Original Research

Heavy Metal Concentrations in Soil and Agricultural Products Near an Industrial District

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Abstract

This study investigated heavy metals in soils and agricultural products near an industrial district in Dongguan City. The concentrations of Cu, Zn, Pb, Cd, Hg, and As in soil and agricultural products from vegetable and banana fields were determined. Results indicated that except for Zn in one sample and Cd in five samples, the majority of the samples were notably enriched by heavy metals compared with background values. The concentrations of heavy metals ($mg \cdot kg^{-1}$ dry soil) in agricultural soils in the study area ranged from 22.2 to 93.0 for Cu, 31.2 to 213.6 for Zn, 47.6 to 133.5 for Pb, 0.01 to 0.67 for Cd, 0.15 to 0.56 for Hg, and 20.5 to 28.9 for As. Among these soil samples, concentrations of Cu, Zn, Cd, and Hg in 20.6%, 8.8%, 29.4% and 38.2% soil samples, respectively, exceeded Chinese maximum allowable concentrations (MAC) for agricultural soil. The concentrations of Zn, Pb, and Cd were significantly higher in vegetable than in banana fields. Cu, Zn, Pb, Cd, and Hg accumulated in the topsoil of vegetable fields, but only Pb and Hg accumulated in banana fields. Zn, Cd, and Hg accumulated more easily in flowering cabbage than other vegetables. Cu, Zn, and As were accumulated more easily in banana than lettuce, bunching onion and eggplant. Therefore, the findings suggest more attention should be focused on the accumulation of heavy metals in banana. This study presents a practical methodology for screening crops with lower bio-concentration factors for heavy metals to reduce metal contaminants in the general food supply chain.

Keywords: vegetables, banana, heavy metal, land use pattern, bio-concentration factor

Introduction

Generally, the natural concentration of heavy metals in agricultural soils, derived from soil parent materials, is not sufficiently high to harm human health. However, anthropogenic sources such as mining, smelting, waste disposal, urban effluent, vehicle exhausts, sewage sludge, and agrochemical can greatly increase heavy metal concentrations in agricultural soil [1-3]. Heavy metal accumulation in agricultural soils cannot only lead to the disorder of soil function which in turn affects crop growth, but heavy metals can be transferred to crops thus posing a risk to human health [4-6]. Therefore, it is critical to clarify the status of agricultural soils and quantify their metal concentrations as well as ascertain the safety of the food that the land supports. In Machong town, Dongguan City, Guangdong Province, China, there are many industries, including electroplating, chemical manufacturing, paper making, printing and dyeing, hardware and leather that pose a significant heavy metal contamination risk. Human health would be affected if agricultural soils were contaminated by surrounding industries. The purpose of this study was to investigate and

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evaluate heavy metal contamination in agricultural soils and edible parts of agricultural products in an area close to this industrial district, compare the transfer of Cu, Zn, Pb, Cd, Hg, and As from soil to edible parts of agricultural products, and screen low accumulated plants for heavy metals.

Materials and Methods

Study Area

The study area is located in southeastern Machong Industrial District of Dongguan City (22º39′ to 23º09′N, 113º31′ to 114º15′E) (Fig. 1). The Machong River flows through the industrial district and study area, and subsequently converges into the Pearl River. In the study area, a stream connected to the Dongjiang River serves as the main irrigation water source, the stream flows northwest of the study area, crosses Dasheng village, and finally flows into the Machong. The soil type in the study area is orthic anthrosols developed from delta alluvial deposits. Banana and vegetables, including flowering cabbage, lettuce and eggplant, are the main agricultural products in this area.

Soil and Agricultural Product Sampling

Sampling sites are shown in Fig. 1. A total of 64 soil samples (24 topsoil samples (0-20 cm) and 40 profile samples) were collected from 34 sites. Profile samples were collected at depths of 0-10, 10-20, 20-40, and 40-60cm, respectively, at sampling point Nos. 8, 9, 10, 11, 13, 14, 15, 26, 27, and 32 (Fig. 1). Composite samples were obtained by mixing sub-samples from five random points within 2.5 m^2 at each sampling site. Soil samples were collected using an auger and stored in polyethylene bags. The edible parts of agriculture products were collected at the same time soil samples were collected.

