Baseline Concentrations and Spatial Distribution of Trace Metals in Surface Soils of Guangdong Province, China

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A total of 260 surface soil samples were collected to investigate the spatial distribution of trace metals in Guangdong province, one of the fast developing regions in China. The results show that the upper baseline concentrations of Cu, Pb, Zn, Cd, Ni, Cr, and Hg were 28.7, 57.6, 77.8, 0.13, 23.5, 87.0, and 0.15 mg kg^{-1}, respectively. Regional parent materials and pedogenesis are the primary factors influencing the concentrations of trace metals, and various anthropogenic activities are the second most important factors. The spatial distribution of trace metals is correlated to the geological characters with high concentrations of trace metals always located in regional fault areas, basins, and the Pearl River Delta alluvial plain and to the low concentrations associated with the other areas in Guangdong province.

Due to the rapid economic development and lack of effective pollution control measures, heavy metal contamination in soils has become a serious environmental problem in China (Li et al., 1997a, 1997b; Chen et al., 1999b). Establishing baseline concentrations of toxic trace metals can help us to understand their geochemical behavior, including spatial distribution and possible enrichment pathways, and to determine potential hot spots in soil environment.

Natural background concentration is defined as the ambient concentration of chemicals in soils without human influence (Kabata-Pendias and Pendias, 1992; Gough, 1993). It is almost impossible to establish the true natural background level of trace metals in soils because of long-range atmospheric transport and precipitation of contaminants and various anthropogenic impacts. For example, background levels of Pb are commonly elevated because of long-term use of Pb-based gasoline and paint (Fergusson, 1990), while global surface soils are suffering from Hg contaminations due to the atmospheric deposition (Slemr and Langer, 1992). As a result, baseline concentrations as a reference to determine clean soils have been used to represent element concentrations in a given region within a certain time (Gough et al., 1988; Kabata-Pendias and Pendias, 1992, Chen et al., 1999a). Moreover, because the distorting effects of a few high values can be minimized by log-transformation of the data, the baseline concentrations were a better variable measurement for trace metal concentrations than the observed ranges (Dudka et al., 1995) and have been recommended as the alternative criteria for assessing possible trace metal contamination in soils (Gough et al., 1994).

In general, the background concentration and spatial distribution of trace metals in soils are influenced by natural and anthropogenic factors, such as parent material, climate, vegetation, land use, and fertilizer application. Many investigations on background concentrations of soil trace metals had been performed in various areas (Pierce et al., 1982; Logan and Miller, 1983; Chen et al., 1999; Reimann and Melezhik, 2001; Zhang and Wang, 2001; Tao 1995a, 1995b; Xu and Tao, 2004; and Zhang et al., 2006). In these reports it has

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Published in J. Environ. Qual. 37:1752–1760 (2008).
doi:10.2134/jeq2007.0531
Received 7 Oct. 2007.
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Abbreviations: GM, geometric mean; GSD, geometric standard deviation; PRD, Pearl River Delta.

