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Status, source identification, and health risks of potentially toxic element concentrations in road dust in a medium-sized city in a developing country

S. M. Praveena · A. Z. Aris

Abstract This study aims to determine the status of potentially toxic element concentrations of road dust in a medium-sized city (Rawang, Malaysia). This study adopts source identification via enrichment factor, Pearson correlation analysis, and Fourier spectral analysis to identify sources of potentially toxic element concentrations in road dust in Rawang City, Malaysia. Health risk assessment was conducted to determine potential health risks (carcinogenic and non-carcinogenic risks) among adults and children via multiple pathways (i.e., ingestion, dermal contact, and inhalation). Mean of potentially toxic element concentrations were found in the order of Pb > Zn > Cr(IV) > Cu > Ni > Cd > As > Co. Source identification revealed that Cu, Cd, Pb, Zn, Ni, and Cr(IV) are associated with anthropogenic sources in industrial and highly populated areas in northern and southern Rawang, cement factories in southern Rawang, as well as the rapid development and population growth in northwestern Rawang, which have resulted in high traffic congestion. Cobalt, Fe, and As are related to geological background and lithologies in Rawang. Pathway orders for both carcinogenic and non-carcinogenic risks are ingestion, dermal contact, and inhalation, involving adults and children. Non-carcinogenic health risks in adults were attributed to Cr(IV), Pb, and Cd, whereas Cu, Cd, Cr(IV), Pb, and Zn were found to have non-carcinogenic health risks for children. Cd, Cr(IV), Pb, and As may induce carcinogenic risks in adults and children, and the total lifetime cancer risk values exceeded incremental lifetime.

Keywords Road dust · Toxic element · Urban area · Source identification · Health risks

S. M. Praveena (✉)
Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
e-mail: smpraveena@gmail.com

A. Z. Aris
Department of Environmental Sciences, Faculty of Environmental Studies, Universiti Putra Malaysia, 43400 Serdang, Selangor Darul Ehsan, Malaysia
e-mail: zaharin@upm.edu.my

Introduction

Urbanization rate of Asia is faster than those of other regions in the world which expected to reach 64% by 2050 (United Nations 2014). As a results of urbanization rate, more people prefer to live in urban than rural areas due to driving forces such as job opportunities and services offered. Although urbanization rate has greatly contributed in economic and social growths, it has also created numerous environmental problems ranging from local to global scale via mission of various pollutants into the environment (Cui and Shi 2012). Road dust is seen as a sensitive indicator of

urban area pollution which consists of deposited airborne particulates, organic and inorganic materials of anthropogenic origin as well as soil dust particles redeposited on roads. Furthermore, road dust is considered more suitable indicator of urban area pollution than other environmental samples, such as water or soil, as road dust acts as a primary source and sink of various pollutants derived from surrounding environment (Zhao et al. 2016).

So far, studies have been conducted to examine the quality of road dust to determine pollutant concentrations (Amato et al. 2016; Mummullage et al. 2016), source identification (Pekey et al. 2015), as well as health and ecological risk assessments (Liu et al. 2016). However, most of these studies focused on developed countries or megacities in developing countries. However, at present, little is known with regard to road dust pollution in medium-sized cities in developing countries. Similar to megacities, medium-sized cities in developing countries are also exposed to high urbanization rate and various environmental issues due to urbanization (Keshavarzi et al. 2015; Li et al. 2016; United Nations 2014). Among the pollutants related to road dust, high levels of potentially toxic element concentrations (Pb, Cu, Cd, As) were related to anthropogenic sources in urban areas such as from traffic emissions, construction, industrial activities, pavement wear, and natural weathering (Mathur et al. 2016). Geostatistical analysis has been employed in many studies about source identification involving potentially toxic elements in road dust (Li et al. 2016). However, geostatistical analysis involves large data sets, large number of samples, and adequate distances between sampling points (Gallego et al. 2002). Therefore, geostatistical analysis often resulted in the inversion of a large covariance matrix for computing the likelihood function with lengthy computation time. Thus, Fourier spectral analysis (FSA) via spatial correlogram presents a visual representation of spatial patterns of targeted variables, which are expressed by linear equations of sine and cosine functions. According to Chen et al. (2009) and Gallego et al. (2002), FSA technique has been applied widely in electronics or geophysics field while its application in geochemical application is now being developed. Fourier spectral analysis provides spatial correlation analysis with correlogram to assess the spatial patterns and spatial correlation of the targeted variable, which can display and interpret potential trends in the grid

(Li et al. 2016). Therefore, FSA is seen as a potential help in pollution source identification with reducing corresponding uncertainties. This technique is also seen as the best approach for source identification with limited sampling points and inadequate distances between sampling points, proficient and feasible technology, especially in developing countries with limited financial capacity (Kim and Fuentes 2000; Li et al. 2016; Pardo-Iguzquiza 1993; Sarma 2010; Ying Sun et al. 2012).

Potentially toxic element accumulations in road dust are a critical concern because of its potential health risks through inhalation, ingestion, and dermal contact. Studies have been conducted related to determining health effects of dust particles and its long-term impact on human health due to inhalable dust particles. Human health risk assessment is developed to estimate human health risks caused by contaminants. This approach was developed based on the toxicity of the chemicals included in the analysis according to exposure route (i.e., inhalation, ingestion, and dermal contact), and the level of exposure of those chemicals to potential receptors, taking into account various factors, such as exposure rate and frequency, surface area, body weight, and absorption rate (Praveena et al. 2015). Potentially toxic elements are capable to have adverse long-term effects on human health especially children due to their weak immune system. Besides, potentially toxic elements can also contribute as cofactors in other diseases. Thus, looking at its exposure and long-term effects on human health, more studies have been focused to gain understanding on potentially toxic elements in road dust (Rajaram et al. 2014).

