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Metals in exposed-lawn soils from 18 urban parks and its human health implications in southern China's largest city, Guangzhou

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ABSTRACT

The total concentrations, fractionation of metals and human health risk in surface-exposed lawn soils from 18 urban parks in Guangzhou were investigated. Cd was predominantly associated with the acid-soluble fraction and Pb mainly with the reducible fraction, whereas Cr, Ni, Cu, and Zn were strongly associated with the residual fraction. The hazard indices for the metals were <1, indicating that exposure to the urban park soil does not pose significant risks of non-carcinogenic effects from the metals analyzed. The probabilities of Cd, Cr, and Ni posing carcinogenic risks to children and adults were negligible (probability <1×10^{-6}).

1. Introduction

The unprecedented rate at which urbanization and industrialization have occurred in China in the last few decades has been accompanied by increasing environmental pollution in urban areas because of the increasing intensities of anthropogenic activities in urban areas (Chen, 2007; Wei and Yang, 2010; Bai et al., 2014; Cheng et al., 2014). Human health in a town or city is strongly affected by the status of the soil in that area (Imperato et al., 2003; Wang et al., 2012a). Urban soils can be regarded as the sinks for metals and other pollutants, the main sources of which are industrial activities, vehicle emissions, the combustion of coal and other fuels, and the disposal of municipal solid waste (Wang et al., 2012b; Zhao et al., 2014; Karim et al., 2015). Excessive inputs of trace metals and other pollutants to urban soils may cause the urban soil ecosystem to deteriorate and other environmental problems to occur (Imperato et al., 2003; Zhao et al., 2014).

Metals have elicited much attention because they are toxic and non-degradable and can bio-accumulate (Järup, 2003; Sabine and Wendy, 2009; Gu et al., 2012). According to numerous studies, metals have been found to accumulate in fatty tissues, affect organ functions, and disrupt the nervous and endocrine systems of animals (Waisberg et al., 2003; Bocca et al., 2004; Zhao et al., 2014). Metals in urban soils can be transferred readily to humans through the ingestion, inhalation, and dermal absorption routes, and they will pose potential threats to urban residents, especially to children and senior citizens who are more susceptible to such threats and tend to use parks more often than other people (Miguel et al., 1997; Guney et al., 2010; Wei and Yang, 2010; Peña Fernández et al., 2014).

Analyzing total metal concentrations in soils can provide valuable information on overall pollution levels. However, total concentrations alone are not sufficient to allow the potential effects of

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contaminated soils on humans to be evaluated because the toxicity and mobility of a metal in the environment strongly depends on the specific chemical forms of the metal that are present and the states in which the metal is bound (Filgueiras et al., 2002; Gleyzes et al., 2002). Sequential extraction is a very important method that has been widely used to gain insights into the environmental behaviors of potentially toxic metals (Sutherland, 2010). Many sequential extraction schemes have been developed that depend on the Tessier procedure. Of these, the BCR procedure has been extensively accepted and used to fractionate metals in different types of environmental media (Gleyzes et al., 2002; Sutherland, 2010; Gu et al., 2014). However, performing a traditional extraction method is extremely tedious and time-consuming (Alonso Castillo et al., 2011). Microwave-assisted sequential extraction is less tedious and time-consuming than traditional extraction methods, and it has been used to analyze all types of solid environmental media, including sediment, soil, sewage sludge, and particulate matter (Jamali et al., 2009; Alonso Castillo et al., 2011; Kumar et al., 2013; Burt et al., 2014).

Guangzhou (112° 57′ to 114° 3′ E, 22° 26′ to 23° 56′ N) is the capital of Guangdong Province, and lies in the northern part of the Pearl River Delta. Guangzhou has existed for more than 2200 years, and has a population of more than 10 million (GZG, 2014). Guangzhou is one of the most important cities in the Pearl River Delta, which is the area with the fastest-growing economy in China. Exposed lawns in urban parks are the main areas used for outdoor recreation by children and adults in Guangzhou. However, to the best of our knowledge, very little information is available on total concentrations and the fractionation of metals and the health risks posed by metals in exposed-lawn soils in 18 urban parks in Guangzhou. The aims of this study were (1) to determine the total concentrations and fractionation of metals in soils under exposed lawns in urban parks in Guangzhou, and (2) to assess the health risks posed by metals in the soils.

