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# Heavy Metal Contamination in a Typical Mining Town of a Minority and Mountain Area, South China

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**Abstract** This study was conducted in Dachang, a small mining town in Gaungxi Zhuang Autonomous Region in southern China. A total of 23 farmland soil samples and two atmospheric samples of particulate matter less than 10 microns ($PM_{10}$) were collected in this town. ICP-MS was used to analyze for 20 elements in each of the samples. All of the samples contained some level of heavy metals. The most commonly detected heavy metals detected in the soil samples were: Cd (up to 29.0 mg $kg^{-1}$), As (up to 776 mg $kg^{-1}$), Sb (up to 36.8 mg $kg^{-1}$), Pb (up to 582 mg $kg^{-1}$), Zn (up to 1379 mg $kg^{-1}$) and Cu (up to 156 mg $kg^{-1}$), Mn (up to 1476 mg $kg^{-1}$). The $PM_{10}$ content in air samples exceeded the Chinese standard by nearly ten-fold. The most commonly detected heavy metals detected in the $PM_{10}$ atmospheric samples were Cd (up to 210 mg $kg^{-1}$), As (up to 15239 mg.$kg^{-1}$), Sb (up to 445 mg $kg^{-1}$), Pb (up to 8053 mg $kg^{-1}$), Zn (up to 13151 mg $kg^{-1}$) and Cu (up to 673 mg $kg^{-1}$), Mn (up to 2826 mg $kg^{-1}$), Mo (up to 120 mg $kg^{-1}$). All of these heavy metals are associated with significant human health effects ranging from reduced intelligent quotients (IQs) in children (cf. Pb) to cancer (e.g., Cd and As). Müller Geo-accumulation Index (Igeo) and enrichment factor (EF) were used to assess the findings. The results to the two assessments showed the same ranking: Cd > As > Sb > Pb > Zn > Cu > Mn, which would imply that the particulate matter in ambient air was the source of the contamination in the soil. The correlation analysis supported this inference. Upon further examination, ore transportation through the town was identified as the most likely source of contamination. Therefore, steps should be taken to improve the management of the ore transportation in order to protect the farmland and the health of the residents.

**Keywords** Mining town · Heavy metal contamination · Geo-accumulation Index · Dachang town of Guangxi

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It is well known that elevated concentrations of heavy metals in the environment pose a risk to human health through exposure routes of ingestion, inhalation and, in some cases, skin absorption. Therefore, it is reasonable to be concerned about contamination of agricultural soil and ambient air (Tadej et al. 2007; Fernandez-Espinosa and Ternero-Rodrguez 2004).

China is a big country, with lots of resources and a large population. However, the economic conditions vary greatly in different parts of the country. There has been much study of heavy metal contamination in soil and ambient air in the developed cities and the suburbs in places like Beijing, Shanghai, Guangzhou, and Hongkong (Chen et al. 2005; Tan et al. 2006; Huang et al. 2007; Shu et al. 2001; Kung and Ying 1990; Winchester and Bi 1984; Lee et al. 2007). However, there have been relatively few studies on environmental contamination in the mountainous areas of China where roughly 70 million, primarily minority, people live on annual incomes of no more than 30 dollars US.

While leaders have expressed great concern about the economic plight of these people, there has been comparatively little consideration of the environmental conditions in which they live.

One of the few means of raising the standard of living of people living in such areas is through mining, since mine resources trend to distribute in mountainous areas that do not lend themselves to agriculture. Environmental management practices associated with mining in these areas are generally poor due to lack of engineering and technological expertise and capital investments. As a result, serious contamination problems can arise that can pose significant health risks to the inhabitants, who have little or no choice but to endure living in these contaminated environments.

Our aim in this study has been to: (1) Choose a typical mining town in a remote mountain area populated by minority peoples; (2) Analyze the major and trace elements in the ambient air and the farmland of this town, in attempt to identify the status of contamination that the community is confronted with; (3) Analyze the correlation between contamination in the ambient air and in the soil in an attempt to determine the source of contamination.

