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Baseline Concentrations of Toxic Elements in Metropolitan Park Soils of Taiwan

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ABSTRACT

Twenty-four soil profiles were investigated at the urban parks in Taiwan to evaluate the contamination and sources of potentially toxic elements (Cd, Cr, Cu, Ni, Pb, Zn, As, and Hg). The experimental results indicted that a positive significant correlation existed between Pb and Zn (r = 0.38*, $p < 0.05$) and Ni and As (r = 0.35*, $p < 0.05$), and it suggests that these two groups of toxic elements were from different sources. Industrial activities in Kaohsiung city were considered to cause contamination with Cu (91.1 mg/kg in average) and Zn (126 mg/kg in average) in urban surface soils. High traffic flow in Taipei city leads a clear risk of Pb contamination (56.8 mg/kg in average) in the urban surface soils. Although observable concentrations of As (28.7 mg/kg in average) and Ni (12.8 mg/kg in average) were found in the recreational city, Yilan, most of both elements were still lower than the background levels in Taiwan and which are mainly released from parent materials, slate and argillite.

Keywords: baseline concentration, contamination, metals, potentially toxic elements, urban soil

INTRODUCTION

Urbanization and associated activities such as production and disposal of waste materials and rapid changes of land use has led to a clear accumulation of potentially toxic elements (PTEs) in urban soils, and further resulted in the degradation of environmental quality (Harrison *et al.* 1981; Thornton 1991; Chen *et al*. 2008). In recent years, the exploration of enrichment of PTEs in soils has become a pressing ecological and environmental concern. Human health, especially for children, can be severely affected by soils and soil-derived dust contaminated with PTEs in metropolitan areas. Furthermore, any contamination of urban soils might cause river and groundwater pollution because of the leaching processes of PTEs in the soils (Manta e*t al*. 2002; Bai *et al*. 2009). The geochemistry of PTEs in urban soils has been explored in many European cities (Manta *et al*. 2002; Madrid *et al*. 2006; Biasioli *et al*. 2007) and Asian cities (Wilcke *et al*. 1998; Li *et al.* 2004; Chen *et al*. 2005). The sources of the PTEs in these urban soils have been identified and their baseline concentrations have been established. Cd, Cu, Pb, Zn and Hg were frequently found in the urban soils of these cities.

Alloway (1990) and Adriano (2001) demonstrated that Cd, Cu, Pb, and Zn were good elements to evaluate contamination in urban soils because these metals were present in gasoline, car components, oil lubricants, factories and incinerator emissions. He *et al.* (2005) indicated that Cd, Pb, and Zn coming from traffic emissions were major contaminants in urban soils. Li *et al.* (2001) also found that the urban soils were highly contaminated by Pb and Zn from street dust in Hong Kong.

Taiwan has the second highest population density in the world (DGBAS/ROC 2006). Rapid urbanization and industrialization clearly leads to contamination in urban environments of Taiwan, particularly in the major cities. Due to the scarcity of land in Taiwan, most residential areas and metropolitan parks were built close to traffic arteries or near industrial areas, especially in Taipei and Kaohsiung wherein they are subject to clear contamination by PTEs from various sources (Hsieh 2001; Tsai 2007). The concentrations of PTEs in these urban soils are very spatially variable due to diverse human activities in Taiwan, but Pb, Zn and Cd were the most common PTEs in the soils (Chen *et al.* 2008). Moreover, more than 20 million vehicles have been registered in Taiwan, which were concentrated in Taipei and Kaohsiung. The enrichment and contamination of PTEs in the rural soils of Taiwan has been documented in some publications (Chen 1992; Chen *et al.* 1998, 2002). However, it is important to know the background concentrations of PTEs prior to evaluating their contamination levels in urban soils. The threshold values of PTEs in urban soils have not been established in different cities in Taiwan. In this study, we aimed to: (1) determine the concentrations of Cd, Cr, Cu, Ni, Pb, Zn, As, and Hg in the soils of metropolitan parks from different cities in Taiwan, and (2) identify the sources of the PTEs in these metropolitan park soils.

MATERIALS AND METHODS

Study areas

The cities of Yilan, Taipei and Kaohsiung, which are located eastern, northern and southern Taiwan, respectively, were selected in this study (**Fig. 1**). The relative population, vehicle number, and factory density are shown in **Table 1**. Yilan city is located on alluvial plain and it has less population and with low density of industrial factory due to inconvenience of traffic conditions. Taipei city is the capital, as well as trade center, with the largest population and high daily traffic flow in Taiwan. Kaohsiung is the second largest city and with the highest factory density in Taiwan. Due to many factories are located at this city, large daily traffic flow is also found.

