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Potentially harmful metals and metalloids in the urban street dusts of Taipei City

Daoyong Zhang [a,c,d], Xiangliang Pan [d], Duu-Jong Lee [a,b,*]

[a] Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan
[b] Department of Chemical Engineering, National Taiwan University of Science and Technology, Taipei 106, Taiwan
[c] State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang, Guizhou 550002, China
[d] Laboratory of Environmental Pollution and Bioremediation, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, Xinjiang 830011, China

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ABSTRACT

In total, 34 urban street dust samples were collected in Taipei City. Concentrations of potential harmful metals Cr, Pb, Hg, Ni, Cd, Zn, Cu, and Sr and metalloids As and Sb in street dust samples were measured and their sources and potential health risks to humans were evaluated. Traffic emissions were the main source of the potential harmful metals and metalloids in street dust samples from Taipei. Exposure routes for all studied potential harmful metals and metalloids, except for that of Hg, follow ingestion > dermal contact > inhalation. Children are at higher health risk than adults. The As, Sb, Cr, and Pb concentrations in Taipei have adverse non-cancer health effects on residential children. Carcinogenic risk of As exposure for children and adults in Taipei were higher than the threshold value (10^{-6}–10^{-4}). The study highlights the determinant role of anthropogenic factors in the formation of street dust.

1. Introduction

Street dust is comprised of solid particles with complex compositions that is deposited on outdoor surfaces for a short time and can be easily re-suspended into air by wind or traffic [1–3]. Sources of street dust include vehicle emissions, industrial discharges, domestic heating, waste incineration, and other anthropogenic activities [4–6]. Potential harmful metals are important contaminants in street dust in urban areas. Their species and solubility affect significantly their mobility, bioavailability, and toxicity. Precipitation can also deposit potential harmful metals and discharge toxic components of street dust into street run-off, further polluting water bodies and food chains [7–10]. For instance, the primary source of water pollution in Singapore is street contaminants from vehicles [11]. High levels of potential harmful metals have adverse effects on the health of individuals [12–14]. The potential contributions of ingested dust to metal toxicity in humans have been studied [15,16]. In urban regions, children might suffer higher more severer hazard than adults due to ingestion since children are typically hand-to-mouth active [17], and children have a much higher absorption rate of potential harmful metals from their digestion system and higher hemoglobin sensitivity to potential harmful metals [18].

Street dust is ubiquitous and easily re-suspended in urban environments, such that potential harmful metals in dust threaten the health of those in traffic and in residences near streets [7]. Taipei, a coastal metropolis in northern Taiwan, has abundant rainfall of >2100 mm yr^{-1} and an average annual temperature of 22.7 °C. Its population density of about 9600 km^{-2} and vehicle density of 6786 km^{-2} are extraordinarily high. Mao et al. [19] characterized the acid aerosols in areas in Taipei with different traffic densities.

The objectives of this study are to measure the concentrations of eight potential harmful metals (Cr, Pb, Hg, Ni, Cd, Zn, Cu and Sr) and two metalloids (As, Sb) in street dust samples from Taipei City and to identify their sources using correlation analysis. The health risks of these elements are evaluated using the methodology proposed by the USEPA [20] and de Miguel et al. [21].

2. Materials and method

2.1. Study areas and sampling

In total 34 street dust samples were collected from street pavements in Taipei City (Fig. S1). The sampling sites were selected randomly to reflect geological averages in Taipei. Dust

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* Corresponding author at: Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan. Tel.: +886 2 23625632; fax: +886 2 23623040.
E-mail addresses: djlee@ntu.edu.tw, djleetw@yahoo.com.tw (D.-J. Lee).

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samples were not collected adjacent to specific pollution sources such as industrial sites. At each sampling site, approximately 250 g of dust that accumulated on impervious surfaces was collected with a plastic brush and dustpan. Samples were kept in sealed polyethylene bags and transported to the laboratory. They were then dried at room temperature for 5 d with grids being removed.