2. Materials and methods

2.1. Topsoil sample collection

Topsoil samples (0–10 cm) were collected from exposed lawns that are the main areas used for outdoor recreation by children and adults. The samples were collected from 18 public parks in Guangzhou City (Fig. 1) in May 2014. Between 15 and 45 subsamples (the actual number depended on the area of the park lawn) of topsoil were collected from each park, and the subsamples were mixed thoroughly to get a representative sample for the whole park lawn. Each sample was then dried at 50 °C in an oven until it reached a constant weight, then the soil was gently disaggregated and sieved through a nylon sieve to give particles with diameters less than 150 μm and to homogenize the soil. Each prepared sample was then stored in a black self-sealing polyethylene bag until it was analyzed.

2.2. Analytical methods

The organic matter (OM) content was determined through losses on ignition to constant mass at 550 °C for 4 h (De Jonge et al., 2012). For soil pH, a 1: 2.5 (W/V) soil-water suspension was determined by a Single-Channel pH Meter (Mettler-Toledo International Inc. Switzerland) (Nanos and Rodríguez Martín, 2012). Pretreatments of particle size were implemented based on the China National Standards (GB/T12763.8–2007) and granulometry of each sample was determined using a Malvern Mastersizer 2000 (Malvern Instruments Co., Ltd. UK).

Each sample was sequentially extracted to give information on the metal fractionation following a method described by Rauret et al. (1999). In this method, the metals are separated into four operationally defined geochemical fractions, the acid-soluble, reducible, oxidizable, and residual fractions. The optimized microwave-assisted sequential extraction method used in this study has been described in detail elsewhere (Alonso Castillo et al., 2011). The metals remaining in a sample residue were digested following the United States Environmental Protection Agency (US EPA) method 3050B (microwave digestion). The total metal concentrations in soil samples were estimated by summing up the metal concentrations in the four fractions. The Chinese national standard sediment sample GBW07436 was analyzed to check the accuracy of the sequential extraction procedure and to monitor the performance of the analytical method. The Cd, Pb, Cr, Ni, Cu, and Zn recoveries were 87–103% in the acid-soluble fraction, 86–93% in the reducible fraction, 92–106% in the oxidizable fraction, and 89–104% in residual fraction. The concentrations of metals in the four chemical fractions were measured by a Hitachi Z2000 atomic absorption spectrophotometer (Hitachi High-Tech Instruments Co., Ltd. Japan). The instrument detection limits were calculated as 3σ/S (σ is standard deviation of blank signal, and S is the sensitivity) and the detection limits (mg/kg) were 0.04 for Cd, 0.1 for Pb, 0.2 for Cr, 0.1 for Ni, 0.05 for Cu and 0.6 for Zn, respectively.

2.3. Human health risk model

Children and adults are exposed to metals through three main pathways: ingestion, inhalation, and dermal contact. According to the US EPA (1997) and Lu et al. (2014a), the average daily dose (ADD in Eqs. (1)–(3)) (in mg/(kg d)) received via each of the three exposure routes can be estimated using Eqs. (1)–(3). Of the six metals that were studied, Cd, Cr, and Ni are known to be carcinogenic (Ferreira-Baptista and De Miguel, 2005; Xue et al., 2012). Slope factors for carcinogenic risks posed by these metals after exposure through ingestion and dermal contact have not been determined by the US EPA, so we only considered carcinogenic risks posed by the metals after exposure through inhalation. The lifetime average daily dose (LADD in Eq. (4)) was calculated using Eq. (4) (Xue et al., 2012) to allow the potential carcinogenic risk to be determined.

$$ADD_{ingestion} = \frac{C \times R_{ingestion} \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (1)$$

$$ADD_{inhalation} = \frac{C \times R_{inhalation} \times EF \times ED}{PEF \times BW \times AT} \quad (2)$$

$$ADD_{dermal} = \frac{C \times SA \times SL \times ABF \times EF \times ED}{BW \times AT} \times 10^{-6} \quad (3)$$

$$LADD_{inhalation} = \frac{C \times EF}{AT \times PEF} \times \left(\frac{CR_{child} \times ED_{child}}{BW_{child}} + \frac{CR_{adult} \times ED_{adult}}{BW_{adult}}\right) \quad (4)$$

In Eqs. (1–4), a C value of C_{UCL} (the exposure-point concentration, in mg/kg) is considered to give an estimate of the “reasonable maximum exposure”, which is the upper 95% confidence interval for the mean (US EPA, 2002; Sun et al., 2013). The upper 95% confidence limit (UCL) was calculated using the statistical software provided by the US EPA (ProUCL 5.0.00). The other parameters used in Eqs. (1)–(4) are defined in Table 1, and the real data for Chinese people that were used in the calculations are also given in Table 1.