We selected five major urban parks in the cities of Yilan,

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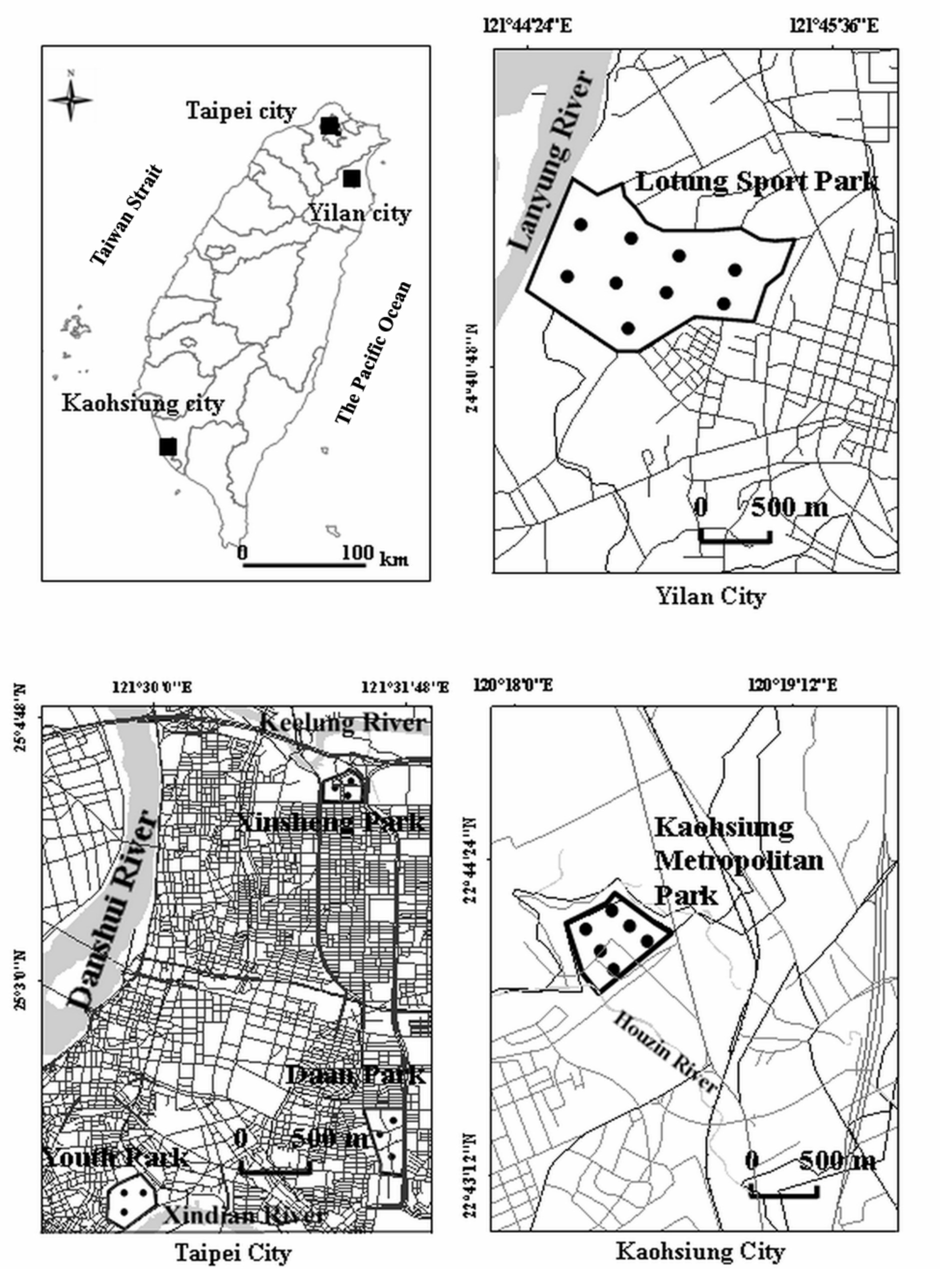

Fig. 1 Location of sampling sites at the urban parks of Yilan, Taipei and Kaohsiung in Taiwan.

Taipei, and Kaohsiung for investigating the situation of contamination of urban soils by PTEs (**Fig. 1**). Lotung Sports Park (LSP), constructed in 1986, was selected in Yilan city, and which borders the Lanyung River on the east. Daan Park (DP), Xinsheng Park (XP), and Youth Park (YP) were selected in Taipei city and which are 26, 20, and 24 ha in area, respectively. DP is located downtown, and YP and XP are bordered by the Keelung and Xindian Rivers, respectively. Kaohsiung Metropolitan Park (KMP), about 90 ha in area, was selected in Kaohsiung city, and which borders the Houzin River on the north, and it was established in 1996. The soils of urban parks were derived from sandstone alluvium in Taipei, from shale and argillite in Yilan, and from sandstone and shale alluvium in Kaohsiung, respectively (Ho 1988).

Soil sampling and chemical analyses

Nine soil profiles were excavated and investigated at the LSP in Yilan city, nine were at the DP, XP and YP in Taipei city (three soil profiles were randomly selected at each urban park), and six were at the KMP in Kaohsiung city (**Fig. 1**). We sampled horizon by horizon through the profile. The soils samples were air-dried at room temperature (20-22°C) in several days and then removed

Table 1 Geographic information of the parks in the studied cities.

