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Short communication

Potentially harmful metals and metalloids in urban street dusts of Urumqi City: Comparison with Taipei City

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

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

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ABSTRACT

Urumqi City is the farthest metropolis from an ocean in the world. This communication measured the concentrations of eight potentially harmful metals Cr, Pb, Hg, Ni, Cd, Zn, Cu, and Sr and metalloids As and Sb in the street dusts collected from Urumqi City and compared them with those noted in Taipei City. Although the geological environments of Taipei and Urumqi differ markedly; however, the potential harmful metals and metalloids studied are surprisingly similar in their distributions in these two cities. Particularly, As is a common pollutant that poses severe health risks to residents in both cities. Hence, the anthropogenic rather than geogenic factors pre-dominate the formation and distributions of street dusts. This finding suggests common control strategy may be applicable to different metropolis on the confinement of adverse health effects by the street dusts.

1. Introduction

Urban street dust is produced in cities, which composed of solid particles with complex compositions. High levels of potentially harmful metals in street dust, after entering the human body, can have adverse effects on the health of individuals [1,2]. Taipei City is a coastal metropolis with high population density (9600 per km^2) and high vehicle density (6786 per km^2). Zhang et al. [3] sampled the street dusts in Taipei City and demonstrated the concentrations of eight metals and two metalloids in the collected samples. These authors noted that the studied potential harmful metals and metalloids in Taipei street dusts were mainly from traffic emissions, with adverse health effects from exposure to As, Sb, Cr and Pb by children.

Urumqi, the capital city of China's Xinjiang Uygur Autonomous Region, is the metropolis farthest from an ocean in the world, whose geological characteristics limit the removal of produced pollutants in and near the city. Urumqi has a continental and arid climate and was rated as 4th in the 15 most heavily polluted cities worldwide by the World Health Organization (WHO) [4]. Wei et al. [5–7] reported the levels of heavy metals in street dust of Urumqi.

Literature works on street dusts in Urumqi neglected the impacts of potentially harmful metals (Hg and Sr) and metalloids (As and Sb). Also, these studies did not conduct health risk analysis using the obtained data. The objectives of this communication are to measure the concentrations of eight potential harmful metals (Cr, Pb, Hg, Ni, Cd, Zn, Cu and Sr) and two metalloids (As, Sb) in street dust samples from Urumqi using the same protocols by [3] on Taipei City and then make comparisons of the results between these two cities.

2. Materials and method

2.1. Study areas and sampling

Fig. S1 and Table S1 in Supplementary materials shows the sampling sites. 63 street dust samples were collected in Urumqi during of July 2011. Dust samples were not collected adjacent to specific pollution sources such as industrial sites. At each sampling site, approximately 250 g of dust that accumulated on impervious surfaces was collected with a plastic brush and dustpan. Samples were kept in sealed polyethylene bags and transported to the

* Corresponding author at: National Taiwan University, Department of Chemical Engineering, No 1, Sec 4, Roosevelt Rd, Taipei 10617, Taiwan. Tel.: +886 2 23625632/+886 2 33663028; fax: +886 2 23623040.
E-mail addresses: djlee@ntu.edu.tw, djleetw@yahoo.com.tw (D.-J. Lee).

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laboratory. They were then dried at room temperature for 5 d with grids being removed.

2.2. Sample treatment and analysis

The sampling, treatment and analysis protocols of street dusts from Urimqi City were the same as those in Zhang et al. [3]. Statistical analyses were performed with SPSS 11.5. Descriptive analysis, correlation analysis (CA), and principal component analysis (PCA) were used. The exposure assessment of the studied metals and metalloids to human bodies was conducted according to Ref. [3]. Details of the exposure assessment are also listed in the Supplementary materials.

Quantitative risk characterization requires the evaluation of exposure (or intake) estimates, such as a cancer SFAn HQ is a ratio of the daily exposure level to the reference dose (RfD). A Hazard Index (HI) equals the sum of HQs. For carcinogens, the dose is multiplied by the corresponding SF to produce a degree of cancer risk. The general equations used to calculate risk from street dust are Eqs. (S7)–(S9) [8].

Enrichment factors (EFs) were used to highlight the origin of elements in soil. The EF was calculated based on methods proposed by Lim et al. [9] and Zhang et al. [3].