This study aims to determine potentially toxic element concentrations in road dust in Rawang City, Malaysia. This study adopts source identification via enrichment factor, Pearson correlation analysis, and FSA via spatial distribution maps to identify sources of potentially toxic element concentrations in road dust in Rawang City. Lastly, this study also aims to evaluate potential human health risks (non-carcinogenic and carcinogenic) among children and adults and to identify local priority pollutants of concern.

Materials and method

The study area, Rawang, is a medium-sized city located in the district of Gombak, Selangor state,

Malaysia, with a population of 120,447 (Department of Statistics 2013). The State Structure Plan of Selangor (2020) indicated that rapid urbanization has led to extreme changes in the land use pattern in Selangor. The urbanization rate of Rawang has increased with an average annual rate of 12.3% since 2001 with the opening of new industrial sites, housing, shop lot construction, and cement plant operations. With an average annual urbanization rate of 12.3%, profound changes to size and spatial distribution may lead to pollution and environmental deprivation. Lafarge Malayan Cement Berhad has been operating in Rawang and was selected as one of the top five public-listed companies in Malaysia for the Workplace and Marketplace Awards for demonstrating outstanding corporate responsibility (Lafarge Malaysia Berhad Annual Report 2013).

Sampling and analysis

A total of 51 road dust samples (17 sampling locations and 3 parallel samples for each sampling location) were collected at trunk roads throughout Rawang City, as shown in Fig. 1. The sampling of road dust was done in October 2016 by gentle sweeping using a clean plastic dustpan and brush in an area of 1 m² adjacent to the curb of the road. Road dust samples amounting to 300 g each were transferred to a polyethylene bag and transported to laboratory for further analysis. Since road dust with diameters below 100 μm can be considered to mainly occur from atmospheric deposition and resuspension (Huang et al. 2016; Li et al. 2016; Rajaram et al. 2014), a 200 mesh nylon sieve (diameters below 73 μm) was used to sieve all the road dust samples in this study.

The road dust samples were digested using *aqua regia* (1: 3 HCl: HNO3) in a Teflon bomb. A Teflon bomb provides an airtight environment with a closed digestion system to avoid cross-contamination and volatilization among the samples (Praveena et al. 2015). Subsequently, 5 g road dust samples were placed in Teflon tubes with 15 mL aqua regia for 2 h at 120 °C (Radojevic and Bashkin 2013). After cooling, the digested samples were filtered using a 0.45-m Whatman filter paper and were kept in plastic bottles before analysis. The digested samples were diluted with 2% *v/v* HNO3 with dilution ratio of 10 and analyzed for potentially toxic element concentrations determination (Cu, Cd, Co, Cr, Pb, Ni, Zn, and As) using inductive couple plasma mass spectrometry (ICP–MS: PerkinElmer ELAN DRC-e). In this study, arsenic concentration was assumed as inorganic
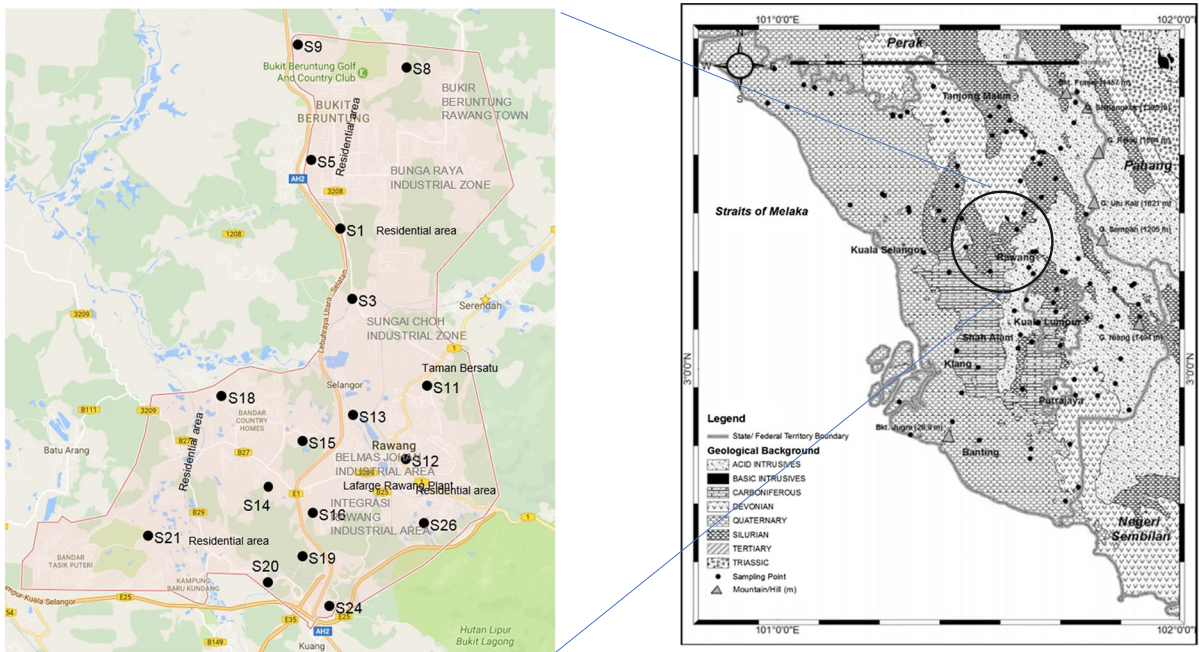