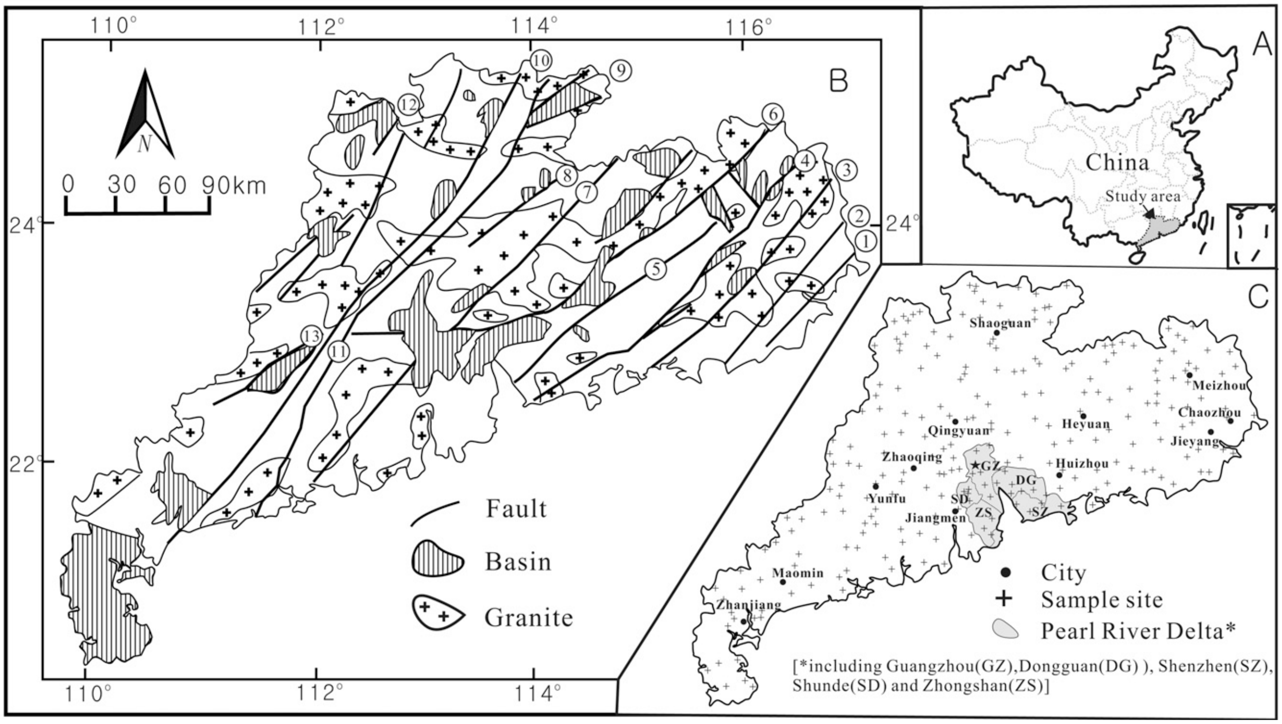

Fig. 1. Location of Guangdong province in China (A); geological sketch indicating the distribution of regional basins, faults, and granite (B); and sampling locations (C) (modified according to Qiu [1992] and Zhang [1999]). (1) Shantou fault; (2) Chao'an-Puning fault; (3) Dapu-Haifeng fault; (4) Wuhua-Shenzhen fault; (5) Zijin fault; (6) Heyuan fault; (7) En'ping-Xinfeng fault; (8) Wenyuan-Fogang fault; (9) Nanxiong fault; (10) Renhua-Yingde fault; (11) Wuchuan-Shihui fault; (12) Chenhuai fault; (13) Luoding-Guangning fault.

been shown that the primary factors influencing trace metal concentrations and spatial distribution in soils are parent materials and anthropogenic activities. Factors such as climate, the organic and inorganic components of soils, and redox potential status also affect the level of trace metals in soils.

The objectives of this investigation were to (i) establish the upper baseline concentrations of the seven toxic trace metals of Guangdong surface soils and (ii) evaluate natural versus anthropogenic influence factors that affect the spatial distribution of these toxic trace metals in surface soils in the study area. The information obtained may help to identify the potential hotspots of heavy metal contamination and can provide possible guidelines for assessing metal contamination and establishing proper soil cleanup standards for toxic trace metals in this region.

Materials and Methods

Description of the Study Area

Guangdong Province is located in South China, between latitude 20°10' to 25°31' (N) and longitude 109°41' to 117°17' (E) with a total area of 1.78×10^5 km^2 (Fig. 1A). The area is influenced by a subtropical monsoon climate with an average annual precipitation of 1336 mm and an annual average evaporation of 1100 mm. The annual average temperature ranges from 18.7 to 23.4°C, with an average of 1828 h sunshine annually. From north to south, the landscape changes from mountain to plateau to flood plain. The hilly area is up to about 60% of the total area. Many Cenozoic pull-apart basins are mainly distributed along 13 regional fault zones running NNE or NE (Fig. 1B). The total area of basins is more than 3.0×10^4 km^2, about 17% of the total area of Guangdong province (GSGIO, 1993). Granite is the most common parent rock for soils, accounting for more than 40% of the total area of Guangdong province. Limestone, sandstone, and shale occupy about 40% of the total area. Basalt parent rocks are located in the Leizhou Peninsula. Fluvial and marine sediments are in the alluvial plain.

In Guangdong province, the limestone and sandshale were formed dominantly during the early Carboniferous Period to the early Permian. In the Cenozoic Period of tectonic movement, the landform of Guangdong province was uplifted, forming many Cenozoic basins along regional faults. Igneous rocks intruded along regional faults and margins of basins. As a result, many polymetal ores formed during that period, such as pyrite ores, lead-zinc ores, and gold mines (GSGIO, 1993).

Over the last 30 yr, rapid urbanization and industrialization has taken place in this area. Heavy metal contents in soils and sediments were elevated compared with historical monitoring results. The distribution of Pb in sediments showed strong influence of atmospheric input (Li et al., 2000), and soil ^{206}Pb/^{207}Pb ratios strongly suggested the anthropogenic Pb (automobile exhaust and industrial sources) inputs to the soils in the Pearl River Delta (PRD) area (Wong et al., 2002). Tao (1995a, 1995b) showed that the locally high mercury content of surface soil might result from the agricultural activities in the study area.

Sampling

Soil samples used in this study were collected from locations shown in Fig. 1C. The sampling points in each area were

Table 1. Summary statistics of the data for 260 surface soils in Guangdong.

	Min.	Median	Max.	Skewness	AM ± ASD†	GM ± GSD‡	UBC§	China soils¶	World soils#
Cu, mg kg^{-1}	0.12	13.3	98.0	2.1a;–1.33b††	18.0 ± 17.1	11.2 ± 1.6	28.7	20.0	12
Pb, mg kg^{-1}	2.6	29.0	235.0	3.0a;–0.27b	37.5 ± 30.2	29.4 ± 1.4	57.6	23.6	29.2
Zn, mg kg^{-1}	5.6	37.8	378.0	3.4a; 0.14b	51.4 ± 44.6	39.7 ± 1.4	77.8	67.7	40
Cd, mg kg^{-1}	0.00	0.05	3.94	10.4a; 0.06b	0.10 ± 0.29	0.04 ± 1.7	0.13	0.07	0.4
Ni, mg kg^{-1}	0.8	12.0	273.0	6.2a; 0.20b	18.0 ± 25.1	12.0 ± 1.4	23.5	23.4	25
Cr, mg kg^{-1}	3.6	46.9	379.3	3.1a;–0.08b	57.8 ± 48.9	44.4 ± 1.4	87.0	53.9	50
Hg, mg kg^{-1}	0.01	0.06	1.12	4.1a; 0.36b	0.10 ± 0.13	0.07 ± 1.5	0.15	0.04	0.06
Sand, %	12.0	51.6	90.0	–0.1	50.4 ± 13.9	48.2 ± 1.2			
Clay, %	0.3	17.3	46.7	0.7	18.4 ± 8.9	15.8 ± 1.3			
Organic matter, g kg^{-1}	1.7	24.2	99.4	1.5	27.5 ± 15.5	23.7 ± 1.29			
pH-H$_2$O	4.0	4.9	8.5	1.6	5.17 ± 0.78	5.12 ± 1.06			

† AM, arithmetic mean; ASD, arithmetic standard deviation.

