Comparison of Source Identification of Metals in Road-Dust and Soil

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Abstract

Source identification of toxic metals is very critical for pollution prevention and human health protection. Many studies only use either road dust metal data or soil metal data to evaluate metal contamination and identify pollution sources, and this may lead to the exclusion of some important information. In this study, the differences of metal spatial distribution and source identification between road dust and associated soil in an industrial area were investigated.

Results indicate the metal concentrations in road dust were generally higher than those in soil. Based on the average concentrations, the order for dust metal concentrations was Fe>>Zn>>Pb>Cu>Cr>Ni. The order for soil metal concentrations was slightly different, namely Fe>>Zn>>Cu~Pb>Ni>Cr. The spatial distributions of metals in the road dust were very different from those in the soil, except for Fe. The GIS results indicate that elevated levels of Fe, Zn, and Pb were present in road dust near a steel plant. High concentrations of Cu, Cr, and Ni appeared at a road intersection. Elevated metal concentrations of Fe, Zn, Pb,

Cu, and Cr were present in soil around the steel plant. A coal-fired power plant did not seem to be a significant metal source in this study. Significant correlations for dust metals imply that these were well mixed in the study area. The metal sources identified by PCA with soil metal data were obviously different from those identified with road dust metal data. When road dust metal data were used, the changes of PCA analyzed areas slightly influenced the source identification. The PCA results were obviously influenced by changes of analyzed areas when soil metal data were used.

Keywords: Road dust; Soil; Heavy metal; GIS; Multivariate analysis

1. Introduction

Road dust and soil often contain high concentrations of toxic metals. The possible sources of metals include traffic emissions (exhausts, wear and tear of tires, brake lining abrasion, and automobile body and yellow paint abrasion), waste incinerators, steel plants, smelters, foundries, metal manufacturers, power generation plants, and atmospheric deposition of dust and particulates. Bruckard et al. (2005) reported that particle size distribution in an electric arc furnace was bi-modal, with peaks at about 0.3 and 1.4 μ m. The largest particle of the fine particle aggregates was about 300 μm; the aggregated EAFD should quickly settle and sorb onto road dust. Kittelson (1998) indicates that most of the particles emitted by engines range from 50 nm to 1000 nm. These small particles can quickly coagulate with particles and sorb onto dust. Road dust and soil are the long-term recipients of metal particulates from different sources. However, the particulates may also re-suspend to the atmosphere by wind erosion and enter the human body by respiration. Residents may also be exposed to metals through the food chain, resulting in an

accumulation of metals in their bodies. High blood metal levels attack neurological functions and may affect intelligence and behavior (USEPA, 1994).

Source identification is critical for pollution prevention. The metal sources for road dust and soil metals are complicated. Many approaches have been employed for source identification including the GIS technique and multivariate regression. The GIS technique can overlap the metal contour map and the maps that locate the industry, road, and other potential pollution sources (Imperato et al., 2003; Li et al., 2004; Lee et al., 2006; Zhang, 2006). The multivariate statistical approaches applied to determine pollution sources include correlation coefficient analysis (CA), principal component analysis (PCA), and cluster analysis (Banerjee, 2003; Lee et al., 2006; Tokalıoğlu and Kartal, 2006; Zhang, 2006; Dragovic et al., 2008).

Many studies only use either road dust metals (Banerjee, 2003; Yongming et al., 2006; Tokalıoğlu and Kartal, 2006) or soil metals (Imperato et al., 2003; Lu et al., 2003; Ahmed and Ishiga, 2006; Lee et al., 2006; Zhang, 2006; Li et al., 2007; Dragovic et al., 2008) to evaluate environmental quality and identify metal sources. Even though several studies have used dust and soil samples at the same time (Li et al., 2001, Al-Khashman, 2004), there are limited studies on comparisons of metal distribution and source identification between road dust and soil.

Road dust and associated soil samples in a selected industrial area were collected and six metals (Fe, Zn, Pb, Cu, Cr, and Ni) were analyzed. The aims of the study were (1) to compare the spatial distribution of metals in road dust to that in soil; (2) to compare the metal sources identified by multivariate regression by using road dust and soil metal data; (3) to evaluate the influences of PCA analyzed areas on results of source identification.

2. Materials and Methods

2.1 The study area

The study area is located in the western side of central Taiwan and near the Taiwan Strait (Fig.1). The total area is approximately 71 km^2. Figure 1 shows the location of several major pollution sources including a steel plant, a coal-fired power plant, an industrial park, and main roads. The steel plant was established in 1993 and annual steel production is estimated at one million tons. The electric arc furnace process is the principle process for steel production and scrap iron is the feedstock. The coal-fired power plant was established in 1983 and electricity production is about 468.8 million kilowatts. The industrial park contains machinery, casting, electronics, food-processing, and asphalt and textile industries. From June to August, the prevailing wind direction is southeast. During the rest of the year, the prevailing wind directions are north and northeast. During 1996-2005, the average wind speed, temperature, relative moisture, and annual precipitation rate were 4.9m, 23.1 °C, 77%, and 1358 mm, respectively.