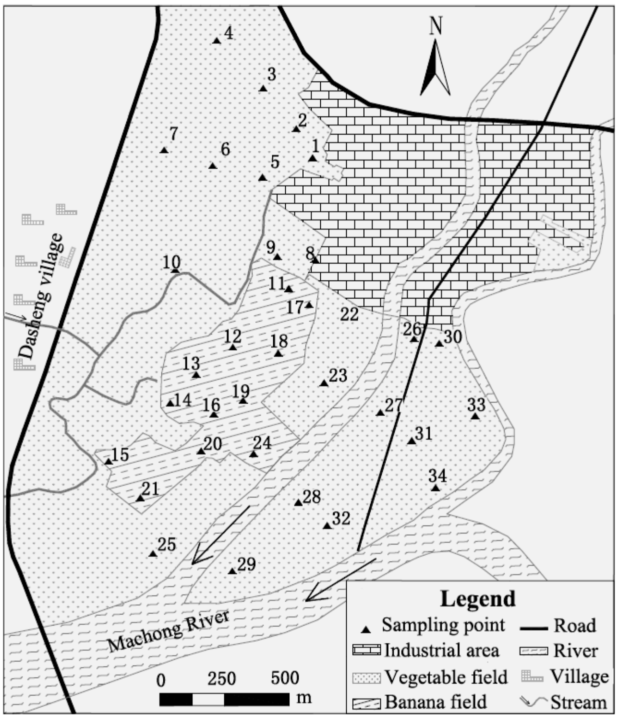

Fig. 1. Soil sampling points in the study area

Analytical Methods

The method of determining Cu, Zn, Pb, Cd, Hg, and As concentrations in soils and the edible parts of agricultural products followed established procedures [7]. The concentration of heavy metals in the edible parts of vegetables was based on fresh weight. Bio-concentration factor (BCF) of metals from soils to plants (edible parts) was calculated as the ratio of heavy metal concentration in edible parts (based on fresh weight) to metal concentration in soil.

Statistical Analysis

All statistical analyses were performed using a data processing system (DPS) for Windows [8]. Analysis of variance (ANOVA) was used to examine statistically significant differences in the mean metal concentrations among groups of soil. A probability level of $p<0.05$ was considered significant.

Results and Discussion

Heavy Metal Concentrations in Soils

The concentrations of Cu, Zn, Pb, Cd, Hg, and As in almost all soil samples were higher than background values for natural soil in Guangdong [9] (Table 1). Mean concentrations of heavy metals in the topsoils were lower than the maximum allowable concentrations (MAC) [10] in agricultural soil of China, with the exception of Hg (Table 1). The concentrations of Cu, Zn, Cd, and Hg for part of the samples exceeded the MAC, and Pb and As concentrations in all topsoils were lower than the MAC. The Cu, Pb, and As concentrations in this area were higher than those in other industrial areas [11, 12]. This indicates that Cu, Zn, Pb, Cd, Hg, and As have accumulated in agricultural soils in this area.

The statistical analysis reveals that the concentrations of Zn, Pb, and Cd were significantly higher in the vegetable fields than banana field (Table 2). However, concentrations of Cu, Hg, and As were not significantly different between two land uses. A similar study indicated that pollution indexes of Cu, Zn, Pb, and Cd in the vegetable field were higher than in the banana field [13]. Previous studies [14, 15] indicated that the accumulation of Cu, Zn, Cd, and As in soils was significantly affected by land use patterns. However, Hg and Pb appear not to exhibit the same trend. The effects of land use patterns on Cu, Zn, Cd, and As accumulation were different in different studies. Up to now, there are few studies on heavy metals concentrations in banana fields. Pb and Hg concentrations were higher and Cd concentrations was lower in the banana field of this study compared to other studies. Cu and Zn concentrations

Table 1. heavy metal concentrations in topsoils ($mg \cdot kg^{-1}$).

		Cu	Zn	Pb	Cd	Hg	As
Range		22.2-93.0	31.2-213.6	47.6-133.5	0.01-0.67	0.15-0.56	20.5-28.9
Mean±S.D.		42.4±2.8	129.9±7.6	71.4±3.1	0.22±0.03	0.31±0.02	23.8±0.3
CV (%)		38.3	34.3	25.0	77.8	29.9	8.0
Background value [a]		17.0	47.3	36.0	0.06	0.08	8.90
Percentage of over background value (%)		100.0	97.1	100.0	85.3	100.0	100.0
MAC [b]	pH<6.5	50 (orchard) 150 (farmland)	200	250	0.3	0.30	30
	6.5<pH<7.5	100 (orchard) 200 (farmland)	250	300	0.6	0.50	25
Percentage of over MAC (%)		20.6	8.8	0.0	29.4	38.2	0.0

[a]soil trace element background for Guangdong Province (GPEMC, 1990); [b]MAC – "maximum allowable concentrations of heavy metal elements" for agricultural soils of China.