City	Area	Population	IFD[a]	Vehicle number	MAT/MAR[b]	Studied parks	Age of park	Studied profile number
	km^2		plant/km^2		°C/mm		years	
Yilan	29.40	96,000	0.53	422,000	22/2,700	Lotung Sports Park (LSP)	24	9
Taipei	270.0	2,600,000	7.99	1,798,000	22/2,100	Daan Park (DP)	13	3
						Xinsheng Park (XP)	50	3
						Youth Park (YP)	50	3
Kaohsiung	153.6	1,510,000	11.5	1,627,000	24/1,700	Kaohsiung Metropolitan Park (KMP)	14	6

[a]: Industrial factory density, plant/km^2.
[b]: Mean annual temperature/Mean annual rainfall.

stones, artifacts or other debris. The soil samples were then passed through 2 mm sieve for further analyses in the laboratory.

Soil pH was measured in 1: 1 (w/v) soil: water suspension (McLean 1982). Particle size analysis was made by using the pipette method (Gee and Bauder 1986). Organic carbon (OC) contents were determined by using the Walkley–Black wet oxidation method (Nelson and Sommer 1982). Cation exchange capacity (CEC) was determined by leaching with neutral ammonium acetate (Thomas 1982). The *aqua regia* method involving concentrated HNO_3 and HCl (1: 3), using a conical beaker heated on a hot plate, was used as the standard method to digest the samples for the total analysis of Cd, Cr, Cu, Ni, Pb, and Zn (McGrath and Cunliffe 1985). Prior to the digestion by *aqua regia*, the organic matter was destroyed by concentrated (35%) H_2O_2. The Stewart and Bettany method was used for Hg analysis, digesting soils with concentrated H_2SO_4 and HNO_3 and 5% of $KMnO_4$ (Stewart and Bettany 1982). The Ganje and Rains (1982) method was used for As analysis extracted with 9.6M HCl. The concentration of PTEs in all solutions was determined by a flame atomic spectrometer (Hitachi Z-8100, Japan). For quality control and assurance in PTE analyses, standard reference materials such as No. 1646a (estuarine sediment) selected from the National Institute of Standards and Technology (NIST), USA, and No. 034 to 050 selected from Resource Technology Corporation (RTC), USA, were digested in triplicate and analyzed using the above mentioned procedures. Satisfactory recoveries of the PTEs were obtained from the standard reference materials, ranging from 86 to 116%. In each batch of soil samples, 10% of the total number of samples was analyzed in duplicate for checking precision.

Assessment methods of heavy metal contamination in the soils

The contamination index (P_i) suggested by Bai *et al.* (2009) was used to assess the soil contamination at the studied urban parks. A formula of contamination index (*Pi*) was described as follows:

$$P_i = C_i / C_f$$

where is the where C_i is the mean content of the substance, C_f is the reference value for the substance. The background concentrations in Yunnan Province were used as the reference baselines in this study. The following terminologies are used to describe the contamination index: $P_i \leq 1$ no contamination; $1 < P_i \leq 2$ low contamination; $2 < P_i \leq 3$ moderate contamination; Pi > 3 high contamination.

Statistical methods

Statistical analysis such as summary statistics and Pearson correlation analysis are performed with SPSS® for Windows, version 10.0 (SPSS 1999). Pearson correlation coefficients are calculated to examine the relations among the variables including the PTEs and soil properties.

RESULTS AND DISCUSSION

Soils characteristics

All studied soils have similar texture which was sandy loam (**Table 2**). The pH values were slightly acid to neutral. The organic carbon (OC) contents ranged from 2.30 g/kg to 20.7 g/kg. Slightly higher OC contents at the LSP of Yilan than those at parks of Taipei and Kaohsiung could be ascribed to slow decomposition rate of organic matter which resulted from seasonally high water table at LSP. The CEC values ranged from 5.50 cmol/kg to 11.9 cmol/kg which corresponded with OC contents in the soils. However, the heterogeneous distribution of CEC in the soil profiles of the KMP was probably attributed to mixing of soils from human activities. Additionally, the base saturation percentage ranged from 44.4 to 100%.

Concentrations of PTEs in the surface soils

Table 3 presents the mean, minimum, maximum, standard deviations, coefficient of variation (CV) and numbers of

Table 2 Means of selected physical and chemical properties of the urban soils.