3. Results and discussion

3.1. Potential harmful metal concentrations in street dust

Fig. 1 shows the metal and metalloid concentrations in street dust samples from Urumqi. In Urumqi, the mean concentrations of potential harmful metals in street dust samples were as follows: As, 229 mg/kg; Cu, 179 mg/kg; Cd 1.97 mg/kg; Cr 186 mg/kg; Hg 1.50 mg/kg: Ni 289.7 mg/kg; Pb 187 mg/kg; Zn 227 mg/kg; Sb 73.5 mg/kg; and Sr 226 mg/kg. The average concentrations of potential harmful metals and metalloids in the street dust followed $Ni > As \approx Zn \approx Sr > Pb \approx Cr \approx Cu > Sb > Cd > Hg$. Overall, heavy metals contents in the road dust of Taipei were much higher than those in Urumqi except for As and Sb, with those being 60% and 70% of those in Urumqi, respectively.

3.2. Correlation studies

The Pearson correlation coefficient (r) was used to quantify the linear relationship between two quantitative variables. Table S2 lists the coefficients for inter-element correlations in street dust in Urumqi. In Urumqi, only Cr–Cu concentrations were strongly correlated. The Cr–Pb, Pb–Cu, and Sb–Hg concentrations were weakly correlated. Fig. S2 shows the dendrograms for potential harmful metals and metalloids in Urumqi. In Urumqi, 4 clusters are noted: (1) Hg, Cd, and Sb; (2) Cu, Cr, Zn, and Pb; (3) As and Sr; and (4) Ni.

Table S3 shows PCA results and Varimax rotation matrix. Four principle components were extracted. In Urumqi, Factor 1 was extracted by loadings of Cu, Zn, Cr and Pb, which may be related to vehicle emissions [10,11]. Factor 2 was loaded primarily by Hg and Sb, which obviously originated from anthropogenic activities such as incineration of municipal solid waste. Factor 3 was dominated by Cd and Ni. Traffic emissions and oil combustion can contribute to some extent to Cd and Ni concentrations in street dust. Nickel pollution is caused by emissions from vehicle engines that use gasoline containing Ni and by the abrasion and corrosion of Ni from vehicle parts [12]. Factor 4 was explained by As and Sr. Metal As was likely from the combustion of fossil fuels such as waste oil and coal [1,10,13].

3.3. Health risk assessment and potential sources

The exposure assessment is listed in Table 1. In Urumqi, all exposure routes for non-carcinogenic effect by Ni, As, Zn, Sr, Pb, Cr, Cu, Sb and Cd in road dusts have the following risk order for both children and adult ingestion > dermal contact > inhalation. In particular, the ingestion exposure is the main route for heavy metals and metalloids in road dust to human, correlating with [14,15]. Conversely, the inhaling Hg vapor was higher than those of ingestion and dermal exposures. Also, the exposure of studied metals and metalloids for children exceeded those for adult, which is attributable to the hand-to-mouth activity of children [3,15].

On carcinogenic effects, intakes of As, Cr, Cd and Ni in the road dust through three exposure routes were listed Table 1. The As in road dust has higher carcinodenic effect on children than on adults.

The noted metal or metalloids in street dust may be of geogenic or anthropogenic origins. Only the EF value of Sr (7.3) in street dust from Urumqi was in the range of 1–10, suggesting that Sr in street dust in Urumqi is mainly from crustal sources.

In Urumqi, only the Cr–Cu concentrations were strongly correlated. The Cr–Pb, Pb–Cu, and Sb–Hg concentrations were weakly correlated (Table S2). Cluster analysis identified correlations among studied potential harmful metals and metalloids (Fig. S2 and Table S3). Street dust samples from Urumqi had much higher As concentrations than those for other cities [16,17]. Some gasoline reportedly contains 30–120 ng/g of As [18]. However, since the vehicle density of Urumqi is low ($557\ km^{-2}$) and since