Fig. 1 Geological information and sampling locations of road dust in Rawang (Selangor)

Table 1 Wavelengths and analytical performances using a material certificate of reference in this study

Metal	Wavelength (nm)	LOD (μg/L)	LOQ (μg/L)	Correlation coefficient	Certified value (mg/kg)	Measured value (mg/kg)	Recovery rate (%)
Cu	325	0.4	4	0.99	114 ± 0.21	109.4 ± 0.17	96
Cd	226	0.1	1	0.99	–	–	
Co	228	0.2	2	0.99	–	–	
Cr	268	0.2	2	0.99	47 ± 0.11	46.5 ± 0.47	98.9
Pb	220	1	10	0.99	–	–	
Ni	231	0.5	1	0.99	–	–	
Zn	206	0.2	2	0.99	350.4 ± 0.15	367.9 ± 0.61	105
As	189	0.1	1	0.99	105 ± 0.32	103.9 ± 1.12	99

arsenic as this form of arsenic is present greater than that of the organic forms found in environmental samples (ATSDR 2000). Quality assurance and quality control were conducted through method blank, triplicates, and state first-level Standard Reference Material (Montana II Soil 2711) in every 10 samples to assess the precision and accuracy of the analysis process. Detection limit is defined as the concentration corresponding to three times the standard deviation of ten blanks. Detection limit values of potentially toxic element as microgram per liter were found to be 2 for Co, Cr, and Zn, 4 for Cu and 1 for Cd, Pb, Ni, and As. Recovery of standard samples ranged from 96 to 105%. Stock standard solution (Multi-element Calibration Standard 1, PerkinElmer) was used to obtain calibration curves (Table 1). Standard and blank solutions matrix used was 5% (*v/v*) nitric acid throughout the analysis to avoid a fixed error in the solution uptake rate and/or nebulization efficiency, which is sometimes referred to as the matrix interference. The analytical precision for triplicate analysis of samples was within 10%. All of the reagents used were analytical reagent grade and free from any contaminants that can interfere with the analysis. Moreover, ultrapure water was used throughout the analysis process. All of the glassware and apparatus were acid washed with nitric acid and rinsed with ultrapure water before analysis.

Data analysis

Descriptive statistics were calculated using SPSS version 20 to interpret the data distribution. Maximum, minimum, standard deviation, and coefficient of variation (CV) were analyzed to reflect the degree of

discrete distribution of different potentially toxic element concentrations [Cu, Cd, Co, Cr(IV), Fe, Pb, Ni, Zn, and As] in road dust samples.

Approaches via enrichment factor, Pearson correlation analysis, and FSA

Enrichment factor (EF) is a calculation method that has been extensively used to quantify the degree of potentially toxic element enrichment or pollution in dust (Wan et al. 2016). EF is based on the standardization of a measured element against a reference element (Eq. 1). A reference element (*R*) is characterized by low occurrence variability and can be used to differentiate potentially toxic element originating from human activities with those from natural sources. Element Fe was selected as the reference element in this study.

$$EF = (X_i/R)_{dust}/(X_i/R)_{background} \qquad (1)$$

where X_{idust} is the concentration of potentially toxic element in road dust sample, R_{dust} and $R_{background}$ are Fe concentration in dust sample and for background value. $X_{ibackground}$ and $R_{background}$ (Fe) are background concentrations of naturally occurring potentially toxic element suggested by the Department of Environment (2009). Pollution degrees of EF were classified into five categories based on (Barbieri 2016), where EF < 2 (minimal enrichment), $2 \leq EF < 5$ (moderate enrichment), $5 \leq EF < 20$ (significant enrichment), $20 \leq EF < 40$ (very high enrichment), and $EF \geq 40$ (extremely high enrichment.

Pearson correlation analysis was applied to provide information, which will help in identifying potential sources and relationships among potentially toxic

elements in road dust. Pearson correlation coefficient, r, was used to measure the strength of the interrelationship between two quantitative variables (potentially toxic elements). A correlation coefficient of -1 or $+1$ indicates a linear relationship (LeBlanc 2007).

In this work, FSA was conducted with Surfer (version 11.6) to obtain preference directions of potentially toxic elements distribution (Cu, Cd, Co, Cr, Fe, Pb, Ni, Zn, and As) and to locate their possible sources. FSA results are expressed as spectrum analysis is related to pixels at constant intervals, and the final solutions are expressed as linear equations of sine and cosine functions known as Fourier transformations. Spatial correlogram was used as a visual presentation of FSA results of potentially toxic elements distribution (Cu, Cd, Co, Cr, Fe, Pb, Ni, Zn, and As) and locate their possible sources in Rawang city.