## Material and Methods

Dachang town is located in the northwest of Guangxi Zhuang Autonomous Region (east longitude 107°34′37″; north latitude 24°49′26″), at the eastern foot of Duyang Mountain at the southern end of the mountainous range that runs from the Yungui Plateau to the Guangxi Basin. It is one of the famous Karst regions of southwest China, accounting for 66% of the local area. Rocky desertification is very serious. The population living in these areas includes many minority peoples, such as Zhuang, Yao, Molao, Maonan, Miao, Dong, and Shui nationalities.

Dachang town enjoys a semi-tropical mountain climate with an average annual temperature range of 16.9–21.5°C and rainfall of 1200–1600 mm. The main wind direction is from the southeast. The town is surrounded by hills with an altitude between 200 and 500 m which accounts for the fact that in Dachang there is no wind 36% of the time. More than 80% of the 33,000 population of the town are mining industry workers and their family members. Around the Dachang town there are many mines. Historically, the economy of this small town has depended on the mining industry. In fact, Dachang enjoys the reputation of being "the township of the non-ferrous metal" and "the tin capital of China in the future".

There is only an asphalt street that passes through this town. It carries a large flow of traffic, mainly the vehicles associated with ore transportation. The dust resulting from this traffic causes a serious amount of suspended particle pollution in the air, much of which is deposited on the ground in the surrounding area. Some people of this town and the farmers nearby cultivate some of the arid land in order to grow corn and other vegetables for consumption by humans and animals in the area. Therefore, there is an opportunity for human exposure to pollution through inhalation, ingestion and dermal exposure. The potential risks associated with such exposures have not been carefully studied. The goal of this study was to determine a level of contamination in Dachang and to consider the correlation between the soil contamination and air contamination. Therefore, atmospheric particles and farmland soils were sampled and analyzed, providing the scientific basis for further quantitative assessment of the inhabitants' health risks, as an aid in local environmental management decision-making.

In April, 2006, 23 soil samples were collected from vegetable gardens, within 500 m distance from the road, at locations shown in Fig. 1. Each sample, consisting of 3–5 subsamples (about 200 g each), was collected at depths between 0 and 20 cm, which were intended to be representative of the plough depth. All soil samples were collected using a hand auger and then stored in polyethylene bags.

In April, 2006, two sampling locations (see Fig. 1) along the street were chosen as sites for the collection of ambient particle samples using moderate-volume sampler (Wuhan Tianhong Co. TH-150C) at a flow rate of 0.100 $m^3$ $min^{-1}$. The sampling height was about 1.5 m. Two samplers were placed at each spot, one sampled total suspended particulate matter (TSP), the other sampled particulate matter that was less than 10 microns in size ($PM_{10}$). The sampling was conducted for eight hours, from 10:00 am to 18:00 pm.

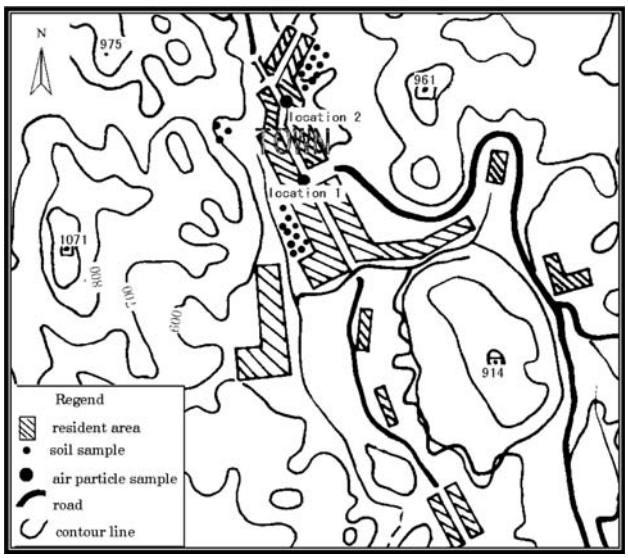


**Fig. 1** Topographic map of Dachang town with sampling locations

Glass fiber filters were used for the collection. After sampling, the filters were carefully removed, folded, placed in polyethylene bags and brought back to the laboratory for analysis, using Chinese standard method (GB/T 15432-1995) in order to determine the content of TSP and $PM_{10}$.