2.2 Road dust and soil sampling and metal analysis

A systematic sampling strategy was conducted and 28 sampling sites were selected as shown in Fig. 1. A road dust sample and associated soil samples were collected in March 2006. Clean plastic brooms and brushes were used to collect the dust samples (Ashbaugh et al., 2003; Banerjee, 2003; Yongming et al., 2006). Four dust sub-samples collected within 20 m from each sampling site were mixed thoroughly to make up a composite dust sample. Stainless shovels were used to collect the soil samples from a depth of 2-10 cm. The soil surface layer was removed before sampling. In addition, five soil sub-samples from each

sampling site were mixed thoroughly to make up a composite soil sample. All samples were put in airtight polyethylene bags and taken back to the laboratory. Generally, metal concentrations increase with a decrease in the size of dust and soil particles (Fergusson and Ryan, 1984; Lee and Touray, 1998). In this study, dust and soil with particle size < 63 um (silt and clay) were selected to measure their metal concentrations (Stone and Marsalek, 1996; Bounds and Jobannesson, 2007). Before analysis, all samples were air-dried and passed through a 63 μm sieve. All samples were digested with *aqua-regia* (3:1 HCl/HNO_3, v/v) and analyzed by atomic absorption spectrometry (Perkin Elmer 500) to determine the concentrations of Fe, Zn, Pb, Cu, Cr, and Ni. Standard metal solutions used for the analysis were obtained from J.T. Baker (USA). For quality assurance, the certificated reference material, CRM-141R (calcareous loam soil; BCR, Belgium), was used for the evaluation of measurement precision. The recovery values of metals of the standard reference material were all >80% of the certified values provided by BCR. The reagent blank and duplicate of CRM-141R were also conducted in the analytical program to evaluate the contamination, precision, and bias. The precision in the analysis was generally <10%.

2.3 Spatial distribution of metals

A GIS map showing the main road, power plant, steel plant, and industrial park was generated by using ArcView software. A contouring mapping software, Surfer (version 6.0, Golden Software Inc., Colorado), was employed to produce contour maps of metal concentrations. The GIS map and contour maps were overlaid to investigate the relationships of metal distribution in dust and soil samples and evaluate the potential metal pollution sources.

2.4 Statistical analysis

The dust and soil metal concentration data were analyzed by correlation coefficient analysis and principal component analysis using SPSS (SPSS Inc., Chicago, Illinois, USA) according to the SPSS 16.0 User's Guide (SPSS, 2007). The correlation coefficient measures the strength of a linear relationship between two variables. Principal component analysis (PCA), using a minimum number of significant components to explain statistical variance, can be used to investigate the latent relationships between metals and to investigate the pollution sources (Harrison et al., 1997). In this study, PCA with varimax rotation and retention of principal components with eigenvalues >1 were applied to identify the possible metal sources.

3. Results and Discussion

3.1 Metals in road dust and soil

Table 1 indicates that the metal concentrations in the road dust generally were higher than those in the soil in the study area were. Based on the average concentrations, the order for dust metals was Fe>>Zn>>Pb>Cu>Cr>Ni. The maximum concentrations of dust Fe was as high as 58,313 mg kg^{-1}. The maximum dust Zn concentration in this study was 2339 mg kg^{-1}, which exceeds Taiwan EPA's Soil Pollution Control Standard (Zn: 2000 mg kg^{-1}). The maximum Pb concentration of 447 mg kg^{-1} was above the Taiwan's Soil Pollution Monitoring Standards for edible vegetables (300 mg kg^{-1}). The concentrations of other dust metals were below the Taiwan EPA's Soil Pollution Control Standards (Cu: 400, Cr: 250, and Ni: 200 mg kg^{-1}) (Taiwan EPA, 2008).

The ratio of C/C_{min} is used to judge whether metal sources are anthropogenic or natural. In this study, the C_{max}/C_{min} ratios for dust Cr (site 17), Cu (site 22), Zn (site 12), and Pb (site 27) were as high as 53.7, 37.7, 19.7, and 8.8, respectively. This implies that these dust metals came from anthropogenic sources. The C_{max}/C_{min} ratio for dust Fe was only 2.6. However, the difference between the highest (site 22) and lowest (site 1) concentrations of dust Fe was 35,563 mg kg^{-1}, which indicates that there was an anthropogenic source for dust Fe.

Based on the average concentrations of metals, the order for soil metals was slightly different from that for dust metals. The order for the soil metals was Fe>>Zn>>Cu~Pb>Ni>Cr (Table 1). The ratios of C_{max}/C_{min} for Zn (site 27), Cr (site 4), and Pb (site 7) were 5, 4.5, and 4, respectively. This implies that soil Zn, Cr, and Pb came from anthropogenic sources.

