Environ Earth Sci (2015) 74:2701–2706
DOI 10.1007/s12665-015-4291-0

ORIGINAL ARTICLE

Concentration of selected heavy metals in the surface dust of residential buildings in Phitsanulok, Thailand

T. Srithawirat[1] · **M. T. Latif**[2]

Received: 17 July 2014 / Accepted: 9 March 2015 / Published online: 18 March 2015

Abstract This study determined the levels of selected heavy metals (Zn, Fe, Cd, Cu and Pb) in surface dust samples collected from the walls of residential buildings. Samples were collected from buildings near a main road and a secondary road in Phitsanulok, Thailand. Samples were collected from a 1 m^2 area of exterior wall using Kimwipes. The results were dominated by Fe, with a range of 4384.2–8376.4 and 4631.4–7582 mg kg^{-1} for the main and secondary road locations, respectively. The heavy metal concentrations followed the trend Fe > Zn > Pb > Cu > Cd. Statistical analysis revealed a significant difference between the samples located near the major road compared to those near the secondary road for both Cu and Pb. High levels of heavy metals in settled street dust and motor vehicle emissions are expected to be the main contributors of heavy metals in the surface dust samples.

Keywords Surface dust · Street dust · Heavy metals · Residential buildings

Introduction

Heavy metals are natural constituents of the Earth's crust and can be dispersed into the environment by various anthropogenic activities. The main anthropogenic sources of heavy metals are industrial point sources, e.g. present and former mining activities, foundries and smelters, and diffuse sources such as piping, constituents of products, combustion by-products, traffic, industrial and human activities (Al-Khashman 2004). Heavy metals are among the most important pollutants in the urban environment, and are becoming a severe public health problem due to their acute toxicity and carcinogenicity (Leung et al. 2008).

Heavy metal contamination in urban street dust has become a growing concern in recent years (Inyang and Bae 2006; Yongming et al. 2006; Lu et al. 2009; Hu et al. 2011; Martuzevicius et al. 2011; Saeedi et al. 2012; Wang et al. 2012; Li et al. 2013a, b). Street dust and top roadside soils in urban areas are indicators of heavy metal contamination from atmospheric deposition. Major heavy metals are Pb from leaded gasoline and Cu, Zn and Cd from car components, tyre abrasion, lubricants, and industrial and incinerator emissions (Markus and Mcbratney 1996; Wilcke et al. 1998; Christoforidis and Stamatis 2009). The main sources of Ni and Cr in street dust are believed to be the corrosion of cars (Fergusson and Kim 1991; Salim Akhter and Madany 1993) and the chrome plating of some motor vehicle parts (Al-Shayep and Seaward 2001), respectively. Street dust can be resuspended and distributed into the ambient air and buildings by the wind and the movement of motor vehicles (Han et al. 2014).

Several heavy metals, such as Cu and Zn, are harmless in small amounts and will not affect human health. However, heavy metals such as Pb and Cd, even at extremely low concentrations, are toxic and are potential cofactors, initiators or promoters in many diseases and cancers (Dockery and Pope 1996; Willers et al. 2005; Christoforidis and Stamatis 2009). The investigation of heavy metals in street dust is of particular importance due to the inhalation of dust by those traversing the streets and those

✉ T. Srithawirat
t.srithawirat@psru.ac.th

1 Department of Environmental Science, Faculty of Science and Technology, Pibulsongkram Rajabhat University, Phitsanulok 65000, Thailand

2 School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

residing within the vicinity of the streets. The more the dust on such streets becomes contaminated with heavy metals, the more such people are exposed to the health problems (Mashi et al. 2005).