Potential human health risks (non-carcinogenic and carcinogenic)

Risk assessment involves a multi-step procedure that comprises data collection and evaluation, exposure assessment, toxicity assessment, and risk characterization (Luo et al. 2012; US Environmental Protection Agency 1989). According to toxicological profiles by US Department of Environment (2011), US Environmental Protection Agency (2011) and World Health Organization (2011), all of the studied elements have toxicological health effects on humans while elements such as Cd, Cr(IV), Pb, and As induce both carcinogenic and non-carcinogenic risks. Chromium (IV) was considered in both carcinogenic and non-carcinogenic risk assessments. For carcinogenic risk, anthropogenic sources of chromium (VI) may be exposed through inhalation or ingestion of contaminated drinking water (ATSDR 2000; U.S. Environmental Protection Agency 2002).

Corresponding receptors are exposed to road dust through three pathways, namely ingestion, inhalation of dust particles through mouth and nose, and dermal contact absorption. The corresponding doses (D) received by children and adults through each pathway namely ingestion (ing), inhalation (inh), and dermal were calculated using Eqs. 2 and 3. Table 2 shows the values of the parameters (i.e., IngR, InhR, EF, ED, SA, AF, ABS, and AT) used in the calculated dose adopted from the Exposure Factors Handbook (US Environmental Protection Agency 2011) and the Department of Statistic Malaysia (2013).

$$D_{\text{ing}} = \frac{C_{\text{dust}} \times \text{IngR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times \text{CF} \quad (2)$$

$$D_{\text{inh}} = \frac{C_{\text{dust}} \times \text{InhR} \times \text{EF} \times \text{ED}}{\text{PEF} \times \text{BW} \times \text{AT}} \quad (3)$$

$$D_{\text{dermal}} = \frac{C_{\text{dust}} \times \text{SA} \times \text{AF}_{\text{soil}} \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \times \text{CF} \quad (4)$$

where C_{soil} concentration of the contaminant in road dust (mg/kg), $IngR$ ingestion rate (mg/day), EF exposure frequency (days/year), ED exposure duration (years), BW average body weight (kg), AT average time (days), CF conversion factor (1×10^{-6} kg/mg), SA surface area of the skin that contacts the soil (cm^2), AF_{soil} skin adherence factor for soil (mg/cm^2), ABS dermal absorption factor (chemical specific), $InhR$ inhalation rate (mg/cm^2), PEF particle emission factor $= 1.36 \times 10^9$ m^3/kg.

For risk characterization, hazard quotients (HQ) for each potentially toxic elements and exposure pathways were calculated based on the ratio of calculated dose to the reference dose level (RfD), as summarized in Tables 2 and 3. Hazard index (HI) represents the cumulative non-carcinogenic risk as the sum of the HQ, as expressed in Eqs. 5 and 6. The US Environmental Protection Agency (2002) stated that an HI value less than 1 implies no significant risk of non-carcinogenic effects. By contrast, an HI value more than 1 denotes the probability that non-carcinogenic risks effects may occur and will increase as the value of HI increases. The lifetime cancer risk (LCR) was calculated based on the calculated dose with slope factor (SF), as summarized in Tables 2 and 3. Total lifetime cancer risk (TLCR) represents the cumulative carcinogenic risk from each exposure pathway (Eqs. 7 and 8). The US Environmental Protection Agency (2002) recommended the acceptable TLCR for regulatory purposes be in the range of 1×10^{-6}–1×10^{-4} (USEPA 2002), which indicates the probability of an individual developing any type of cancer from lifetime exposure to carcinogenic hazards.

$$\text{HQ (non carcinogenic risk)} = D/\text{RfD} \quad (5)$$

$$\text{HI} = \sum \text{HQ} = \text{HQ}_{\text{Ing}} + \text{HQ}_{\text{Inh}} + \text{HQ}_{\text{dermal}} \quad (6)$$

Table 2 Values for parameter used for non-carcinogenic risk

Symbol	Value	Reference
IngR	200 mg/day: children	USEPA (2002)
	100 mg/day: adult	
ED	6 years: children	USEPA (2002)
	24 years: adult	
EF	350 day/year	USEPA (2002)
AT	$365 \times ED$ child or adult	USEPA (2002)
BW	15 kg: children	USEPA (2002)
	70 kg: adult	
SA	5700 cm^2 event^{-1} (adult)	USEPA (2002)
	2800 cm^2 event^{-1} (children)	
AF$_{soil}$	0.2 mg/cm^2: children	USEPA (2002)
	0.07 mg/cm^2: adult	
ABS	0.001	USEPA (2011)
InhR	m^3/day	USEPA (2002)
PEF	1.36×10^9 m^3/kg	USEPA (2002)
AT$_{Cancer}$	LT $\times$ 365	USDOE (2011)
LT	74 for Malaysian	Department of Statistic Malaysia (2013)
ED$_{cancer}$	30	USDOE (2011)
RfD	Refer to Table 3	–
SF	Refer to Table 3	–

$$\text{LCR} = D \times \text{SF} \tag{7}$$

$$\text{TLCR} = \text{LCR} = \text{LCR}_{Ing} + \text{LCR}_{Inh} + \text{LCR}_{dermal} \tag{8}$$