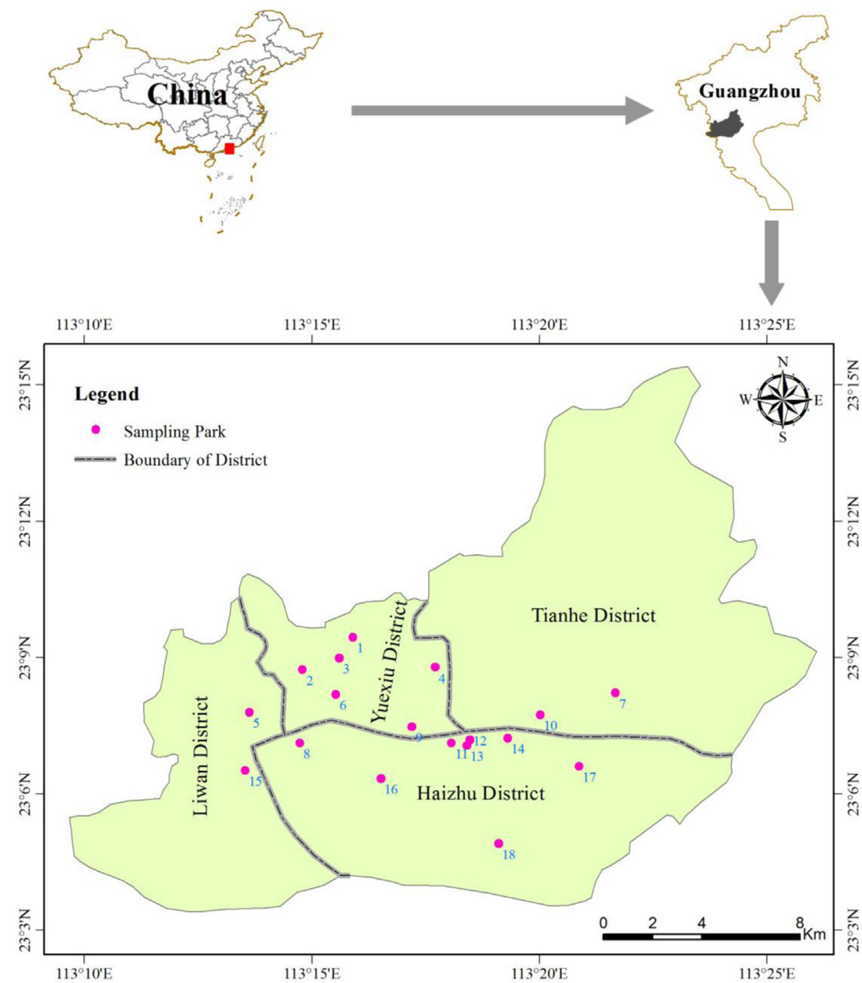

Fig. 1. Map showing the parks in Guangzhou City from which samples were taken. 1: Sculpture Park; 2: Liuhua Lake Park; 3: Yuexiu Park; 4: Huanghuagang Park; 5: Liwan Lake Park; 6: People's Park; 7: Tianhe Park; 8: Cultural Park; 9: Dongshan Lake Park; 10: Pearl River Park; 11: Development Park; 12: Chuanqi Park; 13: Ersha Island Sports Park; 14: Haixinsha Asian Games Park; 15: Zuiguan Park; 16: Xiaogang Park; 17: Guangzhou Exhibition Park; 18: Haizhu Lake Park.

Table 1
Parameters and values used in the human health risk models.