The rapid growth of the municipal area of Thailand has created numerous environmental problems and considerably more attention has been paid to the study of heavy metal pollution in urban air in recent years (Boonyatumanond et al. 2007; Puangthongthub et al. 2007; Ma and Singhirunnusorn 2012). Phitsanulok was chosen for this study because the study area is a rapidly developing area due to the East–West economic corridor linking Burma, Thailand, Laos and Vietnam. However, there is a lack of awareness of the presence of trace metals in street and surface dust around the housing areas. To our knowledge, no studies have been undertaken to investigate the heavy metal accumulation in this area. Therefore, the present work aims to determine the concentration of heavy metals in the surface dust on selected buildings located on a busy road (main road) and a non-busy road (secondary road) in Phitsanulok, Thailand. This study was designed to investigate heavy metal concentrations of dust in residential areas as an urban environmental health indicator.

Materials and methods

The study was performed in the province of Phitsanulok, which is located in the lower north of Thailand and has a population of 853, 575. It is located at 16°50′N, 100°15′E (Fig. 1). The average precipitation, temperature and relative humidity in this area are 1470.8 mm, 27.9 °C and 74.7 %, respectively (Thai Meteorological Department 2013).

Forty residential buildings near either a main road, with a heavy traffic load, or a secondary road in the city were chosen as the sampling sites during the period July to December, 2013. The sampling sites were located in the city centre about 2 km from the river. These sites were selected based on differing traffic loads. The Baromtriloknart road was selected for the main road stations (M1–M20), representing the urban area and is also recognised as an administrative and commercial centre of Phitsanulok. Thus, high traffic volume may contribute to the high amount of particulate matter in this area. The motor vehicle and soil dust dominated the composition of particles in the urban area (Wahid et al. 2013; Ee-Ling et al. 2015). The secondary road stations (S1–S20) were on the Rathutid road, which is located adjacent to the main road and can be considered suburban with a large number of residential areas.

Surface dust samples were collected from the exterior walls that faced the road of twenty houses located near the main road (M1–M20) and another twenty houses facing the secondary road (S1–S20). All sampling sites in this study were from buildings made from cement. Samples were collected from a 1 m^2 area of the wall using dried and pre-weighed Kimwipes and using a method adapted from ASTME1728-03 (American Society for Testing and Materials 2003). Dust samples were collected at approximately the same time (9 am) each sample day.

Monthly random sampling was undertaken during the dry season to avoid rain washing out the heavy metals ($n = 12$). Sample areas were marked out and measured, allowing all results to be standardised to a concentration expressed in mg kg^{-1}. Each sample was collected within 1.5 m from the ground then transferred into a resealable plastic bag, brought to the laboratory and placed in a desiccator for 24 h.

The whole Kimwipe containing the dust was cut into small pieces before being digested on a hot plate in a mixture of pure concentrated acids (HNO_3 and $HClO_4$ in a ratio of 4:1) and diluted with deionised water up to 25 mL, then filtered through a 0.45-μm Millipore filter paper to obtain a clear solution. The filtrate was collected and stored at 4 °C in polypropylene bottles prior to total metal analysis. The sample preparation as used by Latif et al. (2014) was adopted in this work. Reagent blanks for the samples of dust from the walls were similarly prepared using unused Kimwipes. Heavy metals were determined using an Atomic Absorption Flame Spectrophotometer (Shimadzu, AA-6200). Calibration of the instrument was performed with standard multi-element solutions. The detection limits for the analysis of heavy metals using this methodology were 0.05 mg kg^{-1} for Pb, 0.03 mg kg^{-1} for Cu, 0.01 mg kg^{-1} for Cd, 0.01 mg kg^{-1} for Zn and 0.05 mg kg^{-1} for Fe. The solvents and chemicals used in this study were analytical grade. All glassware was soaked using nitric acid (20 %) overnight and rinsed with ultra-pure water several times before they were dried in the laboratory (Latif et al. 2014). All instruments involved in the study were calibrated before use. The field blank sample was also analysed for the control analysis. The results were corrected based on the average blank concentration. A recovery test, which was in the range of 97–105 %, was also conducted for each analysis.

