



Contamination, source attribution, and potential health risks of heavy metals in street dust of a metropolitan area in Southern Vietnam

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Abstract

This study investigates distribution, pollution indices, and potential risk assessment for human health and ecology of eight heavy metals in twenty-five street dust samples collected from metropolitan area—Ho Chi Minh City, Vietnam. Results showed that Zn was of the highest concentration (466.4 ± 236.5 mg/kg), followed by Mn (393.9 ± 93.2 mg/kg), Cu (153.7 ± 64.7 mg/kg), Cr (102.4 ± 50.5 mg/kg), Pb (49.6 ± 21.4 mg/kg), Ni (36.2 ± 15.4 mg/kg), Co (7.9 ± 1.9 mg/kg), and Cd (0.5 ± 0.5 mg/kg). The principal component analysis revealed that three sources of heavy metals measured in street dust include vehicular activities (32.38%), mixed source of vehicular and residential activities (26.72%), and mixture of industrial and natural sources (20.23%). The geo-accumulation index values showed levels of non-pollution to moderately pollution for Mn and Co; moderately pollution for Ni; moderately to strongly pollution for Cd, Cr, and Pb; and strongly pollution for Cu and Zn. The potential ecological risk values of all sampling sites were close to the high-risk category. Zn (28.9%), Cu (25.4%), and Mn (24.4%) dominantly contributed to the ecological risk. For non-carcinogenic risk, the hazard quotient values for both children and adults were within a safety level. For carcinogenic risk, the $TCR_{Children}$ was about 3 times higher than TCR_{Adults} , but still within a tolerable limit (1×10^{-6} to 1×10^{-4}) of cancer risk. Cr was a major contribution to potential risks in humans. Such studies on heavy metal in street dust are crucial but are still limited in Vietnam/or metropolitan area in Southeast Asia. Therefore, this study can fill the information gap about heavy metal contaminated street dust in a metropolitan area of Vietnam.

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Introduction

Street dust has attracted widespread attention of scientists in recent years, because it is considered as a major reservoir for various pollutants, including heavy metals derived from different sources nearby (Wei et al. 2015). Heavy metals (Cd, Co, Cr, Mn, Ni, Pb, and Zn, etc.) accumulating in the street dust are highly bioavailable and mobile, thus they potentially pose adverse influences on both ecosystem and human health (Kabadayi and Cesur 2010; Qadeer et al. 2020). Heavy metals in street dust might be derived from various origins such as vehicular activities, residential oil burning, waste incineration, power generation facilities, industrial parks, and construction depending on where they are collected (Wei et al. 2015). Understanding the distribution, pollution level, and risk to human health and ecosystem, sources of heavy metals in street dust is critical for environmental quality management in the metropolitan area.

Recently, numerous investigations on heavy metals in street dust have been conducted worldwide such as in Europe (Ewen et al. 2009; Kabadayi and Cesur 2010; Trojanowska and Świetlik 2019; Khademi et al. 2020), Africa (Onjefu et al. 2017; Shabbaj et al. 2018; Alharbi et al. 2020), and Asia (Joshi et al. 2009; Duong and Lee 2011; Li et al. 2013; Akram et al. 2014; Keshavarzi et al. 2015; Wei et al. 2015; Phi et al. 2017; Kamani et al. 2018; Phi et al. 2018; Ghanavati et al. 2019; Roy et al. 2019; Shabanda et al. 2019; Bartholomew et al. 2020; Qadeer et al. 2020). Results obtained by previous studies showed detectable and notably high concentration of heavy metals in street dust (67.9–8430 mg/kg for Zn, 309–451 mg/kg for Mn, 28.4–177 mg/kg for Pb, 19.1–136 mg/kg for Cu, 47.6–106 mg/kg for Cr, 5.3–77.5 mg/kg for Ni, 6.8–34 mg/kg for Co, and 0.5–7.5 mg/kg for Cd), which can cause severe impacts on ecosystem and human health. This proves that the assessment of pollution levels, the source attribution, and potential risks of these heavy metals to ecosystem and human is very necessary.

The pollution degree of street dust by heavy metals was determined by different indexes such as geo-accumulation index (I_{geo}) (Kamani et al. 2018; Duan et al. 2019; Idris et al. 2020), enrichment factor (Ghanavati et al. 2019; Alharbi et al. 2020; Khademi et al. 2020), and contamination factor (Duong and Lee 2011). Besides, the potential risks to human health caused by the heavy metals in street dust through three exposure pathways including inhalation, ingestion, and dermal contact were evaluated via the non-carcinogenic and carcinogenic risks (Bartholomew et al. 2020; Idris et al. 2020; Qadeer et al. 2020). Additionally, potential ecological risk index (E_i) and potential ecological

risk (PER) were used by Kamani et al. (2018), Ghanavati et al. (2019), and Roy et al. (2019).

As an industrial and populous city located in Southern Vietnam, Ho Chi Minh City (HCMC) with the highest traffic density is facing with serious air pollution issues which need to be addressed. Heavy metal contamination should be the top of environmental concern in HCMC due to high potential sources of heavy metal, including heavy traffic load and densely industrial zone in and around the city. As a potential reservoir and sink of heavy metals, measuring heavy metals in street dust should be a priority for evaluating the occurrence and risk of heavy metals due to its less complicated work. In Vietnam, Phi et al. (2017) investigated the occurrences of Ca, Fe, K, Mn, Pb, and Zn in street dust collected at many locations in Hanoi, and they indicated that the concentrations of Pb and Zn varied with sampling site. This study also revealed that the highest concentrations were observed in downtown areas, while the lowest levels in new suburban areas. Phi et al. (2018) collected fifty-five dust street samples in North-east Vietnam to determine concentration of Ca, Cu, Cr, Fe, K, Mn, and Pb and assess the potential risk causing by five metals (Cu, Cr, Mn, Pb, Zn). They found that higher concentrations of heavy metals were observed at where of high traffic density. They also indicated that Cr caused the highest non-carcinogenic risk although the hazard index of heavy metals was within the acceptable ranges. They also reported that children were the group of the greatest potential risk for heavy metal contaminated street dust. To the best of our knowledge, these studies both reported the characteristics of heavy metals in street dust collected in Hanoi, and no relevant information was reported for HCMC area. Therefore, study on heavy metals in street dust collected in HCMC is deemed necessary.

In this study, street dust samples collected from three major streets (Ha Noi Highway, Pham Van Dong street, and National Route 1A) were determined for eight heavy metals (Cd, Co, Cu, Cr, Mn, Ni, Pb, and Zn) to reveal the characteristics of heavy metals (including level and distribution), and to compare with those from other areas over the world. The source attribution of heavy metals and their relationships were also elucidated by specific statistical analyzes, namely the principal component analysis (PCA) and the Pearson's correlation coefficient. In addition, the geo-accumulation index (I_{geo}) and enrichment factor (EF) were carried out to estimate the levels of anthropogenic enrichment (Idris et al. 2019). The contamination factor (C_f^i) and degree of contamination (C_{deg}) were conducted to assess contamination levels of the eight heavy metals. Furthermore, potential ecological risk index (E_i), potential ecological risk (PER), and health risk

assessment (non-carcinogenic risk and carcinogenic risk) were also evaluated. Results from this study can contribute to fill the information gap in the heavy metal pollution status in street dust from Vietnam and other densely populated areas worldwide, and can provide evidence to engage more audiences to reduce public health risks.