Depth (cm)	Particle size distribution (%)			pH	OC[a]	CEC[b]	BS[c]
	Sand	Silt	Clay				
LSP in Yilan							
0-15	44.7	35.9	19.4	5.40	17.7	11.9	44.4
15-30	49.6	35.6	14.9	5.60	10.4	9.10	41.3
30-50	47.3	36.2	16.5	5.60	8.90	8.70	40.0
50-80	41.8	40.1	18.5	5.50	9.70	7.70	51.9
>80	44.4	36.6	18.5	5.50	10.0	8.90	50.1
DP in Taipei							
0-15	56.0	27.4	16.6	6.70	20.7	10.4	78.7
15-30	50.4	30.8	18.7	7.40	3.40	7.70	88.0
30-50	51.9	30.5	17.6	6.80	3.40	6.20	95.0
50-80	51.3	30.3	18.4	7.40	2.30	9.90	89.0
>80	54.1	29.4	16.5	7.00	4.10	8.20	100
XP in Taipei							
0-15	44.8	34.7	20.5	6.40	18.7	9.30	68.0
15-30	52.1	30.4	17.5	7.30	7.30	9.50	75.7
30-50	62.4	25.4	12.2	7.70	4.80	6.10	98.7
50-80	56.1	29.6	14.3	6.80	3.50	6.50	100
>80	66.4	22.5	12.5	7.20	2.90	5.90	98.3
YP in Taipei							
0-15	54.3	27.4	16.2	5.40	15.0	7.50	49.0
15-30	53.7	30.8	14.2	5.90	5.70	6.20	53.0
30-50	56.0	30.5	12.9	5.90	3.80	5.50	61.0
50-80	54.4	30.3	12.4	6.10	3.10	6.20	60.3
>80	53.9	29.4	13.9	6.10	3.00	7.00	57.3
KMP in Kaohsiung							
0-15	69.1	17.3	13.7	6.10	4.10	6.50	78.2
15-30	67.3	16.9	15.8	7.20	3.90	5.90	79.5
30-50	66.1	18.4	15.4	7.30	4.20	6.80	77.4
>50	67.7	20.0	12.4	7.00	5.20	5.70	70.0

[a]: Organic carbon, g/kg.
[b]: Cation exchange capacity, cmol/kg.
[c]: Base saturation percentage, %.

Table 3 Summary statistics of concentrations (mg/kg) of PTEs in the surface soils of the urban parks.

Parameters	Cd	Cr	Cu	Pb	Zn	Ni	As	Hg
LSP in Yilan								
Mean	0.04	27.1	20.8	25.0	92.7	28.7	12.8	0.02
Median	0.00	27.5	20.5	25.6	98.9	27.4	12.0	0.00
Min.	ND[a]	12.1	12.1	14.8	48.9	19.2	7.10	ND
Max.	0.17	40.4	32.6	29.9	111	38.7	20.7	0.09
S.D.	0.10	8.20	5.60	4.60	18.6	7.00	4.50	0.03
C.V.	-[b]	30.1	26.7	18.3	20.1	24.3	35.2	-
DP, XP, and YP in Taipei								
Mean	ND	27.5	17.5	37.0	90.0	23.4	5.26	0.04
Median	-	24.7	17.2	29.8	94.9	24.3	4.78	0.00
Min.	-	12.1	8.88	12.5	54.9	13.1	4.17	ND
Max.	-	46.9	25.6	56.8	113	31.3	6.91	0.21
S.D.	-	12.5	4.73	20.3	17.1	6.42	0.90	0.07
C.V.	-	45.3	27.1	55.0	19.0	27.5	17.1	-
KMP in Kaohsiung								
Mean	0.91	14.2	91.1	21.8	126	17.6	5.69	0.02
Median	0.13	14.3	80.7	19.3	74.3	16.7	5.67	0.01
Min.	0.00	10.4	76.4	8.12	57.6	16.0	4.83	ND
Max.	3.37	17.4	117	46.5	379	20.7	6.56	0.07
S.D.	1.56	2.42	19.3	13.4	125	1.90	0.74	0.03
C.V.	-	17.1	21.2	61.1	99.4	10.8	13.0	-
Elemental background concentration in Taiwan								
	3.00	50.0	35.0	60.0	120	60.0	18.0	0.50

[a]: Not detectable.
[b]: Not available.

samples of the PTEs concentrations in the surface soil of the urban parks. Except for little parts of the surface at the KMP, the concentrations of Cd and Cr in the soils were lower than the background levels reported by Chen et al. (2002). It indicated no potential contamination of Cd and Cr in the urban soils. The highest concentration of Cu (91.1 mg/kg) exceeded background level and with higher *Pi* value (between 2 and 4) (**Fig. 2**) were found in the surface soils at the KMP as compared with other urban parks, indicating moderate contamination of Cu at the KMP (Bai *et al.* 2009). High spatial variation of Pb and Zn at the KMP was observed by the large coefficients of variation in Pb and Zn concentration (**Table 3**). The variation of Pb and Zn concentrations found at the KMP probably resulted from our random sampling site, and the very high concentration of Zn was probably nearby major roads boarding the park, and this was consistent with the results of Borůvka *et al.* (2005) and Madrid *et al.* (2006). In addition, Manta *et al.* (2002) and Chen *et al.* (2008) indicated that high concentrations of PTEs associated with high CV could be considered as the occurrence of clear anthropogenic source. Therefore, we suggested that the sources of Pb and Zn in our case were anthropogenic inputs, especially in the soils of Kaohsiung and Taipei city. Additionally, *Pi* value of Zn was higher than 1 and less than 2 in the surface soils at the KMP, indicating low contamination of Zn here. Meanwhile, *Pi* value of Pb at the urbal parks in Taipei was higher than 1, suggesting potential contamination of Pb.