Factor	Definition	Unit	Value		Reference
			Children	Adult	
$R_{ingestion}$	ingestion rate of soil	mg/day	200	100	(MEP, 2014)
EF	exposure frequency	days/year	350	350	(MEP, 2014)
ED	exposure duration	years	6	25	(MEP, 2014)
BW	average body weight	kg	15.9	56.8	(MEP, 2014)
AT	average time	days	26,280 (non-carcinogen) 9125 (carcinogen)		(MEP, 2014)
$R_{inhalation}$	inhalation rate	m^3/day	7.5	14.5	(MEP, 2014)
PEF	particle emission factor	m^3/kg	1.36×10^9	1.36×10^9	(US DOE, 2011)
SA	exposed skin area	cm^2	2800	5700	(US DOE, 2011)
SL	skin adherence factor	mg/cm^2	0.2	0.07	(MEP, 2014)
ABF	dermal adsorption factor	unitless	0.001 (non-carcinogen) 0.01 (carcinogen)		(Shi et al., 2011)
CR	the contact or adsorption rate	ingestion ($CR = R_{ingestion}$), inhalation ($CR = R_{inhalation}$), and dermal adsorption ($CR = SA \times SL \times ABF$)			(Ferreira-Baptista and De Miguel, 2005)

The calculated dose for each metal and exposure route was divided by the appropriate reference dose (RfD) (in mg/(kg d)) to give a hazard quotient (HQ) for non-carcinogenic risks, whereas for each carcinogenic metal the calculated dose was multiplied by the appropriate slope factor (in mg/(kg d)) to estimate the carcinogenic risk. The hazard index (HI) is the sum of the HQs (Ferreira-Baptista and De Miguel, 2005; Hu et al., 2011; Kelepertzis, 2014). A HI of less than one was assumed to indicate that there was no significant risk of non-carcinogenic effects. A HI of more than one was assumed to indicate that there was a chance that non-carcinogenic effects may occur. The probability of non-carcinogenic effects occurring tends to increase as the HI increases. Carcinogenic risk is the probability that an individual will develop cancer because of exposure to carcinogenic hazards over the individual's lifetime. The acceptable or tolerable risk for regulatory purposes is defined as a carcinogenic risk of between 1×10^{-6} and 1×10^{-4}. In this study, the HI and carcinogenic risk methods were used to evaluate the health risks posed to local residents from exposure to metals in soils in urban parks in Guangzhou.

3. Results and discussion

3.1. General soil characteristics

The particle size distributions and organic matter contents were determined so that the general characteristics of the soils analyzed in this study could be understood. The soil samples were predominantly composed of silt, followed by sand, as is shown in Fig. S1. The soil samples from all of the parks had clay contents below 25.50%. The soil samples had mean silt contents of 51.15% (range 32.98–65.13%) and mean sand contents of 31.43% (range 9.60–61.39%). The samples had organic matter contents of 5.99–10.00% by dry weight, and the mean was 7.69%.

The pH values were ranged from 5.27 to 7.34 and their median value was 6.71, indicating weak acidity to neutrality (Fig. S2). Previous soil survey results demonstrated that the background soil pH in Guangzhou varied from 4.5 to 5.1 (Xu and Liu, 1996). By comparison, the urban park soils relatively had higher pH values than the original soils, most likely owing to the existence of alkalizing products (e.g., calcium carbonate or calcium-magnesium carbonate in gravel, flagstones, cement, concrete, mortar) and the atmospheric particulate deposition (Scharenbroch et al., 2005; Guo et al., 2011; Li et al., 2013b).

3.2. Total metal concentrations

The means, standard deviations, medians, and ranges of the Cd, Pb, Cr, Ni, Cu, and Zn concentrations in the urban park soils from Guangzhou are shown in Table 2, and the number of parks with different soil quality grades (using the Chinese environmental quality standard for soils, GB 15618-1995) are summarized. The total concentrations generally decreased in the order Pb > Zn > Cu > Cr > Ni > Cd. As can be seen, Pb was found at the highest concentrations in the urban park soil samples. The mean total Ni concentration was 28.18 mg/kg, and the mean total Cd concentration was less than 0.22 mg/kg. The Cd, Pb, Ni, Cu, and Zn concentrations were significantly higher than their benchmark values ($p < 0.01$, determined using the one-sample t test), which strongly suggests that the soils had been enriched in these metals because of human activities.

The Chinese soil quality standard GB 15618-1995 has classified three classes of soils, in which the contents of Cd, Pb, Cr, Ni, Cu, and Zn are regarded as parameters used for classifying soil quality. Based on this criterion, class I is defined as unpolluted, classes II and III are defined as slightly and moderately polluted, respectively, and exceeding the class III threshold is defined as heavily polluted. Accordingly, the concentrations of some of the metals in most of the parks put the soils into class II according to Chinese soil quality standard GB 15618-1995. The proportion of the parks for which the soil samples were in class II was 72.22% (13 parks) for Cd, 100% for Pb, 88.89% (16 parks) for Cu, and 50.00% (9 parks) for Zn. The soil samples from two parks (Culture Park and Xiaogang Park) contained Cu concentrations that put them in a higher class than class II, suggesting that the two parks were moderately polluted.