The dust metal concentrations in the study area were compared with those in related industrial areas elsewhere in the world. Table 2 shows dust metal concentrations in related industrial areas elsewhere in the world. Fe, Zn, and Cu levels in this study area were higher than those in other industrial areas, except for Zn and Cu in Delhi (Banerjee et al., 2003). The concentrations of other metals in this study area were close to those of other studies. However, from the above information, the dust metals in this area may pose health risks for residents, and further investigation should be conducted to identify the possible metal sources.

3.2 Spatial distribution patterns of metals in road dust and soil

The GIS mapping technique was used to generate the spatial distribution of metals in road dust and soil and to identify the possible metal sources. Figure 1 shows the possible

metal sources including a steel plant (site 27), coal-fired power plant (site 24, 25, 26, and 28), an industrial park (site 14 and 15), main roads (R1, R2, and R3), and a road intersection (site 22). Figure 2 illustrates that spatial distributions of road dust metals are different from those of soil metals, except for Fe. The concentration contours of each metal also were different in the road dust as well as in the soil.

The spatial distributions of dust metals were evaluated. The highest concentration of dust Fe appeared close to the steel plant and the road intersection (Fig. 2a). Elevated concentrations of dust Zn were found at the steel plant, the main roads (R1, R2, and R3), and the industrial park (Fig. 2c). The hotspot for Pb was at the steel plant (Fig. 2e). Elevated concentrations of dust Cu, Cr, and Ni were found at the road intersection (Figs. 2g, 2i, and 2k). A hotspot for Ni was at the industrial park.

Road dust Fe and Zn possibly originated from the emissions of electric arc furnace dust (EAFD). Several studies have reported that EAFD contains high concentrations of Fe, Zn, Pb, and Cr (Sammut et al., 2006; Fernández-Olmo et al., 2007; Geagea et al., 2007). Many studies indicate that road dust Pb is usually related to vehicular emissions. However, in this study, high concentrations of dust Pb were found near the steel plant. It is possible that Pb is an intergradient for Fe-Pb alloy, and steel plant fly ash may contain high levels of Pb (Fernández-Olmo et al., 2007; Geagea et al., 2007). Leaded gasoline has been prohibited in Taiwan since 2000; therefore, it is not a significant source of Pb in the road dust.

Elevated concentrations of dust Fe, Zn, Cu, Cr, and Ni were found around the road intersection (site 22). The road intersection had a traffic light and a heavy traffic volume. Vehicles accelerated and braked frequently at this intersection. The serious wear and tear of tires and brake linings may produce high concentrations of Fe, Zn, Cu, Cr, and Ni (Li et al., 2001; Adachi and Tainosho, 2004; Iijima et al., 2007). The wear of yellow traffic paint may also generate dust Cr ($CrPbO_4$) (Adachi and Tainosho, 2004). Even though EAFD may

contain significant amounts of Cr (Fernández-Olmo et al., 2007; Geagea et al., 2007), the dust Cr around the steel plant was not as high as at the road intersection. The fly ash of coal-fired power plants reportedly contains metals like Fe, Ni, Cr, Cu, Zn, and Pb (Reddy et al., 2005; Gómez et al., 2007). However, the coal-fired power plant in this study does not seem to be a significant metal source in the study area.

The spatial distributions of soil metals were also evaluated. Hotspots of soil Fe, Zn, Pb, and Cr were observed around the steel plant (Figs. 2b, 2d, 2f, 2h, and 2j). Several sites with elevated concentrations of soil Cu were found in the study area (site 3, 10, 23, and 27) (Fig. 2h). This implies that there were several sources for soil Cu. Elevated Cr and Ni concentrations were found near site 4 (Fig. 2j and 2l). However, there was only a gas station on site 4, and gas stations do not seem to be a major source for Cr and Ni. Whether there were factories on this site previously should be confirmed.

The differences between the spatial distribution patterns of metals in dust and those in soil can be attributed to the metal speciation in dust and physiochemical properties of soil. Dragović et al. (2008) indicated that distributions of soil metals were influenced by their physiochemical characteristics, organic matter, and clay. In this study, similar spatial distributions of Fe were found in the road dust and the soil. This is because most dust Fe from EAFD is bound with Fe-Mn oxide and residual phases (Lu et al., 2003; Sammut et al., 2006) and tends to accumulate in soil. High concentrations of dust Zn were found around the steel plant and main roads. However, elevated concentrations of soil Zn only appeared around the steel plant and not on roads. This is because Zn (up to 63%) in EAFD is associated with the residual phase (Sammut et al., 2006). In contrast, Zn in road dust is associated with the mobile phases (the carbonate and Fe-Mn oxide phases) (Li et al., 2001).

