

Seasonal variation of heavy metal contents in road dust from residential, industrial and rural areas of Hong Kong

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ABSTRACT

Heavy metal contents in road dust have been an important indicator of heavy metal pollution arising from traffic-related activities. In this study, 108 road dust samples were collected from four locations of Hong Kong, namely Kwai Hing (industrial area), Sau Mau Ping (residential area), Sai Kung and Tai Lam (rural area), over a one-year period and analysed for zinc (Zn), nickel (Ni), copper (Cu), lead (Pb), chromium (Cr), cadmium (Cd), and arsenic (As). The geo-accumulation indices (I_{geo}) and contamination factors (C_f) indicated zinc, copper, chromium, to a lesser extent, nickel, and cadmium pollution of road dust in industrial and residential areas. The potential ecological risks (E_i) of Cu were found to be particularly high in both areas. Residential and industrial areas are prone to considerable and very high risks, respectively, based on the risk indices (RI). The sources of heavy metals may vary slightly between the areas based on Pearson's correlation analysis. It was found that the metal contents in the road dust samples vary differently between the dry and wet seasons. The concentrations of Zn were higher in the dry season while those of Cu, Cr and Ni were generally higher in the wet season.

KEYWORDS Road dust; heavy metals; potential ecological risk; risk index; seasonal variation

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1. Introduction

The concentration of heavy metals in road dust is an important indicator of traffic-induced pollution in the natural environment (Li et al., 2001; Abdel-Latif and Saleh, 2012; Qiao et al., 2013). Particulates originating from on-road vehicle exhaust and non-exhaust emissions, industrial activities, and natural sources are components of road dust (Penkala et al., 2018). Wearing of vehicle tyres, braking components, and road pavements and markings from daily traffic activities have been identified as the sources of non-exhaust emissions (Adamiec et al., 2016). Elements that are potentially toxic, including cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and arsenic (As), are found to be enriched in the road dust of many cities around the world (Cai and Li, 2019). Finer dust particles that become windborne could exacerbate the respiratory conditions of sensitive individuals through inhalation (EPA progress report, 2010) or contaminate roadside soil. Dust accumulated on road surfaces could be flushed away during rainstorms, discharged into coastal waters through urban drainage systems without treatment, and eventually become deposited in the sediments of the receiving bodies. Nawrot et al. (2020) have confirmed the linkage between heavy metal contaminations in sediments and nearby traffic activities. Heavy metals in the air, water sources and soil may cause human health issues and environmental pollution.

A couple of research studies conducted about 20 years ago showed that road dust from some regions of Hong Kong was contaminated by heavy metals (Li et al.,

2001; Yeung et al., 2003). Table 1 summarises the levels of heavy metals in road dust reported by two studies from Hong Kong. The Zn levels were by far the highest among the heavy metals of concern and much higher than that observed in other cities. Out of a list of known origins, tyre abrasion was considered a major source of heavy metals in road dust, especially Zn, by several research groups (Kennedy et al., 2002; Shakya et al., 2006). There are relatively few studies that have investigated road dust pollution in Hong Kong and the potential impacts on the receiving water bodies in the last decade.

Table 1. Mean concentrations of heavy metals (mg/kg) in road dust from Hong Kong.

	As	Cd	Cr	Cu	Pb	Ni	Zn
Li et al. (2001)	-	3.77	-	173	181	-	1450
Yeung et al. (2003)	66.8±5.7	-	124±7	110±4	120±4	28.6±5.2	3840±70

This study aims to compare the contamination levels of road dust from three areas of Hong Kong that belong to different land use categories and evaluate the effect of seasonal variation. The concentrations of seven heavy metals that are often found to be enriched in road dust, namely As, Cd, Cr, Cu, Pb, Ni, and Zn, are monitored by sampling and analysing road dust from selected industrial, residential, and rural areas. While the monthly average concentrations will provide insights into seasonal variations in heavy metal contents in road dust, the annual averages can be contrasted with previous studies to provide

an indication of the trend in the levels of heavy metal contamination. Comparisons among categories reflect the impacts of industrial activities, traffic activities and urban developments on the environment.

2. Assessment of contamination

The Geo-accumulation Index (I_{geo}), Contamination Factor (C_f), Degree of Contamination (C_d), Potential Ecological Risk (E_r), and Risk Index (RI) were used to quantify the levels of heavy metal pollution of road dust and the levels of potential ecological risks associated with the presence of heavy metals.