The metal concentrations found in this study and that have been found in soils from urban parks in other Chinese cities are shown in Fig. S3. The Cd concentrations found in this study were relatively low compared to concentrations that have been found in other studies, but the Pb and Cu concentrations found in this study were higher than have been found in urban parks in other cities. The average Cr and Zn concentrations were significantly lower in this study than have been found in soil from urban parks in Shanghai. The mean Pb concentration found in this study was higher than was found in any of the other studies, and this may have been because of the high benchmark value for Pb in Guangzhou (36.0 mg/kg).

3.3. Metal fractionation

The contributions (in percent) of the concentrations in the four chemical fractions to the total Cd, Pb, Cr, Ni, Cu, and Zn concentrations are summarized in Table 3. The speciation of each metal in the soil samples is shown in Fig. 2. The Cd concentration was highest in the acid-soluble fraction (44.19% of the total), and lower in the reducible fraction (26.93%) and the residual fraction (22.40%). The oxidizable fraction contained the lowest Cd concentration (6.48% of the total). Cd was also found to be mainly associated with the acid-soluble fraction in urban soils from Guangzhou in a previous study (Lu et al., 2007).

Pb was predominantly found in the reducible and residual fractions, and the contributions of the fractions to the total Pb concentration decreased in the order reducible fraction ≈ residual fraction > oxidizable fraction ≈ acid soluble fraction. The average contribution of the reducible fraction to the total Pb concentration was 47.18%, and this may be because Pb can form stable complexes with Fe and Mn oxides (Filgueiras et al., 2002; Gleyzes et al., 2002). Lu et al. (2009) found that Pb in urban park soils from Shenzhen was mainly associated with the Fe–Mn oxide fraction. The reducible fraction contributed the highest proportion of the total Pb concentration, indicating that the Pb mainly originated from

Table 2
Basic statistics for the metal concentrations (mg/kg) found in soil samples from 18 urban parks in Guangzhou, and the classifications of the metal concentrations.

Metal	Mean, SD	Median	Range	BV[a]	No. of parks in each class of soil quality[b]			
					I	II	III	Exceeding III
Cd	$0.22^{**} \pm 0.04$	0.23	0.13–0.27	0.056	5	13	0	0
Pb	$124.35^{**} \pm 47.36$	110.80	72.96–270.57	36.0	0	18	0	0
Cr	58.40 ± 17.84	51.98	30.26–102.70	50.5	17	1	0	0
Ni	$28.18^{**} \pm 6.64$	28.76	12.63–36.95	18.2	18	0	0	0
Cu	$73.49^{**} \pm 22.07$	73.29	33.80–119.28	17.0	0	16	2	0
Zn	$98.31^{**} \pm 11.24$	100.91	77.78–114.45	47.3	9	9	0	0

Note: $^{**}p < 0.01$ significance level.
[a] Background values for soils in Guangdong Province (CEMS, 1990), the survey program of background values of soil elements was organized and carried out by Chinese government during 1985–1990. In this survey, the systematic sampling pattern (known as "grid or cell sampling") coupled with a random sampling pattern was used for each province, and the data of values of soil elements were collected to calculate background values for each province through statistics.
[b] The Chinese soil quality standard GB 15618-1995.

Table 3
Metal fractionation (as the percentage contribution to the total concentration of each metal) in the urban park soil samples from Guangzhou.

		Acid-soluble	Reducible	Oxidizable	Residual
Cd	Mean, SD	44.19 ± 2.65	26.93 ± 1.90	6.48 ± 4.46	22.40 ± 1.90
	Median	45.08	27.07	5.28	22.54
	Range	37.59–47.15	23.73–31.11	2.53–18.03	18.79–26.94
Pb	Mean, SD	3.05 ± 1.92	47.18 ± 7.57	3.76 ± 3.36	46.01 ± 7.77
	Median	3.10	48.02	2.12	44.12
	Range	0.73–7.42	33.91–59.71	0.54–10.92	33.99–58.06
Cr	Mean, SD	2.27 ± 1.86	2.39 ± 2.58	3.90 ± 2.20	91.44 ± 3.91
	Median	1.87	2.01	3.67	92.79
	Range	0.36–8.83	0.13–12.05	0.92–7.37	81.92–96.20
Ni	Mean, SD	1.15 ± 0.56	3.12 ± 1.54	3.95 ± 2.02	91.78 ± 2.61
	Median	0.98	3.14	3.49	91.78
	Range	0.54–2.67	0.53–7.87	0.89–8.55	87.08–96.44
Cu	Mean, SD	1.16 ± 0.52	11.65 ± 5.50	12.18 ± 3.28	75.01 ± 6.85
	Median	1.09	10.91	11.88	76.75
	Range	0.32–1.95	5.63–29.82	5.40–17.23	51.00–82.52
Zn	Mean, SD	16.20 ± 5.10	27.38 ± 10.30	14.30 ± 4.78	42.13 ± 18.17
	Median	14.17	23.86	13.07	47.59
	Range	10.46–27.02	14.82–52.75	7.41–24.21	3.34–67.31