Table 2. Heavy metal concentrations in topsoils of two landuse patterns ($mg \cdot kg^{-1}$).

	Vegetable field (*n*=12)			Banana field (*n*=22)		
	Mean±S.D.	CV (%)	Ratio of overrunning (%)*	Mean±S.D.	CV (%)	Ratio of overrunning (%)*
Cu	45.72±3.64^{a}	27.6	0.0	40.64±3.83^{a}	30.7	31.8
Zn	164.98±11.79^{a}	24.8	25.0	110.69±7.25^{b}	44.2	0.0
Pb	83.84±7.01^{a}	29.0	0.0	64.26±1.60^{b}	11.6	0.0
Cd	0.37±0.04^{a}	38.8	58.3	0.11±0.02^{b}	81.3	13.6
Hg	0.29±0.01^{a}	8.3	16.7	0.32±0.02^{a}	35.8	50.0
As	24.01±0.50^{a}	7.2	0.0	23.64±0.43^{a}	8.5	0.0

Mean±S.D. followed by different letters within a row for two landuse patterns are significantly different at the 0.05 level.
*compared to the China Environmental Quality Standard for Soil Metals.
n is number of samples.

in the banana fields in this study were higher than those in four of the five banana fields in Hainan province [16] and banana plantations adjacent to the Agusan River [17].

Vertical Distribution of Heavy Metal Concentrations in Soil Profiles

The concentrations of heavy metals in soil profiles under two land uses were different (Fig. 2). Fig. 2 shows that Cu, Zn, Pb, Cd, and Hg concentrations in topsoils were higher than those in the subsoil of vegetable fields. In banana fields, only Pb and Hg concentrations in topsoil were obviously higher than those in subsoils. There was no significant difference in the As concentrations between the top and subsoil for either land use. These data indicate that Cu, Zn, and Cd have accumulated only in topsoil of vegetable fields, but Pb and Hg accumulated in topsoils of both banana and vegetable fields. The Pb concentration was higher in the vegetable field than in the banana field, and there was no significant accumulation of As in fields of two land uses.

Previous studies indicated that the agro-chemical compounds and manure applications were one of the main reasons accounting for heavy metals enrichment [14]. Lead was less affected by land use [14-16] as Pb in soil commonly originates from wastewater and atmospheric deposition, while Hg originates principally from atmospheric deposition [18, 19]. Understanding the sources of heavy metals in these soils is complex because the study area was located in a nearby industrial district. The possible sources of contamination included industrial dust, vehicle exhausts, wastewater irrigation, and agro-chemicals and manures. Industrial dust and vehicle exhausts were relatively homogeneous in the study area, so they should not be a main cause for spatial variability in heavy metal concentrations between the two land uses. Obvious accumulation of Cu, Zn, and Cd in the vegetable field topsoil should be related to higher cropping index and fertilizing frequency, accompanied by a larger amount of applied fertilizers. The main source of Hg may be atmospheric deposition for topsoils of two land uses. But higher Pb concentrations in the topsoil

Table 3. Heavy metal concentrations in agricultural products (mg·kg^{-1} for Cu and Zn, μg·kg^{-1} for other elements).

	Cu	Zn	Pb	Cd	Hg	As
Flowering cabbage (*Brassica parachinensis* L.)	0.27±0.08[bc]	3.11±0.64[a]	22.1±11.7[a]	34.8±30.7[a]	1.43±0.38[a]	5.81±1.83[b]
Lettuce (*Lactuca sativa* L.)	0.17±0.07[c]	1.62±0.35[b]	21.2±8.5[a]	32.6±30.3[a]	0.71±0.55[b]	7.61±6.02[b]
Welsh onion (*Allium fistulosum* L.)	0.38±0.12[b]	2.10±0.95[b]	22.6±15.2[a]	6.12±2.87[ab]	0.95±1.06[ab]	4.02±1.62[b]
Eggplant (*Solanum melongena* L.)	0.39±0.03[b]	1.43±0.47[b]	9.11±2.26[a]	16.6±12.9[ab]	n.d.	2.57±2.15[b]
Banana (*Musa nana* Lour.)	1.26±0.26[a]	2.87±0.55[a]	24.3±15.9[a]	2.34±1.76[b]	n.d.	22.5±13.6[a]

n.d. – not detected;
Mean±S.D. within a row for a certain element followed by different letters are significantly different at α=0.05.

of vegetable fields compared to banana fields was likely related to wastewater irrigation [18, 19].