Cr, Ni and As have small CVs as compared with Pb and Zn (**Table 3**), and these PTEs did not exceed the background levels. Except slightly higher CVs were found for As at the LSP in Yilan and Cr at the urban parks in Taipei. Due to the relatively low concentrations of Cr, Ni and As and with small CVs of these PTEs; they could be reasonably considered as natural. However, few part of As and Cr resulted from anthropogenic inputs could not be excluded. The some parts of As concentration at the LSP and Cr at the urban parks in Taipei could be probably attributed to anthropogenic inputs. The anthropogenic inputs of As at the LSP probably be due to herbicides applying, and Cr at the urban parks in Taipei could be from vehicle component. The higher As contents in parent materials and anthropogenic inputs led to potential contamination of As at the LSP in Yilan (**Fig. 2**).

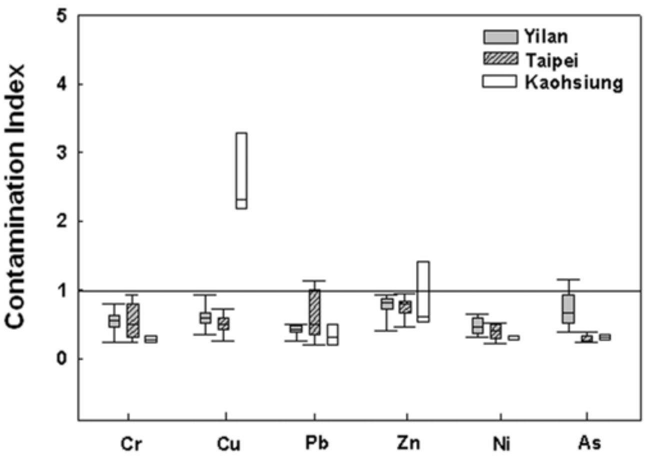

Fig. 2 Boxplot of the contamination index (*Pi* value) of the PTEs in the surface soils at the urban parks in each studied city. (The solid line inside the box represents the median; the boxes mark the 25th and 75th percentiles; the horizontal line outside the box, as it also called whisker, which are range excluding outliers.)

Variation of PTEs with soil depths

The PTEs coming from atmospheric depositions or other anthropogenic inputs were expected to be accumulated in the surface soils, and thus their concentrations generally decreased with soil depth (Biasioli *et al.* 2007). **Table 4** shows the depth distribution of PTEs in the studied soil profiles. The concentrations of Cd at most of urban parks were undetectable. The concentrations of Cr, Cu, Pb and Zn were highly variable in all soil layers, especially for Cr at the KMP, Pb at the YP, and Zn at the LSP, which suggested that the soils at the urban parks had undergone some disturbances from human activities. The soil mixing or disturbances probably occurred as the setting of some public installations in the parks. This was further confirmed by heterogeneous distribution of OC contents in soil profiles at LSP in Yilan city and at the KMP in Kaohsiung city (**Table 2**). In addition, the heterogeneous distribution of pH was also found at the DP in Taipei city. It therefore suggested that the soils at the urban parks had undergone some anthropogenic disturbances, and thus caused the significant heterogeneity of

Table 4 The PTEs concentrations (mg/kg) in a selected profile of each urban park.