Methods and materials

Sample collection

Ho Chi Minh City, the most densely populated city with a total area of 2095 km², is located in the south-eastern of Vietnam and extends up to Cu Chi district and down to Can Gio district on the Eastern Sea (Fig. 1). Typical weather here is a tropical climate with the precipitation of 1800 mm, and the average temperature of 28 °C. The typical weather condition in HCMC is characterized by wet (May–November) and dry (December–April) (GSO Vietnam 2019). In this study, twenty-five street dust samples were collected from some typical streets connecting HCMC with provinces from the north-east site (Dien Bien Phu Street, Ha Noi Highway, Pham Van Dong street, National Route 1A, and National Route 13) as depicted in Fig. 1b. The streets are cleaned approximately twice a week, and vehicle composition of these streets is generally dominated by gasoline motorbikes and buses in daytime and heavy trucks in nighttime. Additionally, three background samples were collected at the remote area of HCMC (Can Gio District) (as shown in Fig. 1a). Detailed information of sampling sites (abbreviation, coordinates, and site description) was shown in Table S1. Can Gio District, where Can Gio Mangrove Biosphere Reserve is located, was selected as the

background site because of the area without the industrial zone, low population density and traffic (Hien et al. 2019). Background samples were collected along Rung Sac Street passing through Can Gio forest.

All samples were collected from 9 AM to 4 PM during dry days (Feb. 2020) to be convenient for collection and to eliminate the wash-out of road dust due to rainfall. Each 500 g of samples was collected by clean plastic brushes and dustpans in the area along to the kerb (from 5 to 20 m) and then storing them into a polyethylene zip lock bag and transporting to the lab for heavy metal analysis (Trojanowska and Świetlik 2019). The recorded temperature during sampling time ranged from 30.3 to 38.1 °C. All samples were dried naturally for about 2 weeks to drive out moisture and then sieved through a 150-mesh nylon sieve to remove sand, stones, plastic, coarse debris, and other impurities and stored in a desiccator before analysis of heavy metals.

Sample pretreatment and analysis

The heavy metals were extracted according to USEPA method 3051A (USEPA 2007b) and Method 200.8, Revision 5.4 (USEPA 1994), and then analyzed for Cu, Pb, Zn, Ni, Co, Cd, Cr, and Mn using ICP-MS (7700x, Agilent, USA) according to EPA method 6020B (USEPA 2014). All reagents met analysis grade (Merck) and were purified using a sub-boiling quartz distillation equipment prior to digestion. Each sample was triplicated and one reagent blank was analyzed after each 10 samples. All metal concentrations in the blanks were lower than the method detection limit (MDL). The analytical precision and accuracy were ensured by analyzing certified reference materials of urban particulate (SRM-1648a), showing the recoveries of 90–120% for all metals. SRM-1648a is atmospheric particulate matter collected in an urban area and is

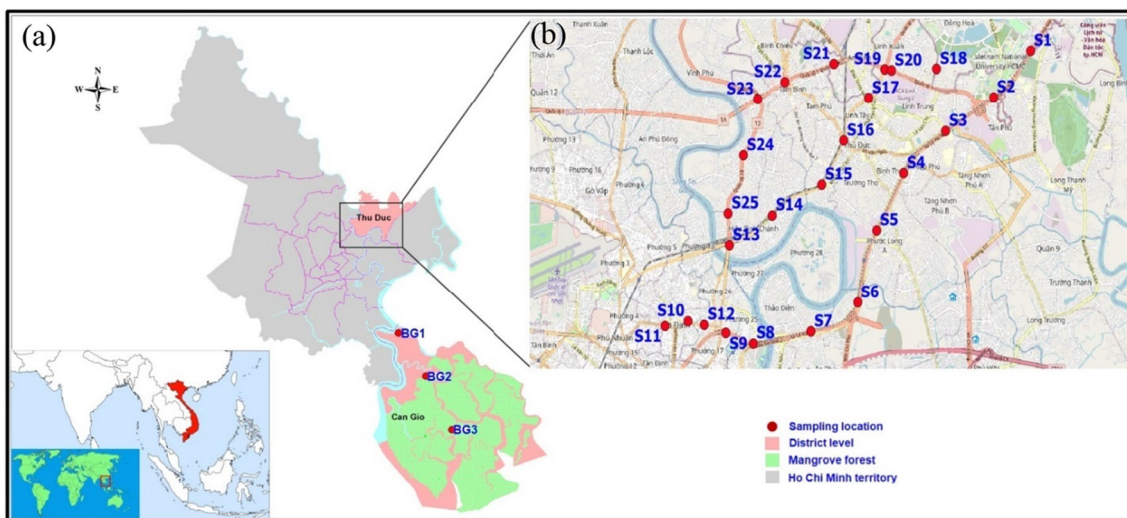


Fig. 1 The study area: Ho Chi Minh City (a); sampling sites in Ho Chi Minh City (b)

used as a quality control material to evaluate the analytical method of heavy metals. This SRM contains the known amount of all heavy metals reported in this study (i.e., Cu (610 mg/kg), Pb (6550 mg/kg), Zn (4800 mg/kg), Ni (81.1 mg/kg), Co (17.93 mg/kg), Cd (73.7 mg/kg), Cr (402 mg/kg), and Mn (790 mg/kg)). In addition, SRM-1648a has been widely used by numerous studies for testing the analytical methods of heavy metals (Palomo-Marín et al. 2015; Kyllönen et al. 2020). The MDL of Cu (0.2 mg/L), Pb (20 µg/L), Zn (5 mg/L), Ni (0.2 mg/L), Co (0.2 mg/L), Cd (20 µg/L), Cr (0.2 mg/L), and Mn (2 mg/L), respectively, which well below the metals concentration in the samples collected in this study.

Degree of contamination

Geo-accumulation index (I_{geo})

I_{geo} was employed for assessing level of contamination by comparing current and pre-industrialized levels, which was initially proposed by Muller (1969) for bottom sediment samples. In recently years, I_{geo} has been widely used to assess the contamination levels by heavy metals in street dust and soil (Duan et al. 2019; Hini et al. 2019; Bartholomew et al. 2020). After calculated by the Eq. 1, I_{geo} value will be compared with seven levels of contamination proposed by Muller (1969) (as presented in Table S2).

$$I_{geo} = \log_2 \left(\frac{C_i}{1.5C_{ref}} \right) \quad (1)$$

where C_i and C_{ref} are the concentration of heavy metal n in a street dust and background sample, respectively. The factor of 1.5 is to correct potential background variation. In this study, the selected background site is the area without the industrial zone, low population density and traffic. Detailed contaminated levels of the I_{geo} were shown in Table S2.

Enrichment factor

Enrichment factor (EF) is a useful tool for assessing the magnitude of contamination and differentiating source (anthropogenic or natural sources) of heavy metals measured in soil and street dust. Recently, EF value has been widely used to assess the contamination status of heavy metals in street dust (Ghanavati et al. 2019; Alharbi et al. 2020; Khademi et al. 2020). After estimated following Eq. 2, the EF value will be compared with the criteria of enrichment levels as presented in Table S3 (Yap and Pang 2011).

$$EF = \frac{(C_i/C_{ref})_{Sample}}{(C_i/C_{ref})_{Background}} \quad (2)$$

where $(C_i/C_{ref})_{Sample}$ and $(C_i/C_{ref})_{Background}$ are the ratio of metal concentration (C_i) to the concentration of reference metal (C_{ref}) in the street dust sample and background sample, respectively. In the current study, Fe was selected as the normalizer or reference metal (Joshi et al. 2009).