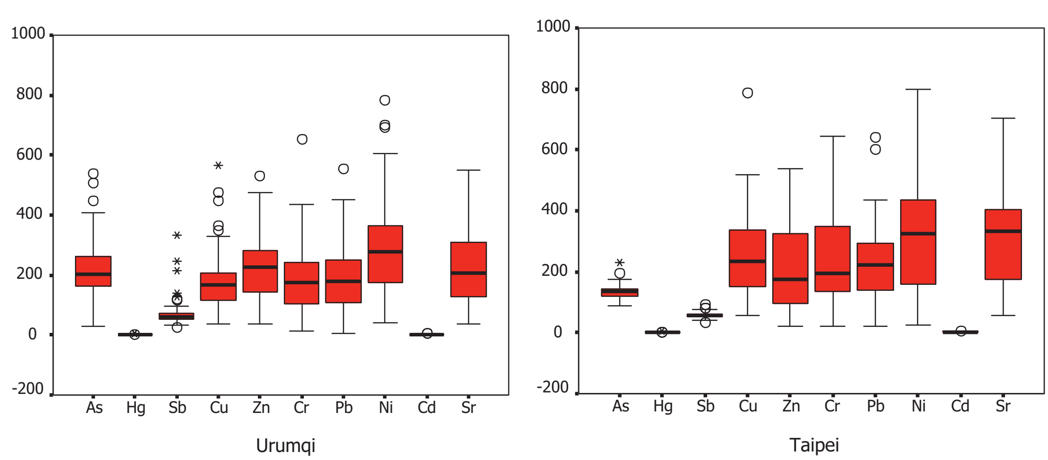

Fig. 1. The contents of the heavy metals in the road dust. (a) Urumqi and (b) Taipei [3]; boxes delineate interquartile range (25–75%) with indication of median; whiskers indicate range excluding outliers; dots are outliers.

Table 1
Hazard quotient and risks for metals in road dust in Urumqi through three exposure routes.

mg/kg/d	As	As-cancer	Hg	Sb	Zn	Cu	Cr	Cr-cancer	Pb	Cd	Cd-cancer	Sr	Ni	Ni-cancer
C(95%UCL)	2.51E+2	2.51E+2	1.67E+0	8.58E+1	2.55E+2	2.05E+2	2.16E+2	2.16E+2	2.15E+2	2.25E+0	2.25E+0	2.57E+2	3.29E+2	3.92E+2
Oral RfD	3.00E−4		3.00E−4	4.00E−4	3.00E−1	4.00E−2	3.00E−3		3.50E−3	1.00E−3		6.00E−1	2.00E−2	
Dermal RfD	1.23E−4		2.10E−5	8.00E−6	6.00E−2	1.20E−2	6.00E−5		5.25E−4	1.00E−5		1.20E−1	5.40E−3	
Inhal. RfD			8.57E−5				2.86E−5							
Oral SF		1.50E+0												
Dermal SF		3.66E+0												
Inhal. SF		1.51E+1						4.20E+1			6.30E+0			8.40E−1
Children														
HQ_{ing}	1.07E+1	4.14E−4	7.14E−2	2.74E+0	5.60E−3	2.12E−2	9.14E−1		7.84E−1	2.88E−2		5.48E−3	2.12E−3	
HQ_{inh}	2.99E−4	8.07E−8	1.98E−6	7.68E−5	1.56E−7	5.89E−7	2.70E−3	9.05E−7	2.2E−5	0.80E−9	1.41E−9	1.53E−5	5.89E−6	3.28E−8
HQ_{dermal}	7.31E−2	2.12E−6	4.34E−6	3.85E−1	7.83E−5	2.96E−4	1.29E−1		1.47E−2	8.05E−3		7.68E−5	2.20E−3	
HQ_{vapor}			2.90E−1											
$HI = \sum HQ_i$	1.08E+1		3.61E−1	3.13E+0	5.68E−3	2.14E−2	1.04E+0		7.99E−1	3.68E−2		5.56E−3	4.32E−3	
Cancer risk		4.16E−4						9.05E−7			1.41E−9			3.28E−8
Adult														
HQ_{ing}	1.15E+0	1.77E−4	7.64E−3	2.94E−1	1.17E−3	7.06E−3	9.86E−2		8.38E−2	3.09E−3		5.87E−4	2.26E−2	
HQ_{inh}	1.69E−4	2.62E−7	1.12E−6	4.32E−5	1.72E−7	1.04E−6	1.52E−3	9.05E−07	1.24E−5	4.53E−7	1.41E−09	8.65E−8	3.32E−6	3.28E−8
HQ_{dermal}	1.12E−2	1.72E−6	4.34E−6	5.85E−2	2.33E−5	9.35E−5	1.96E−2		2.24E−2	1.23E−3		1.17E−5	3.34E−4	
HQ_{vapor}			1.73E−1											
$HI = \sum HQ_i$	1.16E+0		1.81E−1	3.52E−1	1.19E−3	7.16E−3	1.18E−1		8.61E−2	4.32E−3		8.39E−3	2.29E−2	
Cancer risk		1.79E−4						9.05E−7			1.41E−9			3.28E−8