Results and discussion

The overall results of heavy metal determination in surface dust samples collected at all sampling points are given in Table 1. The highest metal concentrations were observed for Fe with the mean concentrations of 6166.8 and 6315.1 mg kg^{-1} in surface dust samples located near the main and secondary road, respectively. Cd had the lowest metal concentration recorded with the mean concentration of 24.7 mg kg^{-1}. Overall, the heavy metal concentration in

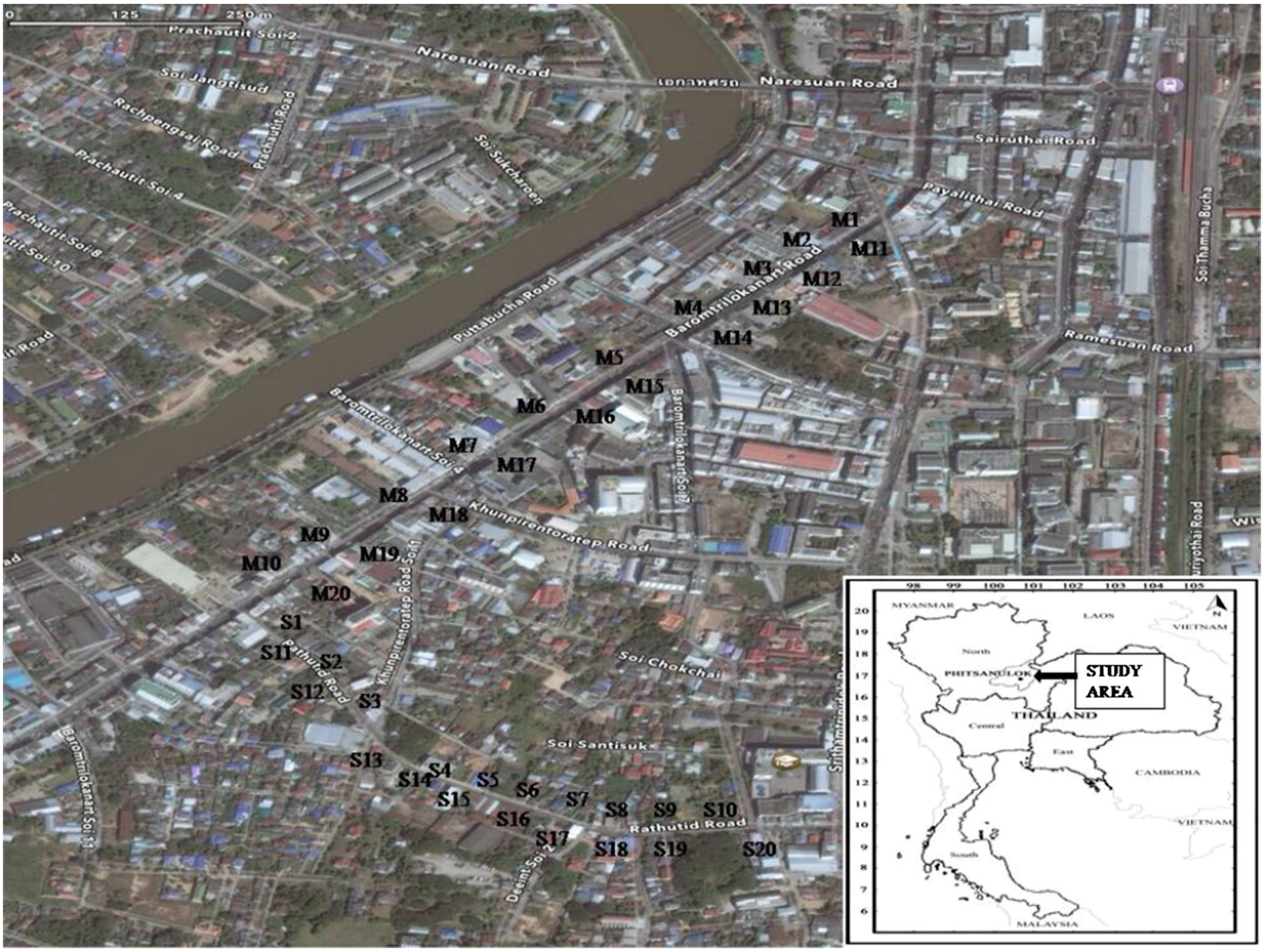

Fig. 1 Sampling locations of main and secondary roads

Table 1 Concentration levels of heavy metals in the surface dust of house walls (mg kg^{-1})