Results and discussion

Table 4 shows the descriptive statistics of potentially toxic elements in road dust samples from Rawang City. Mean potentially toxic elements concentrations were found in the order of Pb > Zn > Cr(IV) > Cu > Ni > Cd > As > Co. The results of the Shapiro–Wilk test revealed that all of the potentially toxic elements were normally distributed with a significance level of more than 0.05. The concentrations of potentially toxic elements were ranged from 23.5 to 34.7% indicating high variability and heterogeneous, associated with anthropogenic sources. A comparison of guideline values is crucial to determine potentially toxic elements concentration in dust. Given that no dust guideline is available, soil guideline values were used as applied by several studies in other settings (Li et al. 2016; Mathur et al. 2016; Wang et al. 2016). Soil guidelines applied as comparison in the current study were obtained from California Human Health SSLs (California Human Health Screening Levels 2005), Dutch Soil Guidelines (VROM 2000), and Maximum Permissible Level (US Environmental Protection Agency 2008). The comparison between potentially toxic elements and soil guidelines indicated that some of the potentially toxic elements exceeded the recommended values. In addition, the mean concentrations of potentially toxic elements in road dust under study are compared with those collected in different cities elsewhere and are summarized in Table 4. Generally, all of the potentially toxic elements in the present study were found to be of higher concentrations in road dust than those obtained in other cities. According to Mathur et al. (2016), potentially toxic elements concentrations vary from one city to another depending on the predominant activities and local pollution in cities. All of the cities compared in Table 4 are more exposed to automobile and road traffic emissions, whereas in the present study, Rawang City is not only exposed to automobile and road traffic emissions but also to dust pollution from cement factory operations. Meanwhile, it is crucial comparisons between guidelines and studies are relative based on extraction

Table 3 RfD and CSF values for HRA calculation

Elements	RfD$_{ing}$ (mg/kg/day)	RfD$_{inh}$ (mg/kg/day)	RfD$_{dermal}$ (mg/kg/day)	SF$_{ing}$ (mg/kg/day)	SF$_{inh}$ (mg/kg/day)	SF$_{dermal}$ (mg/kg/day)	Carcinogen class[a]	
Cu	4.00E−2	–	4.00E−2	–	–	–	D	D
Cd	1.00E−3	1.00E−5	2.50E−5	6.3	1.80E−3	–	B1-inh	B1
Co	3.00E−4	6.00E−6	3.00E−4	–	–	–		
Cr(VI)	3.00E−3	1.00E−4	3.90E−5	5.00E−1	1.20E−2	–	A	
Pb	3.50E−3	–	3.50E−3	8.50E−3	1.20E−5	–		B2
Ni	2.00E−2	9.00E−5	8.00E−4	–	–	–	A	A
Zn	3.00E−1	–	3.00E−1	–	–	–	D	
As	3.00E−4	3.00E−4	3.00E−4	1.50E+00	1.50E+01	1.50E+00		A
References	U.S. Department of Energy (2011), U.S. Environmental Protection Agency (2002), World Health Organization (2008), U.S. Environmental Protection Agency (1991)	U.S. Department of Energy (DOE) (2011), U.S. Environmental Protection Agency (1991)	U.S. Department of Energy (2011), U.S. Environmental Protection Agency (2002), World Health Organization (2008), U.S. Environmental Protection Agency (1991)	U.S. Environmental Protection Agency (2011) and U.S. Department of Energy (DOE) (2011)	U.S. Environmental Protection Agency (1991), U.S. Department of Energy (DOE) (2011)	U.S. Environmental Protection Agency (1991)	U.S. Environmental Protection Agency (2002), ATSDR (2000)	World Health Organization (2011)

[a] Group A—human carcinogen, B—probable human carcinogen, B1—limited evidence from epidemiologic studies, B2—"sufficient" evidence from animal studies and "inadequate" evidence or "no data" from epidemiologic studies, C—possible human carcinogen, D—not classifiable as to human carcinogenicity, E—evidence of non-carcinogenicity for humans

method used, local geology, and diversity of soil sampling locations which can be a constraint for direct comparison.

Source identification

The EF values of the studied potentially toxic elements were calculated based on Eq. (1). All of the EF values of the potentially toxic elements showed that potentially toxic elements above 1 indicated enrichments attributed mainly to anthropogenic inputs (Fig. 2). The ranking of mean enrichment levels of potentially toxic elements is as follows: Cr(IV) (extremely high enrichment) > Pb (very high enrichment) > Cu (significant enrichment) > Cd (significant enrichment) > Zn (significant enrichment) > Ni (significant enrichment) > Co (moderate enrichment) > As (moderate enrichment). These EF values combined with soil guidelines and compared with different cities showed that the road dust in Rawang City is enriched by anthropogenic sources, especially traffic emission (Luo et al. 2015).

Table 4 shows Pearson correlation analysis output involving potentially toxic elements in road dust in Rawang City. Element pairs, namely Cd–Ni, Pb–Zn, Cr(IV)–Cd, Cr(IV)–Zn, Cr(IV)–As and Cu–Zn, had significantly positive correlations at a significance level of 0.01. Significant and positive correlation coefficients between variables indicate a common source with identical behavior in the environment. Cu, Cd, Pb, Cr(IV), Ni, and Zn are associated with dust deposition in road dust from various anthropogenic activities (Lu et al. 2007). Furthermore, Cu is related to automobile thrust bearing and brake lining, while

Zn is related to tire wear. Likewise, Pb has been the most reliable indicator for traffic-induced pollution. Although lead petrol has been banned in Malaysia since 2000, Pb accumulation in road dust has been related to automobile exhaust over the years (Mummullage et al. 2016). Moreover, cement factory operation is a key source of potentially toxic elements such as Cd, Zn, Cu, and Pb, which are generated from the processing of raw materials during cement production and waste disposal (Dong et al. 2015).