The I_{geo} introduced by Muller (1969) was developed for the global standard shale values and has been adopted by many research groups for assessing heavy metal pollution in the 2-micron fraction (Barbieri, 2016). The I_{geo} value of an element is defined as:

$$I_{geo} = \log_2 \left(\frac{C_n}{1.5B_n} \right), \tag{1}$$

where C_n and B_n are the concentration of the given element in the road dust and background soil, respectively; and the constant 1.5 addresses the natural fluctuations in the background values.

The C_f and C_d proposed by Hakanson (1980) have been popular quantitative approaches for evaluating the levels of contamination by heavy metals in road dust, soil, and water (Jiang et al., 2014; EL-Bady, 2014; Ghaleno et al., 2015; Dytlow and G6rka-Kostrubiec, 2020). The C_f and C_d of a site are expressed as:

$$C_f^i = \frac{C_i}{C_k} = \frac{C_n}{B_n}, \tag{2}$$

$$C_d = \sum_{i=1}^7 C_f^i, \tag{3}$$

where C_i (C_n) is the content of an individual element in road dust samples; C_R (B_n) is the background concentration of a given element in soil from country park areas in Hong Kong that are away from industrial and town centre areas; and C_d is obtained by summing the contamination factors of all seven heavy metals analysed.

According to Hakanson’s Method (1980), the parameters of Potential Ecological Risk (E_r) and Risk Index (RI) are used to evaluate the contamination level and toxicity level of heavy metals in road dust. The toxicity response coefficients (T_r) of the heavy metals analysed in the present study are as follows: 1 for Zn, 5 for Cu, 30 for Cd, 2 for Cr, 5 for Pb, 5 for Ni, and 10 for As (Xu et al., 2008). Table 2 summarises the classification of contamination level of analysed heavy metals in respect to the values of I_{geo} , C_f , C_d , E_r and RI.

$$E_r^i = T_r \times C_f^i, \tag{4}$$

$$RI = \sum_{i=1}^7 E_r^i. \tag{5}$$

3. Sampling and analysis

Over a period of 12 months between March 2017 and February 2018, a total of 108 road dust samples were collected from Kwai Hing (industrial area), Sau Mau Ping (residential area), Sai Kung and Tai Lam (rural area). The locations of the sampling points are shown in Figure 1. The three sampling points in Kwai Hing (KHMonNA, KHMonNB, and KHMonNC) were located on the main roads surrounded by industrial blocks and warehouses. Commercial vehicles and heavy trucks use the roads



Category	Sample ID	Sampling Point
Industrial Area	KHMonNA	Kwai Ting Road, Kwai Hing
	KHMonNB	Tai Lin Pai Road, Kwai Hing
	KHMonNC	Wah Sing Street, Kwai Hing
Residential Area	SMPMonNA	Sau Mau Ping Estate, Sau Mau Ping
	SMPMonNB	Sau Fung Street, Sau Mau Ping
	SMPMonNC	Hiu Lai Court, Sau Mau Ping
Rural Area	SKMonNA	Sai Kung East Country Park
	SKMonNB	Sai Kung East Country Park
	TLMonN	Tai Lam Reservoir

Figure 1. Locations of the sampling points.

all year round and are often left idling during loading/unloading. The three points in Sau Mau Ping (SMPMonNA, SMPMonNB, SMPMonNC) were located on the access roads leading to large residential complexes. The fleet is characterised by light to medium duty trucks, private vehicles, and minibuses. The two points in Sai Kung (SKMonNA, SKMonNB) were located on the access roads to the High Island Reservoir which is a part of the Hong Kong UNESCO Global Geopark. The sampling point in Tai Lam (TLMonN) was located on a restricted access road leading to the Tai Lam Chung Reservoir. The background soil (Zn = 53 mg/kg, Cu = 8.5 mg/kg, Cd=0.2 mg/kg, Cr=6.5 mg/kg, Pb=92.5 mg/kg, Ni=4.0 mg/kg, As=1.0 mg/kg) was collected from Sai Shan in Tsing Yi where urban development and industrial activities are a considerable distance away.

Each road dust sample was collected by sweeping an area of one square metre on each side of the road surface with a clean plastic hand-shovel and a dustpan. Samples were collected from each sampling point every month to determine the effects of seasonal influences and the effect of different land uses on the heavy metal contents in road dust. The samples were analysed by an authorised laboratory with HOKLAS accreditation for Cd, Cr, Cu, Pb, Ni, Zn, and As.