Similarly, high levels of dust Pb were present around the steel plant, the main roads, and site 4. High levels of soil Pb only appeared at the steel plant. The different Pb speciation

can be used to explain the different soil Pb distribution. Laforest and Duchesne (2006) reported that about 50% of Pb in EAFD of a stainless steel plant was associated with the immobile phases (Fe-Mn oxide, silica glass, and crystallized Fe oxides). In contrast, most of Pb in road dust was bound to the carbonate and Fe-Mn oxide phases (Li et al., 2001). The hotspots of dust Cu were at the road intersection (Fig. 2g) and elevated concentrations of soil Cu was found around site 9 and 23 (Fig. 2h). High levels of dust Cr and Ni were found at the road intersection (Figs. 2i and 2k) and elevated levels of soil Cr and Ni were found around the steel plant and site 4 (Figs. 2j and 2l). The reason for the difference between distribution of Cu, Cr and Ni in dust and that in soil is unclear.

Road dust and soil are believed to be the long-term recipients of metal particulates from different sources and are important metal pollution sources that may pose health risks for residents. As wind, water, and traffic (wheels of vehicles) could transport road dust and significantly affect the distribution of dust metals, more dust metal data should be collected to investigate their influence on distribution.

3.3 Correlation coefficient analysis

Correlation coefficient analysis (CA) was conducted to evaluate the inter-element relationships in the road dust and the soil. The intra-element relationships between the soil and dust were also investigated. Table 3 indicates that two groups of dust metals are significantly positively correlated with each other: Fe, Zn, Pb, Cu, and Cr ($p<0.01$), and Cu, Cr, and Ni ($p<0.01$). The high correlations of soil metals show some differences. Three groups of soil metals had positively significant correlations with each other: Zn, Pb, and Cr (<0.01), Fe and Ni (<0.05), and Cu, Cr, and Ni ($p<0.05$).

For the road dust metals, the significant correlations between dust metals

(Fe-Zn-Pb-Cu-Cr; Cu-Cr-Ni) indicate that dust metals were probably well mixed through transportation by winds and by vehicle wheels in this study area. Figure 2 indicates that dust Fe, Zn, Pb, Cu, and Cr were related with metal sources of the steel plant and the road intersection (site 22). The high correlations of dust Cu, Cr, and Ni might have come from a common metal source from the road intersection.

Fig. 2 shows that soil Zn, Pb, and Cr were associated with the steel plant. Both elevated concentrations of Fe and Ni appeared in the soil at the steel plant and site 4 (Figs. 2a and 2k). Cu, Cr, and Ni show high correlations in both the road dust and the soil. However, Figure 2 shows that these three metals in the road dust were associated with the road intersection (site 22). In contrast, the high correlations of Cu, Cr, and Ni in the soil are associated with the steel plant and site 4. This suggests that even though the same metals with high correlations were found in the road dust and the soil, their major metal sources may be different.

Table 4 shows the correlations of each tested metal (Fe, Zn, Pb, Cu, Cr, and Ni) between the road dust and soil. Only Fe ($r^2 = 0.21$, $p<0.05$) and Pb ($r^2 = 0.32$, $p<0.01$) have significant correlations between the road dust and the soil. The hotspots for Fe were around the steel plant and road intersection, while those for Pb were found around the steel plant and site 4. The high correlations of both Fe and Pb between the road dust and site 4 resulted from two or more common metal sources. GIS mapping should be employed to help explain the results of statistic analysis.

3.4 Principal component analysis

The road dust metal data were analyzed with PCA to identify the potential metal source (Table 5). Factor 1 explained 39.3% of the total variance and had its highest loadings on Zn

and Cu. The metal spatial distribution indicates that Zn and Cu were primarily emissions from vehicles (Fig. 2). The second factor, which explained 28.1% of the total variance, had high loadings on Ni, which are primarily related to the road intersection (site 22) and the industrial park (site 15). The third factor accounted for 22.9% of the total variance and had a high loading on Pb, which was primarily related to the steel plant source and site 4. High concentrations of Fe were observed around the steel plant and the road intersection; however, due to the low variations of Fe concentrations in this study area, Fe sources were not identified, even though these were strong sources. Therefore, when PCA employs the variation for source identification with low variations of metals, the metal sources cannot be identified, even if high concentrations of metals are present. When PCA is employed for source identification, the spatial distributions of metals should be employed to assist identification of pollution sources.

Table 5 also indicates the source identification by PCA using soil metal data. The metal sources identified by PCA with soil metal data were obviously different from those identified with road dust metal data. The first factor explained 35.8% of the total variance and had the highest loadings on Cr and Ni, which were primarily related to the steel plant and site 4. The second factor accounted for 29.3% of the total variance and had high loadings on Zn and Pb, which were primarily emissions from the steel plant. The third factor explained 18.1% of the total variance and had high loading on Fe, which was a primary emission from the steel plant. The results indicate that metals from the steel plant significantly contaminated the soil.

