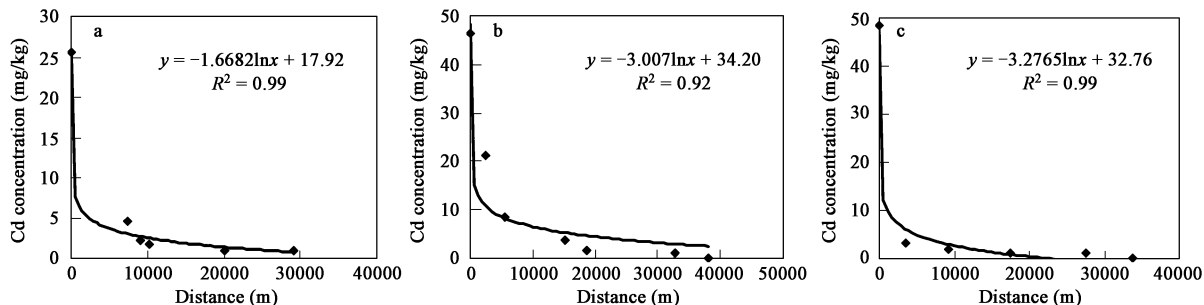


Fig. 4 Relationship between Cd concentration in paddy soil and distance from Baohan (a), Shizhuyuan (b), and Huangshaping (c) mining sites in Chenzhou City, South China.

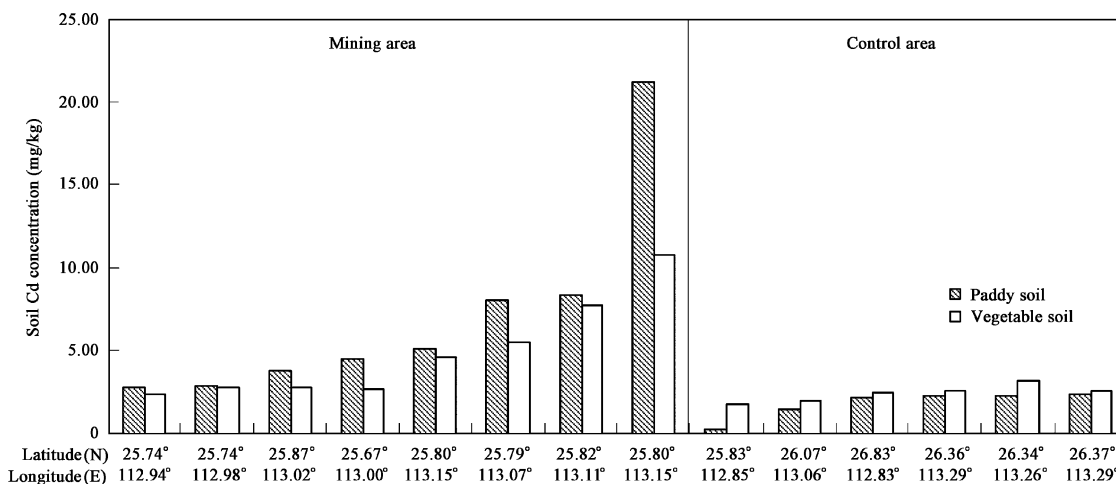


Fig. 5 Cadmium concentrations in paddy and vegetable soils in the mining area compared with that in the control area.

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2.2 Concentrations of Cd in crops

Rice samples collected from Chenzhou City had an average Cd concentration of 0.39 mg/kg. Higher concentrations of 4.8 and 4.43 mg/kg were found in the vicinity of the Huangshaping mine site in GY and in the vicinity of the Shizhuyuan mine site in SX, respectively. The mean soil Cd concentration in SX is higher than in other counties and districts (Table 2). The rice contaminated with Cd was distributed primarily in the central belt of Chenzhou, especially near the dense mining sites in GY and SX (Fig.6).