4. Results and discussion

4.1. Mean concentrations

The mean concentrations (C_n) of Cd, Cr, Cu, Pb, Ni, Zn and As detected in road dust samples are summarised in Table 3 by land use categories. The C_n in descending order was Zn > Cu > Pb > Cr > Ni > As > Cd for all areas. For all the metals analysed, concentrations were highest in the industrial area, followed by the residential area, and the least in the rural area. The higher metal contents in the industrial samples can be attributed to heavy traffic flow, traffic conditions (e.g. frequent start-stop and idling), and composition of the fleet, which collectively led to more exhaust and non-exhaust emissions of heavy metals.

High Zn and Cu contents were detected in all areas. The levels of Zn in the samples collected from the industrial and residential areas under the present study were 1.8 and 1.1 times higher than those reported by Li et al. (2001), respectively. The Cu levels of the industrial and residential areas were 2.9 and 2.2 times higher than the data published by Li et al. (2001), respectively. The comparison suggested that the Zn and Cu concentrations in road dust of Hong Kong have gone up in the last few decades. The noticeable increase in Zn concentration could be due to the changes in tyre rubber composition over the years. Thorpe et al. (2008) compared three studies on metal concentrations in tyre tread materials and showed that the composition of Zn increased notably (13 – 22 times) between 1991 and 2003.

The average Pb concentration that took into account all the samples was 1.1 times above the background level and

Table 2. Classification of the contamination indices.

Geo-accumulation Index (I_{geo}) ^a							
Value	$I_{geo} = 0$	$0 < I_{geo} \leq 1$	$1 < I_{geo} \leq 2$	$2 < I_{geo} \leq 3$	$3 < I_{geo} \leq 4$	$4 < I_{geo} \leq 5$	$I_{geo} > 5$
Class	Uncontaminated (UC)	Uncontaminated to moderately contaminated (UC/MC)	Moderately contaminated (MC)	Moderately to heavily contaminated (MC/HC)	Heavily contaminated (HC)	Heavily to extremely contaminated (HC/EC)	Extremely contaminated (EC)
Contamination Factor (C_f) ^b							
Value	$C_f < 1$	$1 \leq C_f < 3$	$3 \leq C_f < 6$	$C_f \geq 6$			
Class	Low (L)	Moderate (M)	Considerable (C)	Very High (VH)			
Degree of Contamination (C_d) ^c							
Value	$C_d < 8$	$8 \leq C_d < 16$	$16 \leq C_d < 32$	$C_d \geq 32$			
Class	Low (L)	Moderate (M)	Considerable (C)	Very High (VH)			
Potential Ecological Risk (E_r) ^d							
Value	$E_r < 40$	$40 \leq E_r < 80$	$80 \leq E_r < 160$	$160 \leq E_r < 320$	$E_r \geq 320$		
Class	Low (L)	Moderate (M)	Considerable (C)	High (H)	Very High (VH)		
Risk Index (RI) ^e							
Value	$RI < 150$	$150 \leq RI < 300$	$300 \leq RI < 600$	$RI \geq 600$			
Class	Low (L)	Moderate (M)	Considerable (C)	Very High (VH)			

^a Barbieri, 2016; ^{b,c} Hakanson, 1980; ^{d,e} Shi et al., 2010

the Pb content in rural samples was even lower than that in the background soil. The background values were derived from soil samples while the rural values were derived from road dust samples. Heavy metals, especially those with low mobility, may form an archive in soil columns over a prolonged period (Sutherland and Tolosa, 2001) but are unlikely to accumulate on road surfaces over a long period of time. Since leaded petrol was phased out in Hong Kong in the late 90s and the traffic volume near the rural sampling sites is very low, Pb input to road dust collected from these sites would be minimal while Pb from historical emissions may show up in the background sample.

4.2. Seasonal variation

Hong Kong has a subtropical climate, with June to

August being the wettest (i.e., the highest total rainfall and the most number of rainy days) and hottest months while December to January are the driest and coolest months. During the 1-year monitoring period of the present study, the precipitation received between May and September collectively accounted for 88% of the annual rainfall. In the analysis of seasonal variation, therefore, the wet season covers May to September and the dry season covers October to April. The monthly average concentrations of the tested elements in industrial, residential, and rural areas between March 2017 and February 2018 are presented in Figure 2.