Depth (cm)	Cd	Cr	Cu	Pb	Zn	Ni	As	Hg
LSP in Yilan								
0-15	ND[a]	27.1 ± 8.15[b]	20.8 ± 5.57	25.0 ± 4.58	92.7 ± 18.6	28.7 ± 6.99	12.8 ± 4.52	0.02 ± 0.03
15-30	ND	27.3 ± 10.4	19.4 ± 6.89	23.6 ± 8.37	91.6 ± 31.1	28.1 ± 10.3	12.6 ± 4.48	0.03 ± 0.06
30-50	ND	26.6 ± 12.9	19.6 ± 12.2	24.3 ± 14.4	83.5 ± 55.6	30.4 ± 15.9	12.6 ± 3.63	0.02 ± 0.02
50-80	ND	26.4 ± 14.1	21.2 ± 13.8	26.2 ± 15.4	96.0 ± 53.5	30.4 ± 18.8	12.7 ± 6.32	0.08 ± 0.15
>80	ND	27.3 ± 14.8	22.3 ± 12.4	30.4 ± 19.3	104 ± 52.7	32.0 ± 18.9	16.3 ± 17.8	0.20 ± 0.47
DP in Taipei								
0-15	ND	37.7 ± 12.1	14.1 ± 4.62	20.3 ± 7.69	83.3 ± 29.3	22.1 ± 8.13	5.28 ± 0.97	0.02 ± 0.03
15-30	ND	35.4 ± 14.0	14.5 ± 4.94	18.0 ± 6.87	72.8 ± 16.8	21.1 ± 5.60	6.09 ± 1.67	0.01 ± 0.02
30-50	ND	38.5 ± 8.85	14.1 ± 2.97	19.9 ± 4.53	79.2 ± 8.69	24.0 ± 4.36	7.16 ± 0.29	0.08 ± 0.13
50-80	ND	22.5 ± 11.8	11.3 ± 3.34	15.6 ± 1.99	64.4 ± 4.91	19.9 ± 3.97	7.24 ± 1.12	ND
>80	0.11 ± 0.19	28.2 ± 18.7	12.8 ± 1.87	18.2 ± 2.93	71.7 ± 11.6	21.8 ± 4.03	6.78 ± 0.90	ND
XP in Taipei								
0-15	ND	26.3 ± 11.1	22.4 ± 3.14	40.7 ± 24.3	88.2 ± 11.0	25.9 ± 4.70	5.48 ± 1.24	0.11 ± 0.11
15-30	ND	25.1 ± 7.58	24.6 ± 10.4	33.7 ± 11.8	88.3 ± 11.1	25.6 ± 7.04	7.07 ± 0.43	0.08 ± 0.07
30-50	ND	29.2 ± 6.37	14.8 ± 1.51	22.8 ± 1.47	87.8 ± 3.12	32.0 ± 4.83	6.29 ± 0.59	0.16 ± 0.18
50-80	ND	29.6 ± 3.20	17.7 ± 6.11	27.0 ± 5.85	90.3 ± 10.2	28.9 ± 4.58	6.29 ± 0.83	0.09 ± 0.08
>80	ND	28.6 ± 3.19	17.1 ± 6.32	26.4 ± 7.20	95.2 ± 9.20	28.7 ± 6.51	6.37 ± 1.23	0.10 ± 0.09
YP in Taipei								
0-15	ND	18.5 ± 8.84	14.9 ± 1.99	38.9 ± 15.5	94.0 ± 11.1	22.8 ± 8.42	6.74 ± 2.59	ND
15-30	ND	18.8 ± 6.79	13.5 ± 1.29	36.0 ± 34.1	77.4 ± 5.34	23.9 ± 7.13	5.92 ± 0.22	ND
30-50	ND	17.0 ± 10.1	12.6 ± 1.23	134 ± 210	70.1 ± 3.27	23.6 ± 5.42	5.95 ± 0.30	0.13 ± 0.23
50-80	ND	16.9 ± 10.2	12.4 ± 1.48	15.9 ± 8.42	68.8 ± 5.89	24.8 ± 4.60	6.28 ± 0.48	0.06 ± 0.10
>80	ND	19.7 ± 10.8	14.6 ± 2.92	42.0 ± 29.6	81.5 ± 19.0	21.8 ± 4.73	5.08 ± 0.89	ND
KMP in Kaohsiung								
0-15	0.79 ± 1.66	14.2 ± 2.42	91.0 ± 19.3	21.8 ± 13.4	126 ± 125	17.6 ± 1.90	5.69 ± 0.74	0.02 ± 0.03
15-30	ND	15.6 ± 5.07	46.5 ± 15.7	23.9 ± 17.4	84.7 ± 54.5	17.4 ± 1.71	5.61 ± 0.71	0.19 ± 0.35
30-50	1.61 ± 4.33	23.1 ± 29.3	39.4 ± 11.7	22.3 ± 20.6	86.1 ± 49.2	17.4 ± 3.26	5.65 ± 0.64	0.09 ± 0.18
>50	ND	8.82 ± 4.77	36.2 ± 13.4	11.5 ± 4.96	68.2 ± 22.9	18.9 ± 4.50	5.46 ± 0.94	0.01 ± 0.02

[a]: Not detectable.
[b]: Standard deviation.

vertical distribution of PTEs and soil properties through the soil profile.

Correlation analysis

Pearson's correlation was calculated between the PTEs (Cr, Cu, Ni, Pb, Zn, As and Hg) and related soil properties (pH, OC, sand, silt, and clay) in this study. There were significantly positive correlations between Pb and Zn (r = 0.38, $p < 0.05$), as well as Ni and As (r = 0.35, $p < 0.05$) (**Table 5**). However, significantly negative correlations were found between Cr and Cu (r = – 0.52, $p < 0.01$) and Cu and Ni (r = – 0.45, $p < 0.05$), respectively.

As mentioned above, the concentrations Pb and Zn exhibited high CVs in the surface soils at the urban parks, and thus the source of the three elements were considered as anthropogenic. The CVs in Ni and As were not only low, but also their concentrations were lower than the background levels in Taiwan, suggesting Ni and As were mainly from parent materials. This finding was further supported by the significantly positive correlations between Ni and silt (r = 0.65, $p < 0.01$), and As and silt (r = 0.50, $p < 0.01$), because the silt fraction of soils were mainly derived from primary minerals associated with poor exchangeable sites of PTEs. Furthermore, Ni and As exhibited significant negative correlations with sand contents, being consistent with results of Chen *et al.* (2008) who indicated that PTEs derived from natural sources exhibited significant negative correlations with SiO_2 contents, indicting Ni and As could be majorly derived from silt fraction. Only As revealed significant correlations with pH, because the importance of pH on the PTEs distribution was limited by the weak acid to slight alkaline environment (Manta *et al.* 2002; Chen *et al.* 2008).

Identify the source of PTEs in different land use cities

With different city land uses, soils could be potentially contaminated by PTEs from different sources. As shown in **Table 4**, the highest concentration of Cu existed in the surface and subsurface soils at the KMP, which could be attributed to industrial activities nearby this urban park. The KMP is located at the riverside of Houzin River, which Cu contamination caused by petroleum refinery factories was confirmed (Chu 2008). High Cu concentration in the soils at

Table 5 The Pearson's correlation coefficient for PTEs and soil properties in the surface soils of all urban parks.