Heavy metals	*N*	Main street				Secondary street			
		Min	Max	Mean	SD	Min	Max	Mean	SD
Fe	12	4384.2	8376.4	6166.8	2030	4631.4	7582	6315.1	1518.8
Zn	12	498.4	539.4	518.8	20.5	298.4	349.8	322.1	25.9
Pb	12	113.34	140.9	128.7	14.1	28.1	85.7	62.3	30.3
Cu	12	74.0	104.7	89.9	15.4	57.9	79.9	67.7	11.2
Cd	12	16.6	25.6	21.3	4.5	18.1	35.1	24.7	9.1

N number of samples, *SD* standard deviation

the surface dust in the study area followed the order of Fe > Zn > Pb > Cu > Cd.

The high concentrations of Fe in the surface dust samples can be attributed to the high levels of Fe in the soil and street dust. There was no statistically significant difference in Fe concentrations between surface dust samples collected near main and secondary roads ($p < 0.05$). A study by Tippayawong et al. (2006) found that Fe was the major element in the suspended dust due to resuspension of road and soil dust. Đordevic et al. (2005) demonstrated that local resuspended soil dust has a more important influence on atmospheric aerosols in an urban area, even though they may have a remote origin.

The concentrations of Zn in surface dust were in the range 498.4–539.4 and 298.4–349.8 mg kg^{-1} in the dust near the main and secondary road, respectively. The samples taken from the houses close to the main road with high traffic density have contributed to the presence of Zn in the dust more than those close to the secondary road. However, there was no significant difference between the two sample sets from the two locations ($p > 0.05$). The elevated Zn content may have originated from the wear and tear of vulcanised vehicle tyres, and corrosion of galvanised automobile parts (Adachi and Tainosho 2004; Al-Khashman, 2004; Kreider et al. 2010; Li et al. 2001). The concentration of Zn in the house dust is strongly associated with the level of dust in the surrounding area and can also originate from within the house (Fergusson and Kim 1991).

High concentrations of Pb were observed in the investigated area near the main road with a mean concentration of 128.7 mg kg^{-1} while a mean of 62.3 mg kg^{-1} was found in the secondary street area. The enrichment of Pb in this area may be linked to a longer history of contamination from the former use of leaded paint. There are a number of sources of Pb-detached surface dusts of the houses such as soil and paints (Laidlaw et al. 2014; Lucas et al. 2014). A *t* test has shown a significant difference ($p < 0.05$) between Pb from the main and secondary roads, indicating that a source of Pb may be traffic emissions and community activities such as automobile repair shops and battery manufacturers and recycle shops.

The concentrations of Cd were in the ranges 16.6–25.6 and 18.1–35.1 mg kg^{-1} in the dust sampled near the main and secondary road, respectively. Cu was in the ranges of 74.0–104.7 mg kg^{-1} near the main road and 57.9–79.9 mg kg^{-1} near the secondary road. There was no significant difference between Cd in samples collected near the major road and those from near the secondary road. However, the *t* test has shown a significant difference ($p < 0.05$) between Cu in samples from the main and secondary roads, indicating Cu could have various sources in the urban environment. Cd and Cu could be released into the urban system as a result of vehicle traffic and fossil fuel combustion. Cu in dust is believed to be from anthropogenic sources such as traffic emissions and street dust. This includes sources from car components, tyre abrasion, brushing, bearing metals and brake dust (Adachi and Tainosho 2004; Al-Khashman 2004).