The collected soil samples were air-dried at 20°C for 3 days and sieved through a 2 mm-polyethylene sieve to remove large debris, stones and pebbles. They were then ground in an agate grinder until fine particles (<200 μm) were obtained. The prepared soil samples were analyzed for their metal concentrations using an acid digestion method. All glass and plastic ware was soaked in 10% nitric acid overnight and rinsed thoroughly with deionized water before use.

A series of 0.250 g portions of the soil samples were placed into Pyrex test tubes. 10.0 mL high-purity concentrated nitric acid and 2.5 mL high-purity concentrated perchloric acid were added. For the air samples, each filter was carefully placed in an acid-cleaned Pyrex test tube to which 12.0 mL of concentrated high-purity $HNO_3$ and 3.0 mL of concentrated $HClO_4$ were added, completely submerging the filter.

All of the samples were then gently shaken using a vortex mixer and heated progressively to 190°C in an aluminum heating block for 24 h to near dryness. After the test tubes were cool, 12.0 mL of diluted (5% (v/v)) high-purity $HNO_3$ were added. The solutions were thoroughly mixed using a vortex mixer and then heated at 70°C for 1 h. After cooling, the solutions were decanted into acid-cleaned polyethylene tubes for storage. Solutions were later centrifuged at 3500 rpm for 10 min, and then portions of the supernate were removed for measurement using a Perkin-Elmer ELAN 6100 Inductively Coupled Plasma—Mass Spectrometer (ICP-AES).

For quality control, reagent blanks, replicates, soil international standard reference materials (NIST 2709) and ambient particulate standard reference materials (NIST 1648) were incorporated in the analysis to detect any contamination in the analytical materials and to assess precision and bias in the method. The analytical results showed no sign of contamination in the materials used and that the precision and bias of the analytical method were generally <10%. The recovery rates for some major elements in the international standard reference material were between 85% and 105%.

The distribution of data was tested with the Shapiro-Wilk method ($p < 0.05$). All statistical treatments were performed using SPSS 11 statistical software.

Geo-accumulation index (Igeo) and Enrichment factor (EF) were used as the methods for characterizing contamination.

The index of geo-accumulation (Igeo) has been employed it to characterize the contamination of soils (Loska et al. 2003). The value of the geo-accumulation index is defined by the following equation:

$$\text{Igeo} = \log_2 \frac{C_n}{1.5B_n}$$

where $C_n$—the metallic content in tested soil, $B_n$—the level that is accepted as background in an environment with very few anthropogenic influences.

The interpretation of Igeo is as follows:

Igeo $\leq 0$ practically uncontaminated;
$0 <$ Igeo $< 1$ uncontaminated to moderately contaminated;
$1 <$ Igeo $< 2$ moderately contaminated;
$2 <$ Igeo $< 3$ moderately to heavily contaminated;
$3 <$ Igeo $< 4$ heavily contaminated;
$4 <$ Igeo $< 5$ heavily to very heavily contaminated;
Igeo $\geq 5$ very heavily contaminated.

The enrichment factor is a relatively simple tool for characterizing the degree of enrichment (Loska et al. 2003). The EF can be easily adapted for use in various environmental media. The EF is defined by the following formula:

$$EF = \frac{C_n}{C_{\text{ref}}} \Big/ \frac{B_n}{B_{\text{ref}}}$$

where $C_n$—content of the examined element in the examined environment, $C_{\text{ref}}$—content of the examined element in the reference environment, $B_n$—content of the reference element in the examined environment, $B_{\text{ref}}$—content of the reference element in the reference environment.

An element is regarded as a reference element if it is of low occurrence variability and is preferably present in the environment in trace amounts. The most common reference elements are Sc, Mn, Al and Fe.

