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Spatial distribution of heavy metals of agricultural soils in Dongguan, China

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Abstract: Distribution and speciation of heavy metals of agricultural soils (85 surface soil samples and 4 soil profiles) in Dongguan were investigated, while total Cr, Cu, Ni, Pb, Zn (abbreviated as Cr, Cu, Ni, Pb, Zn) and available Cu, Zn (Av-Cu, Av-Zn) were analyzed by a flame absorption spectrophotometer (AAS), and total Cd (Cd) was analyzed using graphite furnace AAS. The content of Cd, Cu and Ni was partially much more than the second grade of GB15618-1995 even though the mean contents of all heavy metal were less than the threshold value of the second grade and only the mean content of Pb was more than the value of national background. Results of descriptive statistic showed that the mean content of heavy metals should depend on land utilization and spatial location at some extent. The heavy metal contents were higher in the Southwest and Northwest than in the Central. In addition, the mean contents of Zn and Pb in Dongguan paddy soils were significantly higher than those of Pearl River Delta (PRD) and Taihu Lake region (TLR). Correlation analyses indicated that there existed significant correlation between Cr and Ni in orchard soils, and among Zn, Cd and Cu, between Av-Cu and Cu, between Av-Zn and Cr, Ni, pH value in vegetable soils, and a weak relationship between Cd, Cu and Pb, between Av-Zn and Zn. Principal component analyses (PCA) showed that the order of importance should be Zn > Pb > Cr > Ni > Cu.

Keywords: heavy metal; spatial distribution; agricultural soil; Dongguan

Introduction

There is a growing public concern and scientific interests over the heavy metal pollution in agricultural soils and agricultural productions because of their potential bioaccumulation, response hysteresis, and un-biodegradability (Kelly, 1996; Tam, 2000; Hong, 2003) even though the contents and spatial distribution of trace metals in the agricultural soils in Guangdong have never been studied systematically. In general, natural background content and distribution of heavy metal in soils were closely related to the biogeochemical cycles, parent material, and process of soil formation, as well as soil material component. However, heavy metal distribution and speciation in suburb soils disturbed by various anthropogenic activities related primarily to the discharge of industrial waste water, atmospheric deposition, and agricultural utilization of sewage sludge, stream sediment and solid waste (Colbourn, 1978; Adriano, 1986; Chang, 1992; Chen, 1999; Cao, 2000; Wong, 2002; Wang, 2003). Heavy metal pollution of agricultural soil can arose not only the decrease of crops output and quality, and then hurt the human health through the food chain, but also result in the further deterioration of the air and water environmental quality (Dietrich, 1990; Mueller, 1994; Chen, 1997; Younas, 1998; Mclaughlin, 1999; Türkdogan, 2002; Su, 2003). Since a survey of soil trace metal contents might supply some fundamental information for the environmental planning, extensive investigations of agricultural soils have been carried out in some countries and regions in recent years (Elsokkary, 1995; Zhang, 1996; Gimeno-García, 1996; Brun, 1998; Cao, 2000; Abollino, 2002; Adamo, 2003; Wang, 2003). However, to our best knowledge, very little information was available on heavy metal pollution in agricultural soils in Guangdong Province (Wong, 2002; Wei, 2002).

Dongguan City (22°39′—23°09′N, 113°31′—114°15′E) having 32 towns is situated within the northeastern Pearl River Delta (PRD), which lies in the southern of Guangdong Province, China, and only has a total area of 2465 km^2 (5.9% of PRD) and a population of over eight million (32% of PRD). This city connects with Guangzhou City to North direct, and with Shenzhen City and Hong Kong to the South direct. There is a humid and mild subtropical weather with an annual mean temperature of 23.3℃ and 2042.6 mm rainfall. The weather condition is beneficial to agricultural production. The dominant agricultural products include rice, vegetable, banana, litchi, longyan, pineapple, and aquatic products. However, the industry has been developed and increased dramatically at annual 22% level with the reforming and opening in China and Dongguan has become an important international manufacturing industry base. From that time, agricultural production has been disturbed strongly, and more and more agro-environmental problems have been caused. A large amount of pollutants including heavy metals were transported continuously into the agricultural soils directly and indirectly.

Therefore, the present study aims to (1) investigate of the concentrations of heavy metal including Cr, Cu, Ni, Zn, Cd and Pb in Dongguan agricultural soils; (2) investigate their spatial distribution characteristics; (3) analyze their

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possible sources in order to provide some fundamental information for heavy metal pollution control.

1 Materials and methods

1.1 Soil sampling

Eighty-five surface soil samples, consisting of 6 paddy soils, 59 vegetable soils, 12 banana soils and 8 orchard soils, were collected and distributed in 6 main agricultural areas on the basis of the importance of crops, the sizes of agricultural area, industrial distribution, waste discharging, and irrigative water. Vegetable soil was preferentially collected. Every soil sample was mixed up with 10—15 samples collected within a depth of 0—20 cm (plough layer). Moreover, four soil profiles (0—100 cm) were representatively selected and 4 soil samples were collected for every profile within the successive depth (0—5, 5—20, 20—40, and 40—100 cm), and then there were 16 soil profile samples. All soil samples were collected by using a hand auger and then stored in clothing bags.