Cd, Pb, Zn, and As levels in the road dust collected from all three areas were higher in the dry season. In the dry season, less rainfall contributes to a lower chance for heavy metals to be washed into the road gullies by

Table 3. Statistical summary of sampling results.

<i>n</i> = 180		Zn	Cu	Cd	Cr	Pb	Ni	As
Parameter								
Industrial area ^a	Max.	4700	2980	7.8	855	434	372	14
	Min.	1060	99	0.3	36	70	18	2
	Range	3640	2881	7.5	819	364	354	12
	Average	2613	503	1.3	232	192	100	7.2
	Geomean	2429	372	1.0	185	172	76	7
	Std. Deviation	986	523	1.5	160	97	80	2.7
	CV ^b	0.4	1.0	1.1	0.7	0.5	0.8	0.4
	Skewness	0.3	3.4	3.7	1.8	1.1	1.7	1.0
	Kurtosis	-1.0	14.5	13.8	5.2	0.5	3.4	1.5
	Residential area ^a	Max.	3310	956	1.6	338	358	116
Min.		465	37	0.3	23	44	5	1
Range		2845	919	1.3	315	314	111	23
Average		1605	3385	0.6	145	113	44	7.4
Geomean		1454	299	0.6	120	98	36	7
Std. Deviation		725	258	0.3	87	67	28	4
CV ^b		0.4	0.7	0.4	0.6	0.6	0.6	0.6
Skewness		0.5	0.7	1.6	0.8	1.7	1.1	2.0
Kurtosis		-0.7	-0.5	3.9	-0.3	3.8	0.9	5.4
Rural area ^a		Max.	485	444	1.9	43	37	32
	Min.	76	9	0.2	5	12	2	1
	Range	409	435	1.7	38	25	30	109
	Average	219	56	0.3	16	23	7.4	3.0
	Geomean	189	35	0.3	14	22	5.6	3
	Std. Deviation	122	87	0.3	9.0	6.1	7.4	22
	CV ^b	0.6	1.6	1.1	0.6	0.3	1.0	2.9
	Skewness	0.9	4.1	4.5	1.5	0.3	2.4	4.8
	Kurtosis	-0.3	19	21	2.5	-0.3	5.4	24
	Tai Lam Country Park ^a	Max.	365	139	1.3	71	200	42
Min.		85	11	0.2	20	24	9	1
Range		280	128	1.1	51	176	33	2
Average		202	45	0.5	46	88	28	1.7
Geomean		190	33	0.4	43	70	26	1.5
Std. Deviation		73	38	0.3	1.6	59	10	0.7
CV ^b		0.4	0.9	0.6	0.4	0.7	0.3	0.4
Skewness		0.7	1.6	2.1	-0.2	0.7	-0.6	0.4
Kurtosis		1.3	2.4	5.6	-1.0	-0.8	-0.1	-0.3
Overall Average		1163	247	0.7	110	104	45	4.8

^a The figures were calculated from all samples from the same land use category over a period of 12 months.

^b Coefficient of variation (CV) = ratio of the standard deviation to the average

stormwater runoff. Furthermore, as pointed out by Kennedy et al. (2002), the friction between tyres and the road surface is higher during the dry season. This may also contribute to the higher concentration of metals related to tyre wear, mainly Zn, in the winter months.

The concentrations of Zn, Cd, Pb, and As in the road dust collected from all three areas were higher in the dry season.

In contrast, Cu, Cr, and Ni contents in the road dust from the majority of the sampling points were slightly higher in the wet season. Many studies that have investigated the causes of road dust contamination used Zn as the key tracer element for tyre wear while using Cu as the tracer element for brake lining wear (Pant and Harrison, 2013). The fact that the concentrations of Zn and Cu varied differently between the wet and dry seasons suggests that the compositions of the sources of heavy metals in the two seasons may be slightly different. The levels of Zn and Cd were notably less in the wet-season samples collected from Sai Kung and Tai Lam (40% and 47% less than the dry season concentration, respectively). This could be the result of less visitors to the country parks during the wet season on top of the washing off effect.