Table 2 Correlation matrix for the concentration of heavy metals

Heavy metals	Zn	Fe	Cd	Cu	Pb
Zn	1				
Fe	0.315**	1			
Cd	−0.054	0.306**	1		
Cu	0.000	0.353**	0.338**	1	
Pb	0.074	0.257**	0.085	0.224	1

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

A Pearson's correlation coefficient was used to measure the degree of correlation between logarithms of the heavy metals data. The correlation matrix for heavy metal concentrations in the studied samples is summarised in Table 2. Statistical analysis indicates a positive relationship between all the possible pairs of heavy metals at the 99 % confidence level. A moderate positive correlation was found between Fe and Zn; Fe and Cd; Fe and Cu and Fe and Pb ($r = 0.315$, 0.306, 0.353 and 0.257), as well as between Cd and Cu ($r = 0.338$). The results suggest that the metals originate from similar sources, which may be automobile emissions, street dust and other related activities.

Comparisons between heavy metals in surface dust samples obtained in this study with heavy metals in street dust reported from previous studies are shown in Table 3. The concentrations of heavy metals in the surface dust on residential buildings in Phitsanulok were generally higher than heavy metals determined in street dust from selected Malaysian cities (Abdul Wahab et al. 2012; Tahir et al. 2007). However, the Zn, Cu and Cd concentrations were lower than that of street dust samples collected from Greater Toronto, Canada (Nazzal et al. 2013). This may be due to anthropogenic factors such as industrial activities, traffic density, population and settlement patterns and different transportation systems. The levels also depend on the natural concentration of those particular heavy metals in the soil. The high concentrations were found at those sampling sites where human activities are more intense, such as the main roads and urban areas.

Table 3 Mean concentrations of heavy metal in the surface dust from this study compared to heavy metals in street dust from previous studies

Area	Heavy metals (mg kg^{-1})					References
	Zn	Fe	Cd	Cu	Pb	
Main street, Phitsanulok, Thailand	6166.8	518.8	128.7	89.9	21.3	This study
Secondary street, Phitsanulok, Thailand	6315.1	322	62.3	67.7	24.70	This study
Guangzhou, China	NR	504	72.6	1160	4.20	Cai et al. (2013)
Seberang Prai Tengah, Malaysia	NR	17.6	39.3	6.8	NR	Abdul Wahab et al. (2012)
Greater Toronto, Canada	40,052	200.3	182.8	162	0.5	Nazzal et al. (2013)
Dungun, Terengganu, Malaysia	559	NR	NR	44	78	Tahir et al. (2007)

NR not reported

Conclusion

In conclusion, the analyses of the surface dust in this study provide important information on the levels of heavy metals in surface dust on residential buildings in Phitsanulok. The concentration of heavy metals in surface dust samples were dominated by Fe followed by Zn > Pb > Cu > Cd. Based on the concentrations of Fe, soil dust and street dust are expected to be major contributors to the amount of heavy metals in the surface dust. There are significant ($p < 0.01$) concentrations of Pb and Cu in the surface dust samples collected near the main road compared to those collected near the secondary road. The major contributors of these heavy metals are the emissions from motor vehicles, car components and community activities. Comparisons with other studies showed that the concentration of heavy metals in the surface dust samples is higher compared to the street dust collected in Malaysian cities but lower compared to the street dust collected in temperate countries. Several precautionary procedures, such as the removal of settled street dust, need to be conducted from time to time to reduce the resuspension of heavy metals into the residential areas.

Acknowledgments The authors would like to thank Pibulsongkram Rajabhat University for the Research Grant (RDI-1-57-6-13) and also would like to thank the owners of the houses for cooperation to successfully conduct this study. Many thanks to Dr. Rose Norman for proofreading this manuscript.