1.2 The preparation and analyses of soil samples

(1) The preparation and analyses of soil samples are as follows: Soil samples were placed at ambient environment (20—23℃) for some days and then removed large debris, stones, and pebbles before sieved with a 2 mm-polyethylene sieve. All grass-ware and plastic-ware was soaked in 10% nitric acid overnight and rinsed thoroughly with bi-distilled water. Soil pH was measured in a 1:2.5(W/V) ratio of soil to water by a glass electrode. The soil samples were digested by a mixed acid (HCl-HNO_3-HF-$HClO_4$) for Cd, Cu, Ni, Pb, Cr and Zn analyses and extracted by 0.1 mol/L HCl for Av-Cu and Av-Zn analyses. The concentrations of Cu, Ni, Pb, Cr and Zn were measured by AAS (VARI06) with detect limits of 0.01, 0.02, 0.02, 0.02 and 0.01 mg/L, respectively while that of Cd was analyzed by using graphite furnace AAS (VARI06 with ZEENIT60) with a detect limit of 0.01 μg/L.

(2) Quality control as follows: Standard reference material, GSS-6 soil was obtained from the Institute of Geophysical and Geochemical Prospecting, Department of Geology and Minerals of the People's Republic of China, and incorporated during the analyses. The recovery rates of all the trace metals were controlled at the range of 85%—106% according to the standard reference material (GBW07406)

1.3 Statistical analysis

In order to investigate the relationship between/among heavy metals and pH value of different agricultural soils, Pearson correlation and descriptive statistic was analyzed by SPSS11.5 while PCA and non-equilibrium ANOVA analysis was done by SAS6.12 system.

2 Results and discussion

2.1 The contents of heavy metals

Descriptive statistic of heavy metal concentrations and soil pH of agricultural soils in Dongguan City are listed in Table 1. The mean value of soil pH was 5.58 (3.69—7.73). The heavy metal contents ranged over several orders of magnitude with larger variations. The coefficients of variation (*C.V.*) of all heavy metals except Pb (0.35) were more than 0.50, and the *C.V.* of Cu was the largest (0.81). As a large scale, mean contents of heavy metals were significant lower than the threshold of the second grade of Soil Environment Quality Standard in China (GB15618—1995) (Ye, 2000). The concentrations of Cr in all soil samples were lower than the threshold value of national background (Table 1), and mean concentration of every heavy metal except Pb (69.43 mg/kg) was also lower than corresponding background value. However, the contents of Cd, Cu and Ni of a few samples were especially more than the second grade, and their maximum was up to 0.433, 65.10 and 57.46 mg/kg respectively. This might be due to the contamination from waste water and atmosphere deposition which were discharged from several hardware mill, paper mill, circuit board mill, textile and plastic plants round these sample sites. Moreover, soil Pb content ranged from 20.6 mg/kg to 137.2 mg/kg and approximately 95.3% of soil Pb levels were more than natural background and lower than the threshold value of the second grade, probably due to intensive nets of highway and sharp increase of mobile vehicles of Dongguan (EPAD, 2002).

Table 1 Heavy metal concentrations (mg/kg) of agricultural soils in Dongguan City

	Av-Cu	Av-Zn	pH	Zn	Cr	Pb	Cd	Cu	Ni
Mean	3.84		5.58	58.22	39.95	69.43	0.120	21.37	21.10
S.D.	3.09	8.94	0.95	30.19	20.60	24.31	0.060	11.36	11.89
Median	2.89	11.76	5.55	53.5	39.76	66.12	0.119	20.34	21.58
Range	0.37 - 18.41	2.89 - 47.62	3.69 - 7.73	8.43 - 131	2.28 - 86.59	20.36 - 137.2	0.021 - 0.433	5.08 - 65.1	2.29 - 57.46
C.V.	0.81	0.64	0.17	0.52	0.52	0.35	0.50	0.53	0.56
Threshold of first grade (natural background)*				≤100	≤90	≤35	≤0.20	≤35	≤40
Threshold of second grade*			<6.5	≤200	≤250(a) ≤150(b)	≤250	≤0.30	≤50(c) ≤150(d)	≤40
			6.5 - 7.5	≤250	≤300(a) ≤200(b)	≤300	≤0.30	≤100(c) ≤200(d)	≤50
			>7.5	≤300	≤350(a) ≤250(b)	≤350	≤0.60	≤100(c) ≤200(d)	≤60

Notes: * A part of environment quality standards for soil of China (Ye, 2000), the letters of a, b, c and d represent paddy field, dry land, other agricultural land and orchard land, respectively