The contamination factor (C_f^i) and the degree of contamination (C_{deg})

In this study, the C_f^i and C_{deg} , which were firstly proposed by Hakanson (1980) for determining contamination level of heavy metals in sediment, were applied to determine the heavy metal contamination levels of street dust (Roy et al. 2019; Trojanowska and Świetlik 2019; Aguilera et al. 2021). Four levels of contamination caused by heavy metals were proposed based on calculated values of C_f^i and C_{deg} as presented in detail in Table S3. The (C_f^i) was calculated as Eq. 3, while C_{deg} was determined as the sum of C_f^i for eight heavy metals measured in this study following Eq. 4.

$$C_f^i = \frac{C_{sample}^i}{C_{Background}^i} \quad (3)$$

where C_{sample}^i (mg/kg) and $C_{Background}^i$ (mg/kg) are the concentration of heavy metal “ i ” in a street dust sample and background sample, respectively.

$$C_{deg} = \sum C_f^i \quad (4)$$

Risk assessment

Potential ecological risk

The potential ecological risk index (E_i) and the potential ecological risk (PER) represent the potential ecological risk factor of one and multiple metals, respectively (Hakanson 1980). The E_i and PER are calculated (Hakanson 1980; Ghanavati et al. 2019; Roy et al. 2019) by the following Eqs. 5 and 6.

$$E_i = T_i \times C_f^i \quad (5)$$

$$PER = \sum E_i \quad (6)$$

where T_i is the toxic factor of heavy metal i (Cu = Ni = Co = Pb = 5; Mn = Zn = Cr = 2; Cd = 30; (Vu et al. 2018), C_f^i is the contamination factor. Detailed levels of the E_i and PER were shown in Table S4.

Human health risk

This study investigated the health risk associated with heavy metals in street dust following USEPA (2011). Non-

carcinogenic risk was evaluated the potential health risk of Cu, Pb, Zn, Ni, Cd, and Cr in street dust, while carcinogenic risk of Cr, Cd, and Ni was estimated. These heavy metals were selected because they were considered as the carcinogenic elements based on IARC (2014). The average daily intake (ADI) was calculated using the following Eqs. 7 to 10.

$$ADI_{ing} = \frac{C_x \times R_{ing} \times EF \times ED \times CF}{BW \times AT} \tag{7}$$

$$ADI_{inh} = \frac{C_x \times R_{inh} \times EF \times ED}{BW \times AT \times PEF} \tag{8}$$

$$ADI_{derm} = \frac{C_x \times SA \times AF \times ABF \times EF \times ED \times CF}{BW \times AT} \tag{9}$$

$$ADI_{total} = ADI_{ing} + ADI_{inh} + ADI_{derm} \tag{10}$$

where C_x is concentration of heavy metal x ; ADI_{ing} , ADI_{inh} , and ADI_{derm} (mg/kg day) are average daily intake for ingestion, inhalation, and dermal routes, respectively. Detail information regarding the values of parameters used in health risk assessment is described in Table S5.

Non-carcinogenic risk

The hazard quotient (HQ) reflects the non-carcinogenic risk for human and is calculated by Eq. 11 (USEPA 2007a).

$$HQ = \frac{ADI}{RfD} \tag{11}$$

where RfD (mg/kg/day) is the reference dose (detailed RfD values shown in Table S6).

The Hazard Index (HI), the sum of HQs for the three exposure pathways, is calculated as follows:

$$HI = \sum HQ = HQ_{ing} + HQ_{inh} + HQ_{derm} \tag{12}$$

The $HI < 1$ is considered to be a negligible non-carcinogen risk whereas the $HI \geq 1$ is a possible adverse health risk to human health (Chen et al. 2012; Ali et al. 2019; Duan et al. 2019).

Carcinogenic risk

According to IARC (2014), Cd, Cr, and Ni were the carcinogenic metals. The carcinogenic risk (CR) and total carcinogenic risk (TCR) of three heavy metals were computed using Eqs. 13 and 14, respectively. The $TCR > 1 \times 10^{-4}$ is considered as an unacceptable risk, while $TCR < 1 \times 10^{-6}$ is an acceptable risk (USEPA 1996; Hini et al. 2019).

$$CR = ADI \times SF \tag{13}$$

$$TCR = \sum CR = CR_{ing} + CR_{inh} + CR_{derm} \tag{14}$$

where SF is the carcinogenic slope factor proposed by the USEPA (2010). The detailed SF values for Cr, Cd, and Ni applied in this study are shown in Table S6.

Source attribution methods

Correlation coefficient analysis

The Pearson’s correlation analysis was employed to determine the relationship of a metal pair (Ashaiekh et al. 2019; Duan et al. 2019). The inter-element relationship between metals reveal helpful information about their pathways and sources (Ghanavati et al. 2019). The Pearson correlation coefficients were performed using SPSS software 21.0.

Principal component analysis

Principal component analysis (PCA) has been widely applied to determine the source attribution of heavy metals in street dust (Roy et al. 2019; Shabanda et al. 2019). The principal components (PCs) are represented as follows:

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} + \dots + a_{im}x_{mj} \tag{15}$$

where Z is the component score, x is the measured value of the variable, a is the component loading, m is the total number of variables, i is the component number, and j is the sample number.

Before the analysis, the Kaiser-Mayer-Olkin (KMO) criteria were checked. A large value of KMO (close to 1) generally reflected that the data set is suitable to carry out PCA analysis while the lower value of KMO indicates the less suitability of the data set for PCA analysis. A KMO value of greater than 0.6 is required for the suitability of the data set in PCA procedure (Jamhari et al. 2014; Manly and Alberto 2016). Principal components (PCs) were chosen based on the Kaiser principle (Li et al. 2020) and performed using SPSS software 21.0. The PCs with eigenvalues greater than 1.0 have been calculated. A PC with a higher eigenvalue is considered to be more significant (Gulgundi and Shetty 2018).

Results and discussion

Heavy metal concentration in street dust

Concentrations of heavy metals associated with street dust samples have been shown in Fig. 2 and the statistical details can be found in Table S7. The average concentrations of heavy metals measured in this study were also compared to previous studies (Table 1). As presented in Fig. 2, concentrations of most heavy metals measured in street dust collected in HCMC were higher than those in background samples (except