An obvious difference in Cd concentrations in the edible parts was found among the six vegetable crops. The means of Cd concentration in edible parts of water spinach and eggplant, 4.92 and 4.53 mg/kg, respectively, were higher than those of the other vegetables (Table 3). Out of the four fruity vegetables, the maximum Cd concentration, 12.37 mg/kg, which greatly exceeded the China's MPL (MHC, 2005) of 0.05 mg/kg, was found in edible parts of eggplant grown near the Huangshaping mine site. Cadmium concentration in the edible parts of all investigated vegetables followed the trend: water spinach > eggplant > leaf of pumpkin > shallot > capsicum > towel gourd > kidney bean. The enrichment concentration (EC) values of Cd varied greatly among vegetables and had the same trend as the Cd concentration in the edible parts

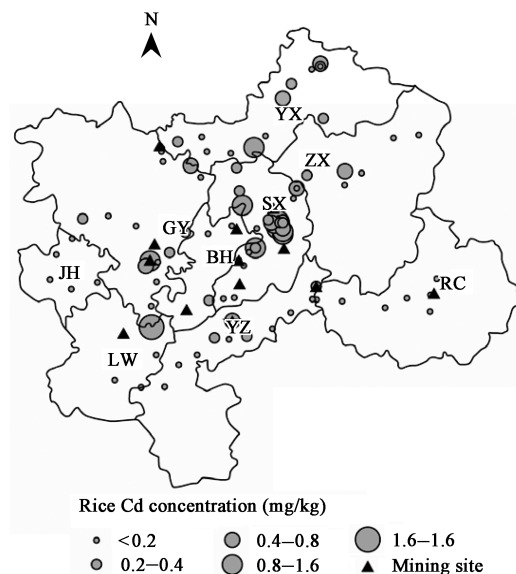


Fig. 6 Concentration of Cd in rice sampled from Chenzhou City, South China.

of all investigated vegetables. Water spinach and eggplant possessed the ability to accumulate more Cd than other kinds of vegetables investigated. About 40% of vegetable samples contained higher Cd concentrations in their edible parts than the MPL of China (MHC, 2005).

Table 2 Daily Cd intake and risk index of rice and vegetables from different counties of Chenzhou City, South China

County	Mean of Cd in food (mg/kg)		Cd intake ($\mu\text{g}/\text{d}$)		Risk index		Total
	Rice	Vegetables	Rice	Vegetables	Rice	Vegetables	
Dense mining area							
GY	0.24	6.71	156	201.3	2.23	28.8	31.0
SX	0.68	5.11	443	153.3	6.33	21.9	28.3
BH	0.41	2.4	267	72.0	3.81	10.3	14.1
LW	0.43	— ^a	280	—	4	—	—
YZ	0.15	—	97.8	—	1.4	—	—
YX	0.31	1.27	202	38.1	2.89	5.44	8.33
Control area							
JH	0.04	—	26	—	0.37	—	—
RC	—	—	—	—	—	—	—
ZX	0.09	—	59	—	0.84	—	—

^a Below detectable limit, RfDo $1 \mu\text{g}/(\text{kg}\cdot\text{d})$ (USEPA, 2000).

Table 3 Cd concentrations of vegetables sampled from Chenzhou City, South China

Crop	Tissue	Cd concentration (mg/kg)			EC
		Range	Mean	Median	
Water spinach ($N=14$)	Leaf ^a	2.11–21.1	4.92	3.06	0.22–4.06
	Root	1.34–23.7	5.25	2.71	— ^c
Capsicum ($N=22$)	Fruit ^a	0.32–6.2	1.58	1.1	0.04–2.26
	Shoot	1.09–17.8	4.48	3.1	—
Kidney bean ($N=11$)	Root	0.27–17.4	4.01	2.19	—
	Fruit ^a	0.34–1.77	0.69	0.59	0.02–0.35
Towel gourd ($N=3$)	Shoot	1.45–9.44	3.13	2.49	—
	Fruit ^a	0.59–1.06	0.78	0.68	0.07–0.38
Eggplant ($N=8$)	Shoot	1.59–7.2	3.66	3.16	—
	Fruit ^a	1.02–12.4	4.53	1.96	0.18–1.32
Shallot ($N=9$)	Shoot	1.85–15.9	5.93	2.77	—
	Root	1.85–19.2	7.47	4.26	—
Pumpkin ^b ($N=3$)	Shoot ^a	1.04–7.14	2.20	1.13	0.08–0.87
	Root	3.01–19.5	8.12	6.63	—
Pumpkin ^b ($N=3$)	Leaf ^a	2.88–3.26	3.02	2.92	0.02–0.61

^a Edible part; ^b the leaf of pumpkin is usually consumed as vegetable by local residents; ^c below detectable limit. EC: enrichment concentration.