2.2 Spatial distribution of heavy metal content

Dongguan City was divided into 6 districts (central, northwest, southwest, central south, northeast and southeast area) according to the spatial location and present status of land utilization. Ranges, means and standard deviations (*S*. *D*.) of heavy metals for each district were calculated and listed in Table 2. Mean content of every heavy metal except Pb in each district was all lower than natural background. The mean content of Cd in each district followed the order northwest area ≥ central area ≥ southeast, northeast, central south and southwest area while Av-Zn followed as southeast area > northeast area ≥ central, central south and southwest area ≥ northwest area. Mean contents of Cu and Av-Cu in central district were the highest among of all districts. Moreover, there were the highest mean contents of Ni, Zn and Cr in the northwest, the lowest that of Ni, Cr, Pb and Zn, Av-Zn in the southeast and northeast area, respectively. In general, each element in soil shows its special content based on its natural conditions. The contamination must occur if rather large variation and obviously more than the background value presented in this area based on the disciplinarian of background values (Sauerbeck, 1991). The results (Table 1, 2) showed that amounts of element and sample sites of heavy metals over the threshold levels of background were the most in the southwest (Pb, Cu, Cd, Zn and Ni) and northwest (Pb, Cd, Zn and Ni) area but the least in the central district (Pb, Cu). This implies that soils of Dongguan City should be contaminated at some degree, probably due to different amounts and types of key pollution sources in each area (EPAD, 2002).

Table 2 The heavy metal content of agriculture soil in different area (mg/kg)

		Central $n = 5$	Northwest $n = 17$	Southwest $n = 18$	Central south $n = 12$	Northeast $n = 23$	Southeast $n = 10$
Cd	Range	0.091—0.192	0.092—0.433	0.029—0.237	0.021—0.256	0.045—0.161	0.057—0.203
	Mean ± *S*. *D*.	0.144 ± 0.04^{ab}	0.17 ± 0.073^{a}	0.09 ± 0.057^{b}	0.102 ± 0.063^{b}	0.11 ± 0.034^{b}	0.123 ± 0.049^{b}
Cu	Range	18.72 - 59.9	11.08—34.07	8.74 ± 45.19	7.70—32.60	6.91—36.93	5.08—65.10
	Mean ± *S*. *D*.	$28.97 \pm 17.48^{a*}$	22.03 ± 6.52^{ab}	25.21 ± 8.74^{a}	17.84 ± 7.73^{b}	18.05 ± 7.96^{b}	21.43 ± 22.66^{ab}
Ni	Range	11.25—28.33	14.06—42.14	3.33—57.46	2.29—29.09	3.01—38.50	2.63—26.46
	Mean ± *S*. *D*.	23.53 ± 7.01^{ab}	29.72 ± 7.5^{a}	27.08 ± 14.44^{a}	14.39 ± 9.24^{bc}	16.84 ± 9.96^{bc}	12.37 ± 7.07^{c}
Zn	Range	52.25—94.2	28.6—131.0	20.01—110.2	8.43—102.4	11.84—100.7	23.7—87.4
	Mean ± *S*. *D*.	72.08 ± 16.76^{ab}	86.17 ± 26.37^{a}	68.3 ± 24.12^{b}	40.63 ± 29.27^{cd}	40.48 ± 24.78^{cd}	47.52 ± 17.91^{c}
Cr	Range	34.11—45.24	28.55—84.5	6.7—79.93	10.64—86.59	2.28—71.81	3.39—53.85
	Mean ± *S*. *D*.	40.87 ± 4.24^{abc}	52.26 ± 17.61^{a}	48.34 ± 19.47^{ab}	36.4 ± 24.14^{bc}	32.6 ± 19.08^{c}	24.67 ± 15.56^{c}
Pb	Range	57.53—88.86	40.08—111.5	40.62—137.2	33.47—110.4	20.36—119.8	39.77—105.3
	Mean ± *S*. *D*.	75.09 ± 12.34^{ab}	73.94 ± 20.06^{ab}	83.67 ± 27.54^{a}	64.12 ± 21.36^{b}	61.77 ± 25.45^{b}	57.29 ± 18.58^{b}
Av-Cu	Range	2.17—17.68	1.66—9.58	1.90—9.28	0.63—9.32	0.37—6.29	0.41—18.41
	Mean ± *S*. *D*.	7.52 ± 6.22^{a}	4.00 ± 2.04^{b}	3.80 ± 2.07^{b}	4.07 ± 3.07^{b}	2.62 ± 1.61^{b}	4.33 ± 5.17^{ab}
Av-Zn	Range	4.73—23.65	4.06 - 13.77	4.61—28.47	4.80 - 34.02	5.78 - 39.52	2.89—47.62
	Mean ± *S*. *D*.	14.56 ± 8.77^{bc}	9.03 ± 3.12^{c}	11.06 ± 6.66^{bc}	14.33 ± 9.22^{bc}	15.79 ± 7.36^{b}	22.52 ± 14.93^{a}