The influences of the changes of the analyzed area range on PCA results were investigated. The study area was divided into two sub-areas: SA1 (far from the steel plant: sites 1 to 12) and SA2 (close to the steel plant: sites 13 to 28). Table 5 indicates that the PCA results of the road dust metal data analysis for the study area and the two sub-areas

(SA1 and SA2) were very similar. The similar PCA results may be explained by the high mixing and diffusion levels of the dust metals in this area. The high mixing and diffusion levels can also be observed in correlation analysis results (Table 3) that show high correlations for two metal groups: Fe-Zn-Pb-Cu-Cr and Cu-Cr-Ni. In contrast, when the soil metal data were analyzed, the PCA results for the different analyzed area ranges (the total area and the sub-areas) were obviously different, possibly because of low mixing and diffusion levels of the soil metals in this study area. The PCA results using soil metal data were obviously influenced by the local metal sources in the sub-areas.

4. Conclusions

The metal concentrations in road dust were generally higher than in soil. Based on the average concentrations, the order for dust metals was Fe>>Zn>>Pb>Cu>Cr>Ni. The order for soil metals was slightly different: Fe>>Zn>>Cu~Pb>Ni>Cr. The concentration distributions in dust were very different from those in soil for all tested metals, except for Fe. The GIS results indicate that elevated dust levels of Fe, Zn, and Pb were present near the steel plant. High concentrations of Cu, Cr, and Ni were found around the road intersection. Elevated soil metal concentrations of Fe, Zn, Pb, Cu, and Cr were present around the steel plant. The coal-fired power plant did not seem to be a significant metal source in this study.

Significant correlations for dust metals imply that dust metals were probably well mixed in this study area. PCA results indicate that the steel plant, road, and intersection were the major metal sources in this area. However, when road dust metal data were employed, their characteristic metals for source identification were different from those when soil metal data were employed. When road dust metal data were used, the changes of the sampling area slightly influenced the source identification. The changes of analyzed area ranges obviously

influenced the PCA results when the soil metal data were used as inputs.

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Table Captions

Table 1 Dust and soil metal concentrations in the study area (N=28)

Table 2 Comparison of mean concentrations (mg kg^{-1}) of metals of road dusts in different industrial areas.

Table 3. Correlation coefficients of heavy metals in road dust and soils (Correlation coefficient r, n= 28)

Table 4 Correlation coefficients of heavy metal between road dust and soils (Correlation coefficient r, n= 28)

Table 5 Principal components analysis for dust metals and soil metals in the whole study area and sub-areas

Figure Captions

Fig. 1. The sampling sites in the study area (n=28)

Fig. 2. Spatial distribution of metals (mg kg^{-1}) of the road dust and soil in the study area. (a) Dust Fe, (b) Soil Fe, (c) Dust Zn, (d) Soil Zn, (e) Dust Pb, (f) Soil Pb, (g) Dust Cu, (h) Soil Cu, (i) Dust Cr, (j) Soil Cr, (k) Dust Ni, (l) Soil Ni.

Table 1 Dust and soil metal concentrations in the study area (N=28)

	Dust					Soil					Ratio mean
Metal	Range	Medium	Mean	SD	Max /min	Range	Medium	Mean	SD	Max/ min	Dust/ oil
Fe	22750-58313	41893	40851	8928	2.6	17992-29420	23120	23388	3169	1.6	1.7
Zn	119-2339	1171	1181	562	19.7	114-811	194	234	130	7.1	5.0
Pb	51-447	156	189	114	8.8	21-136	36	47	29	6.5	4.0
Cu	7-264	118	121	61	37.7	19-91	47	50	25	4.8	2.4
Cr	3-161	80	76	39	53.7	9-49	14	17	8	5.4	4.5
Ni	17-103	48	51	22	6.1	23-53	31	31	6	2.3	1.6

Ratio: Mean metal Conc. in dust/Mean metal Conc. in soil

Table 2 Comparison of mean concentrations (mg kg^{-1}) of metals of road dusts in different industrial areas.

	Fe	Zn	Pb	Cu	Cr	Ni	Reference
This study	22750-58313	119-2339	51-447	7-264	7-264	17-103	This study
Delhi, India[1]	NA	3700	150	1300	9000	980	Banerjee et al., 2003
Karak Industrial Estate, Jordan	25.1-84.7	1.8-123.2	1.4-609.4	0.8-80.2	NA	2.7-5.5	Al-Khashman, 2004
Dhaka city, Bangladesh[2]	NA	169	54	105	136	35	Ahmed and Ishiga, 2006
Kayseri (Turkey)	NA	32.6-733	27.9-312	11.8-144	17.2-81.2	16.1-217	Tokalıoğlu and Kartal, 2006

estimated from Figures in their article.

average values

Table 3. Correlation coefficients of heavy metals in road dust and soils (Correlation coefficient r, n= 28)