Five contamination categories are recognized on the basis of the enrichment factor:

EF $< 2$, depletion to minimal enrichment,
EF $=$ 2–5, moderate enrichment,
EF $=$ 5–20, significant enrichment,
EF $=$ 20–40, very high enrichment,
EF $> 40$, extremely high enrichment.

## Results

The results of particulate air samples at the two sampling locations are found in Table 1.

According to "Chinese Air Environment Quality Standard" (GB 3095–1996), the daily average concentration for TSP and PM10 in an inhabited area should be 0.30 mg/m$^3$ and 0.15 mg/m$^3$, respectively. Therefore, the TSP in Location 1 was about 28-fold higher than the standard and

**Table 1** Results from particulate air sampling in Dachang Town

| | TSP (mg $m^{-3}$) | $PM_{10}$ (mg $m^{-3}$) |
|---|---|---|
| Location 1 | 8.42 | 1.43 |
| Location 2 | 2.97 | 1.44 |

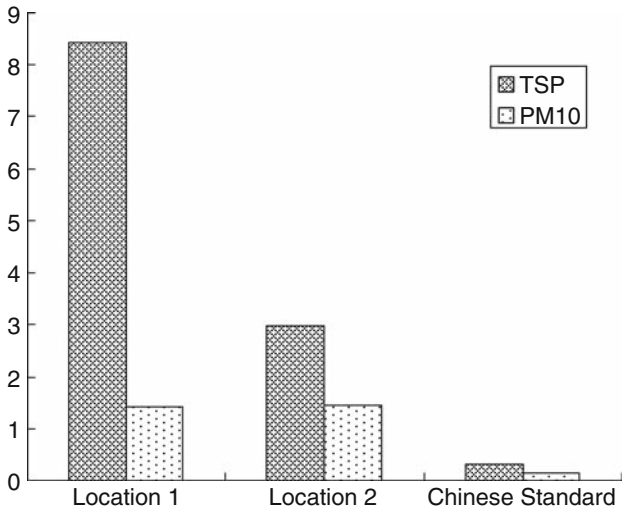


**Fig. 2** Content of air particulates in Dachang town

9.5 higher than the standard in Location 2. Furthermore, the $PM_{10}$ was nearly 10-fold higher than the standard in both locations (See Fig. 2).

These data can be understood by considering that the heavier TSP are more quickly deposited on the ground and therefore tend to reflect conditions at specific locations. In contrast, the lighter $PM_{10}$ remain airborne for a longer period of time, travel a greater distance and, therefore, tend reflect conditions over a wider area.

The 23 soils samples were analyzed for the following 20 metallic elements: Al, As, Ca, Cd, Co, Cr, Cu, Fe, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Sr, Ti, V and Zn. The results of the soil analyses are listed in Table 2a and b. The background concentration (BC) of Chinese soil (Wei et al. 1991) are included as well.

Only $PM_{10}$ air particulate samples were analyzed for their content of 20 metallic elements. The results are shown in Table 3.

The soil data for As, Cd, Cr, Mo, Na, Pb, Sb and Ti had generally lognormal distributions, whereas the other elements had generally normal distributions. Arithmetic mean values were used when the heavy metal concentrations had normal distributions, and geometric mean values were used when the heavy metal concentrations had lognormal distributions. Arithmetic mean values were used for the air particulate data since there were only two samples. Arithmetic mean values of Chinese soil BC were used to calculate the Igeo and EF. Fe was chosen as the reference element for enrichment factor calculation.