Notes: * Values with different letters indicate means are significantly different at $P = 0.05$ probability level (LSD) within each line

2.3 The dependence of heavy metal content on land utilization

The dependence of heavy metal content on land utilization was summarized and listed in Table 3. From Table 3, Zn, Cr for paddy soils and banana soils was significant higher than that for vegetable soils and orchard soils while Cd, Av-Cu and Av-Zn hardly depended on land utilization. With respect to mean content, there were significant difference between the banana soils, vegetable soils and orchard soils for Cu and Ni, and between paddy soils, banana soils and vegetable soils for Pb. Moreover, for the same land utilization, the heavy metal content also depends on the spatial location. The mean contents of heavy metals for paddy soils in different regions are listed in Table 4. Compared with PRD (Wong, 2002) and TLR (Wang, 2003) of China, the mean contents of Zn and Pb in Dongguan paddy soils were obviously higher whereas the mean Cd content is lower. This implies that the Zn and Pb contents in Dongguan should apparently influenced by the discharge of industrial wastes and the emission of automobile exhaust (Chen, 1997).

Fig. 1 shows a great decrease of Cu, Zn, Cd, Cr contents and a slight decrease of Pb, Cr and Ni content with depth in P1 profile site. That may be owing to markedly lower content of Pb, Cr and Ni in P1 profile than other three profiles (Elsokkary, 1980; 1995). Moreover, vertical decrease of distribution of heavy metals in agricultural soils had been reported by some authors (Elsokkary, 1995; Adamo, 2003). At meantime, other research (Brun, 1998; Adamo, 2003) also showed that the profile distribution of Cr, Cu and Ni was irregular, similar to P2, P3, P4, which could be attributed to the strong disturbing of long-term agricultural use of stream sediment and industrial sludge (Miner, 1997), and deep plough (Brun, 1998), as well as the alluvial action of river.

Table 3 Heavy metal contents of different soil utilization(mg/kg)

Subgroup		Zn	Cr	Pb	Cd	Cu	Ni	Av-Cu	Av-Zn
Paddy soils	Mean	92.87^{a}	58.16^{a}	96.63^{a}	0.128^{a}	22.23^{ab}	26.04^{ab}	5.48^{a}	9.35^{a}
$n = 6$	*S.D.*	23.47	21.65	16.73	0.035	5.18	9.47	2.38	4.07
	Median	92.48	59.69	93.31	0.136	22.08	28.86	5.12	8.58
	Range	58.80—128.4	25.93—86.59	72.99—119.8	0.085—0.177	14.77—29.64	7.06—32.59	2.91—9.58	4.73—16.89
Vegetable	Mean	49.96^{b}	34.56^{b}	64.29^{b}	0.123^{a}	20.40^{b}	18.44^{b}	3.81^{a}	15.27^{a}
soils	*S.D.*	26.02	18.91	22.83	0.063	12.51	10.66	3.38	9.90
$n = 59$	Median	43.95	34.11	58.22	0.119	18.72	18.89	2.69	13.00
	Range	10.06—103.8	2.28—84.5	20.36—137.2	0.029—0.433	5.08—65.1	2.29—42.14	0.37—18.41	2.89—47.62
Banana	Mean	87.60^{a}	59.85^{a}	79.19^{a}	0.109^{a}	28.30^{a}	34.47^{a}	3.61^{a}	10.10^{a}
soils	*S.D.*	21.19	10.15	14.76	0.061	7.15	9.03	2.11	4.63
$n = 12$	Median	85.25	57.01	78.79	0.105	26.43	35.21	2.79	9.78
	Range	53.5—131	47.42—79.93	59.08—104.6	0.038—0.237	19.33—45.19	18.01—57.46	1.90—9.28	4.44—17.76
Orchard	Mean	49.03^{b}	36.25^{b}	72.30^{ab}	0.105^{a}	17.48^{b}	16.97^{b}	3.12^{a}	13.62^{a}
soils	*S.D.*	32.43	20.19	34.63	0.056	6.55	12.42	2.38	6.60
$n = 8$	Median	34.42	35.89	65.17	0.103	17.47	16.13	2.97	13.13
	Range	8.43—92.51	8.70—71.16	33.47—122.80	0.021—0.181	5.66—27.53	2.63—38.50	0.41—7.77	5.78—23.27

Notes: * Not significant different at $P = 0.05$ probability level (LSD) within each column are denoted with the same letter

Table 4 Comparison of mean contents of heavy metal in paddy soils in different areas (mg/kg)

Area	Zn	Cr	Pb	Cd	Cu	Ni	Data sources
Dongguan	92.9	58.2	96.6	0.13	22.2	26.0	
PRD	61.1	57.1	35.1	0.34	20.7	17.0	Wong, 2002
TLR	68.7	63.5	23.3		27.8	25.5	Wang, 2003