2.2. Sample treatment and analysis

In total, 1 g of a sample was transferred into a glass Pyrex beaker. The sample was then digested with 20 ml of *aqua regia* (1 HNO_3 and 3 HCl) and 2.5 ml of HF [22]. The mixture was left to sit overnight and then heated on a hot plate at 100 °C to a nearly dry state. The residue was then dissolved in milli-Q water and the resulting solution was filtered through a 0.45-μm acetate cellulose membrane into a 100-ml volumetric flask. Concentrations of metals Cd, Cr, Cu, Ni, Pb, Sr, and Zn were identified by inductively coupled plasma–mass spectrometry (Perkin Elmer SciexDRCII, USA). The concentrations of metal Hg and metalloids Sb and As were measured using hydride generation atomic florescence spectroscopy (AFS-800; Jitian, China). Samples were analyzed in triplicate with standard reference materials and blanks. Before each test, all glassware was submerged in 0.1 M HNO_3 for 48 h, then rinsed with deionized water thoroughly, and dried. All chemicals were analytical grade.

2.3. Statistical analysis

Statistical analyses were performed with SPSS 11.5. Descriptive analysis, correlation analysis (CA), and principal component analysis (PCA) were used. Principle Component Analysis was conducted using factor extraction with an eigenvalue >1 after varimax rotation. To evaluate the relationships among variables, Pearson's correlation coefficient was calculated.

2.4. Health risk assessment model

2.4.1. Exposure assessment

The USEPA [23–25] model for assessing human health risk of exposure to metals in street dust was used. The following assumptions were made: (1) exposure route for humans and potential harmful metals in street dust included ingestion of dust particles (D_{ing}). (2) Reasonable maximum estimates of exposure are used to evaluate human health risk. (3) Exposure parameters from the USEPA [23–25] and the study by Zheng et al. [26] are applied. (4) According to the USEPA guideline for risk characterization, non-carcinogenic and carcinogenic effects are evaluated separately. (5) Toxicity in this analysis was taken from the US Department of Energy's Risk Assessment Information System (RAIS) compilation [27]. The Pb reference doses were derived from the Guidelines for Drinking Water Quality [28]. Due to the lack of a reference dose for the inhalation route, toxicity values of As, Sb, Pb, Cd, Cu, Zn, Ni and Sr were taken as corresponding oral reference doses and slope factors (SFs) [26,27,29].

$$D_{ing} = C \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{1}$$

$$D_{inh} = C \times \frac{InhR \times EF \times ED}{PEF \times BW \times AT} \tag{2}$$

$$D_{dermal} = C \times \frac{SL \times SA \times ABS \times EF \times ED}{BW \times AT} \times 10^{-6} \tag{3}$$

$$D_{vapour} = C \times \frac{InhR \times EF \times ED}{VF \times BW \times AT} \tag{4}$$

For carcinogens, the lifetime average daily dose (LADD) for inhalation exposure route was used in the assessment of cancer risk [23,24].

$$LADD = \frac{C \times EF}{AT \times PEF} \times \left(\frac{InhR_{child} \times ED_{child}}{BW_{child}} + \frac{InhR_{adult} \times ED_{adult}}{BW_{adult}} \right) \tag{5}$$

where D_{ing} presents the daily exposure amount of metals through ingestion (mg/kg d^{-1}); C is the metal content in dust (mg/kg); IngR is dust ingestion rate (mg d^{-1}), taking as 200 mg d^{-1} for children and 100 mg d^{-1} for adult [27]; EF is the exposure frequency, taking as 350 d yr^{-1} [24]; ED is exposure duration, in this study, 6 yr for children and 24 yr for adults [24]; BW presents the average body weight, 15 kg for children and 70 kg for adults [20]; AT is the averaging time, for non-carcinogens, ED × 365 days and for carcinogens, $70 \times 365 = 25{,}550$ d. Additionally, D_{inh} is the daily exposure amount of metals through inhalation (mg/kg d^{-1}); InhR is the inhalation rate, accepting as 7.6 m^3 d^{-1} for children and 20 m^3 d^{-1} for adults [29]; and PEF is the particle emission factor, 1.36×10^9 m^3/kg in this study [24]. On Eq. (3), D_{dermal} is the daily exposure amount of metals through dermal contact (mg/kg d^{-1}); SL is the skin adherence factor, 0.2 mg/(cm^2 h) for children and 0.07 mg/(cm^2 h) for adults [24]; SA is the exposed skin area, 2800 cm^2 for children and 5700 cm^2 for adults [24]; ABS presents the dermal absorption factor (−), 0.001 for all elements. On Eq. (4), D_{vapour} is the inhalation rate of vapour (mg/kg d^{-1}); VF is the volatilization factor, in this study, for elemental Hg, 32,675.6 m^3/kg [24].