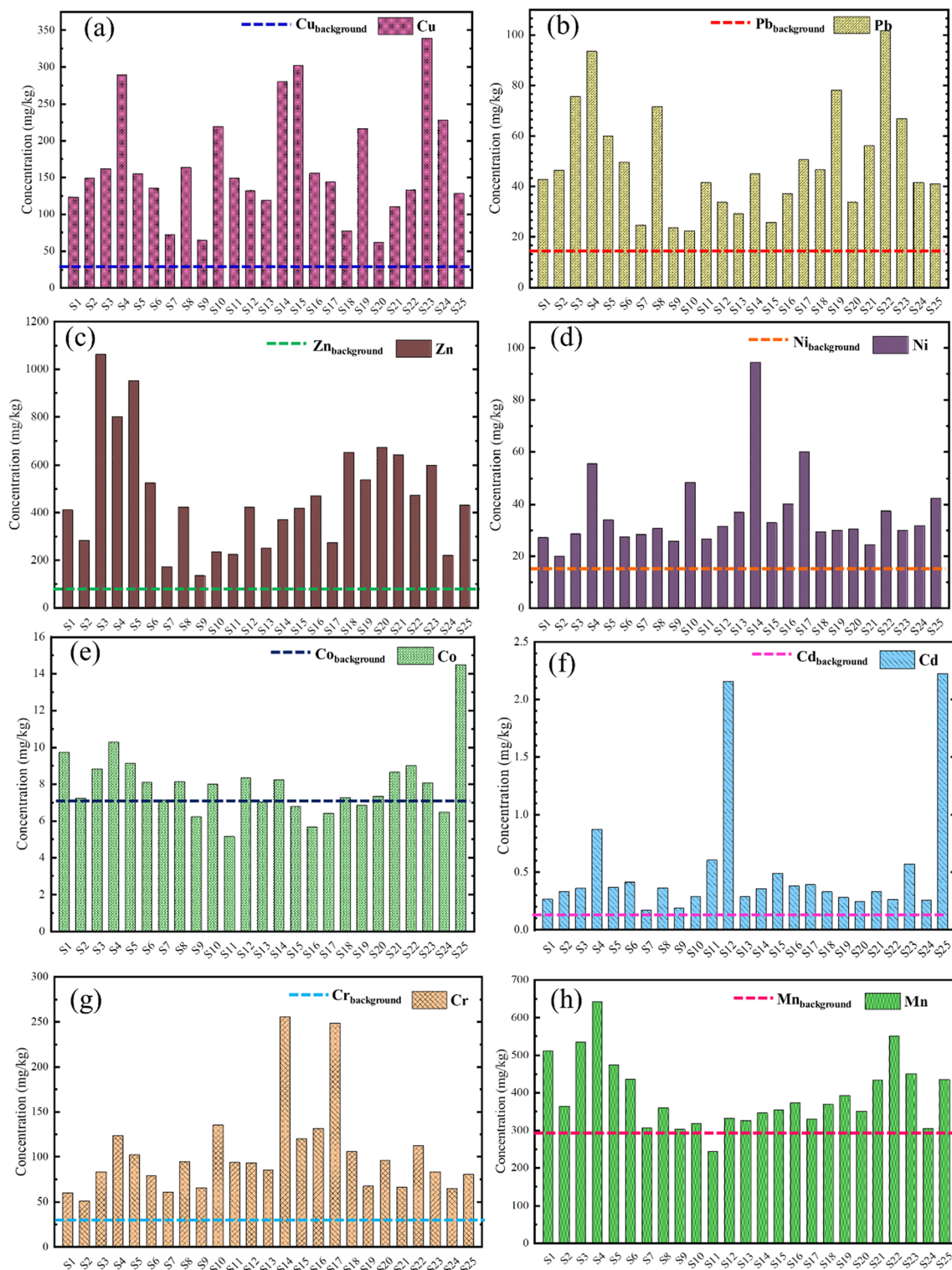


Fig. 2 Concentration of the heavy metals measured in street dust collected in Ho Chi Minh City

for Co concentrations found at S9, S10, S16, S17, and Mn measured at S11). On average, the heavy metal concentrations found in street dust collected in HCMC were found in

decreasing order of Zn (466.43 mg/kg) > Mn (393.87 mg/kg) > Cu (153.70 mg/kg) > Cr (102.43 mg/kg) > Pb (49.59 mg/kg) > Ni (36.19 mg/kg) > Co (7.95 mg/kg) > Cd (0.51 mg/kg).

Table 1 Heavy metal concentrations (mg/kg) in street dust from different sites worldwide

Sites	Country	Cu	Pb	Zn	Ni	Co	Cd	Cr	Mn	Reference
Tongchuan	China	32.6	75.2	–	25.5	34.0	–	106.4	–	Lu et al. (2017)
Huainan	China	36.5	42.6	–	–	9.3	0.3	61.1	–	Tang et al. (2017)
Tianjin	China	62.7	28.4	–	18.4	6.8	0.6	47.6	–	Živančev et al. (2019)
Urumqi	China	36.8	40.5	224.5	34.1	–	0.2	66.8	435.5	Hini et al. (2019)
Jinhua	China	133.7	110.6	8430.3	76.3	–	4.9	105.3	451.0	Bartholomew et al. (2020)
Villavicencio	Colombia	126.3	87.5	133.3	5.3	–	–	–	–	Trujillo-González et al. (2016)
Petra region	Jordan	19.1	177.0	129.0	–	–	1.0	–	–	Als bou and Al-Khashman (2018)
Ulsan	Korea	89.8	92.1	129.0	13.4	–	1.3	–	–	Duong and Lee (2011)
Shiraz	Iran	136.3	115.7	403.5	77.5	–	0.5	67.2	438.5	Keshavarzi et al. (2015)
Lahore	Pakistan	23.9	43.3	67.9	13.9	–	1.4	–	–	Qadeer et al. (2020)
Jeddah	Saudi Arabia	139.1	140.7	487.5	51.3	–	7.5	–	–	Shabbaj et al. (2018)
Hanoi	Vietnam	–	33.3	369	–	–	–	–	309.0	Phi et al. (2017)
Ho Chi Minh	Vietnam	153.7	49.6	466.4	36.2	7.9	0.5	102.4	393.9	This study

Whereas, the levels of these metals collected at background sites were found following the decreasing order as: Mn (296.27 mg/kg) > Zn (71.27 mg/kg) > Cu (27.15 mg/kg) > Cr (27.10 mg/kg) > Ni (15.76 mg/kg) > Pb (13.74 mg/kg) > Co (7.18 mg/kg) > Cd (0.10 mg/kg) (Table S7). As compared in Table 1, relatively high levels of heavy metals (especially Zn, Cu, Ni, Cr) were measured in this study compared to those reported in worldwide. Zn was the dominant heavy metal measured in Ho Chi Minh’s street dust, similar to those reported by Phi et al. (2017) (369 mg/kg), Shabbaj et al. (2018) (487.5 mg/kg), and Bartholomew et al. (2020) (8430.3 mg/kg) for road dust samples collected in Hanoi (Vietnam), Saudi Arabia, and China, respectively. The highest Zn concentration observed in sample S3 (1062.74 mg/kg), where the main gate of Ho Chi Minh City Hi-tech Park is, which is always of a high traffic density, and close to enterprises. Motorbike and heavy truck are the popular means of transport of people in this area; motor vehicles have parts that contain Zn alloy and galvanized components (Aminiyan et al. 2018); the concentration of Zn in street dust can be derived from tires, tire wear, brake pads, brake wear, lubricating oils, diesel exhaust, engine tires, and wear of machine parts (Valdez Cerda et al. 2011; Bourliva et al. 2017); and the lowest level was reported in the S9 (136.14 mg/kg) (Fig. 2c).

The mean Zn concentration (466.43 mg/kg) observed in our study exceeded the reference background level in Can Gio district (71.27 mg/kg) by more than 6.5-fold. In addition, compared to other studies (Table 1), the Zn concentration at HCMC was close to that found in Saudi Arabia (487.5 mg/kg). However, it was much higher than those reported in Jeddah, Ulsan (Korea) (129.0 mg/kg), Villavicencio (Colombia) (133.3 mg/kg), Hanoi (Vietnam) (369 mg/kg), Petra region (Jordan) (129 mg/kg), Urumqi (China) (224.5

mg/kg), Lahore (Pakistan) (67.9 mg/kg), but it is strongly lower than that from Jinhua (China) (8430.3 mg/kg). The high level of Zn in street dust collected might mainly originate from brake and tire wear, lubricating oils, diesel exhaust, engine tires, and wear of machine parts (Valdez Cerda et al. 2011; Bourliva et al. 2017; Idris et al. 2020).