2.4 Correlation analyses

Generally, heavy metal pollution is a kind of multiple and complicated pollution in practical. Correlation analyses will be helpful to disclose the relationship between heavy metals. The result of correlation analyses listed in Table 5 showed that there was the significant correlation between Zn

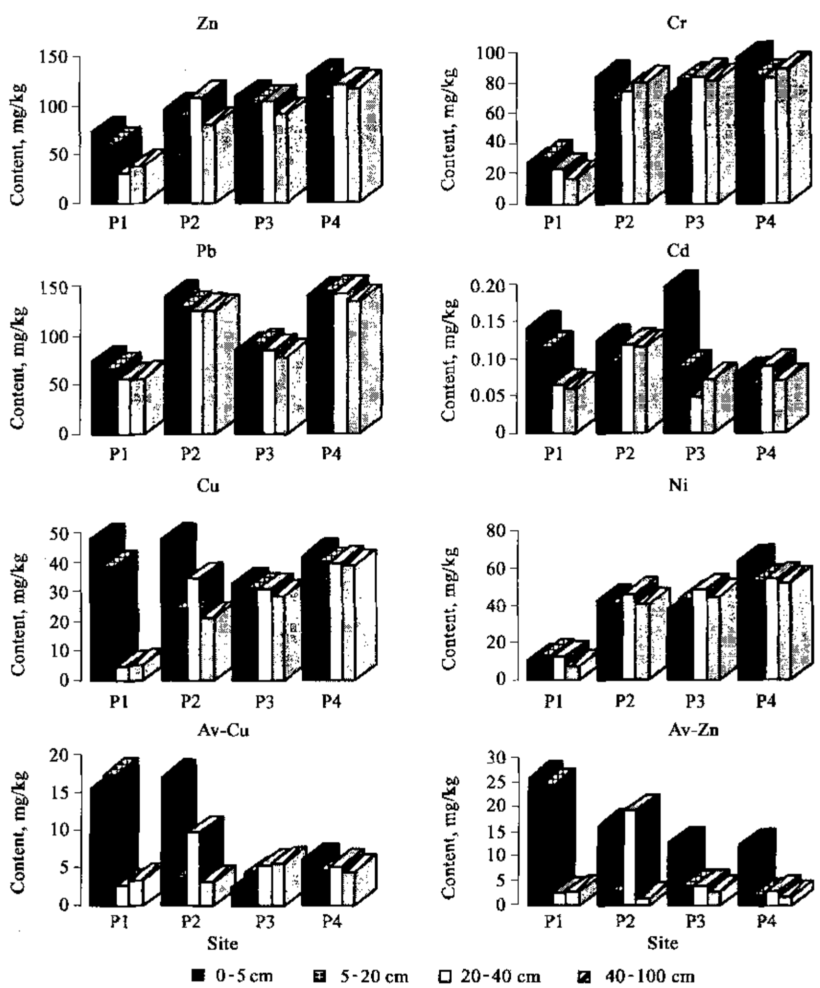

Fig. 1 Vertical distribution of heavy metals in different profile sites

and Cu, Ni, Pb, Cr, Cd, but only between Pb and Ni, Zn, Cr. In contrast to the correlation relation of heavy metals and pH for all of land utilization, it might be found that the correlation between various heavy metals in vegetable soils almost had agreement with that in all agricultural soils. In general, pertinence of various heavy metal contents with each other could be considered as the ground for the correlation assessment. Zn, Pb and Cu all have strong affinity with S, and have similar configuration and property and then similar geochemical behavior too. Zhang *et al*. (Zhang, 1996) reported that there were positive relationship among Zn, Pb and Cu contents, and significantly positive correlation between total and available content of Zn, Pb, Cu in vegetable soils. However, the results are quite different from vegetable and orchard soils in Hong Kong (Chen, 1997) in which there existed positive correlations between Cd and Zn, between Cu and Pb, and also different from vegetable soils, orchard soils and paddy soils of PRD in which there were significantly positive relationship among Zn, Cd, Cu, Cr, and Ni, but weakly correlated with Pb even though there was the positive correlation between Pb and Zn in paddy soils (Wong, 2002). And in the present study (Table 5), Zn, Cd and Cu were significantly correlated with each other, but Cd and Cu had weak correlation with Pb in vegetable soils. This result indicated that the discharge of waste water may be the important source for soil Cd and Cu pollution and a large amount of Pb from the atmospheric deposition (Wong, 2002), as well as the contents of Zn in soils could be affected by above two sources. In addition, most of Ni and Cr contents in agricultural soils were relatively low except for a few sample points which were heavily contaminated by Ni owing to the influence of key pollution plants around these points, especially for orchard soils, there existed significant relationship between Ni and Cr, and the correlation coefficient was up to 0.958, which is likely due to their common geochemical characteristics (Wang, 2002) because orchard soil was less polluted by industrial activities. Furthermore, there were significantly positive correlation between Av-Cu and Cu ($r = 0.735$, $p < 0.01$, $n = 59$) in vegetable soils, which indicated that the increase of Av-Cu content was influenced considerably by the change of Cu content (Zhang, 1996). Moreover, the Av-Zn was significantly negative correlated with Cr and Ni, may suggest the effect of pH on the contents of Av-Zn, Cr and Ni because the relationship between pH and Av-Zn in these soils was positively significant ($r = 0.377$, $p < 0.01$, $n = 59$), and negatively correlated between pH and Cr, Ni ($r1 = -0.275$, $p < 0.05$, $r2 = -0.355$, $p < 0.01$, $n = 59$) of vegetable soils.