To overcome the uncertainty associated with any estimate of the exposure concentration, an estimate of "reasonable maximum exposure" [20] is usually calculated as the 95% upper confidence limit (95% UCL) of the arithmetic mean. The USEPA's Superfund program has routinely used this procedure to evaluate exposure at hazardous sites; that is, the 95% UCL is commonly used as a public health protective estimate of the true annual average. The 95% UCL in this study was derived by Eq. (6) [23,30] assuming being an approximate log-normal distribution of potential harmful metals in road dust samples. Calculation of the exposure-point concentration for log-transformed data is

$$C_{95\%UCL} = \exp\left\{ X + 0.5 \times s^2 + \frac{s \times H}{\sqrt{n-1}} \right\} \tag{6}$$

where X is the arithmetic mean of log-transformed data, s is the standard deviation of log-transformed data, H is the H-statistic [31], and n is the number of samples.

2.4.2. Risk characterization

Quantitative risk characterization requires the evaluation of exposure (or intake) estimates, such as a cancer SFAn HQ is a ratio of the daily exposure level to the reference dose (RfD). A Hazard Index (HI) equals the sum of HQs. For carcinogens, the dose is multiplied by the corresponding SF to produce a degree of cancer risk. The general equations used to calculate risk from street dust are Eqs. (7)–(9).

$$HQ = \frac{D}{RfD} \tag{7}$$

$$HI = \sum HQ_i \tag{8}$$

$$\text{Cancer risk} = D \times SF \tag{9}$$

where HQ is the hazard quotient of each element and exposure route (dimensionless); D is daily exposure dose of metals through an exposure route (mg/kg d^{-1}); RfD is the reference dose (mg/kg d^{-1}); HI is the hazard index (dimensionless); and SF is cancer slope factor $(mg/kg\ d^{-1})^{-1}$.

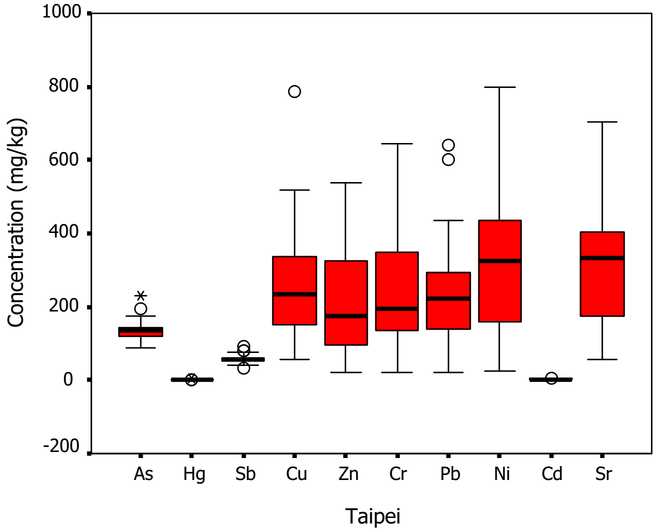

Fig. 1. The contents of the potential harmful metals in the road dust.

2.5. *Enrichment factors*

Enrichment factors (EFs) were used to highlight the origin of elements in soil. The EF was calculated as follows [32]

$$\mathrm{EF} = \frac{(\mathrm{Cx}/\mathrm{Cref})\mathrm{sample}}{(\mathrm{Cx}/\mathrm{Cref})\mathrm{soil}} \tag{10}$$

where Cx and Cref are the concentration of an element and a conservative reference element in a sample and soil (mg/kg) (Al is the reference element in this study), respectively.

3. Results

3.1. *Potential harmful metal concentrations in street dust*

Fig. 1 and Table 1 show the metal and metalloid concentrations in street dust samples from Taipei. In Taipei, the mean concentrations (mg/kg) of potential harmful metals and metalloids in street dust samples were as follows: As, 137.2 mg/kg; Cu, 262.1 mg/kg; Cd, 3.02 mg/kg; Cr, 244.6 mg/kg; Hg, 1.59 mg/kg; Ni, 320.2 mg/kg; Pb, 234.8 mg/kg; Zn, 217.7 mg/kg; Sb, 57.8 mg/kg; and Sr, 320.2 mg/kg. The average concentrations of potential harmful metals and metalloids in street dust followed Ni ≈ Sr > Cu > Cr ≈ Pb > Zn > As > Sb > Cd > Hg.