2.3 Dietary Cd intake and exposure risk

The daily dietary intake of Cd from rice varied from 26 to 443 $\mu\text{g}/\text{d}$ and the mean of the daily dietary intake of Cd from rice was 191 $\mu\text{g}/\text{d}$ for an adult in the investigated area (Table 2). The mean of the daily dietary intake of Cd from rice in the intensive mining area was 241 $\mu\text{g}/\text{d}$, which was 4.7 times higher than the mean of the daily Cd intake, 42.5 $\mu\text{g}/\text{d}$, of the control areas. The daily Cd intake from both rice and vegetables varied greatly among counties and districts, and residents from SX and GY had the highest intake of Cd from both rice and vegetables.

Risk indexes of soil Cd for residents in the areas of SX, GY, BH, LW, YX, and YZ are greater than 1, and those in the areas of JH, RC, and ZX with less mining activities are less than 1 (Table 2). Estimated exposures and risk indices for Cd showed that there is an extremely high risk for adverse health effects from consumption of rice and vegetables grown in the soil in SX where there are dense mining activities. About 70% of the residents in SX, GY, BH, LW, YX, and YZ have a potential health risk resulting from rice and vegetable consumption.

3 Discussion

3.1 Source of the increased Cd in soil

The overall pattern of elevated Cd concentrations in agricultural soils in Chenzhou City is described as two hot spot areas around the mining sites (Fig.3). A sharp decrease in soil Cd concentrations was observed within 2 km from the individual mines sites (Figs.3 and 4) and the Cd concentrations in most soil samples from mining areas were higher than those in control areas (Fig.5), suggesting that the increase in soil Cd concentration is related to mining activities. This was further supported by the high Cd concentrations in metal ores and tailings from Chenzhou City, which varied from 7 to 293 mg/kg. Therefore, the authors conclude that mining is a major contributor to elevated soil Cd levels in Chenzhou City.

The Cd concentrations in paddy soil were higher than the corresponding vegetable soil at the same sampling site (Fig.5), strongly suggesting that paddy soils received a higher input of anthropogenic Cd, possibly related to irrigation with water polluted by mine drainage. Previous investigations have shown that waters are severely polluted by Cd. The Dong River was found to have a maximum Cd concentration of 7 mg/L as a result of runoff from the Pb/Zn mine area in Chenzhou City (Zeng *et al.*, 1995, 1997).

The collapse of a tailing dam led to the spread of mining waste across farmland along the Dongjiang River. Seventeen years later, the mean concentration of Cd in agricultural soil along the Dongjiang River was still 7.6 mg/kg (Liu *et al.*, 2005). Therefore, the river in Chenzhou City facilitates the distribution of Cd over a large area, and thus runoff from the mines and subsequent irrigation with river water may be the main sources of Cd in the agricultural soil.

3.2 Risk of exposure to Cd

As rice is the main crop and a staple food in Chenzhou City, the higher risk from Cd contamination of paddy soils must be considered. The Cd concentrations in rice samples ranged from 0 to 4.43 mg/kg in the investigated area. The mean Cd concentration in rice samples from the Jinzu River basin in Japan ranged from 0.02 to 1.06 mg/kg. It was demonstrated that for the inhabitants living in the investigated rural community from birth, mortality rose when the mean Cd concentration in the rice was ≥ 0.3 mg/kg (Ishihara *et al.*, 2001). Cadmium concentrations in about 33% of the rice in this investigation exceeded 0.3 mg/kg. The WHO (2001) recommended guideline for a safe Cd concentration in rice was 0.1 mg/kg and 55% of the samples exceeded this level.

Rice has been considered as one of the main dietary sources of Cd, which could be a suitable indicator food for Cd monitoring in rice-eating ethnic groups in Cd polluted areas (Kawada and Suzuki, 1998). For example, rice is the main source of Cd intake among the general population in Japan (Shimbo *et al.*, 2001; Tsukahara *et al.*, 2003). The Japanese had a relatively high daily intake of Cd, and the percentage of daily Cd intake obtained from rice decreased from 50% in 1970 to 34% in 1994 (Kawada and Suzuki, 1998). Rice contributes about 40% of the total dietary Cd intake in Asian countries (Watanabe *et al.*, 2000). Prolonged consumption of rice containing elevated Cd levels is a significant health issue particularly in areas that are dependent on rice produced on-farm. This situation is further exacerbated in areas of known nonferrous mineralization adjacent to rice-based agricultural systems where the opportunity for the contamination of rice and for its entry into the food chain is high (Simmons *et al.*, 2005).