Table 5 Correlation coefficients (r) between the trace metals of soils tested

Subgroup	Item	Zn	Cr	Pb	Cd	Cu	Ni	Av-Cu
Agricultural	Cr	0.712**						
soils	Pb	0.557**	0.482**					
$n = 85$	Cd	0.386**	0.257*	0.154				
	Cu	0.424**	0.401**	0.194	0.279**			
	Ni	0.684**	0.838**	0.417**	0.188	0.440**		
	Av-Cu	0.325**	0.312**	0.334**	0.315**	0.692**	0.219*	
	Av-Zn	-0.141	-0.402**	-0.186	0.244*	0.223*	-0.426**	0.199
Vegetable	Cr	0.663**						
soils	Pb	0.467**	0.382**					
$n = 59$	Cd	0.519**	0.409**	0.185				
	Cu	0.414**	0.303*	0.106	0.353**			
	Ni	0.661**	0.822**	0.306*	0.305*	0.364**		
	Av-Cu	0.319*	0.299*	0.227	0.289*	0.735**	0.212	
	Av-Zn	-0.011	-0.327*	-0.159	0.224	0.302*	-0.365**	0.217
Paddy	Cr	0.597						
soils	Pb	0.414	0.012					
$n = 6$	Cd	0.610	-0.059	0.783				
	Cu	0.507	0.986**	-0.070	-0.203			
	Ni	0.311	0.781	0.250	0.109	0.745		
	Av-Cu	0.767	0.464	0.638	0.786	0.349	0.624	
	Av-Zn	0.233	-0.454	0.070	0.265	-0.476	-0.834*	-0.223
Banana	Cr	-0.017						
soils	Pb	0.040	0.733**					
$n = 12$	Cd	0.244	0.120	0.081				
	Cu	-0.155	0.519	0.337	0.247			
	Ni	0.145	0.430	0.773**	-0.068	0.414		
	Av - Cu	0.002	0.820**	0.590*	0.454	0.712**	0.397	
	Av-Zn	0.055	-0.118	-0.205	0.783**	0.494	-0.168	0.293
Orchard	Cr	0.678						
soils	Pb	0.750*	0.532					
$n = 8$	Cd	0.475	0.014	0.119				
	Cu	0.640	0.621	0.772**	-0.221			
	Ni	0.705	0.958**	0.456	0.223	-0.487		
	Av-Cu	0.698	0.270	0.920**	0.181	0.736*	0.188	
	Av-Zn	-0.177	-0.616	0.268	-0.103	-0.026	-0.661	0.489

Notes: *, **, correlation is significant at the 0.05 and 0.01 level (2- tailed), respectively

In order to obtain a visual representation of heavy metal distribution and to find out similarities and correlation among heavy metals in different land utilization, PCA (Abollino, 2002) was employed in this study. The result showed that heavy metal contents in all agricultural soils could be represented with prior three principal components which accounted for 91.5%, 89.2%, 92.6%, 99.1% and 98.7% of the total variance for the agricultural soils, vegetable soils, banana soils, orchard soils and paddy soils, respectively. According to the variance of prior three principal components, the multiple equations of principal component are as follows:

$PC_{agricultural\ soils}$ = 0.6785 PC1 + 0.1488 PC2 + 0.0879 PC3 = 0.5854 Zn + 0.2777 Cr + 0.1756 Pb + 0.0005 Cd + 0.1181 Cu + 0.1578 Ni + 0.0214 Av-Cu − 0.0059 Av-Zn;

$PC_{vegetable\ soils}$ = 0.5986 PC1 + 0.1836 PC2 + 0.1093 PC3 = 0.5243 Zn + 0.2472Cr + 0.1233 Pb + 0.0008 Cd + 0.1714 Cu + 0.144 Ni + 0.0332 Av-Cu + 0.041 Av-Zn;

$PC_{banana\ soils}$ = 0.4889 PC1 + 0.37 PC2 + 0.0668 PC3 = 0.44 Zn + 0.2061 Cr + 0.3145 Pb + 0.0006 Cd + 0.0963 Cu + 0.1719 Ni + 0.043 Av-Cu + 0.0115 Av-Zn;

$PC_{orchard\ soils}$ = 0.7796 PC1 + 0.0455 PC2 + 0.0661 PC3 = 0.4926 Zn + 0.3606 Cr + 0.451 Pb + 0.0001 Cd + 0.0855 Cu + 0.215 Ni + 0.0211 Av-Cu − 0.0559 Av-Zn;

$PC_{paddy\ soils}$ = 0.6238 PC1 + 0.2461 PC2 + 0.1175 PC3 = 0.4691 Zn + 0.2799 Cr + 0.3746 Pb + 0.0007 Cd + 0.0544 Cu + 0.1374 Ni + 0.0536 Av-Cu − 0.0008 Av-Zn.