Besides, concentrations of Pb and Cd were over 3.6, and 5.0 times, respectively, greater than the background levels (13.74 mg/kg, and 0.1 mg/kg, respectively), which indicates the high enrichment of these heavy metals in street dust collected in study area. Lead poisoning can cause mental retardation in children, neuropathy, and hypertension in adults, and Pb can even be fatal when its presence exceeds 25 µg/kg of weight (Duruibe et al. 2007). Cadmium (Cd) was used in the industry in the early 1940s. Nowadays, Cd is commonly applied in cadmium-nickel battery production, plastic production as an effective stabilizing agent, and paints (Kabadayi and Cesur 2010). Cd can cause acute toxicity to various vital organs like the kidneys resulting in kidney failure (Qadeer et al. 2020). Figure 2f showed that the highest Cd concentration (2.22 mg/kg) observed in S25 where is close to wood processing workshop and car garage which may be possible sources of high Cd contamination in this site. Akhter and Madany (1993) indicated that the Cd concentration in automobile tire ranges from 20 to 90 mg/kg, in diesel oils range from 0.07 to 0.10 mg/kg, and in lubricating oils range from 0.20 to 0.026 mg/kg. The lowest level of Cd was observed in S7 (0.17 mg/kg) which is significantly lower than mean Cd concentration (0.51 mg/kg); however, it still exceeded the reference background level (0.1 mg/kg). The Cd level obtained in this study was comparable to that reported by Keshavarzi et al. (2015) in Shiraz (Iran) (0.5 mg/kg), while it was significantly higher than those in Huainan (China) (0.25 mg/kg)

(Tang et al. 2017) and Urumqi (China) (0.2 mg/kg) (Hini et al. 2019). On the other hand, Cd concentration in street dust collected in HCMC was much lower than those from Jeddah (Saudi Arabia) (7.46 mg/kg) (Shabbaj et al. 2018) and Jinhua (China) (4.9 mg/kg) (Bartholomew et al. 2020).

High concentrations of Cu, Pb, Zn, and Mn were also recorded at S4, a location close to the entrance of Cat Lat port, where there is high traffic density of vehicle, especially heavy trucks. The highest values for heavy metals (Zn, Mn, Cu, Cr, Pb, Ni, Co, and Cd) were recorded at locations S3, S4, S23, S14, S22, S14, S25, and S25, respectively, while the low levels for those heavy metals were also noted at locations S9, S11, S20, S2, S10, S2, S11, and S7, respectively (Fig. 2). Obviously, the high concentrations were observed at the sites with high traffic density as crossroads or intersections. Figure 3 shows the contribution of heavy metals in the sampling sites, which indicates that Zn and Mn were of main contributor to total heavy metals in street dust collected (approx. 39% for Zn and 33%, respectively), which is different from that reported for street dust collected in Hanoi (Mn > Zn > Cr) (Phi et al. 2017), suggesting different sources of heavy metals in street dust samples collected in HCMC and Hanoi.

Source attribution of heavy metals

The inter-element correlation in street dust is presented in Table 2. A significantly positive correlation at $p < 0.01$ was found between the pairs of Co-Cd, Ni-Cr, Mn-Co, Mn-Pb, Zn-Pb, and Zn-Mn, whereas Cu-Ni noted a positive correlation at $p < 0.05$. Kengnal et al. (2015) indicated that the Pearson values in the range of 0.0 to < 0.4 for poor, 0.4 to < 0.7 for moderate, and 0.7 to 1.0 for strong correlation. The results revealed that the strong correlation ($p < 0.01$) was found between Ni-Cr ($r = 0.89$), Mn-Pb ($r = 0.75$), and Zn-Mn ($r =$

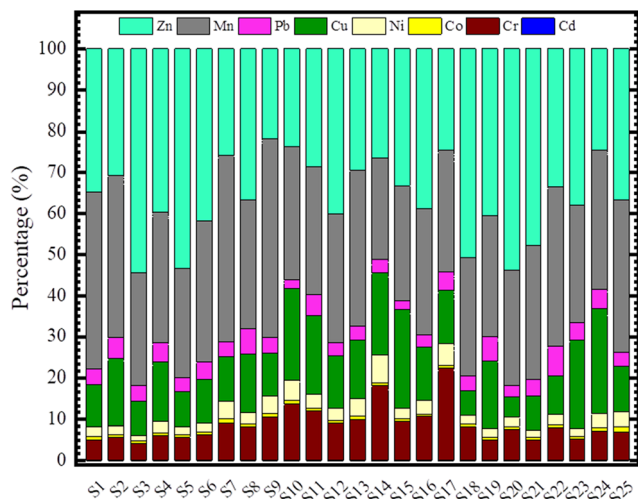


Fig. 3 Distribution of the heavy metals measured in street dust samples in Ho Chi Minh City

Table 2 Pearson correlation coefficients among the heavy metals in street dust in Ho Chi Minh City

	Cd	Cr	Co	Ni	Cu	Pb	Mn	Zn
Cd	1.00							
Cr	-0.03	1.00						
Co	0.59**	-0.10	1.00					
Ni	0.08	0.89**	0.16	1.00				
Cu	0.03	0.31	0.04	0.42*	1.00			
Pb	-0.05	0.02	0.30	0.06	0.28	1.00		
Mn	0.08	-0.09	0.62**	0.04	0.22	0.75**	1.00	
Zn	0.04	-0.06	0.37	-0.06	0.12	0.58**	0.71**	1.00

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

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

0.71), while moderate correlation ($p < 0.01$) was between Co-Cd, Mn-Co, and Zn-Pb. The strong correlation suggests that these elements had similar sources (Roy et al. 2019). Zn, Pb, Mn, Ni, and Cr can be emitted from tires, tire wear, brake pads, brake wear, lubricating oils, diesel exhaust, engine tires, and wear of machine parts (Valdez Cerda et al. 2011; Bourliva et al. 2017), implying that traffic activities might be the major sources of these heavy metals in street dust.

Table 3 shows the results of PCA for heavy metals in samples collected. Detail information about results of PCA can refer to Fig S1. The KMO value of 0.642 was obtained in this study, indicating a good fit and suitable data set for PCA analysis (Jamhari et al. 2014; Manly and Alberto 2016). As shown in Fig. S1, among 8 components extracted by PCA,

Table 3 Results of principal component analysis for heavy metals in street dust in Ho Chi Minh City

Heavy metals	Principal Components		
	PC1	PC2	PC3
Mn	0.92	0.03	0.23
Pb	0.87	0.12	-0.05
Zn	0.83	-0.05	0.09
Ni	-0.04	0.95	0.14
Cr	-0.12	0.92	-0.05
Cu	0.29	0.61	-0.06
Cd	-0.09	0.01	0.92
Co	0.43	0.02	0.83
Eigenvalues	2.83	2.11	1.41
% of Variance	32.38	26.72	20.23
Cumulative %	32.38	59.10	79.33

Extraction method: principal component analysis

Rotation method: Varimax with Kaiser normalization

Bold values indicate high load

three principal components (with Eigenvalue > 1) accounting for more than 79% variance of the data were obtained. The first component (PC1) was dominated by Mn, Pb, and Zn accounted for 32.38% of the total variance, which was loaded by Mn (0.92) Pb (0.87) and Zn (0.83) (as presented in Table 3). Mn, Pb, and Zn can be derived from tires, tire wear, brake pads, brake wear, lubricating oils, diesel exhaust, engine tires, and wear of machine parts (Valdez Cerda et al. 2011; Bourliva et al. 2017; Idris et al. 2020). Therefore, this PC can present the vehicular sources of heavy metals in street dust samples collected in HCMC. The average concentrations of these heavy metals were higher than the background values. Besides, the EF value of Pb (2.54) varied from 1 to 3, representing minor enrichment, and the EF value of Zn (4.61) range from 3 to 5, indicating level moderate enrichment. It means that these heavy metals might be caused by human activity.