‡ GM, geometric mean; GSD, geometric standard deviation.

§ UBC, upper baseline concentrations.

¶ Geometric mean (from Wei [1990]).

Geometric mean (from Berrow and Reaves [1984]).

†† a, untransformed data; b, log-transformed data.

selected on flat terrain far away from major roads. About 3 kg of each soil sample were collected from 0 to 20 cm depth. The exact location was recorded with GPS reading. The sampling density was about one sample per 30 km^2 based on the map of bedrock distribution. The soil samples, free of plant roots, were air-dried, crushed, and then divided into two portions. One portion was sieved through a 20-mesh nylon screen (1 mm aperture size) for analysis of soil properties and stored at room temperature (25°C). The second portion was passed through a 200-mesh nylon sieve before the acid digest.

Chemical Analyses

Total Hg in soils was measured using the procedure by Malm et al. (1995). Approximately 0.5 g of prepared sample was weighed and placed in a 50-mL volumetric flask. Two milliliters of 1:1 HNO_3–$HClO_4$, 5 mL of concentrated H_2SO_4 (18 mol L^{-1}), and 1 mL of distilled water were added. After reacting for a few minutes, the suspension was heated at 230°C for 20 min on a digestor. After cooling, purified water was added to the the digested sample to a volume of 50 mL, and the sample was analyzed by cold-vapor atomic absorption spectrometry (Model PS 200 II; CV-AAS). To determine the concentrations of Cu, Pb, Zn, Cd, Ni, and Cr in soils, 0.2 g of each soil sample was digested to dryness using an acid mixture of 10 mL HF, 5 mL $HClO_4$, 2.5 mL HCl, and 2.5 mL HNO_3. The residual was then dissolved in 20% aqua regia, and the solution was brought to 10 mL for analysis by inductively coupled plasma-atomic emission spectrometry (Model PS 1000 AT; ICP-AAS). The digestion process provides an effective dissolution of silicate minerals.

Twenty-four standard reference soil materials of State Environmental Protection Administration (ESS-4, Beijing, China; State Environmental Protection Administration of China, 1995) were used for QA/QC control in analyses. The results from the analyses were consistent with the reference value. The relative standard deviations of Cu, Pb, Zn, Cd, Cr, Ni, and Hg were 2.03, 0.6, 2.4, 5.14, 1.03, and 19.0%, respectively.

The pH of soil was measured by placing 10 g of sample into 25 mL of deionized water (Chinese National Standard Agency, 1988). The soil organic matter content was measured using a potassium bichromate oxidation process. Soil clay and sand contents were based on wet and dry sieving techniques and the pipette method (Gee and Bauder, 1986).

Statistical Analyses

All trace metal contents were determined on a dry matter basis. Because the data fit a log-normal distribution (Table 1), the geometric mean (GM) and geometric standard deviations (GSDs) were used to represent the central tendency and variation of the data. Baseline concentrations of the seven trace metals were defined as the range between GM/GSD^2 and GM × GSD^2. This range included 95% of the samples (Tidball and Ebens, 1976; Dudka et al., 1995; Chen et al., 1999a). To display the soil trace metal concentrations on a contour map, the log-transformed data were used to calculate the semivariograms of heavy metals in Guangdong surface soils using VARIOWIN 2.2 software. The semivariogram obtained can better fit the spherical model combined with the nugget effect model. The spatial interpolation and contour maps were produced using the software of Surfer (Version 8.00; Golden Software, Inc., Golden, CO). Principle factor analysis was performed for the dataset using SPSS 12 software.

Results and Discussion

Baseline Concentrations of Trace Metals

Concentrations of the seven trace metals in Guangdong surface soils are listed in Table 1. Log-transformed metal concentrations form a linear trend when they are plotted on a normal probability diagram (Fig. 2). This suggests that the data can be assumed to be a single population after log transformation. Thus, the data are suitable to estimate the current metal baseline concentrations in the surface soils of the Guandong province. Baseline concentrations can be better expressed as the range of trace metal background concentrations because of the distorting effects of a few high concentrations that have been minimized by using a log-transformation (Dudka, 1993; Chen et al., 1999a).