Heavy Metal Concentrations in Agricultural Products

In order to evaluate the potential threat of heavy metals to human health, the concentrations of heavy metals in the edible parts of the vegetables and bananas were determined (Table 3). The results indicate that the concentrations of the six measured elements in vegetables and bananas were all below the Chinese maximum allowable concentrations for these heavy metals in foods [20]. Variance analysis indicated that Zn and Hg concentrations in flowering cabbage were significantly higher than in other vegetables. Cu, Pb, Cd, and As in four vegetables was not significantly different, except Cu in lettuce was significantly lower than in the other three vegetables. The mean concentration of all elements in the four vegetables was lower than in similar studies [19, 21]. Cu and As concentrations in the bananas was significantly higher than the four surveyed vegetables types. Zn concentrations in banana was significantly higher than in lettuce, welsh onion, and eggplant, but Cd concentrations in banana was significantly lower than in flowering cabbage and lettuce. This average concentration of Cd and Hg in banana was lower than that reported by Appletona et al. [17]. These results showed that heavy metal contamination in bananas is an important concern.

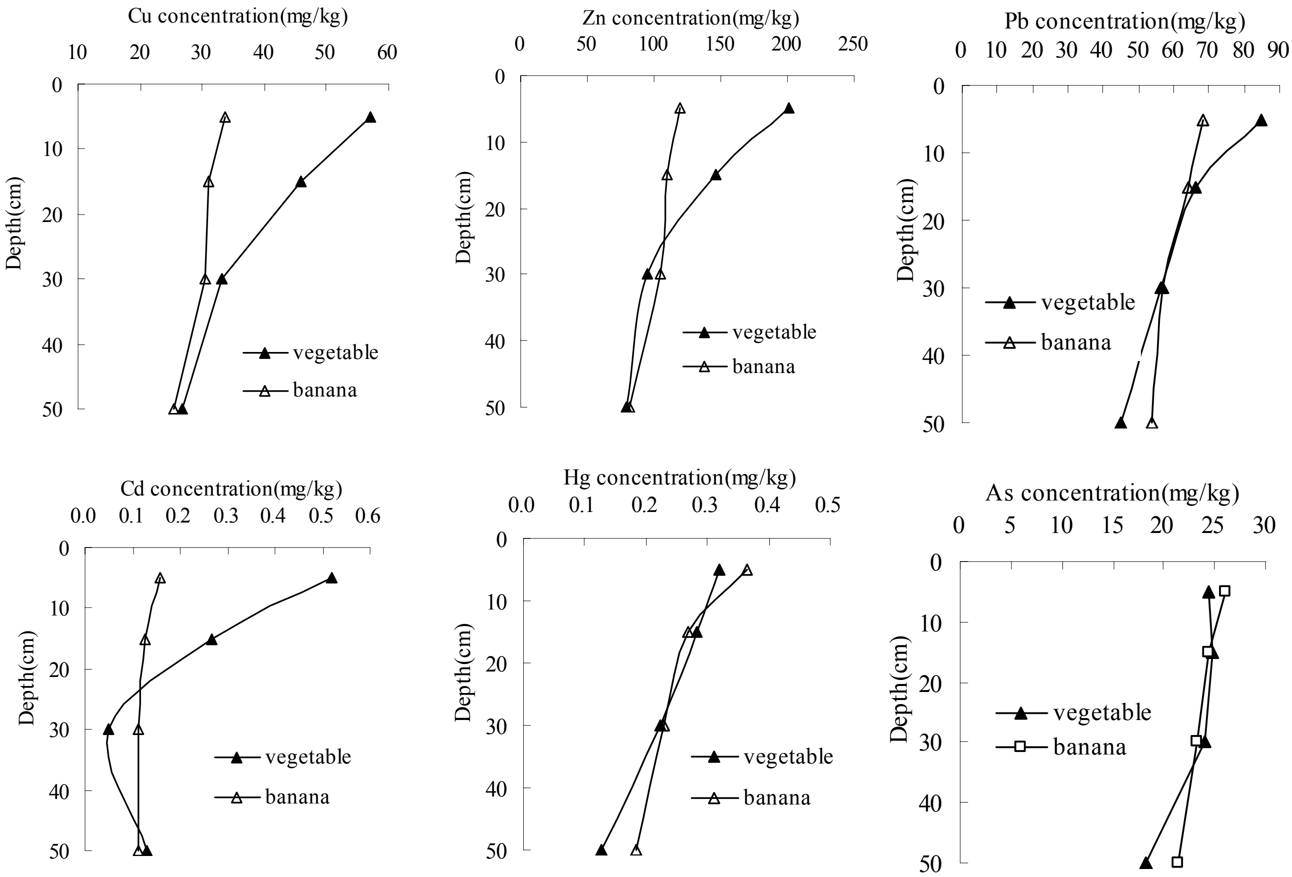

Fig. 2. Distribution of heavy metal concentrations in soil profiles.

Table 4. Bio-concentration factor of four vegetables and banana (×10^{-3}).

	Cu	Zn	Pb	Cd	Hg	As
Flowering cabbage	6.45±0.7^{b}	19.48±2.7^{b}	0.27±0.05^{ab}	92.90±24.18^{a}	4.88±0.47^{a}	0.24±0.02^{b}
Lettuce	3.76±0.34^{b}	9.64±0.54^{c}	0.25±0.03^{ab}	93.83±24.98^{a}	2.56±0.47^{b}	0.31±0.06^{b}
Bunching onion	8.25±0.80^{b}	11.92±1.35^{c}	0.30±0.09^{ab}	20.05± 5.59^{a}	3.24±1.66^{ab}	0.16±0.03^{b}
Eggplant	10.02±0.85^{b}	10.72±2.23^{c}	0.13±0.03^{b}	53.73±17.22^{a}	-	0.10±0.05^{b}
Banana	34.02±5.03^{a}	28.31±2.97^{a}	0.38±0.08^{a}	23.84± 5.38^{a}	-	0.95±0.19^{a}

Mean±S.D. within a row for a certain element followed by different letters are significantly different at α=0.05.
n.d. – not detected