References

Abdul Wahab NA, Darus FM, Isa N, Sumari SM, Hanafi NFM (2012) Heavy metals concentration of settled surface dust in residential building. Malays J Anal Sci 16:18–23

Adachi K, Tainosho Y (2004) Characterization of heavy metal particles embedded in tire dust. Environ Int 30:1009–1017

Al-Khashman OA (2004) Heavy metal distribution in dust, street dust and soils from the work place in Karak Industrial Estate, Jordan. Atmos Environ 38:6803–6812

Al-Shayep SM, Seaward MRD (2001) Heavy metal content of roadside soils along ring road in Riyadh (Saudi Arabia). Asian J Chem 13:407–423

American Society for Testing and Materials (2003) Standard practice for collection of settled dust samples using wipe sampling methods for subsequent lead determination. Available at (http://www.astm.org/Standards/E1728.htm). Accessed 2 Dec 2013

Boonyatumanond R, Murakami M, Wattayakorn G, Togo A, Takada H (2007) Sources of polycyclic aromatic hydrocarbons (PAHs) in street dust in a tropical Asian mega-city, Bangkok, Thailand. Sci Total Environ 384:420–432

Cai QY, Mo CH, Li HQ, Lu H, Zeng QY, Li YW, Wu XL (2013) Heavy metal contamination of urban soils and dusts in Guangzhou, South China. Environ Monit Assess 185:1095–1106

Christoforidis A, Stamatis N (2009) Heavy metal contamination in street dust and roadside soil along the major national road in Kavala's region, Greece. Geoderma 151:257–263

Dockery D, Pope A (1996) Epidemiology of acute health effects: summary of time-series studies. Particles in our air. Concentration and health effects. Harvard University Press, Cambridge

Đorđević D, Mihajlidi-Zelić A, Relić D (2005) Differentiation of the contribution of local resuspension from that of regional and remote sources on trace elements content in the atmospheric aerosol in the Mediterranean area. Atmos Environ 39:6271–6281

Ee-Ling O, Mustaffa NIM, Amil N, Khan MF, Latif MT (2015) Source contribution of PM2.5 at different locations on the Malaysian Peninsula. Bull Environ Contam Toxicol 87:108–116

Fergusson JE, Kim ND (1991) Trace elements in street and house dusts: sources and speciation. Sci Total Environ 100:125–150

Han NMM, Latif MT, Othman M, Dominick D, Mohamad N, Juahir H, Tahir NM (2014) Composition of selected heavy metals in road dust from Kuala Lumpur city centre. Environ Earth Sci 72:849–859

Hu X, Zhang Y, Luo J, Wang T, Lian H, Ding Z (2011) Bioaccessibility and health risk of arsenic, mercury and other metals in urban street dusts from a mega-city, Nanjing, China. Environ Pollut 159:1215–1221

Inyang HI, Bae S (2006) Impacts of dust on environmental systems and human health. J Hazard Mater 132:v–vi

Kreider ML, Panko JM, McAtee BL, Sweet LI, Finley BL (2010) Physical and chemical characterization of tire-related particles: comparison of particles generated using different methodologies. Sci Total Environ 408:652–659

Laidlaw MAS, Zahran S, Pingitore N, Clague J, Devlin G, Taylor MP (2014) Identification of lead sources in residential environments: Sydney Australia. Environ Pollut 184:238–246

Latif MT, Yong SM, Saad A, Mohamad N, Baharudin NH, Mokhtar MB, Tahir NM (2014) Composition of heavy metals in indoor dust and their possible exposure: a case study of preschool children in Malaysia. Air Qual Atmos Health 7:181–193

Leung AOW, Duzgoren-Aydin NS, Cheung KC, Wong MH (2008) Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. Environ Sci Technol 42:2674–2680

Li X, Poon CS, Liu PS (2001) Heavy metal contamination of urban soils and street dusts in Hong Kong. Appl Geochem 16:1361–1368