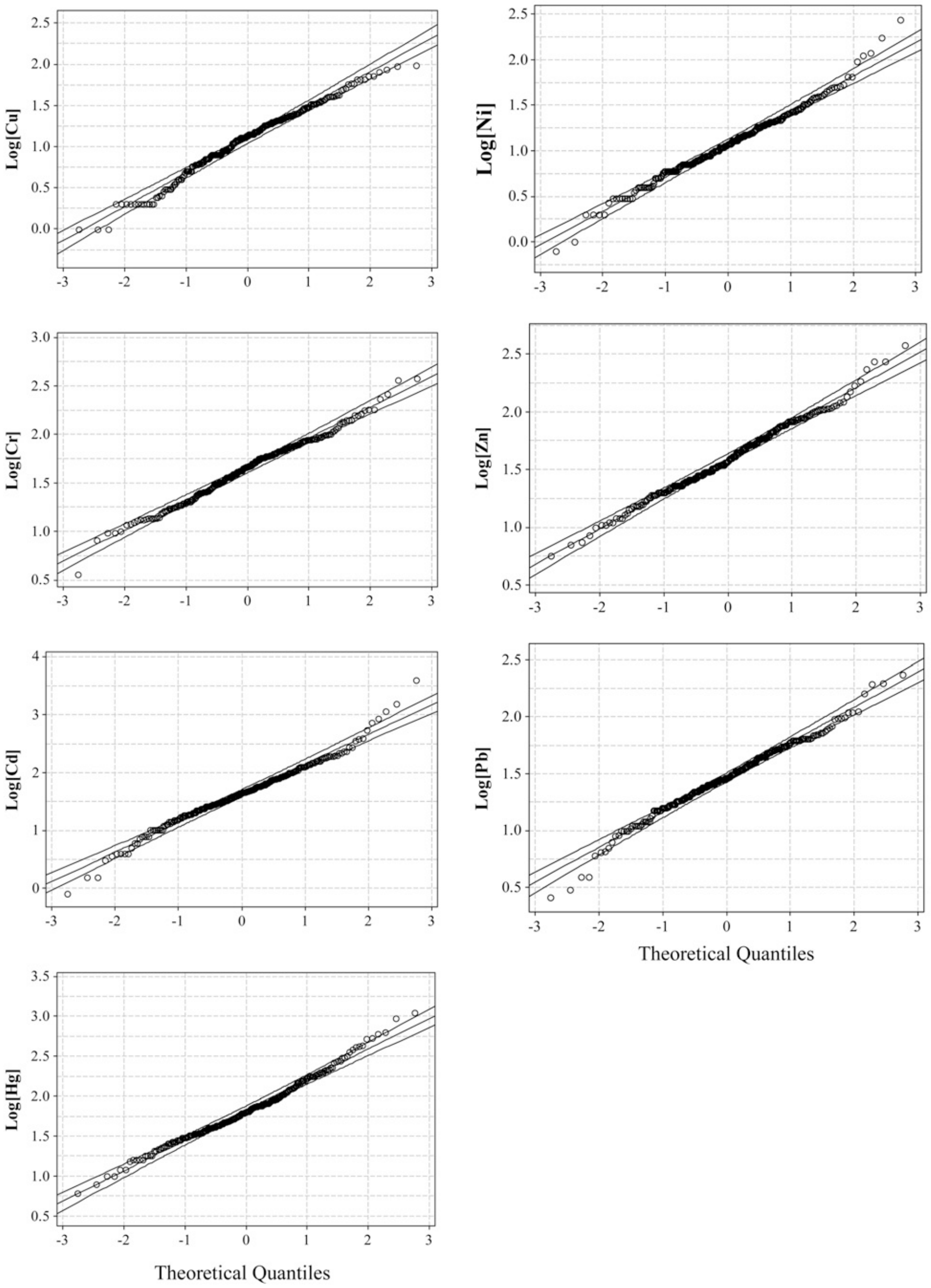

Fig. 2. Lognormal probability plot for heavy metal concentrations in Guangdong surface soils.

The present study shows that the concentrations of most trace metals (i.e., Cu, Zn, Cd, Ni, and Cr) except for Pb and Hg were lower than those in Chinese soils (Wei, 1990) and worldwide soils (Berrow and Reaves, 1984). The upper baseline concentrations of the seven trace metals (Cu, Pb, Zn, Cd, Ni, Cr, and Hg) fell well within the Natural Environmental Quality Standard for the soils in China (GB 15618–1995) and the upper baseline concentrations of soils in China (Wei, 1990). This indicates that Guangdong surface soils had comparatively lower baseline concentrations.

Correlation Analysis for Trace Metals and Soil Properties

Significant correlation was found among most trace metals, especially Cu, Ni, and Cr (Table 2). Similar correlations had been reported for surface soils of Florida (Ma et al., 1997; Chen et al., 1999a) and Inner Mongolia (Xu and Tao, 2004). This suggested that soil Cu, Ni, and Cr may be associated mainly with the mineral phase in soils. In the study area, the concentrations of Pb, Zn, Cd, and Hg in soils had significant positive correlations with each other for the similar geochemical paragenetic relationship, although the study area had widespread Pb and Hg contamination from anthropogenic input (Li et al., 2000). The correlation among trace metals as such in the study area suggests that similar processes might control trace metal associations in soils (Chen et al., 1999a).

The present results show that there is a correlation between clay contents and trace metal concentrations except Cd (Table 2). This is consistent with the reports in surface soils in Florida (Ma et al., 1997; Chen et al., 1999a) and in Poland (Dudka, 1993). The correlation coefficients of Cu, Pb, and Hg with soil organic matter content are much lower than that of the other trace metals with soil organic matter content in this study area (Table 2). This might indicate that the concentrations of Cu, Pb, and Hg may be heavily influenced by the atmospheric deposition in the surface soils. Soil pH has a correlation with concentrations of Zn, Cd, Pb, and Hg but has a weak correlation with Cu, Ni, and Cr (Table 2) in this province. This correlation might be the result of intensive eluviations, geochemical paragenetic relationship, and frequent acid rains in this area.

Principal Factor Analysis for the Distributions of Trace Metal Concentrations

Factor analysis is an extension of correlation analysis and can be used to explore the data from hidden multivariate structures, which can be explained by different means (Reimann et al., 2002). The results can divide variables into groups consistent with anthropogenic or natural processes (Davies and Wixson, 1987; Dudka, 1992; Chen et al., 1999a). The present results showed that three principal factors satisfactorily described vari-

Table 2. Pearson correlation coefficients of log-transformed trace metal concentrations in 260 Guangdong surface soils.