concentrations of As, Cd, Pb and Zn were correlated with combustion of fossil fuels such as coal and waste oil [19], the high levels of As in street dust from Urumqi were principally attributable to coal combustion, not traffic emissions. In Urumqi, residential heating in the 6-month winter consumes huge amounts of coal, which may result in high As concentrations in street dust samples.

3.4. Street dusts in Taipei and Urumqi

Comparing data in the present study and in [3], street dust samples from both Urumqi and Taipei cities had high mean concentrations of As, Hg, Sb, Pb, Cd, Cu, Zn, Ni, Sr, and Cr, which generally exceed the background soil levels in China, USA, Japan, and the UK [20]. The metals Zn, Pb, Cr, Cu, and Ni were not only traffic-related elements, but also typical brake-related elements [10,11]. Notably, Pb was a common gasoline additive but was eliminated many years ago. The strong correlation among Pb, Cr, and Cu concentrations suggests that these metals in Taipei were principally from brake-related materials. The Cr in street dust was reportedly related to chrome plating on some motor vehicle parts [21]. Additionally, Cr is a common component in street construction materials such as concrete and mortar. The Hg in the street dust can come from anthropogenic emissions, including that from the incineration of municipal solid waste, and emission from the electronic, paper, and pharmaceutical industries [22]. Antimony is widely used in flame retardant, ceramics, plastics, brake linings, and batteries [23]. Brake pad and disk friction releases Sb [10,24].

The geological environments of Taipei and Urumqi differ markedly. However, as discussed, the potential harmful metals and metalloids studied are surprisingly similar in their distributions in these two cities. During sampling, the quantities of street dust that can be collected were much higher in Urumqi than in Taipei, partly due to the very dry weather of the former, which made dust accumulation easy. However, the quality of street dust from these two cities was not very different. Particularly, As is a common pollutant that poses severe health risks to residents in both cities. Hence, this study noted the determinant role of anthropogenic factors in the formation of street dust. Such an observation encourages reductions in traffic emissions and/or coal combustion pollution by the authorities to improve the urban environment. This conclusion is particularly significant when one considers the fact that children in both Taipei and Urumqi are the most sensitive subpopulation to potential harmful metal exposure in street dust. Preventing intake by ingestion of street dust also effectively reduces carcinogenic and non-carcinogenic risks of potential harmful metals and metalloids for children.

4. Conclusions

Street dusts from Urumqi were collected. The concentrations of the eight potential harmful metals and two metalloids were measured with possible sources identified and potential health risks evaluated. Street dust samples in Urumqi were polluted by potential harmful metals Cr, Pb, Hg, Ni, Cd, Zn, Cu, and Sr and by metalloids As and Sb; their mean concentrations were much higher than soil backgrounds. Heavy metals in the road dust were principally contributed by anthropogenic activities such as traffic emissions and combustion of fossil fuels in Urumqi. The very different geological environments in Taipei and Urumqi led to different quantities of street dust to accumulate, but did not yield very different qualities of associated potential harmful metals and metalloids. Therefore, under the conditions of an overwhelming anthropogenic input, extensive engagement of reducing traffic emission and/or coal combustion pollution by authority for improving the urban environment is suggested.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jtice.2014.04.018.

References

[1] Christoforidis A, Stamatis N. Potential harmful metal contamination in street dust and roadside soil along the major national street in Kavala's region, Greece. Geoderma 2009;151:257–63.

[2] Xia XH, Chen X, Liu RM, Liu H. Heavy metals in urban soils with various types of land use in Beijing, China. J Hazard Mater 2011;186:2043–50.

[3] Zhang DY, Lee DJ, Pan XL. Potentially harmful metals and metalloids in the urban street dusts of Taipei City. J. Taiwan Inst. Chem. Eng. In press. 2014. http://dx.doi.org/10.1016/j.jtice.2014.01.003.