The Igeo and EF data from Tables 2a, b and 3 are summarized in Tables 4 and 5 according to the different

**Table 2** Concentration of major and trace elements in soil around Dachang town

| | Al* (mg $kg^{-1}$) | As (mg $kg^{-1}$) | Ca* (mg $kg^{-1}$) | Cd (mg $kg^{-1}$) | Co (mg $kg^{-1}$) | Cr (mg $kg^{-1}$) | Cu (mg $kg^{-1}$) | Fe* (mg $kg^{-1}$) | Li (mg $kg^{-1}$) | Mg* (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| (a) | | | | | | | | | | |
| Range | 1.50–6.18 | 126–5520 | 0.23–7.44 | 4.00–184 | 3.30–18.7 | 27.1–132 | 21.9–448 | 1.83–4.48 | 10.1–115 | 0.15–0.64 |
| Arithmetic mean | 3.82 | 1295 | 1.96 | 50.4 | 9.40 | 50.0 | 156 | 2.90 | 49.6 | 0.30 |
| Geometric mean | 3.59 | 776 | 1.27 | 29.0 | 8.17 | 46.2 | 120 | 2.81 | 43.3 | 0.28 |
| Background in China | 6.62 | 11.2 | 1.54 | 0.097 | 12.7 | 61 | 22.6 | 2.94 | 32.5 | 0.78 |
| Igeo | −1.38 | 5.53 | −0.86 | 7.64 | −1.02 | −0.98 | 2.20 | −0.60 | 0.02 | −1.96 |
| EF | 0.58 | 70 | 0.84 | 303 | 0.75 | 0.77 | 7.00 | 1.00 | 1.55 | 0.39 |

| | Mn (mg $kg^{-1}$) | Mo (mg $kg^{-1}$) | Na* (mg $kg^{-1}$) | Ni (mg $kg^{-1}$) | Pb (mg $kg^{-1}$) | Sb (mg $kg^{-1}$) | Sr (mg $kg^{-1}$) | Ti (mg $kg^{-1}$) | V (mg $kg^{-1}$) | Zn (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| (b) | | | | | | | | | | |
| Range | 182–4180 | 2.20–8.48 | 0.017–0.26 | 18.0–75.2 | 167–5680 | 10.4–233 | 19.4–237 | 0.0091–0.21 | 58.1–96.8 | 316–3140 |
| Arithmetic mean | 1476 | 4.07 | 0.094 | 45.1 | 1085 | 56.0 | 99.8 | 0.052 | 79.2 | 1379 |
| Geometric mean | 1041 | 3.87 | 0.07 | 41.3 | 582 | 36.8 | 77.6 | 314.1 | 78.4 | 1127.6 |
| Background in China | 583 | 2 | 1.02 | 26.9 | 26 | 1.21 | 167 | 0.38 | 82.4 | 74.2 |
| Igeo | 0.76 | 0.37 | −4.52 | 0.16 | 3.90 | 4.34 | −1.33 | −4.20 | −0.64 | 3.63 |
| EF | 2.57 | 1.96 | 0.07 | 1.70 | 22.7 | 30.8 | 0.61 | 0.14 | 0.97 | 18.8 |