	Cu	Pb	Zn	Cd	Ni	Cr	Hg	Sand	Clay	OM	pH-H$_2$O
Cu	1	0.21**	0.37**	0.14*	0.62**	0.60**	0.21**	−0.30**	0.38**	0.14*	0.10
Pb		1	0.30**	0.12	0.01	−0.06	0.35**	−0.05	0.20**	0.16*	0.17**
Zn			1	0.66**	0.48**	0.37**	0.26**	−0.25**	0.31**	0.33**	0.25**
Cd				1	0.43**	0.39**	0.13*	0.05	0.08	0.25**	0.19**
Ni					1	0.82**	0.08	−0.22**	0.24**	0.26**	0.14*
Cr						1	0.06	−0.22**	0.25**	0.24**	0.05
Hg							1	−0.05	0.24**	0.12	0.30**
Sand								1	−0.68**	−0.04	0.15*
Clay									1	0.11	0.04
OM										1	0.01
pH-H$_2$O											1

* Significant at the 0.05 probability level.

** Significance at the 0.01 probability level.

ance of trace metal concentrations in the tested soils and could explain about 79% of the total variation (Table 3).

Principal factor 1 is mainly attributable to Cu, Zn, Cd, Ni, and Cr and explains 44% of the total variation (Table 3). Relatively lower principal factor eigenvectors of Pb and Hg suggest that they might be the result of other factors in the Guangdong surface soils. Generally, trace metal concentrations of soils mainly depend on the compositions of the parent rock minerals, the process of weathering, and the soil formation without human interferences (Adriano, 1986; Tack et al., 1997; Reimann and Melezhik, 2001; Burt. et al., 2003; Xu and Tao, 2004). In this investigation, widely distributed granite was the primary parent material for the formation of soils (Lan et al., 2003). Moreover, limestone and sandshale occupied about 40% of the study area, and the hydrothermal condition will increase the rate of weathering and accelerate the process of soil formation. Due to intensive chemical weathering and low water permeability, the soil horizon developed on the limestone and sandshale areas was thin, and soil and water loss is a serious issue in these areas (GSGIO, 1993). Granite weathering profiles with a thickness of >20 m are widely distributed in the study area (Lan et al., 2003). Because of the enrichment of trace metals and intensive weathering along regional faults, the influence of granite on the total content of trace elements in surface soils might be related to the processes of soil formation or pedogenesis to some extent, which may lead to the mobilization and redistribution of trace metals within the neighboring soil types (Thornton and John, 1980). Therefore, the parent material is the dominant factor in determining the soil trace metal status for the relatively young soils of Guangdong.

Principal factor 2 explains 21% of the total variances (Table 3). Eigenvectors are high for Pb and Hg and low for Zn and Cd. These differences might be due to anthropogenic activities from rapid industrialization and urbanization during recent decades in Guangdong province. Soil Pb, Hg, Zn, and Cd had significant positive correlations with each other (Table 2). Atmospheric deposition was the most likely factor for Pb and Hg contamination in soils because atmospheric concentrations of Pb and Hg have been increasing at a global scale. Lead and Hg deposition are generally driven by large-scale regional process as opposed to local emission or deposition processes (Fergusson, 1990; Slemr and Langer, 1992). The results of this investigation indicate that soil Pb and Hg have significant positive correlations with soil clay contents and soil pH but a low positive correlation with soil organic matter content (Table 2), which may suggest that levels and spatial distributions of soil Pb and Hg were primarily suffering from the atmospheric deposition of contaminants and acid rain effects (Larssen and Carmichael, 2000). Moreover, the distribution of Pb in the sediment and soil ^{206}Pb/^{207}Pb ratios has revealed that atmospheric inputs of Pb were mainly derived from anthropogenic sources (e.g., vehicular exhaust and Pb ore in the PRD area) (Li et al., 2000; Wong et al., 2003).

Spatial Variability of Trace Metal Concentrations

Spatial variability of trace metal concentrations in this investigation reveals that spatial distributions of trace metal concentrations are correlated to the regional geological characters with high concentrations of trace metals always located in regional fault areas, basins, and the PRD alluvial plain and low concentrations associated with the other areas in Guangdong province (Table 4). The GM of concentrations of Cu, Pb, Zn, Cd, Ni, Cr, and Hg in the regional fault areas, basins areas, and PRD area were about 2.1- to 3.1-, 2.5- to 3.6-, 2.0- to 2.2-, 2.2- to 2.9-, 1.5- to 1.9-, 1.1- to 1.5-, and 1.4- to 2.2-fold of those in the normal areas, respectively.

Geographic distributions of trace metal concentrations are mapped in Fig. 3 through 9 to further describe the spatial distribution relationships between soil trace metal concentrations and regional geological characters (faults, basins, and PRD) in Guangdong Province. The general patterns of the trace metal variability shown in these maps indicate that the soil samples with higher trace metal concentrations are distributed along the regional faults areas and coincide with the distribution of basins (Fig. 3–9). The enrichment of trace metals may have resulted from frequent ther-

Table 3. Eigenvectors of principal factor analysis and cumulative percentage of variations explained by the first three principal factors

Factor	Cu	Pb	Zn	Cd	Ni	Cr	Hg	Cumulative explained variation (%)
1	0.725	0.252	0.755	0.654	0.860	0.809	0.305	43.9
2	−0.089	0.773	0.292	0.123	−0.340	−0.422	0.663	64.5
3	0.530	0.194	−0.387	−0.669	0.103	0.149	0.287	79.2

mal fluid activities induced by regional faults during the Cenozoic period (Zhu and Yu, 1995) and the negative landform effect of basins during the soil formation process in the study area. Anthropogenic activities also play an important role in the distribution and content of soil trace metals, especially for soil Pb and Hg in the PRD area (Li et al., 2000; Wong et al., 2002, 2003). The rank of areas from high to low concentrations of trace metals is PRD ≥ basin areas ≥ fault areas >> the other areas (Table 4).