The ratios between the concentrations of the seven heavy metals in the samples collected in different seasons have been calculated using Equation (6), which was obtained by modifying the equation used by Xiang et al. (2010):

$$R_{D/W} = \frac{C_{dry}^i}{C_{wet}^i}, \quad (6)$$

where C_{dry}^i is the mean concentration of a given element in the road dust samples gathered in the dry season; and C_{wet}^i is the mean concentration of the same element in the samples collected during the wet season. The wet and dry season mean concentrations and $R_{D/W}$ of each metal are grouped in Table 4 by land use category. The overall $R_{D/W}$

values for Zn, Cd, Pb, and As were 1.45, 1.45, 1.17, and 1.17, respectively. These suggest that the concentrations of those metals varied noticeably between the dry and wet seasons. The seasonal effect is less obvious in the cases of Cu, Cr and Ni, whose overall $R_{D/W}$ values were 1.08, 0.91, and 0.89, respectively. Residential area with a $R_{D/W}$ value for Cu of 1.53 was the only landuse category that exhibited a significant seasonal variation in the concentration of Cu. Further investigation will be needed to find out if the seasonal variation of Cu observed in the present study is common to other residential areas in Hong Kong. The seasonal variations of Cr were found to be negligible in all three study areas. This indicates that the sources of Cr may be different to those of other metals.

ZnO and ZnS added to tyres during vulcanisation can enter the environment as a result of abrasive wearing. According to Kaiser et al. (2020), the rate at which tyres wear is higher in a dry environment than that in a wet environment due to the lubricating effect of moisture that reduces the coefficient of friction between the tyre and the road surface. Tyre wear generally creates micron-sized particles (Kim and Lee, 2018) and, therefore, can be carried away by stormwater. The build-up and wash-off processes together could explain the higher Zn concentrations observed in the dry season. Brake dust is emitted during rapid braking when the brake lining is heated by friction. The fine brake dust particles contain significant amounts of Cu, Ni, and other metals (Adamiec et al., 2016). Braking systems are expected to work harder in the wet season due to the lubricating effect. This could explain the higher concentrations of the brake-related metals in the wet season. Cd is found in higher concentrations in the exhaust gases of gasoline vehicles than that of diesel vehicles (Winther and Slentø, 2010). The higher Cd concentrations in the residential and rural sites dominated by gasoline vehicles (i.e., cars and light good vehicles) align with the fact that a typical car is less fuel efficient on cooler days as the ambient air becomes denser.

Table 4. Levels of heavy metals in road dusts by seasons and land-use categories.

		Zn	Cu	Cd	Cr	Pb	Ni	As
Industrial Area	Annual mean	2613	500	1	232	192	100	7
	Wet mean ^a	1892 (-28%)	574 (15%)	1.3 (-2%)	244 (5%)	168 (-13%)	114 (13%)	6 (-18%)
	Dry mean ^b	3094 (18%)	450 (-10%)	1.3 (1%)	223 (-4%)	210 (9%)	91 (-10%)	8 (13%)
	D/W ratio	1.53	0.87	1.12	0.87	1.20	0.79	1.36
Residential Area Rural Area	Annual mean	1605	400	1	145	113	44	7
	Wet mean ^a	1342 (-16%)	283 (-29%)	0.5 (-26%)	145 (0%)	97 (-14%)	49 (11%)	7 (-11%)
	Dry mean ^b	1780 (11%)	479 (20%)	0.7 (18%)	145 (0%)	125 (10%)	41 (-8%)	8 (8%)
	D/W ratio	1.14	1.53	1.37	0.89	1.18	0.78	1.18
Rural Area	Annual mean	215	53	0.4	26	45	14	3
	Wet mean ^a	134 (-38%)	35 (-34%)	0.3 (-33)	26 (0%)	38 (-15%)	12 (-13%)	3 (4%)
	Dry mean ^b	270 (25%)	66 (23%)	0.5 (23%)	26 (0%)	50 (11%)	16 (9%)	2 (-3%)
	D/W ratio	1.66	0.85	1.87	0.97	1.14	1.10	0.97
Overall	D/W ratio	1.45	1.08	1.45	0.91	1.17	0.89	1.17

^a The mean values were calculated from the samples collected between May and September.

^b The mean values were calculated from the samples collected between October and March.