3.2. *Correlation studies*

3.2.1. *Correlation analysis*

The Pearson correlation coefficient (r) was used to quantify the linear relationship between two quantitative variables. Table 2 lists the coefficients for inter-element correlations in street dust. In Taipei, Cr–Zn, Cr–Cu, Ni–Cr, and Ni–Pb concentrations were strongly correlated at the 99% confidence level. This observation is related to the high concentrations of Cr, Zn, Cu, Ni, and Pb indicating the same source for these five metals [33].

3.2.2. *Cluster analysis*

The hierarchical clustering method was applied to calculate Euclidean distances for similarities using Ward's method. Fig. 2 shows the dendrograms for potential harmful metals and metalloids in Taipei. In Taipei, two clusters were identified: (1) Cu, Cr, Zn, Pb, Ni, and Sr; (2) Hg, Cd, Sb and As. Group 1 included Cu, Cr, Zn, Pb, Ni, and Sr that had very high concentrations in street dust and were brake-related elements. Group 2 had four elements including Hg, Cd, Sb and As.

3.2.3. *Principal component analysis*

To find the correlations between pollutant concentrations in street dust, PCA was applied [7]. Table 3 shows PCA results and Varimax rotation matrix.

In Taipei street dust samples, four principle components were extracted, accounting for 76.7% of total variances for potential harmful metals and metalloids. Factor 1 was dominated by loadings of Zn, Pb, Cr, Cu, Sr and Ni, implying that these potential harmful metals in street dust were mainly generated by traffic emissions [11,33]. Factor 2 contained only Cd, whose presence in

Table 1
The mean concentration of potential harmful metals and metalloids in soil and road dust samples (mg/kg).

	As	Hg	Sb	Cu	Zn	Cr	Pb	Ni	Cd	Sr	References
China soil	11.2	0.065	1.21	22.6	74.2	61	26	26.9	0.097	167	[47]
USA soil	7.2	0.089	0.67	25	60	54	19	19		240	[47]
Japan soil	9.02	0.28		36.97	63.8	41.3	20.4	28.5	0.413		[47]
UK soil	0.62	0.098		25.8	59.8	84	29.2	33.7	0.62		[47]
London				73.00	183.0		294.0		1.0		[53]
Birmingham				466.9	534.4		48.0	41.1	1.62		[35]
Coventry			6	226.4	385.7	61	47.1	129.7	0.90	344	[35]
Madrid				188			1927	44			[54]
Oslo				123			180	41	1.4		[54]
Palermo				98.0	207.0	103.0	544.0	14.00	1.10		[55]
Kayseri				36.9	112.0	29.00	74.80	44.9	2.53		[56]
Kavala	13.7	0.2		172.4	354.8	232.4	386.9	67.9	0.2		[7]
Luanda	5.00	3.4	0.13	42	317	26.00	351	10	1.1	172	[31]
Hangzhou		0.7		116.04	321.40	51.29	202.16	25.88	1.59		[57]
Huludao		1.22		264.4	5271		533.2	72.84			[30]
Nanjing	13.4	0.12		123	394	126	103	55.9	1.1		[58]
Beijing		0.3		42	214	85.6	61		1.2		[3]
Shanghai		0.3		141	699	242	148		0.9		[3]
Xi'An	0.84	0.638	5.41	94.98	421.46	167.28	230.52				[59]
Hongkong (2008)		0.6		534	4024	324	240		0.6		[3]
Hongkong (2003)		7.0		600	5149	327	1061		24		[43]
Urumqi				94.54	294.47	54.28	53.53	43.28	1.17		[28]
Urumqi				94.54	294.47	54.28	53.53	43.28	1.17		[28]
Uqumai	137.2	1.59	57.8	100.81	349.07	55.86	57.03	43.54	0.82	320.2	[28]
Taipei				262.1	217.7	244.6	234.8	320.2	3.02		This study
Enrichment factor (Taipei)	94.8	189	369	89.5	22.8	31.0	69.8	92.0	241	14.8	This study

Table 2
Pearson correlation coefficients for potential harmful metals concentrations in the road dust in Taipei.