Similar spatial distribution patterns are shown in the maps for soil Cu, Ni, and Cr (Fig. 3–5), suggesting that the regional parent material and the process of pedogenesis were the most important factors for Cu, Ni, and Cr (Table 3). Cadmium and Zn have similar spatial distribution patterns (Fig. 6–7). The soil samples with high concentrations of Zn have high Cd concentrations because Cd and Zn often have similar geochemical behaviors in the environment due to the similarity of their physicochemical properties (Kabata-Pendias and Pendias, 1992).

Soil Pb is spatially associated with soil Hg in the study area (Fig. 8–9). Contamination of Pb and Hg is more evident in surface soils of the PRD area than in other areas (Table 4) due to rapid industrial development and urbanization. Previous research has indicated that concentrations of soil Pb in the region have been strongly influenced by atmospheric inputs, primarily from coal burning activities (Li et al., 2000), automobile exhaust, and industrial sources (Wong et al., 2002). Despite these nonpoint sources of Pb and Hg, our results show good spatial correlation with regional basins. The spatial extend direction of Pb and Hg was about north-north-west (NNW), trending different from the extend direction of the other heavy metals (Fig. 8–9). This suggests that at the regional scale, the low-level spatial distribution patterns of soil Pb and Hg may be related to the prevailing wind direction of Guangdong Province (GSGIO, 1993) (Fig. 8–9), and the nonpoint source contaminant only elevates the overall background concentrations.

Conclusions

Our results indicate that trace metal concentrations in Guangdong surface soils are mainly the consequence of the parent rock and the process of pedogenesis and that anthropogenic activities have a secondary influence. Due to rapid economic growth and urban development, soil Pb and Hg have accumulated, especially in the PRD. Maps of the spatial distribution of trace metal concentrations reveal that there is a close spatial relationship between the regional faults, basins, and the spatial distributions of trace metals. The concentrations of trace metal in soils were ranked in the order of PRD > basin areas > fault areas >> other areas.

Table 4. Concentrations of trace metals in 260 Guangdong surface soils based on the regions.

Element (mg kg^{-1})	Cu	Pb	Zn	Cd	Ni	Cr	Hg
Fault areas, n = 79							
GM†	13.0	38.9	49.2	0.05	13.1	47.3	0.08
GSD‡	1.5	1.2	1.3	1.7	1.4	1.3	1.5
Minimum	1.0	16.0	15.0	0.00	1.0	12.0	0.02
Median	14.0	37.9	50.0	0.05	13.00	47.00	0.07
Maximum	98.0	113	378	3.94	174	364	0.95
Skewness	2.4	1.2	3.7	6.7	6.0	3.3	3.7
Basin areas, n = 79							
GM	16.4	39.6	53.5	0.07	16.3	55.6	0.07
GSD	1.6	1.3	1.3	1.7	1.4	1.3	1.6
Minimum	0.12	15.0	12.0	0.00	2.0	8.1	0.01
Median	20.2	38.0	54.0	0.08	18.0	60.4	0.07
Maximum	88.0	235	278	1.55	118	265	1.12
Skewness	1.5	3.4	2.4	4.9	2.5	2.0	3.3
PRD§ areas, n = 24							
GM	19.6	57.5	53.8	0.07	12.7	39.8	0.11
GSD	1.6	1.3	1.4	1.5	1.6	1.4	1.5
Minimum	2.0	16.0	14.0	0.01	2.0	9.8	0.02
Median	21.0	55.4	59.8	0.07	11.5	45.4	0.12
Maximum	72.0	235	169	0.73	50	109	0.52
Skewness	0.7	2.4	0.8	3.2	0.7	0.2	1.4
Other areas, n = 78							
GM	6.3	15.8	24.7	0.02	8.4	36.9	0.05
GSD	1.6	1.3	1.3	1.6	1.3	1.3	1.3
Minimum	0.12	2.6	5.6	0.00	0.8	3.6	0.01
Median	8.0	16.8	24.9	0.03	8.0	35.3	0.05
Maximum	40.0	52	107	0.16	38.1	181	0.31
Skewness	1.4	0.7	2.0	1.6	1.4	1.8	2.4

† GM, geometric mean.

‡ GSD, geometric standard deviation.

§ PRD, Pearl River Delta.