* The unit is %

**Table 3** Concentrations of major and trace elements in $PM_{10}$ of Dachang town

| | Atmospheric concentration ug $m^{-3}$ | | | Particulate concentration mg $kg^{-1}$ | | | Igeo | EF |
|---|---|---|---|---|---|---|---|---|
| | Location1 | Location2 | Mean | Location1 | Location2 | Mean | | |
| Al* | 253 | 263 | 258 | 7.05 | 7.83 | 7.44 | −0.42 | 0.57 |
| As | 18.6 | 25.0 | 21.8 | 13101 | 17378 | 15239 | 9.83 | 692 |
| Ca* | 145 | 157 | 151 | 10.2 | 10.9 | 10.5 | 2.18 | 3.47 |
| Cd | 0.28 | 0.32 | 0.30 | 195 | 225 | 210 | 10.50 | 1101 |
| Co | 0.01 | 0.02 | 0.02 | 9.91 | 13.8 | 11.8 | −0.69 | 0.47 |
| Cr | 0.26 | 0.34 | 0.30 | 186 | 234 | 210 | 1.20 | 1.75 |
| Cu | 0.96 | 0.97 | 0.96 | 675 | 671 | 673 | 4.31 | 15.1 |
| Fe* | 80.9 | 84.5 | 82.7 | 5.69 | 5.87 | 5.78 | 0.39 | 1.00 |
| Li | 0.56 | 0.81 | 0.68 | 391 | 564 | 478 | 3.29 | 7.48 |
| Mg* | 147 | 224 | 186 | 10.3 | 15.6 | 13.0 | 3.47 | 8.48 |
| Mn | 4.07 | 4.02 | 4.04 | 2859 | 2792 | 2826 | 1.69 | 2.47 |
| Mo | 0.14 | 0.21 | 0.17 | 96.3 | 143.1 | 119.7 | 5.32 | 30.4 |
| Na* | 52.0 | 55.1 | 53.5 | 3.65 | 3.82 | 3.74 | 1.29 | 1.87 |
| Ni | 0.06 | 0.07 | 0.07 | 45.1 | 46.8 | 46.0 | 0.19 | 0.87 |
| Pb | 12.4 | 10.6 | 11.5 | 8732 | 7374 | 8053 | 7.69 | 158 |
| Sb | 0.60 | 0.68 | 0.64 | 421 | 470 | 445 | 7.94 | 187 |
| Sr | 0.94 | 1.01 | 0.98 | 659 | 705 | 682 | 1.44 | 2.08 |
| Ti* | 4.71 | 6.07 | 5.39 | 0.33 | 0.42 | 0.38 | −0.58 | 0.51 |
| V | 0.24 | 0.31 | 0.28 | 168 | 216 | 192 | 0.64 | 1.19 |
| Zn | 18.7 | 18.9 | 18.8 | 13164 | 13138 | 13151 | 6.88 | 90.2 |

**Table 4** Characterization of contamination of soil and $PM_{10}$ by Igeo

| Igeo | Media | Chemical | Contaminated categories |
|---|---|---|---|
| Igeo $\leq$ 0 | PM10 | Co, Ti, Al | Practically uncontaminated |
| | Soil | Na, Ti, Mg, Al, Sr, Co, Cr, Ca, V, Fe | |
| 0 < Igeo < 1 | PM10 | Ni, Fe, V | Uncontaminated to moderately contaminated |
| | Soil | Li, Ni, Mo, Mn | |
| 1 < Igeo < 2 | PM10 | Cr, Na, Sr, Mn | Moderately contaminated |
| | Soil | | |
| 2 < Igeo < 3 | PM10 | Ca | Moderately to heavily contaminated |
| | Soil | Cu | |
| 3 < Igeo < 4 | PM10 | Li, Mg | Heavily contaminated |
| | Soil | Zn, Pb | |
| 4 < Igeo < 5 | PM10 | Cu | Heavily to very heavily contaminated |
| | Soil | Sb | |
| Igeo $\geq$ 5 | PM10 | Mo, Zn, Pb, Sb, As, Cd | Very heavily contaminated |
| | Soil | As, Cd | |

qualitative levels of contamination severity described above. Although there are seven categories of contamination severity in the Igeo approach compared to only five categories in the EF, the rank order of the contamination of the elements is the same in the two methods (see Table 6). Therefore, the two methods are consistent with each other in their characterization of the contamination.

These data show that the greatest amount of contamination in the soil samples is associated with Cd, As, Sb, Pb, Zn, Cu, Mn and Mo, while the greatest amount of contamination in the air particulate samples is associated with Cd, As, Sb, Pb, Zn, Mo, Cu and Mn. With the exception of Mo, the rank order of the contaminating elements was that same in both the solid and the air samples; that is, Cd > As > Sb > Pb > Zn > Cu > Mn.

**Table 5** Characterization of contamination of soil and $PM_{10}$ by EF

| | Media | Chemical | Enrichment degree |
|---|---|---|---|
| EF < 2 | $PM_{10}$ | Co, Ti, Al, Ni, Fe, V, Cr, Na | Minimal enrichment |
| | Soil | Na, Ti, Mg, Al, Sr, Co, Cr, Ca, V, Fe, Li, Ni, Mo | |
| EF = 2–5 | $PM_{10}$ | Sr, Mn, Ca | Moderate enrichment |
| | Soil | Mn | |
| EF = 5–20 | $PM_{10}$ | Li, Mg, Cu | Significant enrichment |
| | Soil | Cu, Zn | |
| EF = 20–40 | $PM_{10}$ | Mo | Very high enrichment |
| | Soil | Pb, Sb | |
| EF > 40 | $PM_{10}$ | Zn, Pb, Sb, As, Cd | Extremely high enrichment |
| | Soil | As, Cd | |