	Cr	Cu	Pb	Zn	Ni	As	pH	OC[a]	Sand	Silt	Clay
Cr	1.00										
Cu	**-0.52 (0.005)**	1.00									
Pb	0.12	-0.26	1.00								
Zn	-0.04	0.16	**0.38 (0.032)**	1.00							
Ni	0.18	**-0.45 (0.013)**	0.05	-0.04	1.00						
As	0.10	-0.30	-0.25	-0.14	**0.35 (0.048)**	1.00					
pH	0.09	0.08	-0.07	0.25	-0.26	**-0.45 (0.013)**	1.00				
OC	0.07	**-0.57**	0.07	-0.15	**0.48**	**-0.39 (0.029)**	**0.96 (0.000)**	1.00			
Sand	-0.13	**0.60 (0.001)**	-0.10	0.18	**-0.62 (0.001)**	**-0.44 (0.016)**	0.08	-0.10	1.00		
Silt	0.23	**-0.63 (0.000)**	0.14	-0.20	**0.65 (0.000)**	**0.50 (0.006)**	-0.09	-0.13	**-0.94 (0.000)**	1.00	
Clay	-0.07	**-0.36 (0.040)**	0.01	-0.08	**0.38 (0.033)**	0.20	-0.04	-0.03	**-0.81 (0.000)**	**0.55 (0.003)**	1.00

Significant correlation is shown in bold, and p value is shown in the parentheses.
[a]: Organic carbon contents.

Table 6 Background levels, means, and limits of PTEs (mg/kg) in the urban soils from other countries compared to data for this work in Taiwan.

Cities	Cd	Cr	Cu	Pb	Zn	Ni	As	Hg	References
London[a]	1.0	-[j]	73	294	183	-	-	-	Thornton *et al.* 1991
Hamburg[b]	2.00 ± 2.98[k]	95.4 ± 40.4	146 ± 232	218 ± 301	515 ± 680	62.5 ± 13.8	-	-	Lux 1986
Glasgow[c]	-	37.0	52.0	161	179	33.0	-		Rodrigues *et al*. 2009
Sevilla[d]	-	32 ± 9.40	55.0 ± 44.6	223 ± 284	157 ± 98.6	31.0 ± 6.00	-	-	Ajmone-Marsan *et al.* 2008
Torino[d]	-	303 ± 218	107 ± 86	277 ± 397	235 ± 181	260 ± 169	-	-	Ajmone-Marsan *et al.* 2008
Jordan[e]	6.55 ± 1.29	17.2 ± 9.40	3.02 ± 1.08	60.2 ± 10.3	51.4 ± 9.37	-	-	-	Al-Khashman and Shawabkeh 2009
Background values in Europe[f]	-	9.0 - 56	7.0 - 24	9.0 - 63	25 - 100	7.0 - 39	-	-	Düwel and Utermann 2003
Bangkok[g]	0.05 ± 2.53	26.4 ± 13.6	41.7 ± 54.2	47.8 ± 52.7	118 ± 185	24.8 ± 13.1	-	-	Wilcke *et al*. 1998
Beijing[h]	0.15 ± 0.11	35.6 ± 13.9	71.2 ± 74.7	28.6 ± 10.3	65.5 ± 29.8	27.8	8.35 ± 2.70	-	Zheng *et al*. 2008
Hong Kong	0.62	23.1	23.3	94.6	125	12.4	-	-	Wei and Yang 2010
Background values in China			19.7 ± 6.30	25.1 ± 5.10	59.6 ± 16.3	27.9 ± 7.90			Chen *et al*. 2005
Maximum acceptable level in China (pH < 6.5)	5.00	600	250	300	500	100	75.0	15.0	Chen *et al*. 2002
Taiwan									
LSP in Yilan	ND[l]	27.1 ± 8.20	20.8 ± 5.60	25.0 ± 4.60	92.7 ± 18.6	28.7 ± 7.00	12.8 ± 4.50	ND	
DP, XP, and YP in Taipei	ND	27.5 ± 12.5	17.5 ± 4.73	37.0 ± 20.3	90.0 ± 17.1	23.4 ± 6.42	5.26 ± 0.90	0.04 ± 0.07	
KMP in Kaohsiung	0.79 ± 1.66	14.2 ± 2.42	91.1 ± 19.3	21.8 ± 13.4	126 ± 125	17.6 ± 1.90	5.69 ± 0.74	0.02 ± 0.03	
Monitoring level (Tolerated value)[i]	10.0	175	220	1000	1000	130	30.0	10.0	EPA 2001
Polluted-control level[i]	20.0	250	400	2000	2000	200	60.0	20.0	EPA 2001

London, Hamburg and Torino are industrial cities; Beijing and Bangkok are commercial city; Hong Kong is a commercial/industrial city.
[a] Topsoils (0 – 5 cm, n = 654) in garden soils; [b] South-east Hamburg (0 - 5 cm, n = 163); [c] Topsoils (0 – 10 cm, n = 94); Median values; [d] Topsoils (0 – 10 cm, n = 20); [e] Topsoils (0 - 10 cm, n = 32); [f] Range of heavy metal background values (medians) of European soils from calcareous rocks and clayey materials; [g] 0 - 5 cm (n = 30); [h] 0 - 20 cm (n = 650-772); [i] Monitoring level and polluted-control level of PTEs in general land use of Environmental Protect Administration (2001) in Taiwan; [j] No data; [k] Standard deviation; [l] Data not available.

the KMP was probably resulted from the irrigation water which coming from the Houzin River.