Dust	Fe	Zn	Pb	Cu	Cr	Ni
Fe	1					
Zn	0.84**	1				
Pb	0.81**	0.70**	1			
Cu	0.66**	0.69**	0.64**	1		
Cr	0.66**	0.55**	0.70**	0.80**	1	
Ni	0.32	0.19	0.35	0.56**	0.54**	1
Soil	Fe	Zn	Pb	Cu	Cr	Ni
Fe	1					
Zn	0.29	1				
Pb	0.07	0.67**	1			
Cu	0.31	0.37	0.31	1		
Cr	0.36	0.51**	0.56**	0.44*	1	
Ni	0.41*	0.31	0.37	0.53**	0.84**	1

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

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

Table 4 Correlation coefficients of heavy metal between road dust and soils (Correlation coefficient r, n= 28)

	Fe	Zn	Pb	Cu	Cr	Ni
Dust\Soil	0.46*	0.20	0.57**	0.29	0.12	0.20

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

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

Table 5 Principal components analysis for dust metals and soil metals in the whole study area and sub-areas

	Total area (sites from 1 to 28)						Sub-area 1(sites from 1 to 12)						Sub-area 2 (sites from 13 to 28)					
	Dust			Soil			Dust			Soil			Dust			Soil		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Fe	0.71	0.26	0.54	0.25	0.06	**0.94**	0.70	0.38	0.49	0.51	0.60	-0.48	**0.77**	0.16	0.56	0.20	0.06	**0.97**
Zn	**0.94**	0.05	0.23	0.16	**0.89**	0.27	**0.80**	-0.23	0.43	0.70	-0.19	0.58	**0.89**	0.09	0.37	**0.92**	0.28	0.14
Pb	0.23	0.05	**0.96**	0.32	**0.87**	-0.13	0.27	0.21	**0.93**	0.23	0.10	**0.93**	0.41	0.11	**0.90**	**0.94**	0.22	0.12
Cu	**0.75**	0.60	0.11	0.62	0.21	0.29	**0.85**	0.43	0.09	0.15	**0.96**	0.10	**0.78**	0.56	0.24	0.41	**0.83**	-0.14
Cr	0.59	0.61	0.30	**0.84**	0.39	0.10	0.48	**0.70**	0.48	**0.88**	0.23	0.18	**0.64**	0.49	0.40	**0.88**	0.39	0.24
Ni	0.10	**0.96**	0.54	**0.94**	0.11	0.16	0.05	**0.95**	0.11	**0.92**	0.34	0.12	0.14	**0.97**	0.07	0.22	**0.90**	0.22
Var.(%)[1]	39.3	28.1	22.9	35.8	29.3	18.1	36.1	30.2	25.6	40.6	24.9	24.7	43.1	25.6	24.7	45.9	29.6	18.3
Cumul(%)[2]	39.3	67.4	90.3	35.8	65.0	83.1	36.1	66.2	91.8	40.6	65.5	90.2	43.1	68.7	93.4	45.9	75.6	93.8

[1]Var.: Variance

[2]Cum.: Cumulative

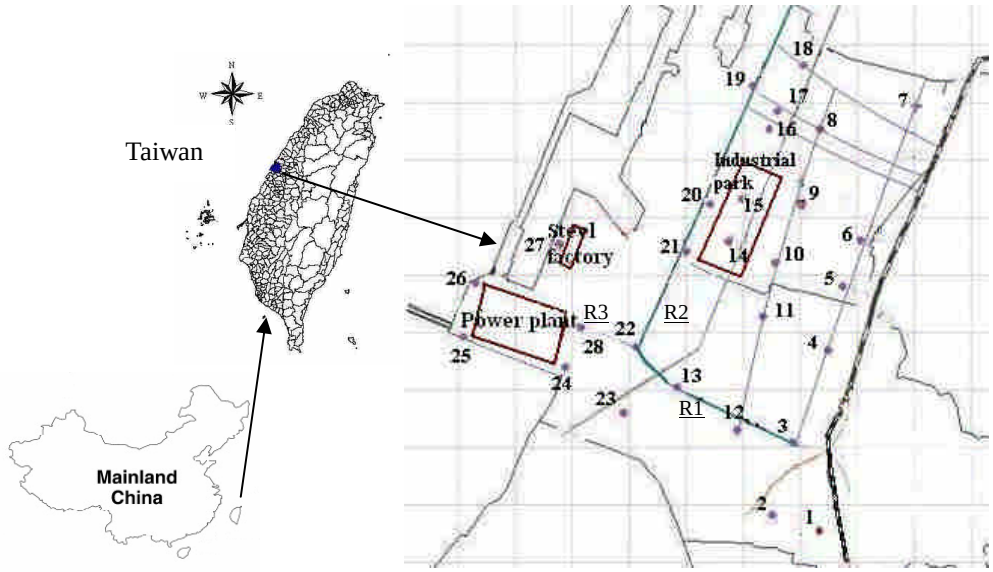

Fig. 1. The sampling sites in the study area (n=28)