The result of PCA analyses showed that soil Zn was the most important factor for soil environment quality in Dongguan, and followed as Pb, Cr, Ni, and Cu. Correlation coefficients between principal components and heavy metals are listed in Table 6. The combination of correlation analysis and circumstances of factor loadings in the above equations indicated that the first and the second principal component primarily responded the situation of Zn and Pb contents in vegetable soil and banana soils, respectively, the third principal components mainly dominated the situation of Cr, Ni and Av-Zn content of vegetable soils. Moreover, the first and second principal components still reflected a part of information of the situation of Pb, Cr, Ni, Cu content in vegetable soils and Cr, Ni content in banana soils, respectively. In addition, significantly positive correlation occurred between the first principal component and the element of Zn and Pb in orchard soils, which indicated the similar sources of Zn and Pb for orchard soils.

Table 6 Correlation coefficients (*r*) between prior three principal components and heavy metals

PC	Zn	Cr	Pb	Cd	Cu	Ni	Av-Cu	Av-Zn
Agricultural soils (n = 85)								
PC1	0.941**	0.840**	0.741**	0.338**	0.449**	0.782**	0.387**	−0.257*
PC2	0.196	0.229*	−0.669**	0.144	0.255*	0.265*	−0.040	0.003
PC3	0.258*	−0.458**	−0.023	0.222*	0.099	−0.377**	0.095	0.606**
Vegetable soils (n = 59)								
PC1	0.925**	0.811**	0.690**	0.481**	0.414**	0.758**	0.375**	−0.160
PC2	0.228	0.240	−0.719**	0.220	0.339**	0.301*	0.113	0.131
PC3	0.221	−0.469**	0.036	0.191	0.414**	−0.368**	0.283*	0.756**
Paddy soils (n = 6)								
PC1	0.909*	0.860*	0.368	0.409	0.792	0.640	0.763	−0.134
PC2	0.288	−0.482	0.790	0.811	−0.563	−0.338	0.378	0.555
PC3	−0.299	0.145	0.486	0.029	0.150	0.621	0.188	−0.710
Banana soils (n = 12)								
PC1	0.993**	0.064	0.152	0.243	−0.114	0.243	0.067	0.025
PC2	−0.114	0.820**	0.964**	0.044	0.510	0.783**	0.693*	−0.164
PC3	0.025	0.402	−0.167	0.425	0.691*	−0.248	0.584*	0.611*
Orchard soils (n = 8)								
PC1	0.935**	0.744*	0.918**	0.274	0.776*	0.713*	0.808*	−0.061
PC2	0.185	0.539	−0.373	0.162	−0.107	0.626	−0.532	−0.938**
PC3	−0.302	0.391	0.130	−0.639	0.230	0.254	−0.132	−0.176

Notes: *, **, correlation is significant at the 0.05 and 0.01 level(2-tailed), respectively.

3 Conclusions

The heavy metal contents depended on the land utilization and spatial location at some degree in Dongguan due to the disperse distribution of industrial enterprises, especially for Zn, Cu, Cd and Ni. The contents of Cd, Cu and Ni was much more than the second grade of GB15618-1995 in some places even though the mean content of heavy metals was less than the threshold value of the second grade and only the mean content of Pb was more than the value of national background. The irregular vertical distribution of heavy metals in soil profiles implies the strong disturbing.

Correlation analyses showed that there was significant relationship among Zn, Cd and Cu, between Av-Cu and Cu in vegetable soils, and between Cr and Ni in orchard soils. Correlation analyses imply that soil Cd, Cu, Pb and Zn might be greatly affected by industrial. PCA analyses showed the order of importance should be Zn > Pb > Cr > Ni > Cu.

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References:

Abollino Q, Aceto M, Malandrino M *et al*., 2002. Heavy metals in agricultural soils from Piedmont, Italy. Distribution, speciation and chemometric data treatment[J]. Chemosphere, 49: 545—557.

Adamo P, Denaix L, Terribile F *et al*., 2003. Characterization of heavy metals in contaminated volcanic soils of the Solofrana River valley (southern Italy) [J]. Geoderma, 2027: 1—25.

Adriano D C, 1986. Trace elements in the terrestrial environment[M]. New York, NY: Springer-Verlag.

Brun L A, Maillet J, Richarte J *et al*., 1998. Relationships between extractable copper, soil properties and copper uptake by wild plants in vineyard soils[J]. Environmental Pollution, 102: 151—161.

Cao Z H, Hu Z Y, 2000. Copper contamination in paddy soils irrigated with wastewater[J]. Chemosphere, 41(1—2): 3—6.