The highest concentrations of Pb (75.4 mg/kg) and Zn (379 mg/kg) found in the surface soils at urban parks of Taipei and Kaohsiung, respectively, could be attributed to the deposition of Pb- and Zn-bearing dust. The great contribution of Pb-bearing dust was mainly produced by the emission of traffic vehicles and wearing of vehicle tires in Taipei (Tsai 2007), while high concentration of Zn in Kaohsiung was due to the emission from industrial plants and incinerators (Hsieh 2001). These results agreed with those reported by Li *et al.* (2001) who found that high concentrations of Pb (93.4 mg/kg) and Zn (168 mg/kg) frequently occurred in urban soils of commercial and industrial areas. Alloway (1990) reported that Cd, Cu, Pb, and Zn were good indicators of soil contamination because these PTEs are present in gasoline, car components, oil lubricants and industrial emissions.

The concentrations of Cr, Ni and As were lower than background levels in all urban parks, although slightly higher mean concentrations of As (12.8 mg/kg) and Ni (28.7 mg/kg) were found in the surface soils at the LSP as compared with those in other urban parks (**Tables 3, 6**). These metals could be mainly considered as natural sources from parent materials, because of their relatively low concentrations. However, slightly high values of Cr (0.25) and As (–0.46) were also found in PC2 (anthropogenic sources); therefore, a little part of anthropogenic inputs of Cr and As were also occurred in this parks. The concentrations of Ni and As at the LSP did not exceed the natural ranges provided by Kabata-Pendias and Pendias (2001) and He *et al.* (2005). Therefore, we considered that Ni and As in the soils of the park in Yilan were mainly derived from shale and argillite, which were main parent materials in Yilan City. This was also confirmed by Hseu *et al.* (2002) who investigated that background levels of PTEs in various parent materials in Taiwan.

Comparison with PTEs in other countries and recommend limits

In comparison with the concentrations of PTEs in the urban soils between old industrial cities in Europe such as London, Glasgow, and Torino and our studied cities, there was at least 0.8 to 1.8 times of Cu concentration at the KMP higher than those in the cities of London, Glasgow and Torino (**Table 6**). Although the mean concentrations of Zn in Kaohsiung city were lower than those in the urban soils from other older and larger industrial cities as shown in **Table 6**; however, the mean concentrations of Zn were higher than those in the urban soils of cities of Bangkok and Beijing which were considered as commercial ones. It indicated that the industrial activities influenced the concentrations of Cu and Zn in the soils at the KMP in Kaohsiung. The estimated source of PTEs in Kaohsiung was the atmospheric emission from industrial activities including metallurgical/smelting industry, fossil fuels, and the rubber industry. Additionally, the potential contamination of Cu in Kaohsiung was resulted from the drainage of wastewater of (Chu 2008), and Zn was caused from fume emission of industries and vehicles (Hsieh 2001). Similar results were also reported by Li *et al.* (2001) and Chen *et al.* (2005) who indicated that high Cu and Zn concentrations were resulted from anthropogenic inputs such as traffic emission. The As concentration at the LSP in Yilan for this work, ranging from 7.10 mg/kg to 20.7 mg/kg, approached the background level (18.0 mg/kg) of Taiwan. This was attributed to the natural enrichment of As in shale and argillite which were the dominant in parent materials of the soils in Yilan. The highly natural background levels of Ni and As in the soils also agreed with the investigation of background levels of PTEs of the soils in Yilan (Hseu *et al.* 2002).

CONCLUSIONS

The sources and potential contamination of different PTEs in the metropolitan parks in Taiwan could be associated with different land uses nearby the parks. The concentrations of Cu and Zn in the surface and subsurface soils at the KMP in Kaohsiung exceed the background levels in Taiwan. The order of maximum and mean concentrations of Cu and Zn in the surface and subsurface soils is Kaohsiung > Taipei ≈ Yilan. The high concentrations of Cu and Zn at the KMP were attributed to highly industrial activities such as metallurgical/smelting and fossil fuels industry. Owing to the major source of Pb into the urban soils from traffic emission, the order of maximum and mean concentrations of Pb was Taipei > Kaohsiung > Yilan. According to our results, Cu, Pb and Zn could be considered as anthropogenic inputs, and Cr, Ni and As were probably as natural sources in this study. The findings also indicated that more attention should be paid to the problem of contamination of Cu and Zn in Kaohsiung and Pb in Taipei. It can be concluded that different land use of cities may influence distribution of PTEs in the urban soils.

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