To further determine the possible sources of potentially toxic elements in road dust in Rawang City, FSA was performed, and spatial correlograms were plotted. For spatial correlograms, if the spatial characteristic distribution of studied potentially toxic elements is similar, then a common factor and behavior is shared during pollutant transport (Lu et al. 2010). Figure 3 shows that the spatial correlation distribution of Pb, Cd, Zn, Cr(IV), Ni, and Cu, is in the same direction, which may indicate mutual dependence to a certain extent. Spatial correlation of Fe, Co, and As may imply that their source is mainly from natural input related to geological information and lithologies.

Source identification via EF (Fig. 2), geostatistical analysis (Table 5), FSA (Fig. 3), and present land map use (Fig. 1) was adopted to identify and integrate the sources of potentially toxic elements in road dust and reduce corresponding uncertainties involving the road dust in Rawang City. As a result of source identification, the main sources of potentially toxic elements in the road dust in Rawang City are identified: (1) Cu, Cd, Pb, Zn, Ni, and Cr(IV) are associated with anthropogenic sources, and (2) Co and As are related to
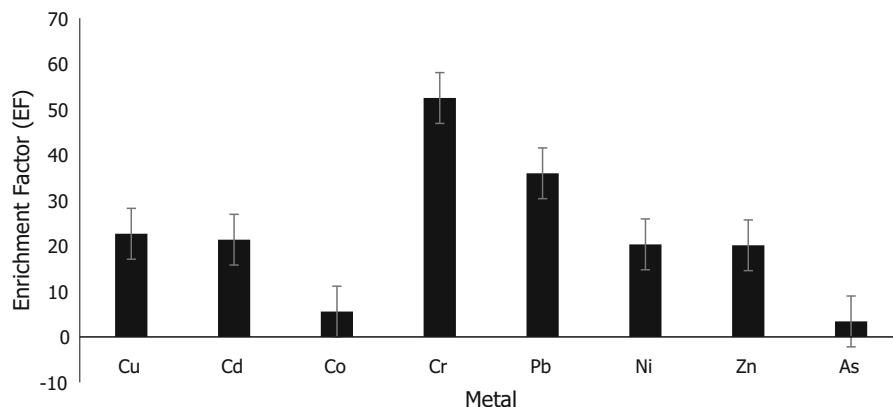

Fig. 2 Enrichment factors of metals in road dust

Table 4 Descriptive statistics of metal concentrations (mg/kg) in road dust of Rawang city

	Cu	Cd	Co	Cr	Fe	Pb	Ni	Zn	As
Minimum	102.6	2.6	0.2	146.2	15,873.6	277.9	48.1	216.5	3.8
Maximum	774.8	63.1	5.4	743.5	18,411.2	879.3	1902.1	854.5	12.5
Mean	425.1	71.71	5.6	501.3	19,336.9	593.3	113.3	526.8	18.4
SD	128.5	5.6	0.7	173.8	6562.9	188.1	102.1	203.2	4.32
CV (%)	30.2	32.9	12.5	34.7	33.9	31.7	24.7	38.6	23.5
normality test	0.89	0.76	0.53	0.66	0.58	0.57	0.72	0.54	0.51
Target[a]	36	1	9	100	–	85	35	140	29
Intervention[a]	190	12	240	380	–	530	210	720	55
California Human Health SSLs (Cal/EPA 2005)									
Residential area	3000	2	660	100,000	–	150	1600	23,000	0
Industrial area	38,000	8	3200	100,000	–	3500	16,000	100,000	0
Cities									
Present study	425.1	71.7	5.6	501.3	19,336.9	593.3	113.3	526.8	18.4
Changsha city (China)[b]	43.9	7.48	–	71.6	–	66.6	–	171	–
Delhi (India)[c]	174.43	17.92	–	189.62	–	284.55	–	241.73	–
Tehran (Iran)[d]	225.3	10.7	–	33.5	–	257.4	–	873.2	–
Tokyo (Japan)[e]	–	0.98	–	52.3	–	245	–	1888	–

[a]Values of Dutch Soil Guidelines (VROM 2000)

[b]Li et al. (2016)

[c]Banerjee (2003)

[d]Saeedi et al. (2012)
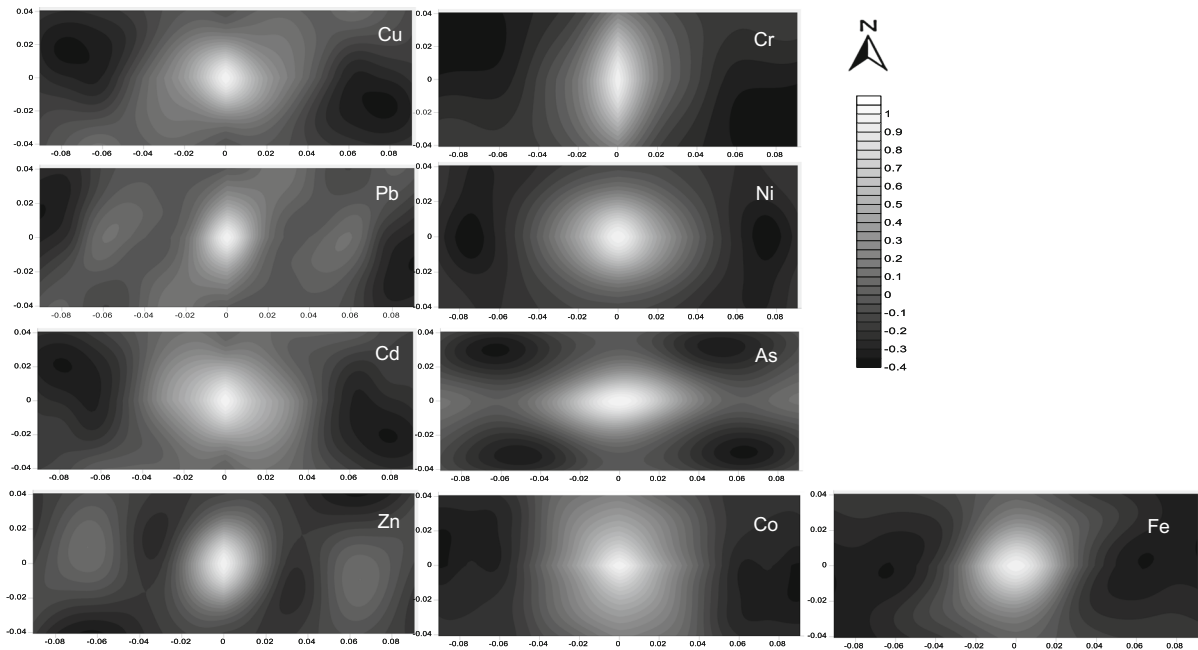
[e]Wijaya et al. (2012)