**Table 6** Rank order of heavy metal contamination by Igeo and EF methods

| Method | Medium | Ranking of contamination in decreasing order | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Igeo | $PM_{10}$ | Cd | As | Sb | Pb | Zn | Mo | Cu | Mg | Li | Ca | Mn | Sr | Na | Cr | V | Fe | Ni | Al | Ti | Co |
| | Soil | Cd | As | Sb | Pb | Zn | Cu | Mn | Mo | Ni | Li | Fe | V | Ca | Cr | Co | Sr | Al | Mg | Ti | Na |
| EF | $PM_{10}$ | Cd | As | Sb | Pb | Zn | Mo | Cu | Mg | Li | Ca | Mn | Sr | Na | Cr | V | Fe | Ni | Al | Ti | Co |
| | Soil | Cd | As | Sb | Pb | Zn | Cu | Mn | Mo | Ni | Li | Fe | V | Ca | Cr | Co | Sr | Al | Mg | Ti | Na |

According to the geo-accumulation index, the ranking of these contaminating metals was basically the same in $PM_{10}$ as in soil. Moreover, the concentration of contaminating metals in $PM_{10}$ was generally greater than the concentrations in the soil (Fig. 3). These data are consistent with the air particulate matter being the source of the contamination in the soil.

To verify this inference, a correlation analysis was performed examining the relationship between the contamination levels of the metals in the soil with the contamination levels of the metals in the air particulates. The correlation coefficient (Spearman's rho) of all the elements in $PM_{10}$ and soil was 0.938 which is a significant correlation.

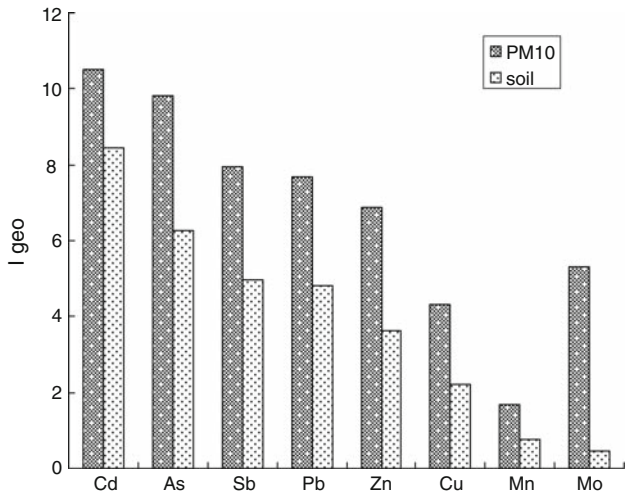


**Fig. 3** Comparison of Igeo values in $PM_{10}$ and soil

Table 7 shows the correlation coefficients between concentrations of the main heavy metals in the 23 soil samples. Significant correlations were found among Cd, As, Sb, Pb, Zn and Cu again suggesting that they came from the same source.

## Discussion

We can see that the most serious heavy metals in soil are Cd, As, Sb, Pb, Zn and Cu. Compared with previous study in China (Chao et al. 2007; Long et al. 2006), the As and Cd contamination in Dachang soil is significant (See Table 8). We also can see the total Cd contamination in Dachang soil (50.4 mg/kg) is near to the Cd concentration found in paddy soil in Jinzu River area (68 mg/kg) where the infamous itaiitai disease occurred (Yoshika 1970). Cd and As have been determined to be carcinogens both by the International Agency for Research on Cancer (IARC) and by the United Stated Environmental Protection Agency (US EPA). These data suggest that safety issues associated with the use of this soil should be carefully considered.