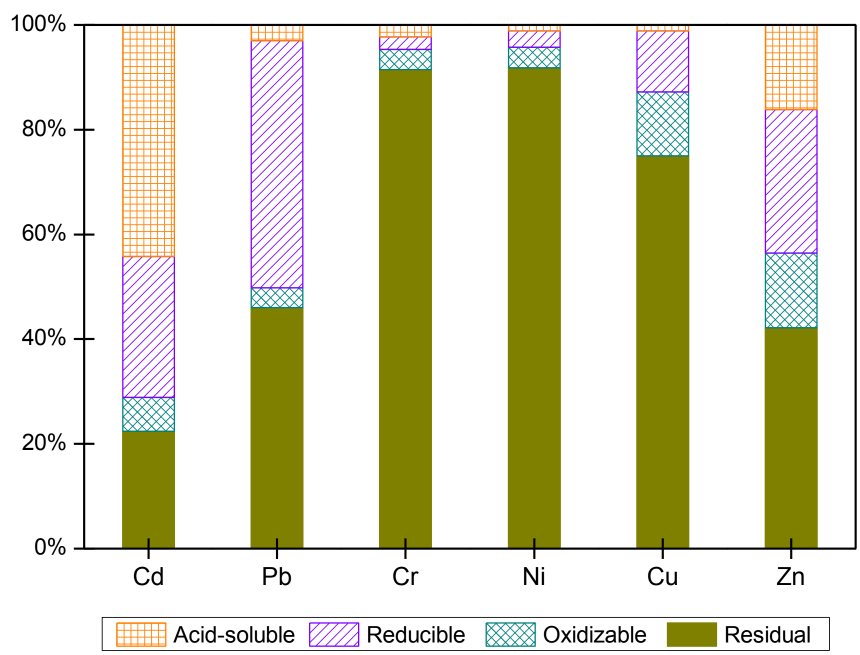

Fig. 2. Mean chemical fractionation of metals in urban park soils from Guangzhou.

atmospheric deposition (such as from particulate and gaseous emissions from traffic and factories) (Lee et al., 2007; Li et al., 2007; Cai et al., 2013; Gu et al., 2014).

The residual fraction contributed the highest proportions of the total Cr, Ni, and Cu concentrations (81.92–96.20% for Cr, 87.08–96.44% for Ni, and 51.00–82.52% for Cu). Similar results have been found for urban soils from Nanjing and Shanghai (Liu and Liu, 2008). Zn was predominantly found in the residual and reducible fractions, and the contributions of the concentrations in the different fractions to the total Zn concentration decreased in the order residual fraction > reducible fraction > acid-soluble fraction > oxidizable fraction. Similar results have been found for soil samples from Naples (Italy) (Imperato et al., 2003), Aberdeen (UK) (Yang et al., 2006), and Nanjing (China) (Lu et al., 2003).

Generally, metals in the residual fraction remain relatively stable and inert, which are not easily released into the mobile and bioavailable phases (Tessier et al., 1979). In contrast, metals in the non-residual fractions, including acid-soluble, reducible, and oxidizable fractions, may reflect various degrees of reactivity and potential bioavailability (Wong et al., 2007). They may also change depending on the surrounding physical and chemical conditions. In recent years, some advance techniques have been developed to explore the metal real status in materials (Li et al., 2013a, 2014a, 2014b; Qiu et al., 2015), which can help us to further understand the metal pollution related to fractionation. These techniques can be considered to use in further metal study in environment.