	As	Hg	Sb	Cu	Zn	Cr	Pb	Ni	Cd	Sr
Taipei										
As	1									
Hg	−0.089	1								
Sb	−0.070	−0.192	1							
Cu	−0.256	+0.124	+0.297	1						
Zn	−0.074	+0.162	+0.241	+0.571**	1					
Cr	−0.004	+0.314	+0.077	+0.744**	+0.721**	1				
Pb	+0.068	+0.238	+0.103	+0.422*	+0.553**	+0.422*	1			
Ni	+0.082	+0.264	+0.007	+0.513**	+0.565**	+0.684**	+0.620**	1		
Cd	−0.133	−0.037	−0.080	+0.374*	+0.141	+0.316	+0.320	+0.593**	1	
Sr	−0.196	+0.045	+0.147	+0.568**	+0.575**	+0.508**	+0.173	+0.422*	+0.293	1
	As	Hg	Sb	Cu	Zn	Cr	Pb	Ni	Cd	Sr

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

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

street dust could be a product of motor vehicles [11,34]. Cd is used not only in petrol and diesel but also in road building, that is released in the environment by road surface wearing [35,36]. Factor 3 was explained by loadings of Hg. Hg emissions mainly come from anthropogenic activities including coal combustion, municipal solid waste incineration, fluorescent lamp, battery production, oil combustion and so on [37]. Factor 4 contained only As, likely due to the combustion of fossil fuels such as oil, waste, and coal [38,39]. In Taipei, metal As might be attributed to vehicle engine abrasion, tire wear, use of pigments and pesticides, and oil combustion [40,41].

3.3. *Health risk assessment of potential harmful metals and metalloids of street dusts*

The exposure assessment is listed in Table 4. In Taipei, all exposure routes for non-carcinogenic effect by Ni, As, Zn, Sr, Pb, Cr, Cu, Sb and Cd in road dusts have the following risk order for both children and adult ingestion > dermal contact > inhalation. In particular, ingestion is 3–5 orders of magnitude higher than inhalation exposure in non-carcinogenic risk, suggesting that the ingestion exposure as the main route for heavy metals and metalloids in road dust to human. This finding correlates with those noted for other cities [26,27]. Conversely, the estimates of inhaling Hg vapor were higher than those of ingestion exposure, suggesting that inhalation of Hg vapor from road dust is more hazardous to human body than dermal contact or ingestion routes.

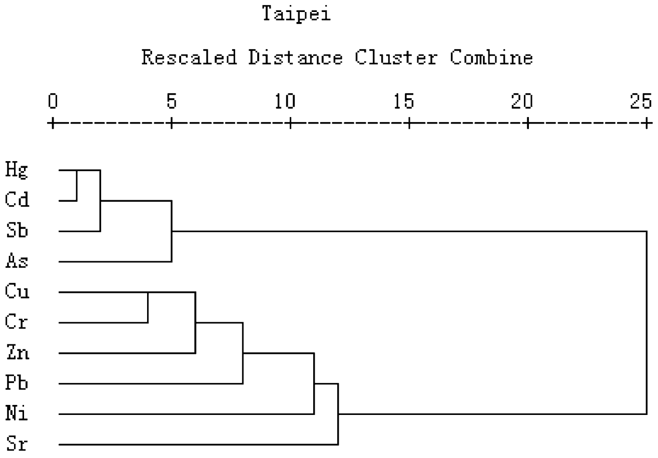

Fig. 2. Hierarchical dendrograms for potential harmful metals in road dust in Taipei (the distances reflect the degree of correlation between different elements).

The total exposure estimates of 10 studied elements for children exceeded those for adult. This observation is attributable to the hand-to-mouth activity of young children [17,26,40]. Also children more readily ingest heavy metals and the hemoglobin than the adults [18].

On carcinogenic effects, intakes of As, Cr, Cd and Ni in the road dust through three exposure routes were listed Table 4. (Note: the inhalation slope factors (SF) were noted for Cd, Cr, Ni [26,27], so their lifetime average daily dose (LADD) for inhalation exposure route was quantitatively estimated.) The cancer risk of intaking As ($>10^{-4}$) is much higher than those of inhalation and dermal contact (10^{-6}–10^{-8}). Similar to the non-carcinogenic effects the As in road dust has higher carcinogenic effect on children than on adults. The levels of carcinogenic risk of As for children and adult were higher than threshold value (10^{-6}–10^{-4}), suggesting potential health risk for As in the road dusts on human health.