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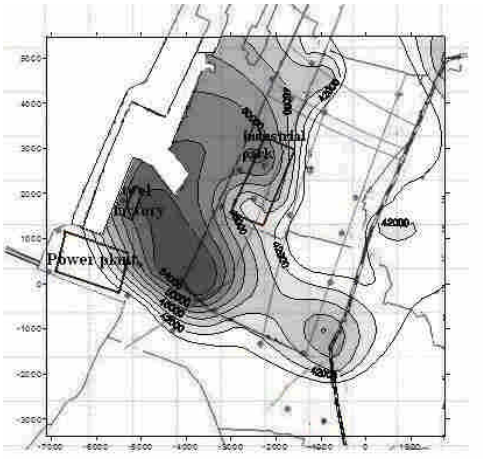
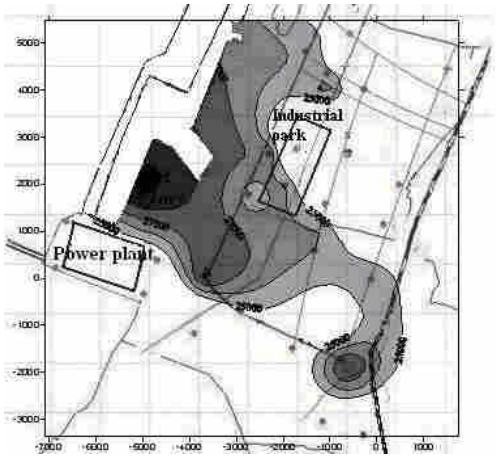
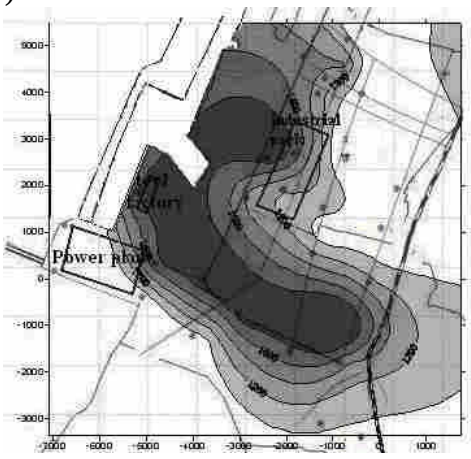