Chang A C, Granato T C, Page A L, 1992. A methodology for establishing phytotoxicity criteria for chromium, copper, nickel, and zinc in agricultural land applications of municipal sewage sludges[J]. J Environ Qual, 21: 521—536.

Chen T B, Wong J W C, Zhou H Y *et al*., 1997. Assessment of trace metal distribution and contamination in surface soils of Hong Kong[J]. Environment Pollution, 96(1): 61—68.

Chen H M, Zheng C R, Tu C *et al*., 1999. Heavy metal pollution in soils in China: status and countermeasures[J]. AMBIO, 28: 130—134.

Colbourn P, Thornton I, 1978. Lead pollution in agricultural soils[J]. J Soil Sci, 29: 513—26.

Dietrich K N, Succop P A, Bornschein R L *et al*., 1990. Lead exposure and neurobehavioral development in later infancy[J]. Environ Health Perspect, 89: 13—19.

Elsokkary I H, Låg J, 1980. Status of some trace element in Egyptian soils and in wheat grains[J]. Beitrage Trop Landwirtsch Veterinarmed, 18: 35—47.

Elsokkary I H, Amer M A, Shalaby E A, 1995. Assessment of inorganic lead species and total organo-alkyllead in some Egyptian agricultural soils[J]. Environmental Pollution, 87: 225—233.

EPAD(Environmental Protection Agency of Dongguan City), 2002. The report of environmental quality of Dongguan City[Z]. Dongguan, China.

Gimeno-García E, Andreu V, Boluda R, 1996. Heavy metals incidence in the application of inorganic fertilizers and pesticides to rice farming soils[J]. Environmental Pollution, 92(1): 19—25.

Hong L Y, Hong H S, Chen W Q *et al*., 2003. Heavy metals in surface sediments from Minjiang Estuary-Mazu and Xiamen-Jinmen sea areas[J]. Journal of Environmental Sciences, 15(1): 116—122.

Kelly J, Thornton I, Simpson P R, 1996. Urban geochemistry: a study of influence of anthropogenic activity on heavy metal content of soils in traditionally industrial and non-industrial areas of Britain[J]. Appl Geochem, 11: 363—370.

Mclaughlin M J, Parker D R, Clarke J M, 1999. Metals and micronutrients—food safety issues[J]. Field Crop Research, 60: 143—163.

Miner G S, Gutierrez R, King L D, 1997. Soil factors affecting plant concentration of cadmium, copper, and zinc on sludge-amended soils[J]. J Envir Qual, 26: 989—994.

Mueller M, 1994. Distribution of cadmium in the food chain(soil-plant-human) of a cadmium exposed area and the health risks of the general population[J]. The Science of the Total Environment, 156: 151—158.

Sauerbeck D R, 1991. Plant, element and soil properties governing uptake and availabilities of heavy metals derived from sewage sludge[J]. Water Air and Soil Pollution, 57—58: 227—237.

Su D C, Wong J W C, 2003. Chemical speciation and phytoavailability of Zn, Cu, Ni and Cd in soils amended with fly ash-stabilized sewage sludge[J]. Environment International, 1060: 1—6.

Tam N F Y, Wong Y S, 2000. Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps[J]. Environmental Pollution, 110: 195—205.

Türkdogan M K, Kilicel F, Kara K *et al*., 2002. Heavy metals in soil, vegetables and fruits in the endemic upper gastrointestinal cancer region of Turkey[J]. Environmental Toxicity and Pharmacology, 13: 175—179.

Wang Q R, Liu X M, Cui Y S *et al*., 2002. Soil contamination and sources of heavy metals at individual sites of industry and mining associate with wastewater irrigation in China[J]. Acta Scientiae Circumstantiae, 22(3): 354—358.

Wang X C, Yan W D, An Z *et al*., 2003. Status of trace elements in paddy soils and sediment in Taihu Lake region[J]. Chemosphere, 50: 707—710.

Wei X G, He J H, Wang S Y *et al*., 2002. Concentration and evaluation on pollution of Cd in vegetable farm soils and vegetables of Guangzhou[J]. Soil and Environmental Sciences, 11(2): 129—132.

Wong S C, Li X D, Zhang G *et al*., 2002. Heavy metals in agricultural soils of the Pearl River Delta, South China[J]. Environmental Pollution, 119: 33—44.

Ye Y B *et al*., 2000. Compilation of environmental protection standards of China: environment quality and pollutant release[M]. Beijing: China Standard Press. 96—99.

Younas M, Shahzad F, Afzal S *et al*., 1998. Assessment of Cd, Ni, Cu and Pb pollution in Lahore Pakistan[J]. Environmental International, 24(7): 761—766.

Zhang M, Gong Z T, 1996. Contents and distribution of some heavy metal elements in the vegetable cultivated soils in China[J]. Acta Pedologica Sinica, 33(1): 85—93.

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