4. Discussion

4.1. *Pollutant sources*

Element EFs were calculated to identify and quantify natural or anthropogenic sources. Table 1 shows EF values for potential harmful metals and metalloids in urban street dust from Taipei. EF > 1 can be used as an indicator that element enrichment in soil is from anthropogenic sources. In this study we adopt a threshold of 10, 10 times unity, indicates anthropogenic sources [31,42]. The greater-than-unity EFs for the elements in street dust samples from Taipei indicate that they were from anthropogenic sources. Particularly, elements As, Hg, Sb, and Cd in street dust samples in

Table 3
Principal component analysis results for road dust in Taipei (extraction method: maximum likelihood; rotation: Varimax).

Element	Taipei			
	Component			
	1	2	3	4
As	−0.029	−0.036	−0.059	+0.907
Hg	+0.311	−0.212	+0.836	−0.072
Sb	+0.359	−0.374	−0.676	−0.057
Cu	+0.787	+0.171	−0.127	−0.319
Zn	+0.880	−0.064	−0.034	−0.015
Cr	+0.856	+0.141	+0.162	−0.039
Pb	+0.659	+0.213	+0.136	+0.329
Ni	+0.719	+0.518	+0.171	+0.188
Cd	+0.249	+0.902	−0.044	−0.104
Sr	+0.622	+0.174	−0.156	−0.389

Table 4
Hazard quotient and risks for metals in road dust in Taipei through three exposure routes.

$mg/kg\,d^{-1}$	As	As-cancer	Hg	Sb	Zn	Cu	Cr	Cr-cancer	Pb	Cd	Cd-cancer	Sr	Ni	Ni-cancer
C (95%UCL)	1.46E+2	1.46E+2	1.73E+0	6.21E+1	2.67E+2	3.15E+2	2.98E+2	2.98E+2	2.83E+2	3.49E+0	3.49E+0	3.81E+2	3.92E+2	3.92E+2
Oral RfD	3.00E−4		3.00E−4	4.00E−4	3.00E−1	4.00E−2	3.00E−3		3.50E−3	1.00E−3		6.00E−1	2.00E−2	
Oral SF		1.50E+0												
Children														
HQ_{ing}	6.22E+0	2.39E−4	7.39E−2	1.98E+0	1.14E−2	1.01E−1	1.26E+0		1.04E+0	4.45E−2		8.13E−3	2.51E−1	
$HI=\sum HQ_i$	6.22E+0		7.39E−1	1.98E+0	1.14E−2	1.01E−2	1.26E+0		1.04E+0	4.45E−2		8.13E−3	2.51E−1	
Cancer risk		2.39E−4						1.25E−6			2.19E−9			3.28E−8
Adult														
HQ_{ing}	6.67E−1	1.03E−4	7.91E−3	2.14E−1	1.22E−3	1.08E−2	1.36E−1		1.11E−1	4.78E−3		8.71E−4	2.70E−2	
$HI=\sum HQ_i$	6.67E−1		7.91E−3	2.14E−1	1.22E−3	1.08E−2	1.36E−1		1.11E−1	4.78E−3		8.71E−4	2.70E−2	
Cancer risk		1.03E−4						1.25E−6			2.19E−9			3.28E−8

Taipei have high EF values, overwhelmingly pointing to anthropogenic input.

In Taipei, the Cr–Zn, Cr–Cu, Ni–Cr, and Ni–Pb concentrations were strongly correlated at the 99% confidence level (Table 2). Cluster analysis identified correlations among studied potential harmful metals and metalloids (Fig. 2 and Table 3). The concentrations of brake-related elements (Ni, Sb, Pb, Cd, Cu, Zn, and Cr) in street dust in Taipei were high, suggesting the marked contribution by traffic sectors. Hong Kong, also a coastal metropolis with high population and vehicle densities, had high potential harmful metals concentrations in street dust [43]. Particularly, street dust samples from Taipei had much higher As concentrations than those for other cities (Table 1). Some gasoline reportedly contains 30–120 ng/g of As [44]. Since the vehicle density of Taipei (6786 km^{-2}) (Table S1), the high level of As may be contributed by traffic emission.