The second component (PC2) was dominated by Ni, Cr, and Cu accounting for 26.7% of the total variance, including Ni, Cr, and Cu with loading values of 0.95, 0.92, and 0.61, respectively. Ni was applied in nickel-cadmium batteries, electroforming, electroplating, and in circuitry (Kabadayi and Cesur 2010). Ghanavati et al. (2019) revealed that Cu was often used to control heat transfer in brakes. In addition, Hini et al. (2019) indicated that Cu originates from lubricants, the corrosion of metal parts, and engine wear, while Cr derives from tool manufacturing, gasoline, and the wearing and aging of tires. Therefore, the PC2 can be considered as mixed source of vehicular and residential activities. These metal concentrations were also significantly higher than the background concentrations and the EF values of Ni (1.62) and Cr (2.66) demonstrated minor enrichment. The EF values of Cu (4.27) ranged from 3 to 5 indicating moderate enrichment level. Therefore, anthropogenic emission and/or human activity can be the major sources of heavy metals in street dust in HCMC.

The PC3 accounted for 20.2% of total variance, including Cd and Co with loading values of 0.92, 0.83, respectively. Cd was commonly applied in cadmium-nickel battery production, and plastic production as an effective stabilizing agent. Furthermore, it was used in paints (Kabadayi and Cesur 2010). The result of enrichment factor Cd (54.02) was considered extremely severe enrichment, confirming that Cd might be affected by human activity. The EF value of Co (0.78) was lower than 1, thereby indicating that Co in street dust collected was derived from local soil. The results suggest that the PC3 present the mixture of industrial and natural sources of heavy metals in street dust collected in HCMC.

Pollution indices

Figure 4a presents the boxplot of enrich factor of heavy metals in this study. The results show the EF mean values were

arranged in the following order of Zn > Cu > Cd > Cr > Pb > Ni > 1 > Mn > Co. The EF values of Co (0.78) and Mn (0.94) were lower than 1, thereby indicating that these heavy metals were no enrichment, no effect of human activity. It suggests that Co and Mn in street dust were of lithological (natural) origin (Zhou et al. 2019). The EF values of Ni (1.62), Pb (2.54), and Cr (2.66) showed minor enrichment, whereas the EF values of Cu and Zn ranged from 3 to 5 (i.e., Cu: 4.27, Zn: 4.61, and Cd: 3.49), indicating level of moderate enrichment. Hini et al. (2019) reported that Cu is caused by engine wear, lubricants, and the corrosion of metal parts, while Cd is commonly used in cadmium-nickel battery production, plastic production, and paints (Kabadayi and Cesur 2010). The occurrence of Zn in street dust can be derived from tires, tire wear, brake pads, brake wear, lubricants, diesel exhaust, engine tires, and wear of machine parts (Valdez Cerda et al. 2011; Bourliva et al. 2017). This suggests that these heavy metals (Cu, Cd, and Zn) might be significantly emitted by vehicular activities (Zhou et al. 2019).

Figure 4b presents the contamination factor (C_f^i) of eight heavy metals, which shows that C_f^i values of Co, Mn, and Ni ranged from 1 to 3, implying that the contamination level caused by these heavy metals was moderately contaminated. The C_f^i values of Cr, Pb, and Cd ranged from 3 to 6 (i.e., Cr: 3.78; Pb: 3.61, and Cd: 4.95), which were categorized as considerable contamination. Meanwhile, Cu and Zn were considered high contamination with C_f^i values greater than 6. The C_f^i mean values were ranked as Zn (6.54) > Cu (6.06) > Cd (4.95) > Cr (3.78) > Pb (3.61) > Cr (2.38) > Pb (2.31) > Ni (2.30) > Mn (1.33) > Co (1.11). The level of contamination of Zn was high (with C_f^i values more than 6); similar observation was found in a previous study by Roy et al. (2019) for the National Capital Territory of Delhi where traffic was the main contributing source of Zn in street dust. The results also indicate that the sources of heavy metals (Zn, Cu) should be eliminated to reduce the contamination level caused by these heavy metals.

I_{geo} values were used to evaluate the accumulation level of the heavy metals in street dust and the results were showed in Fig. 4c. Overall, the trend of I_{geo} values presented in Fig. 4c was similar to that of C_f^i values shown in Fig. 4b. Low I_{geo} values of Mn and Co were in range the of 0–1, indicating that these metals were ranked from uncontaminated to moderately contaminated, while Ni was considered moderately contaminated with the I_{geo} of 1.70. The I_{geo} values for Cd, Cr, and Pb ranged from 2 to 3, indicating levels from moderately to strongly contamination. Meanwhile, Cu and Zn were considered strongly contaminated with I_{geo} from 3 to 4, respectively. Throughout the study area, the I_{geo} mean values were decrease in the