4.3. Pollution indices

The geo-accumulation indices (I_{geo}), contamination factors (C_f), degree of contamination (C_d), potential ecological risks (E_p), and risk indices (IR) were used to classify the levels and risks of heavy metal contamination in the study areas and the values of the indices are presented in Table 5. The mean I_{geo} of each element was calculated from all samples collected in the same areas over the studied period. The road dust of the industrial and residential areas was found to be heavily to extremely contaminated with Cr, Cu, and Zn and moderately to heavily contaminated with Ni and As based on the I_{geo} values. The industrial area was moderately contaminated by Cd while the residential area was uncontaminated. The road dust of the rural area was moderately contaminated by Cr, Cu, and Zn and uncontaminated to moderately contaminated with Ni and As. Pb contaminations were classified as uncontaminated in all areas.

The C_f values further confirmed that Zn, Cu, Cr, and Ni are common concerns for the industrial, residential and rural areas. The mean C_f values of Cu of all three areas were considered very high, while the mean C_f values of Zn, Cr, and Ni were considered very high in the industrial and residential areas and considerable in the rural areas. Cd and As contaminations were considerable to very high in the industrial and residential areas and moderate in the rural areas. Pb contamination was found to be moderate in all areas. C_d for the industrial and residential areas was classified as very high and for the rural areas as considerable.

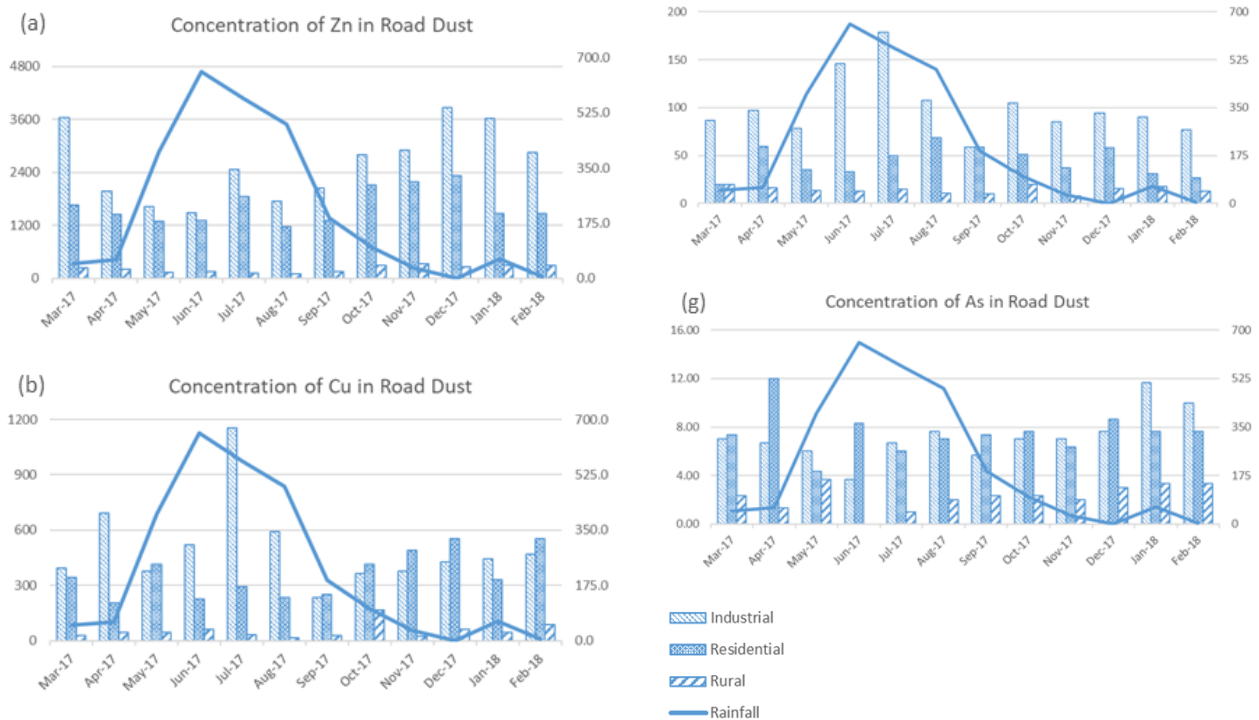


Figure 2. Monthly average concentrations of heavy metals by area.

Table 5. Summary of pollution indices.