Fig. 3 Spatial correlograms of studied metals based on FSA

natural sources. Generally, the results of the Pearson correlation analysis show that in the first group, Cu, Cd, Pb, Zn, Ni, and Cr(IV) are positively correlated, and they share a similar spatial distribution associated with anthropogenic sources. According to Othman et al. (2014), the Rawang area is surrounded by industrial and highly populated areas. The dominant industrial land use includes industrial enterprises located at northern and southern Rawang. Rawang is the most developed area in the Selangor river basin. Industries, urbanization, and human activities in this area have generated point and nonpoint pollution sources. With an existing cement factory operation in southern Rawang, cement production is a source of potentially toxic elements, such as Cd, Cr(IV), Pb, Cu, and Zn (Ogunkunle and Fatoba 2014). Bermudez et al. (2010) have demonstrated that high kiln temperature may allow unintentional formation of pollutants including potentially toxic elements that are deposited and released as gas or dust from cement factories. In addition, deposition of these potentially toxic elements in dust occurring at various distances is associated with factors, such as particle size, stack fumes, and environmental problems (Olowoyo et al. 2015). High concentrations of potentially toxic elements in road dust, such as Cr(IV), Cu, Pb, and Zn, as influenced by cement factory operation in nearby area, have been detected by Al-Khashman and Shawabkeh (2006) in Southern Jordan, Michael et al. (2015) in Gboko (Nigeria), and Solgi (2015) in Western Iran. Moreover, these potentially toxic elements are associated with vehicle emissions, which release potentially toxic elements, such as Cu, Cd, Pb, Zn, Ni, and Cr(IV), as vehicle emission is one of the main potentially toxic elements contaminants in urban areas (Ferreira-

Baptista and De Miguel 2005; Praveena et al. 2015). The rapid development and population growth in northwestern Rawang have resulted in urban traffic congestion, especially during peak hours. High traffic congestion with vehicle movements (vehicular exhaust and road, tire and brake abrasion) led to potentially toxic elements emissions to the environment (Tey 2009). Moreover, Ghazali et al. (2010) investigated the impact of vehicular traffic input with pollutant emission in Gombak district, including Rawang City, and reported that high density of vehicle volume influences pollutant release during peak hours and depends on meteorological parameters on pollutant transport and accumulation environment. Thus, road dust has become a large source of particulate pollution, which accumulates potentially toxic elements released from these vehicle emissions via dry or wet atmospheric deposition (Duong and Lee 2011). In the second group, natural sources dominate the compositions of Fe, Co, and As with anthropogenic sources such as industrial emissions have contribute little to its concentrations. Composition of the main geological backgrounds and the lithologies in Rawang are made of Silurian lithologies with schist, phyllite, limestone compositions. Iron, Co, and As are in association with schist, phyllite, limestone compositions (Houmani et al. 2010; Sanusi et al. 2014) (Table 5).

Risk characterization was applied to determine carcinogenic and non-carcinogenic risks to potentially toxic elements in road dust through ingestion, inhalation, and dermal contact. For non-carcinogenic risks, ingestion appears to be the main pathway for potentially toxic elements to adults and children, followed by dermal contact and inhalation. These results on

Table 5 Pearson correlation analysis output involving heavy metals in road dust in Rawang City

	Cd	Co	Ni	Zn	As	Pb	Cr	Cu	Fe
Cd	1	0.072	0.762**	−0.114	0.037	0.359	0.786**	0.434	0.011
Co		1	0.238	0.060	−0.189	0.416	0.029	0.112	−0.115
Ni			1	0.006	0.081	−0.270	0.061	0.241	−0.202
Zn				1	0.247	0.487**	0.774**	−0.621**	0.247
As					1	0.048	0.666**	0.249	−0.188
Pb						1	0.443	0.420	0.102
Cr							1	0.050	0.149
Cu								1	−0.164
Fe									1