3.4. Human health risks

The C_{UCL} (the 95% upper confidence limit) values, HQs for the three exposure routes, HIs, and carcinogenic risks for the metals that were analyzed in the urban park soil samples from Guangzhou, and RfD values and slope factors from the literature, are shown in Table 4.

Table 4
Hazard quotients, hazard indices, and cancer risks for the metals analyzed in this study.

Metal	Cd-non	Cd-cancer	Pb	Cr-non	Cr-cancer	Ni-non	Ni-cancer	Cu	Zn
C_{UCL}	0.24	0.24	145.70	65.71	65.71	30.90	30.90	82.54	102.90
Oral. RfD	1.00E−03[a]		3.50E−03[a]	3.00E−03[a]		2.00E−02[a]		4.00E−02[a]	3.00E−01[a]
Inhal.RfD	1.00E−05[c]		3.52E−03[b]	2.86E−05[a]		2.06E−02[b]		4.02E−02[b]	3.00E−01[b]
Dermal RfD	1.00E−05[a]		5.25E−04[a]	6.00E−05[a]		5.40E−03[a]		1.20E−02[a]	6.00E−02[a]
Inhal. SF		6.30E+00[a]			4.20E+01[a]		8.40E−01[a]		
Children									
$HQ_{ingestion}$	2.41E−04		4.18E−02	2.20E−02		1.55E−03		2.07E−03	3.45E−04
$HQ_{inhalation}$	6.65E−07		1.15E−06	6.37E−05		4.16E−08		5.69E−08	9.51E−09
HQ_{dermal}	6.75E−05		7.81E−04	3.08E−03		1.61E−05		1.94E−05	4.83E−06
$HI = \sum HQ_i$	3.09E−04		4.26E−02	2.51E−02		1.57E−03		2.09E−03	3.50E−04
Adults									
$HQ_{ingestion}$	1.41E−04		2.44E−02	1.28E−02		9.06E−04		1.21E−03	2.01E−04
$HQ_{inhalation}$	1.50E−06		2.59E−06	1.44E−04		9.37E−08		1.28E−07	2.14E−08
HQ_{dermal}	5.61E−05		6.49E−04	2.56E−03		1.34E−05		1.61E−05	4.01E−06
$HI = \sum HQ_i$	1.99E−04		2.51E−02	1.55E−02		9.19E−04		1.23E−03	2.05E−04
Cancer risk		3.93E−10			7.17E−7		6.74E−09		

[a] Ferreira-Baptista and De Miguel (2005).
[b] Lu et al. (2014a).
[c] Peña Fernández et al. (2014).