Area	Parameter	Zn			Cu			Cd			Cr		
		I_{geo}	C_f	E_r	I_{geo}	C_f	E_r	I_{geo}	C_f	E_r	I_{geo}	C_f	E_r
Industrial Area	Max.	8.19	438	438	7.87	351	1753	4.70	39	1170	6.45	132	263
	Min.	3.74	20	20	2.96	11.65	58.24	0	1.50	45	1.88	5.54	11.08
	Mean	5.02	60.09	60.09	4.87	59.18	296	1.74	6.61	198	4.25	35.63	71.30
Residential Area	Max.	4.18	62.45	61.45	6.23	110	551	2.42	8	240	5.12	52	104
	Min.	2.55	8.77	8.77	1.54	4.35	21.76	0	1.50	45	1.24	3.54	7.08
	Mean	4.19	30.49	30.49	4.55	25.62	128	0.91	3.06	91.70	3.62	22.29	44.60
Rural Area	Max.	2.61	9.15	9.15	5.12	52.24	261	2.66	9.50	285	2.86	10.92	21.85
	Min.	-0.06	1.43	1.43	-0.50	1.06	5.29	-0.58	1	30	-0.96	0.77	1.54
	Mean	1.25	4.02	4.02	1.43	6.16	30.90	-0.01	1.83	55	1.07	4.00	8.01

Area	Parameter	Pb			Ni			As			C_d	RI
		I_{geo}	C_f	E_r	I_{geo}	C_f	E_r	I_{geo}	C_f	E_r		
Industrial Area	Max.	1.65	4.69	23.46	5.95	93	465	3.22	14	140	493	2382
	Min.	-0.99	0.76	3.78	1.58	4.50	22.50	0.42	2	20	49.21	213
	Mean	0.31	2.08	10.40	3.67	25.09	126	2.17	7.22	72.20	196	834
Residential Area	Max.	1.37	3.87	19.35	4.27	29	145	4	24	240	196	908
	Min.	-1.66	0.48	2.38	-0.26	1.25	6.25	-0.58	1	10	20.90	101
	Mean	-0.50	1.22	6.11	2.58	11.03	55.20	2.08	7.39	73.90	101	430
Rural Area	Max.	0.53	2.16	10.81	2.81	10.50	52.50	6.20	9	90	74.67	378
	Min.	-3.53	0.13	0.65	-1.58	0.50	2.50	-0.58	1	10	6.34	53.03
	Mean	-2.08	0.48	2.42	0.63	3.56	17.80	0.63	2.54	25.40	22.60	143

The mean E_r of each metal in the road dust samples of the three areas was calculated using the annual average concentrations. The risks posed by Cu and Cd were high in the industrial area while in the residential area they were considerable. The risk of Ni in the industrial area was also considerable. All other mean E_r were within moderate to low. The risks of As in the industrial and residential areas were at the high end of the moderate class. In addition, the RI values showed that the risk of heavy metal contamination was very high in the industrial area, was considerable in the residential area, and was low in the rural area. Immediate action should be taken to address the heavy metal contamination in industrial and residential areas near the roadside as it may contribute to public health issues.

5. Conclusions

Road dust samples from all sampling sites were found to be contaminated to various degrees with toxic metals and trace elements. The risks associated with Zn, Cu, Ni and Cd were found to be particularly high and raise concerns. The land use type was found to have a significant impact on the contamination level. Both the I_{geo} and C_f indices showed the same picture: metal accumulation was highest in the industrial area followed by the residential area and rural area. These suggest that traffic-related sources are major contributors to the contamination as these metals are commonly found in high concentration in brake linings, tyre dust and engine exhaust. In the event of a rainstorm, the contaminated road dust would be washed into gullies and

discharged to surface water bodies without treatment which could potentially cause pollution in the receiving water bodies. The concentrations of Zn, Cd, and Pb were lower in the wet season. This could be attributed to less tyre wear in the wet season and road dust being removed by road surface runoff. On the other hand, the concentrations of Cr, Cu, and Ni were higher in the wet season. The variations were more notable in rural areas than in industrial and residential areas. Since street sweeping may not be efficient in removing fine road dust particles that carry heavy metals (Yuen et al., 2012), reducing heavy metal emissions should be a primary means of controlling heavy metal contamination in urban areas. Tyre and road pavement materials should be investigated to reduce heavy metal emissions due to the interaction between tyres and road surface.

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Notes on contributors



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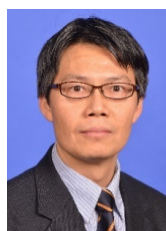
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