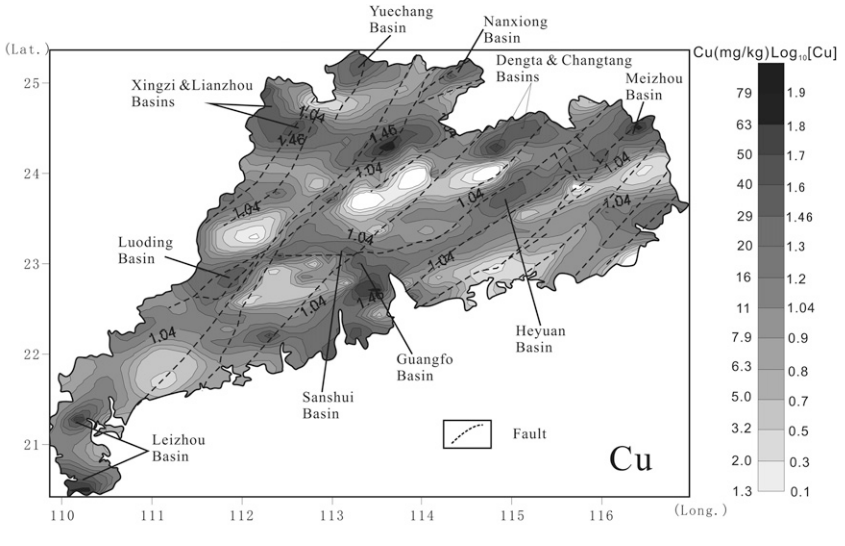

Fig. 3. Spatial distribution of Cu concentration in Guangdong surface soils by using kriging method (range, 0.12–98.0 mg kg^{-1} dry wt).

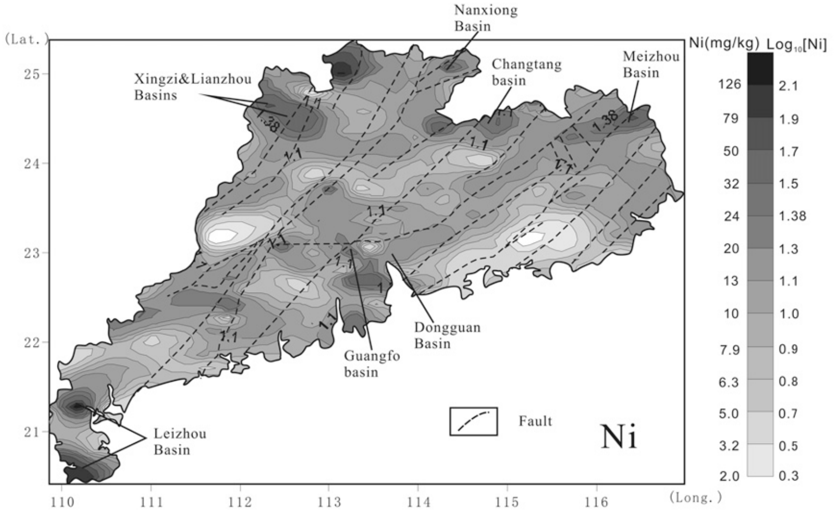

Fig. 4. Spatial distribution of Ni concentration in Guangdong surface soils by using kriging method (range, 0.80–273 mg kg^{-1} dry wt).

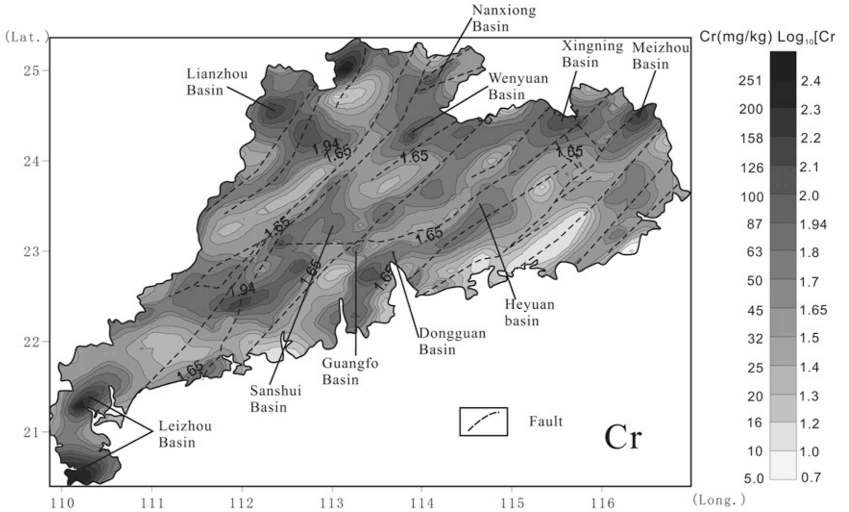

Fig. 5. Spatial distribution of Cr concentration in Guangdong surface soils by using kriging method (range, 3.6–379.3 mg kg^{-1} dry wt).

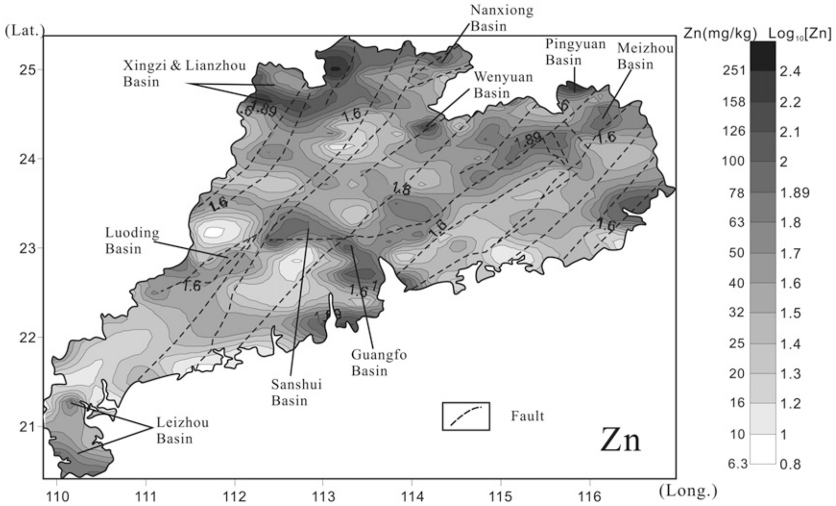

Fig. 6. Spatial distribution of Zn concentration in Guangdong surface soils by using kriging method (range, 5.6–378 mg kg^{-1} dry wt).