From Table 6, the concentrations of Cd, As, Sb, Pb, Zn and Cu appeared in the same rank order in both $PM_{10}$ and soil. However, the concentrations of some other elements, such as Mg, Mo, Ca and Fe differ in their ranking in the two media. This difference may be a result of absorption by plants of certain metals, which are micro-nutrient in plants.

By spot investigation and identification, the origin of the particulate matter in Dachang town is mainly the long-term

**Table 7** Correlation between the main contaminants of soil

| | As | Cd | Sb | Pb | Zn | Cu | Mn | Mo |
|---|---|---|---|---|---|---|---|---|
| As | 1.000 | | | | | | | |
| Cd | .972** | 1.000 | | | | | | |
| Sb | .560* | .598* | 1.000 | | | | | |
| Pb | .591* | .660* | .899** | 1.000 | | | | |
| Zn | .898** | .967** | .651* | .755** | 1.000 | | | |
| Cu | .785** | .785** | .437 | .499 | .772** | 1.000 | | |
| Mn | .398 | .524 | .222 | .253 | .565* | .336 | 1.000 | |
| Mo | .411 | .392 | .116 | .147 | .308 | .446 | .103 | 1.000 |

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

**Table 8** Compare contamination in Dachang soil with previous study

| mg $kg^{-1}$ | As | Cd | Cu | Pb | Zn | Reference |
|---|---|---|---|---|---|---|
| Soil near Dachang Town | 1295 | 50.4 | 156 | 1058 | 1379 | This study |
| Standards for China* | 25 | 0.3 | 100 | 50 | 250 | HJ332-2006 |
| Soil near a refinery plant in Shenyang, China | | 9.35 | 2021 | 1358 | 1280 | Chao et al. (2007) |
| Paddy soil near a refinery plant in Guixi, China | 33.7 | 2.37 | 122.9 | 18.9 | 42.0 | Long et al. (2006) |
| Paddy in Jinzu River area, Japan | | 68 | | 250 | 1300 | Yoshika (1970) |

* Farmland environmental quality evaluation standards for edible agricultural products, HJ332-2006

ore transportation. As observed, the vehicle loads are uncovered which will lead to pollution of the air and surrounding soil. Irrigation water of the arid farmland is mainly taken from water flowing down from the mountain. The metal contamination of this water is assumed to be negligible. Therefore, transportation becomes the most likely source of the contamination in the farmland soils.

The situation seems to call for taking measures to manage local traffic better in order to reduce or eliminate this source of pollution. Such action is not only necessary for protecting the farmland, but it is also necessary for protecting the inhabitants' health. $PM_{10}$ has a direct effect on health as result of respiration because of the small size of the particles and the effect of heavy metals on biochemical mechanisms. The soil heavy metal elements also may enter into the human body through the food chain. Therefore, the inhabitants of Dachang town are confronted with potentially serious heath risks. It is necessary for government and the local environmental protection department to develop and implement a coordinated and effective regulatory program.

## Conclusions

(1) The soil around Dachang town is mainly contaminated with Cd, As, Sb, Pb, Zn, Cu and Mn. According to their geological accumulation index, the rank order of this pollution is Cd > As > Sb > Pb > Zn > Cu > Mn, with concentrations of Cd, As, Sb, Pb, Zn, Cu and Mn up to 29.0, 776, 36.8, 582, 1379, 156 and 1476 mg $kg^{-1}$, respectively. The carcinogens Cd and As were present at levels 48-fold and 26-fold above the of Chinese limit values (GB15618-1995) for these materials in soil.

(2) The air in Dachang town was also polluted. The maximum contents of TSP and PM10 were nearly 30 and 10 fold higher than the Chinese limit value (GB3095-1996), respectively. The $PM_{10}$ samples were also polluted by Cd, As, Sb, Pb, Zn, Mo, Cu and Mn at levels higher than in the soil. Analysis indicated that there was a significant correlation between soil contamination and airborne particulate contamination, suggesting that the latter was a likely source of the former.

(3) The source of the pollution in this town likely comes from the vehicular transportation of ore. Better control of the transportation practices would do much to improve the environment of this town.

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