Li H, Qian X, Hu W, Wang Y, Gao H (2013a) Chemical speciation and human health risk of trace metals in urban street dusts from a metropolitan city, Nanjing, SE China. Sci Total Environ 456–457:212–221

Li Z, Feng X, Li G, Bi X, Zhu J, Qin H, Dai Z, Liu J, Li Q, Sun G (2013b) Distributions, sources and pollution status of 17 trace metal/metalloids in the street dust of a heavily industrialized city of central China. Environ Pollut 182:408–416

Lu X, Wang L, Lei K, Huang J, Zhai Y (2009) Contamination assessment of copper, lead, zinc, manganese and nickel in street dust of Baoji, NW China. J Hazard Mater 161:1058–1062

Lucas JP, Bellanger L, Le Strat Y, Le Tertre A, Glorennec P, Le Bot B, Etchevers A, Mandin C, Sébille V (2014) Source contributions of lead in residential floor dust and within-home variability of dust lead loading. Sci Total Environ 470–471:768–779

Ma J, Singhirunnusorn W (2012) Distribution and health risk assessment of heavy metals in surface dusts of Maha Sarakham municipality. Procedia Soc Behav Sci 50:280–293

Markus J, Mcbratney A (1996) An urban soil study: heavy metals in Glebe, Australia. Soil Res 34:453–465

Martuzevicius D, Kliucininkas L, Prasauskas T, Krugly E, Kauneliene V, Strandberg B (2011) Resuspension of particulate matter and PAHs from street dust. Atmos Environ 45:310–317

Mashi SA, Yaro SA, Eyong PN (2005) A survey of trends related to the contamination of street dust by heavy metals in Gwagwalada, Nigeria. Manag Environ Qual 16:71–76

Nazzal Y, Rosen M, Al-Rawabdeh A (2013) Assessment of metal pollution in urban road dusts from selected highways of the Greater Toronto Area in Canada. Environ Monit Assess 185:1847–1858

Puangthongthub S, Wangwongwatana S, Kamens RM, Serre ML (2007) Modeling the space/time distribution of particulate matter in Thailand and optimizing its monitoring network. Atmos Environ 41:7788–7805

Saeedi M, Li LY, Salmanzadeh M (2012) Heavy metals and polycyclic aromatic hydrocarbons: pollution and ecological risk assessment in street dust of Tehran. J Hazard Mater 227–228:9–17

Salim Akhter M, Madany I (1993) Heavy metals in street and house dust in Bahrain. Water Air Soil Pollut 66:111–119

Tahir NM, Cheer PO, Jaafar M (2007) Determination of Heavy metals content in soils and indoor dusts from nurseries in Dunguin, Teregganu. Malays J Anal Sci 11:280–286

Thai Meteorological Department (2013) Mean monthly rainfall in Thailand. http://www.tmd.go.th/en/climate.php?FileID=7. Accessed Oct 2013

Tippayawong N, Pengchai P, Lee A (2006) Characterization of ambient aerosols in Northern Thailand and their probable sources. Int J Environ Sci Tech 3:359–369

Wahid NBA, Latif MT, Suratman S (2013) Composition and source apportionment of surfactants in atmospheric aerosols of urban and semi-urban areas in Malaysia. Chemosphere 91:1508–1516

Wang G, Oldfield F, Xia D, Chen F, Liu X, Zhang W (2012) Magnetic properties and correlation with heavy metals in urban street dust: a case study from the city of Lanzhou, China. Atmos Environ 46:289–298

Wilcke W, Müller S, Kanchanakool N, Zech W (1998) Urban soil contamination in Bangkok: heavy metal and aluminium partitioning in topsoils. Geoderma 86:211–228

Willers S, Gerhardsson L, Lundh T (2005) Environmental tobacco smoke (ETS) exposure in children with asthma—relation between lead and cadmium, and cotinine concentrations in urine. Resp Med 99:1521–1527

Yongming H, Peixuan D, Junji C, Posmentier ES (2006) Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. Sci Total Environ 355:176–186