Bio-concentration factor (BCF) is commonly used to appraise the ability of a plant to uptake toxic elements from the soil. The results showed that, except for the significantly higher BCF of Zn and Hg for flowering cabbage, there were no significant differences in the BCF for the other elements among four kinds of vegetables tested (Table 4). The order of BCF of the metals for vegetables was Cd>Zn>Cu>Hg>Pb≈As. These results are in agreement with Cai et al. [23] that Cd was most easily transferred from soil to vegetables and this order was very similar to the previous results of other studies [24]. The order of BCF for bananas was Cu>Zn>Cd>As>Pb, different from the vegetables. The BCF of Cu, Zn and As for the banana was higher than for vegetables. The BCFs of Cd, Hg, and Pb for banana were much lower than reported by Appletona et al. [17]. This showed that banana is more susceptible to the accumulation of Cu, Zn, and As than the tested vegetables. Little research about heavy metal accumulation in banana has been reported; therefore, further study should be carried out. This study also shows that the accumulation of heavy metals in different crops varies. It is very important to select suitable plants with lower BCF for heavy metals in order to produce safe agricultural products. Lettuce, bunching onion, and eggplant were safer than flowering cabbage and banana in this study area.

Conclusion

Heavy metal contamination is a severe environmental problem. It is important to make clear that the concentration level of heavy metals in soils and the characteristic of heavy metals uptaken and transferred by agricultural plants. The results indicated that concentrations of Cu, Zn, Pb, Cd, Hg, and As in almost all the soil samples exceeded the background values in Guangdong province. Cu, Zn, Cd, and Hg concentrations in 20.6, 8.8, 29.4, and 38.2% soil samples respectively exceeded Chinese maximum allowable concentrations for agricultural soils. Average concentrations of Zn, Pb, and Cd were significantly higher in vegetable than in banana fields. Zn, Cd, and Hg were transferred easily to the edible part of cabbage and Cu, Zn, and As were transferred easily to the edible part of banana. The study shows that more attention should be paid to Cu, Zn, and As contamination in bananas. Lettuce, bunching onion, and eggplant were safer than flowering cabbage and banana in this study area.

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