[4] Li J, Zhuang GS, Huang K, Lin Y, Xu YC, Yu SL. Characteristics and sources of airborne particulate in Urumqi, China, the upstream area of Asia dust. Atmos Environ 2008;42:776–87.

[5] Wei B, Jiang F, Li X, Mu S. Spatial distribution and contamination assessment of heavy metals in urban road dusts from Urumqi, NW China. Microchem J 2009;93:147–52.

[6] Wei B, Jiang F, Li X, Mu S. Contamination levels assessment of potential toxic metals in road dust deposited in different types of urban environment. Environ Earth Sci 2010;61:1187–96.

[7] Wei B, Jiang F, Li X, Mu S. Heavy metal induced ecological risk in the city of Urumqi, NW China. Environ Monit Assess 2010;160:33–45.

[8] USEPA. Risk Assessment Guidance for Superfund. Human Health Evaluation Manual. EPA/540/1-89/002, vol. I. Office of Solid Waste and Emergency Response; 1989.

[9] Lim JM, Lee JH, Moon JH, Chung YS, Kim KH. Airborne PM10 and metals from multifarious sources in an industrial complex area. Atmos Res 2010;96:53–64.

[10] Furuta N, Iijima A, Kambe A, Sakai K, Sato K. Concentrations, enrichment and predominant sources of Sb and other trace elements in size classified airborne particulate matter collected in Tokyo from 1995 to 2004. J Environ Monit 2005;7:1155–61.

[11] Thorpe A, Harrison RM. Sources and properties of non-exhaust particulate matter from street traffic: a review. Sci Total Environ 2008;400:270–82.

[12] Al-Shayep SM, Seaward MRD. Heavy metal content of street side 1 side soils along ring street in Riyadh (Saudi Arabia). Asian J Chem 2001;13:407–23.

[13] Nakamoto Y. Rapid determination of arsenic in thermally cracked gasoline by graphite-furnace AAS. Bunseki Kagaku 2000;49:43–7 (in Japanese).

[14] Zheng N, Liu JH, Wang QC, Liang ZZ. Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, northeast of China. Sci Total Environ 2010;408:726–33.

[15] Meza-Figueroa D, De la O-Villanueva M, De la Parra ML. Potential harmful metal distribution in dust from elementary schools in Hermosillo, Sonora, Mexico. Atmos Environ 2007;41:276–88.

[16] Hu X, Zhang Y, Luo J, Wang TJ, Lian HZ, Ding ZH. Bioaccessibility and health risk of arsenic, mercury and other metals, in urban street dusts from a mega-city, Nanjing, China. Environ Pollut 2011;159:1215–21.

[17] Ferreira-Baptista L, De Miguel E. Geochemistry and risk assessment of street dust in Luanda, Angola: a tropical urban environment. Atmos Environ 2005;39:4501–12.

[18] Al-Shayep SM, Seaward MRD. Heavy metal content of street side soils along ring street in Riyadh (Saudi Arabia). Asian J Chem 2001;13:407–23.

[19] Yuen JQ, Olin PH, Lim HS, Benner SG, Sutherland RA, Ziegler AD. Accumulation of potentially toxic elements in street deposited sediments in residential and light industrial neighborhoods of Singapore. J Environ Manage 2012;101:151–63.

[20] Wei FS, Chen JS, Wu YY, Zheng CJ. Study on environmental background of Chinese soil. Sci Environ 1991;12:12–9.

[21] Al-Khashman OA. The investigation of metal concentrations in street dust samples in Aqaba city, Jordan. Environ Geochem Health 2007;29:197–207.

[22] Tack FGM, Vanhaesebroeck T, Verloo MG, Rompaey KV, Rannst EV. Mercury baseline levels in Flemish oils (Belgium). Environ Pollut 2005;134:173–9.

[23] Pan XL, Deng CN, Zhang DY, Wang JL, Mu GJ, Chen Y. Toxic effects of amoxicillin on the photosystem II of *Synechocystis* sp. characterized by a variety of in vivo chlorophyll fluorescence tests. Aquat Toxicol 2008;89:207–13.

[24] Pan XL, Zhang DY, Chen X, Bao AM. Antimony accumulation, growth performance, antioxidant defense system and photosynthesis of *Zea mays* in response to antimony pollution in Soil. Water Air Soil Pollut 2011;215:517–23.