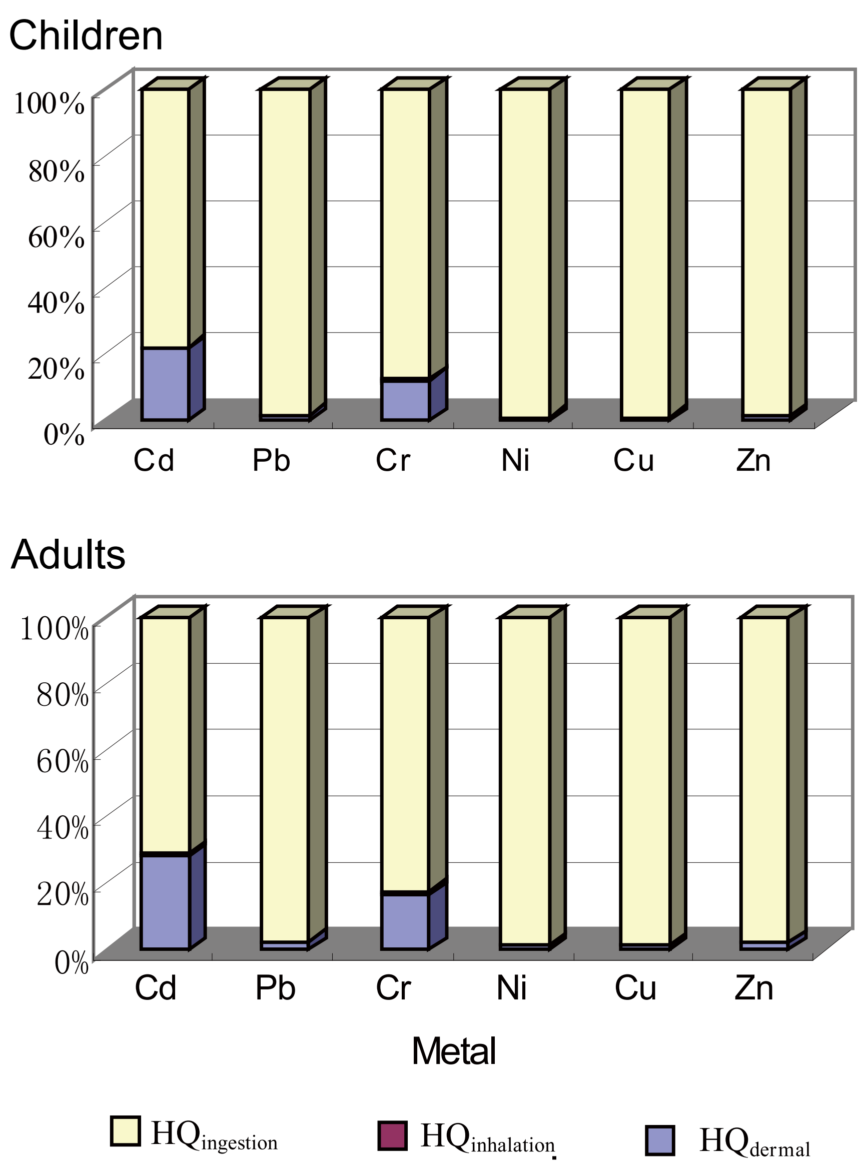

Fig. 3. Relative contributions to the hazard index (HI) for each metal that was analyzed made by the hazard quotients (HQs) for three exposure pathways (ingestion, inhalation, and dermal exposure).

In terms of non-carcinogenic risks, the ingestion of soil particles appeared to be the major pathway through which risks are caused to residents of Guangzhou from exposure to metals in urban park soils, and dermal adsorption was the next most important pathway. Similar results have been found in other urban areas (Ferreira-Baptista and De Miguel, 2005; Kelepertzis, 2014; Lu et al., 2014b). As is shown in Fig. 3, the relative contribution of ingestion to the HI ranged from 77.95 to 99.07% for children and from 71.00 to 98.68% for adults. This indicates that the largest contribution to health risks posed by metals in urban park soils in Guangzhou comes from ingesting soil particles. The HQs for the metals were 3–4 orders of magnitude higher for the ingestion of soil particles than for the inhalation of re-suspended particles (Table 4). The inhalation of re-suspended particles through the mouth and nose actually contributed almost negligible risks compared with the contributions from the other exposure pathways. The HIs for the metals that were analyzed in the urban park soils from Guangzhou for both children and adults decreased in the order Pb > Cr > Cu > Ni > Zn > Cd. The HIs for all of the metals that were analyzed were less than one, indicating that the metals in the urban park soils from Guangzhou do not pose significant risks of non-carcinogenic effects to children or adults through the three exposure pathways mentioned above.

The Cd, Cr, and Ni carcinogenic risks from exposure to the urban park soils from Guangzhou decreased in the order Cr > Ni > Cd. The US EPA generally considers that excess cancer risks lower than about a chance in 1,000,000 (i.e., a probability of 1×10^{-6}) are negligible (Hu et al., 2011). The Cd, Cr, and Ni carcinogenic risks determined in this study were all lower than 10^{-6}, indicating that Cd, Cr, and Ni carcinogenic risks from exposure to urban park soil in Guangzhou City are negligible.

4. Conclusions

The concentrations of Cd, Pb, Cr, Ni, Cu, and Zn and the chemical speciation of each metal in soil samples from urban parks in Guangzhou were determined, and the health risks posed by the metals through exposure to the soils were determined. The Cd, Pb, Ni, Cu, and Zn concentrations were significantly higher than their background values, and the Pb concentrations were higher than the concentrations of the other metals. Cd was strongly associated with the acid-soluble fraction (44.19% of the total Cd concentration), the reducible fraction (26.93%), and the residual fraction (22.40%). Pb was predominantly found in the reducible fraction, and the highest contributions to the total Cr, Ni, Cu, and Zn concentrations came from the residual fractions. The ingestion of soil particles was found to be the major source of increased non-carcinogenic risks from exposure to the metals in urban park soils in Guangzhou. The HIs for all of the metals were less than one, indicating that the urban park soils do not pose significant risks of non-carcinogenic effects to children or adults. The carcinogenic risk from Cd, Cr, and Ni for children and adults was found to be negligible (the probability was $<1 \times 10^{-6}$).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jclepro.2015.12.031.

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