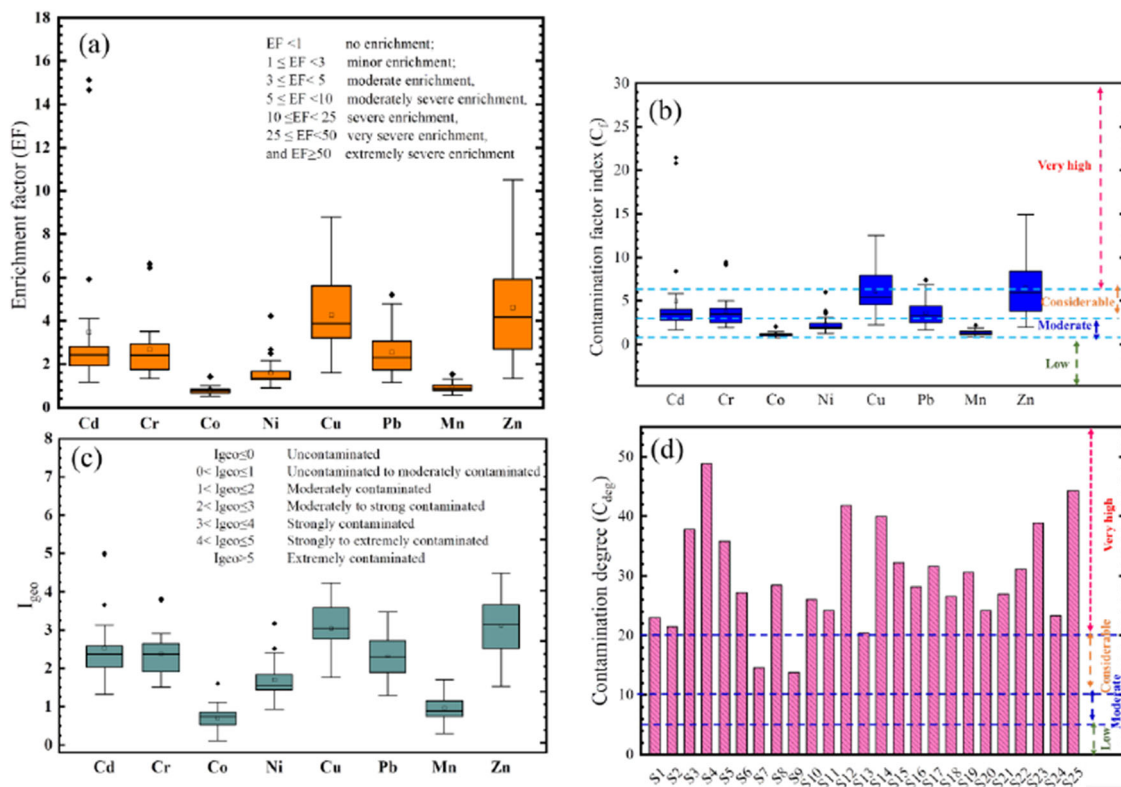


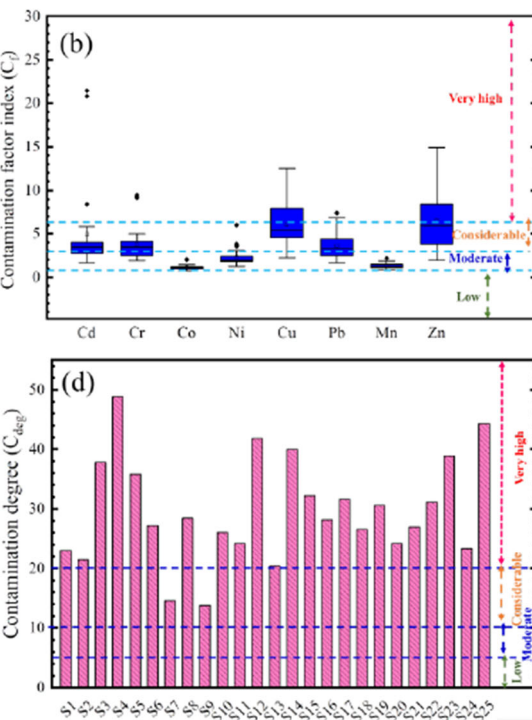
Fig. 4 Boxplot of enrich factor (a), contamination factor (b), and geo-accumulation index (c) and contamination degree (d) of heavy metals in street dust in Ho Chi Minh City

following order of Zn (3.11) > Cu (3.04) > Cd (2.53) > Cr (2.38) > Pb (2.31) > Ni (1.70) > Mn (0.96) > Co (0.70).

The degree of contamination (C_{deg}) is the sum of CF for all of the heavy metals (Fig. 4d). The results of C_{deg} were noted that the contamination levels of most sampling sites (23/25) were sorted as “very high” with C_{deg} over 20, while some sampling sites such as S7 and S9 were categorized as “considerable” ($10 \leq C_{deg} < 20$).

Ecological risk assessment

The PER data was obtained due to the cumulative effect of all metals. The results of potential ecological risk index and potential ecological risk in different sampling sites are presented in Fig. 5a. The PER values of all sampling sites were close to the “high” risk category (PER > 200). Comparing the PER value between different sampling sites, the highest and lowest values were found at S4 and S9, respectively. The mean E_i were ranked in the following order of Zn > Cu > Mn > Pb > Cr > Ni > Co > Cd. The highest E_i for Zn (2125) was obtained at S3, while the lowest E_i value for Cd (5) was obtained at S7. Zn (28.9%), Mn (24.4%), and Cu (25.4%) could be the main impact factors of the ecological risk in the street dust in HCMC, while Co (1.2%), and Cd (0.5%) were considered to be low contribution (Fig. 5b).



It is noted that HCMC is characterized by a dense canal system which might be strongly influenced by the threat caused by the washout of street dust (including heavy metals) into rainwater collection systems and later spread of heavy metals in the canal system. The high values of contamination degree suggest that the level of heavy metals in street dust might pose a great threat to the ecosystem and human life in HCMC. The results obtained on pollution indices and ecological risk assessment indicate that an overall assessment on the occurrence of heavy metals in street dust and their potential impacts over a wider area cover all HCMC and in different environmental compartments are deemed necessary.

Health risk assessment

Non-carcinogenic risk

The average HQ for both children and adults decreased in the following order $HQ_{Cr} > HQ_{Pb} > HQ_{Cu} > HQ_{Ni} > HQ_{Zn} > HQ_{Cd}$. Among the heavy metals, the highest HQ was found for Cr (5.80×10^{-2} for children and 2.13×10^{-2} for adults), while the lowest HQ was found for Cd (8.44×10^{-4} for children and 3.07×10^{-4} for adults), respectively. The HQ_{Cr} was the main contributor of the total HI for children and adults approximately 61.4 and 61.7%,

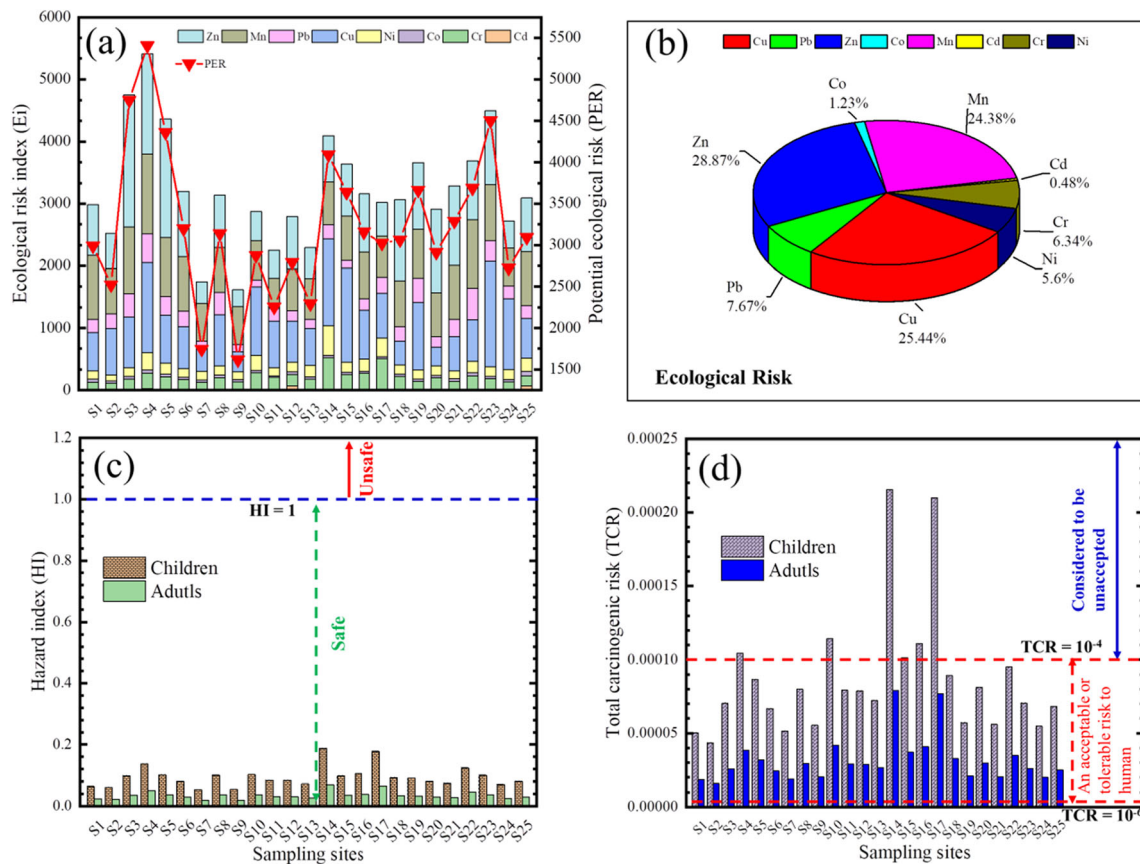


Fig. 5 Ecological risk index (E_i) and potential ecological risk (PER) (a); percent contribution of heavy metals to ecological risk (b); comparison of non-carcinogenic health risks (HI) (c); the carcinogenic risk index of heavy metals (d) in street dust in Ho Chi Minh City