Paddy rice supplemented with vegetables serve as the main food in the diets of people in Southern China. Cadmium in rice and vegetables in Chenzhou City poses a substantial risk to local residents (Table 4). The mean dietary exposure estimate for Cd from rice in Chenzhou City (254.28 $\mu\text{g}/\text{d}$) exceeds the estimates made for other countries and areas listed in Table 4 except for the Jinzu River Basin. The highest potential dietary Cd intake from rice, 443 $\mu\text{g}/\text{d}$, was found in SX near the large Shizhuyuan mine, with a total dietary Cd intake of 596 $\mu\text{g}/\text{d}$ from both rice and vegetables (Table 2). It was estimated that Cd intake via foods by typical Itai-itai disease patients was about 600 $\mu\text{g}/\text{d}$ (WHO, 1992), which is close to the dietary Cd intake of SX inhabitants from rice and vegetables. Based on the average Cd concentration in rice from the polluted area of the Kakehashi River Basin in Ishikawa, Japan, the total Cd intake that produced an adverse effect on health was calculated as approximately 2 g for both men and women (Nogawa *et al.*, 1989). When the lifetime Cd intake reached 2.6 g, the person had the risk of Itai-itai disease (Inaba *et al.*, 2005). In the dense mining area of SX, the total Cd intake, 596 $\mu\text{g}/\text{d}$, would reach 2 g through rice and vegetables consumption in about 9 years and reach 2.6 g in about 12 years. Thus, long-term Cd exposure by regular consumption of rice and vegetable in

Table 4 Daily intake of Cd in this study compared to other countries and areas

Country	Region	Exposure pathway	Cd intake ($\mu\text{g/d}$)	Reference
Japan	Jinzu River Basin (except Itai-itai disease endemic area)	Daily food	300	Ikeda <i>et al.</i> , 2004
	Itai-itai disease endemic area in Jinzu River Basin	Daily food	600	Ikeda <i>et al.</i> , 2004
	The whole country	Daily food	17–79	Ikeda <i>et al.</i> , 1997
China	Chenzhou City, Hunan Province	Rice	254	Present study
	Chenzhou City, Hunan Province	Vegetables	116	Present study
	Beijing City	Vegetables	12.2	Song <i>et al.</i> , 2006
Korea	Vicinity of Sambo Pb/Zn mine area	Rice	121	Jung and Thornton, 1997
Chile	Santiago	Daily food	20	Munoz <i>et al.</i> , 2005
USA	The whole country	Vegetables	18	Alam <i>et al.</i> , 2003
Republic of Croatia	The whole country	Daily food	17.3	Sapunar-Postruznik <i>et al.</i> , 1996
UK	The whole country	Vegetables	14	Alam <i>et al.</i> , 2003
Canada	The whole country	Vegetables	13	Alam <i>et al.</i> , 2003
Spain	Canary Islands	Daily food	11.2	Rubio <i>et al.</i> , 2006
India	Bombay	Daily food	2.5	Tripathi <i>et al.</i> , 1997

the investigated area poses potential health problems to residents in the vicinity of the mines.

4 Conclusions

An overall pattern of elevated Cd concentrations in agricultural soils in Chenzhou City was observed in two hot spot areas around the Shizhuyuan, Jinshiling and Yaogangxian mine sites, and the Baoshan and Huangshaping mining sites. Soil Cd concentrations decreased with increasing distance from the pollutant source. The results imply that the main source of Cd in agricultural soils is the irrigation water. Cadmium concentrations in rice and vegetables in the dense mining areas were found to be remarkably higher than those in areas with less mining. Long-term Cd exposure by regular consumption of the rice and vegetables in the investigated area posed potential health problems to residents in the vicinity of the mine. Therefore, great attention should be paid to remediating the soil contamination to reduce the health risk from soil Cd.

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