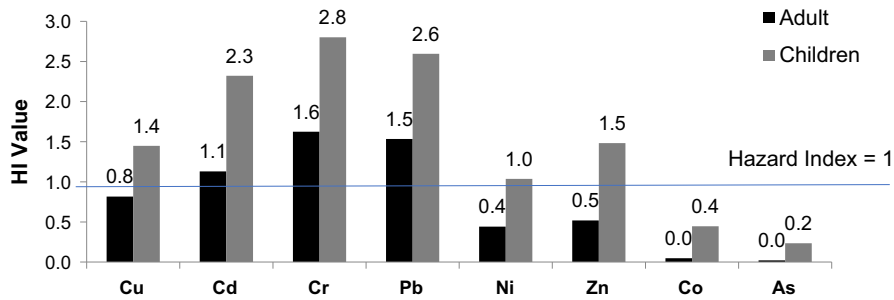**Correlation is significant at the 0.01 level (2-tailed)

Fig. 4 Hazard index values for non-carcinogenic health risks for adults and children involving Rawang city road dust

pathways were also found by other studies conducted in other settings and those dealing with road dust (Li et al. 2016). Figure 4 shows HI values for non-carcinogenic health risks among adults and children involving Rawang City road dust samples associated with exposure to Cu, Cd, Cr(IV), Pb, Ni, Zn, Co, and As. For average non-carcinogenic risks among adults and children, the order of potentially toxic elements by HI value is Cr(IV) > Pb > , Cd > , Cu > , Zn > , Ni > , Co > As. Cr(IV), Pb, and Cd were found to have non-carcinogenic health risks for adults, while Cu, Cd, Cr(IV), Pb, and Zn were found to have non-carcinogenic health risks for children. Similarly, the ingestion pathway was the main pathway attributed to road dust exposure, followed by dermal contact and inhalation. Cd, Cr(IV), Pb, and As may induce carcinogenic risks among adults and children. Figure 5 shows that the TLCR values of Cd, Cr(IV), Pb, and As have exceeded incremental lifetime of 1.0E−05. Thus, the possibilities of having cancer in the long term are evident for adults and children.

Non-carcinogenic and carcinogenic risks represented by HI and TLCR values are disturbing. These disturbing values are also influenced by As form assumption in health risk assessment. Thus, an appropriate form of potentially toxic elements analysis is still needed to determine the exact risk to the health of adults and children in the study area. Given that the current study has applied total potentially toxic elements concentration in health risk assessment, bioavailability metal form analysis is needed to ensure that these forms of potentially toxic elements concentration will determine a realistic probability of human health risks (Praveena et al. 2015). After ingestion, potentially toxic elements from environmental samples, such as road dust, will change to bioavailable form, and the absorption process will occur in the gastrointestinal and intestinal membranes before contaminating the bloodstream (Yuswir et al. 2013). Similarly, inorganic arsenic also needs to be analyzed specially in.

Conclusion

Potentially toxic elements concentrations of Rawang City road dust are generally in the order of Pb > Zn > Cr(IV) > Cu > Ni > Cd > As > Co. Some of the studied potentially toxic elements exceeded the recommended values of soil quality guidelines and
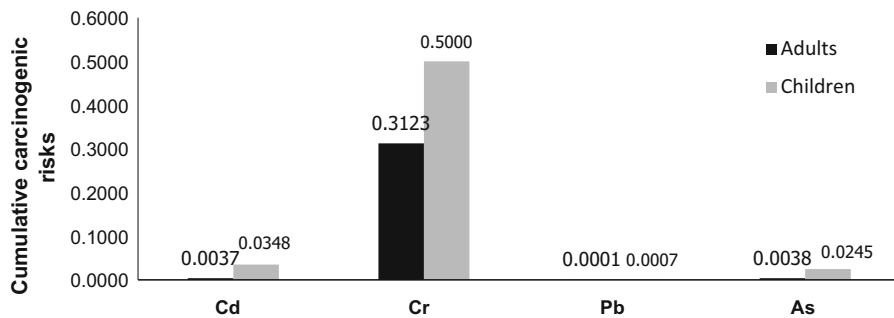

Fig. 5 Total lifetime cancer risk values for carcinogenic health risks for adults and children involving Rawang city road dust

have higher concentrations in road dust than those in other cities. Source identification via EF, Pearson correlation analysis, FSA, and present land map use indicated that spatial correlation distributions of Pb, Cd, Zn, Cr(IV), Ni, and Cu are mainly observed in the same direction, which indicated mutual dependence on anthropogenic input to a certain extent. The spatial correlation of Co and As may imply that their source is mainly from natural input. Anthropogenic sources are related to industrial land use and include industrial enterprises located at northern and southern Rawang, existing cement factory operations at southern Rawang as the source of potentially toxic elements to the environment, and rapid development and population growth in northwestern Rawang, which have resulted in urban traffic congestion, especially during peak hours. In the second group, Fe, Co, and As were mainly derived from natural sources related to geological background and lithologies. For both non-carcinogenic and carcinogenic health risks, ingestion is the main pathway for potentially toxic elements to adults and children, followed by dermal contact and inhalation. This study found potential non-carcinogenic health risks for adults [Cr(IV), Pb, and Cd] and children [Cu, Cd, Cr(IV), Pb, and Zn]. Furthermore, potential health risk from TLCR [Cd, Cr(IV), Pb, and As] was indicated as lifelong for adults and children in Rawang City. With the help of the results of integrated source identification and local land use mapping, sources of potentially toxic elements anthropogenic origin were identified and scientifically interpreted. Although isotope methods can be used to identify the sources, such method is expensive. Thus, the current integrated source identification is significant given the limited financial capacity to apply isotopes in source identification, as well the need for efficient and practicable technology, especially in developing countries.

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