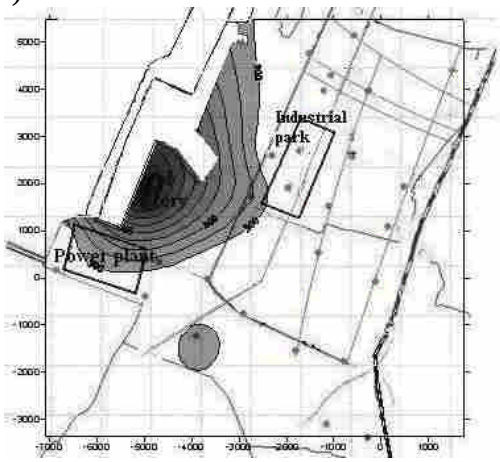
(a) Dust Fe



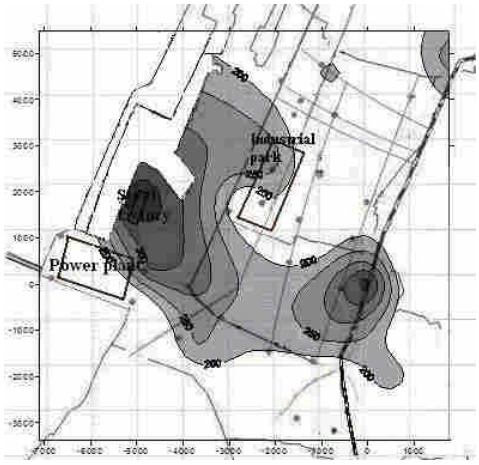
(b) Soil Fe



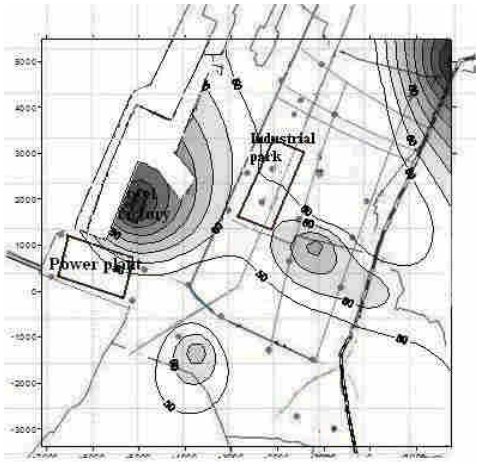
(c)Dust Zn



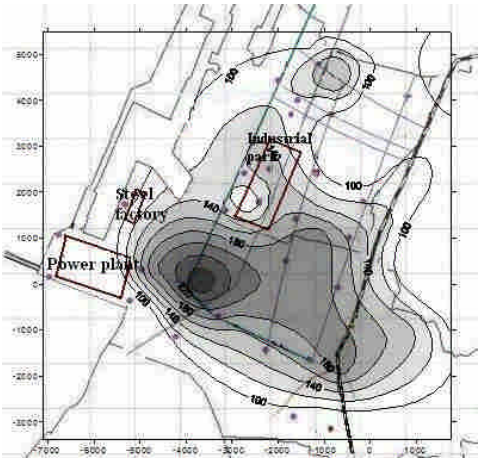
(d) Soil Zn



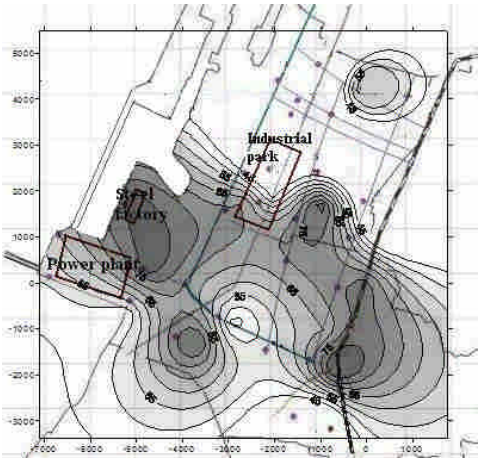
(e) Dust Pb



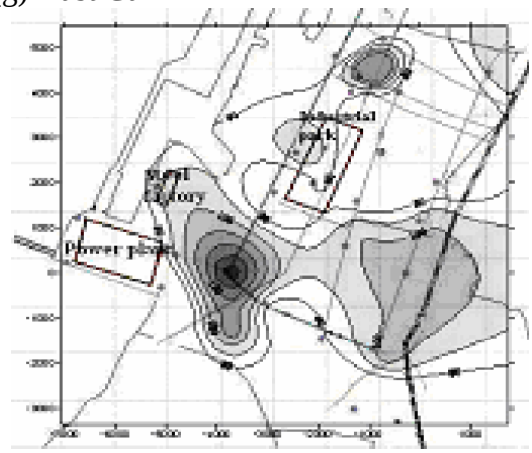
(f) Soil Pb



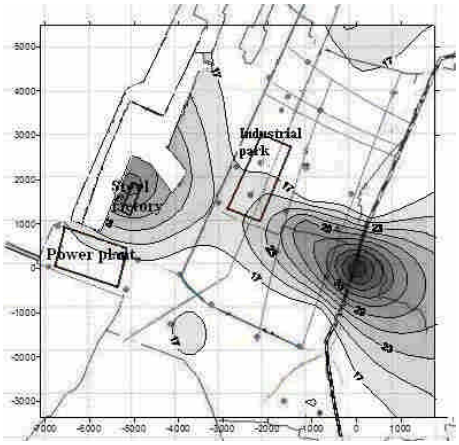
(g) Dust Cu



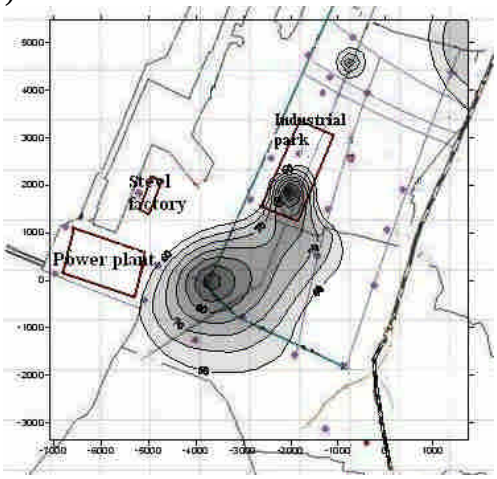
(h) Soil Cu



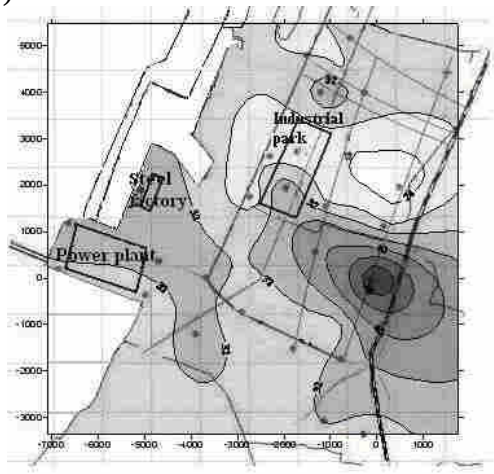
(i) Dust Cr



(j) Soil Cr



(k) Dust Ni



(l) Soil Ni

Fig. 2 . Spatial distribution of metals (mg kg^{-1}) of the road dust and soil in the study area.

(a) Dust Fe, (b) Soil Fe, (c) Dust Zn, (d) Soil Zn,(e) Dust Pb, (f) Soil Pb, (g) Dust Cu, (h) Soil Cu, (i) Dust Cr, (j) Soil Cr, (k) Dust Ni, (l) Soil Ni.

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