respectively. That means, Cr was the major sponsor to potential non-carcinogenic risk in street dusts in HCMC. Similar results have also been obtained by Hini et al. (2019) in China. Table 4 shows that the hazard quotient ranked in the order $HQ_{ing} > HQ_{inh} > HQ_{derm}$. It signifies that the major route of exposure to non-carcinogenic risk was oral ingestion. Figure 5c shows that the $HI_{Children}$ was significantly higher than HI_{Adults} . It denotes that heavy metals in street dust were more harmful to children than to adults. This was also similar to the studies of Yu et al. (2016) and Masto et al. (2017). The reason why children were at a higher risk of metal exposure in street dust than adults could be explained by more frequent street dust exposure activities by ingestion (Xue et al. 2007). However, both of the $HI_{Children}$ and HI_{Adults} were less than 1, suggesting insignificant non-carcinogenic risk (USEPA 2007a; Chen et al. 2012; Duan et al. 2019; Bartholomew et al. 2020). In general, the HI values obtained for Cu, Pb, Zn, Ni, Cd, and Cr due to street dust exposure were within safety limits. It means that there is no potential for non-cancer risk for these metals to humans in the study area.

Carcinogenic risk

The carcinogenic risk (CR) of Cr, Cd, and Ni was evaluated in this study. The calculated results of CR and TCR are shown in Table 4 and Fig. 5d. The carcinogenic risk ranked in the following order as $CR_{ing} > CR_{inh} > CR_{derm}$ (Table 4), indicating that the major route of exposure to carcinogenic risk for both children and adults was oral ingestion (Cheng et al. 2018; Ghanavati et al. 2019). Compared to other metals (Cd and Ni), Cr was the highest average CR value for both children and adults. The CR of Cr accounted for more than 99% of the TCR values for both target groups, indicating that Cr was the main contributor for potential CR to human health. Figure 5d shows that the $TCR_{Children}$ was much higher than TCR_{Adults} , implying that heavy metals in street dust were the most harmful to children (Masto et al. 2017). In fact, children are susceptible to metal poisoning because they are more likely to accidentally ingest a significant amount of street dust. Although the $TCR_{Children}$ and TCR_{Adults} ranged from 1×10^{-6} to 1×10^{-4} which was considered as an acceptable limit of cancer risk (USEPA 1996). These results show that the potential health risks of residents should be warned and the interest of local authorities in environmental quality management should be raised.

Table 4 The non-carcinogenic risk and carcinogenic risk indexes of heavy metals in the street dust in Ho Chi Minh City, Vietnam for children and adults

Non-carcinogenic risk indexes										
Elements	HQ _{ing}		HQ _{inh}		HQ _{derm}		HQ		HI	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Cu	6.76E-03	2.46E-03	2.19E-06	1.05E-06	2.25E-08	5.73E-09	6.76E-03	2.46E-03	9.448E-02	3.458E-02
Pb	2.33E-02	8.47E-03	7.55E-06	3.61E-06	1.55E-07	3.95E-08	2.33E-02	8.47E-03		
Zn	2.56E-03	9.29E-04	8.33E-07	3.99E-07	1.28E-08	3.25E-09	2.56E-03	9.30E-04		
Ni	2.97E-03	1.08E-03	9.41E-07	4.50E-07	1.10E-08	2.80E-09	2.98E-03	1.08E-03		
Cd	8.43E-04	3.07E-04	2.75E-07	1.32E-07	8.43E-08	2.15E-08	8.44E-04	3.07E-04		
Cr	5.61E-02	2.04E-02	1.92E-03	9.18E-04	2.81E-06	7.14E-07	5.80E-02	2.13E-02		
Carcinogenic risk (CR) indexes										
Elements	CR _{ing}		CR _{inh}		CR _{derm}		CR		TCR	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Cr	8.42E-05	3.06E-05	2.31E-06	1.10E-06	–	–	8.65E-05	3.17E-05	8.65E-05	3.17E-05
Cd	–	–	1.73E-09	8.29E-10	–	–	1.73E-09	8.29E-10		
Ni	–	–	1.63E-08	7.79E-09	–	–	1.63E-08	7.79E-09		

Heavy metals in dust and soils enter the human body through three pathways: ingestion (ing), inhalation (inh), and dermal (derm) routes

Conclusions

In this study, the concentration, ecological, and human health risk assessment of heavy metals measured in street dust from Ho Chi Minh City were appraised. As far as we know, this is the first study to evaluate the concentration and risk assessments of heavy metals in street dust in HCMC, a super megacity in southern Vietnam. The mean concentration values of all heavy metal in HCMC were greater than those obtained in background site and relatively higher than those reported worldwide. Among the heavy metals, Zn (466.43 mg/kg) was found to be the highest average concentration, followed by Mn (393.87 mg/kg) > Cu (153.70 mg/kg), while Cd (0.51 mg/kg) was the lowest one. The PCA and EF results revealed that vehicular activities (PC1), mixed source of vehicular and residential activities (PC2), and mixture of industrial and natural sources (PC3) contributed to 32.38, 26.72, and 20.23%, respectively, to heavy metals in street dust collected in HCMC. The potential ecological risk (PER) value of all sampling sites was close to the “high” risk category and Zn (28.87%), Cu (25.44%), and Mn (24.38%) were found to be the main cause of the ecological risk in the street dust. For non-carcinogenic effects, the average HQ for both children and adults were HQ_{Cr} > HQ_{Pb} > HQ_{Cu} > HQ_{Ni} > HQ_{Zn} > HQ_{Cd}. The carcinogenic risk ranked CR_{ing} > CR_{inh} > CR_{derm}, indicating that the major route of exposure to carcinogenic health risk for both children and adults was oral ingestion. Cr was a major contributor to potential non-carcinogenic and carcinogenic risk.

By mean times, we acknowledge that our sampling areas and sample size are relatively small thus might not fully representing the larger HCMC areas. However, our study has implied the potential concern in heavy metal pollution in the most populous city in Vietnam, hence upcoming studies considering larger sampling areas or sampling in different land uses are crucial to better understand the sources of heavy metals in street dust and its relation to health effects. For the calculation of average daily intake (ADI), although there were high uncertainties, this study was expected to provide preliminary information for further studies to continue to improve.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11356-021-14246-1>.

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Author contributions Sampling, sample analysis, investigation, software, writing—original draft, writing—review and editing: NgDD and V-TN; data curation, conceptualization, methodology, writing—review and editing: M-HB, LSPN, X-CN; AT-KT, T-T-AN, Y-RJ, T-M-TH, D-HN, H-NB; supervision, conceived, designed the methodology, writing—review and editing: T-D-HV, X-TB, CL.

Data availability The data that support the findings of this study are openly available at [DOI].

Declarations

Ethics approval The authors confirm that the manuscript has been read and approved by all authors. The authors declare that this manuscript has not been published and not under consideration for publication elsewhere.

Consent to participate The authors have been personally and actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content.

Consent for publication The authors consent to publish this research.

Conflict of interest The authors declare no conflict of interest.

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