4.2. Risk characterization

In Taipei, the ingestion exposure route was significant exposure route for humans for the studied potential harmful metals and metalloids in street dust. For children in Taipei, the HI order of studied potential harmful metals and metalloids in street dust followed As > Sb > Cr > Pb > Hg > Ni > Cd > Zn > Cu > Sr. The non-carcinogen HIs for As, Sb, Cr, and Pb were all larger than unity (Table 4), implying significant risk for children. The potential non-cancer effects should be a concern for environmental and regulatory agencies. For adults, the HIs for the studied ten elements were all below unity. Restated, studied potential harmful metals and metalloids in street dust do not pose adverse health effects for adults in Taipei.

For carcinogens, the USEPA generally sets a 10^{-6} risk level for individual chemicals and pathways, such that the cumulative risks are within the 10^{-4}–10^{-6} for combinations of chemicals typically found at Superfund sites. Carcinogenic risks of As for children and adults of 2.39×10^{-4} and 1.03×10^{-4} are slightly over the 10^{-4} threshold. Arsenic is ranked first in the list of hazardous substances by US EPA [25] and has been identified as a human carcinogen leading to skin, bladder, lung, and other cancers, as well as having adverse cardiovascular effects [45,46]. Ingestion of dust particles contributed significantly to cancer risk of As in Taipei, and sequentially followed exposure by dermal contact and inhalation. The carcinogenic effects of Cd, Cr and Ni in street dust were only estimated for the inhalation exposure route, which is lower than the safe level identified by the USEPA, except for that of Cr in Taipei. The carcinogenic risks of Cd, Cr and Ni in the city should be underestimated, similar to those in existing studies [26,27]. The carcinogenic risk of Cr in Taipei was 1.25×10^{-6}, slightly exceeding the threshold value of 10^{-6} by the USEPA, such that the probability of the population developing cancer from exposure to Cr is not negligible.

4.3. Studied metals of street dusts in Taipei City

Street dust samples from Taipei City had high mean concentrations of As, Hg, Sb, Pb, Cd, Cu, Zn, Ni, Sr, and Cr, which are among the highest values in literature (Table 1) and generally exceed the background soil levels in China, USA, Japan, and the UK [47]. The metals Zn, Pb, Cr, Cu, and Ni were not only traffic-related elements, but also typical brake-related elements [11,26,39]. Notably, Pb was a common gasoline additive but was eliminated many years ago. The strong correlation among Pb, Cr, and Cu concentrations suggests that these metals in Taipei were principally from brake-related materials. Other sources of lead might be oil combustion, tire wear and paint debris from vehicle bodies [11,48]. The Cr in street dust was reportedly related to chrome plating on some motor vehicle parts [49]. Additionally, Cr is a common component in street construction materials such as concrete and mortar. The Hg in the street dust can come from anthropogenic emissions, including that from the incineration of municipal solid waste, and emission from the electronic, paper, and pharmaceutical industries [50]. Antimony is widely used in flame retardant, ceramics, plastics, brake linings, and batteries [51]. Brake pad and disk friction releases Sb [52], whose concentration was in the range of 4–16,900 mg/kg [39]. Notably, Sb is listed as a priority pollutant by the USEPA and European Union [53].

This study noted the determinant role of anthropogenic factors in the formation of street dust. Such an observation encourages reductions in traffic emissions by the authorities to improve the urban environment. This conclusion is particularly significant when one considers the fact that children are the most sensitive subpopulation to potential harmful metal exposure in street dust. Preventing intake by ingestion of street dust also effectively reduces carcinogenic and non-carcinogenic risks of potential harmful metals and metalloids for children.

5. Conclusions

Street dusts from Taipei were collected. The concentrations of the eight potential harmful metals and two metalloids were measured, and that possible sources of these metals were identified and their potential health risks were also evaluated. The following conclusions are based on analytical findings. (1) Street dust samples in Taipei were polluted by potential harmful metals Cr, Pb, Hg, Ni, Cd, Zn, Cu, and Sr and by metalloids As and Sb; their mean concentrations were much higher than soil backgrounds. (2) Potential harmful metals and metalloids in collected street dusts from Taipei were mainly from traffic emissions. (3) Potential harmful metals and metalloids in street dust have potential adverse health effects on humans. Children had higher health risk than adults. (4) For non-carcinogens, children in Taipei suffered adverse health effects from exposure to As, Sb, Cr and Pb.

For carcinogens, As in street dust in Taipei resulted in the probability to develop cancer for children and adults.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jtice.2014.01.003.

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