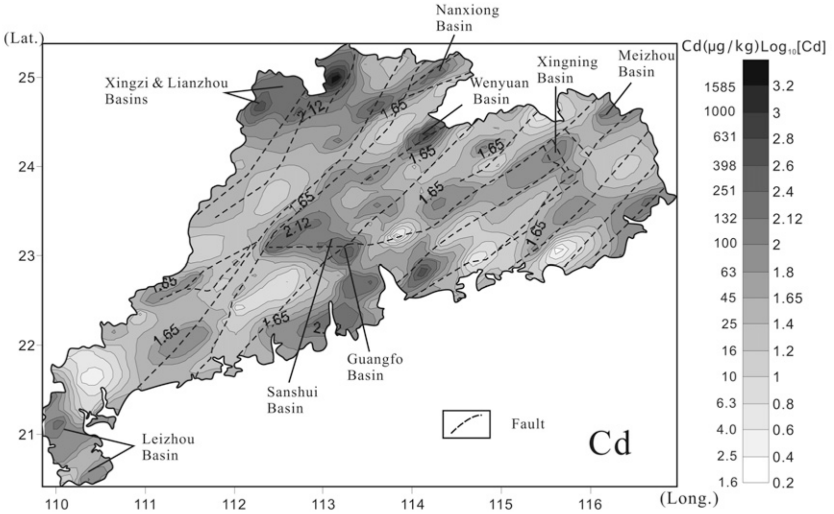

Fig. 7. Spatial distribution of Cd concentration in Guangdong surface soils by using kriging method (range, 0.00–3.94 mg kg^{-1} dry wt).

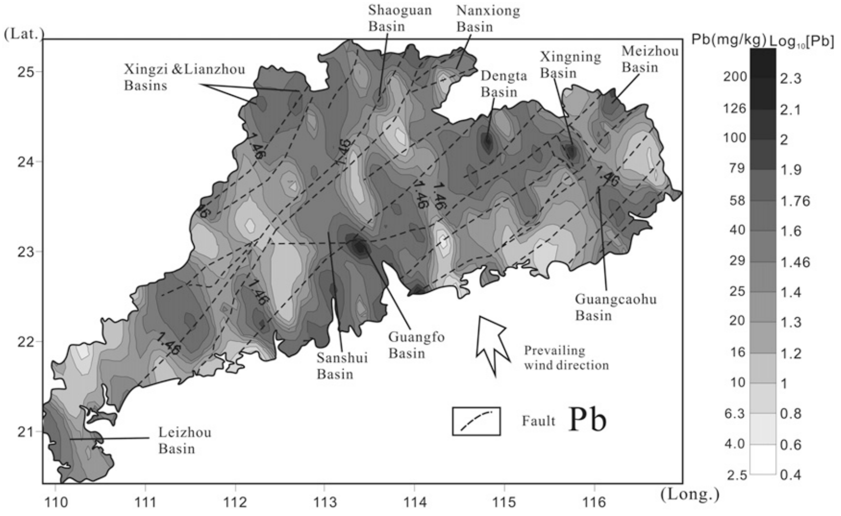

Fig. 8. Spatial distribution of Pb concentration in Guangdong surface soils by using kriging method (range, 2.6–235 mg kg^{-1} dry wt).

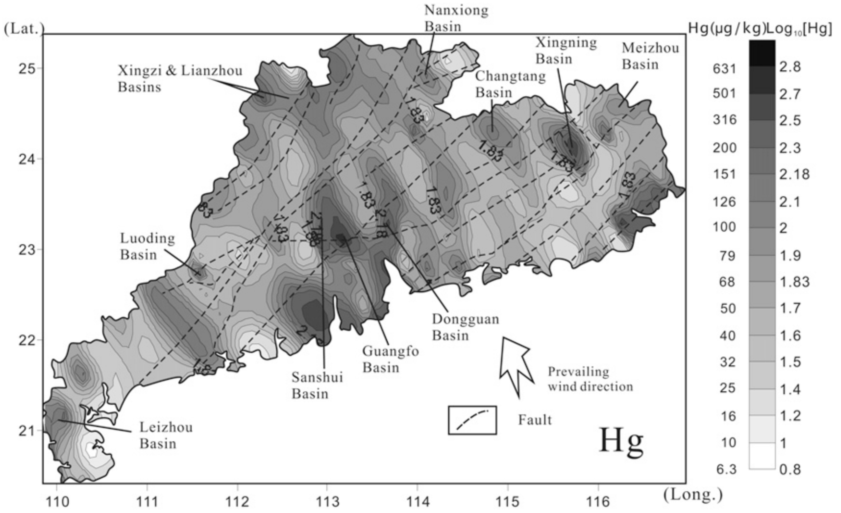

Fig. 9. Spatial distribution of Hg concentration in Guangdong surface soils by using kriging method (range, 0.01–1.12 mg kg^{-1} dry wt).

Acknowledgments

We thank two reviewers for their very useful comments that improved the quality of this manuscript. This work was partly supported by National Natural Science Foundation of China (40571164 and 20377011), the CAS Key Laboratory of Marginal Sea Geology (MSGL07-19 and MSGL06-18), and the Technology R&D Project of Guangdong Province (2004B32501004).

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