

MULTIVARIATE ANALYSIS OF HEAVY METAL CONCENTRATIONS IN SOIL, ROOF DUST, AND DUSTFALL IN NAKHON RATCHASIMA, THAILAND

Sudjit Karuchit* and Titiphat Hirunkam

Received: September 07, 2014; Revised: November 25, 2014; Accepted: November 26, 2014

Abstract

Concentration of 9 heavy metals (HMs) in soil, roof dust, and dustfall samples in 10 communities in Nakhon Ratchasima province, Thailand, were investigated in this study. The soil and dust samples were dried, screened, and digested prior to the analysis of the HMs using ICP-MS equipment. Enrichment factors (EFs) were used to evaluate the level of contamination, and multivariate statistical analyses were performed to identify potential pollutant sources. The results showed that the prevalent elements in both dust types were Fe, Mn, Zn, Cr, Cu, and Pb. Significant differences were found among the concentrations in the soil and the 2 types of dust. Contamination by humans, as indicated by high EF values, was evident at various levels in the study area. Two communities, Nakhon Ratchasima city municipality and Pimai, stood out as the areas with higher enrichment concern, possibly because of their local traffic and industrial sources such as metal plating and metal welding businesses, car painting shops, and large industrial enterprises situated within their areas. Results from the principal component analysis (PCA) and cluster analysis (CA) suggested the possible classification of Cu/Cd/Pb as a group with common anthropogenic sources, and Fe/Mn as another group with natural sources. The findings can foster more focused study on HM contamination and assist efforts to protect urban populations.

Keywords: Heavy metal, contamination, dust, multivariate analysis, Thailand

Introduction

Analyses of heavy metal (HM) elements in soil and dust in a community are frequently carried out to gain a better understanding of the levels of contamination and to make inferences regarding their sources. Possible sources of HMs in urban dust are identified in several relevant studies (Table 1). Pb, Zn, Cu, and Cd are often related to traffic sources, while industrial processes can be

the sources of various HMs, including Cu, Zn, Cr, Ni, and Hg. Specific sources of HMs in the communities include solid waste incineration, coal combustion, power stations, and car painting. Even commercial and domestic products can be substantial sources of certain elements. Elevated levels of these elements in the urban areas compared to their corresponding natural levels

School of Environmental Engineering, Faculty of Engineering, Suranaree University of Technology 111 University Ave., Muang District, Nakhon Ratchasima, Thailand, 30000. Tel. +6681-7253040; Fax. +6644-4224606; E-mail: sudjit@sut.ac.th

* Corresponding author

can be used to indicate possible anthropogenic contamination. For Asian countries, there are growing numbers of studies which investigate the situation – particularly in cities with rapid urbanization or industrialization. However, such studies are rare in Thailand and most of them have focused on the elements in soil and the agricultural aspects of the contamination (Reutergardh and Yen, 1997, Wilcke *et al.*, 1998; Zarcinas *et al.*, 2004).

This study aimed to examine the extent of man-made contamination with HMs and the possible sources of these elements in 10 selected areas in Nakhon Ratchasima province, Thailand. Nine HMs – Pb, As, Cd, Hg, Cr, Mn, Fe, Cu, and Zn – in soil and dust were studied. Two types of dust samples are of interest: roof dust and dustfall or settleable dust. The enrichment factor (EF) calculation, along with 2 main multivariate statistical analyses, principal component analysis (PCA) and cluster analysis (CA), were employed to achieve the stated objectives.

Materials and Methods

Nakhon Ratchasima is the second largest province in Thailand, situated approximately 250 km. northeast of Bangkok (Figure 1). Data collection in the selected 10 communities was from June–August, 2012. In each one, soil samples were collected from green, natural areas around the community which are good representatives of the native and uncontaminated soil. The main type of soil in Nakhon Ratchasima is sandy loam. Soil from 3 different places in each community was taken from a depth of 15 cm. and mixed together to make 1 composite sample for each community. The main administration office building, located in the central area of each community, was selected as the representative location for dust sampling. The sampling method used for roof dust followed common practices found in the relevant literature (Al-Khashman, 2004; Han *et al.*, 2006; Meza-Figueroa *et al.*, 2007; Joshi *et al.*, 2009). The dust deposited on a selected 2-square-meter,

Table 1. Possible sources of heavy metals in urban dust

Reference/ Studied Area	Possible Sources of Heavy Metal in Urban Dust			
	Traffic-related	Industrial-related	Nature-related	Other
Li <i>et al.</i> (2004)/ Hong Kong, China	Pb, Zn, Cu, and Ni	-	Mn, Fe, Cd, Co, Cr, and Al	-
Han <i>et al.</i> (2006)/ Xi'an, China	Pb and Zn	Cu, Cr, Pb, Zn, and Sb	Mn and As	Hg and Ag – commercial and domestic sources
Tokalioglu and Kartal (2006)/ Kayseri, Turkey	Pb	Cu, Cd, Ni, Cr, Co, and Zn	Mn	-
Meza-Figueroa <i>et al.</i> (2007)/ Hermosillo, Mexico	Pb, Zn, Cu, and Cd	Cd, Ni, V, and Pb	Fe, Co, and Ba	Cr – power station, car-painting
Shah and Shaheen (2007)/ Islamabad, Pakistan	Pb, Cd, and Ni	Fe and Mn	Na	Zn K Cr and Co – Solid waste incineration
Huang <i>et al.</i> (2009)/ Yangtze River delta, China	Zn, Cu, Cd, As, Hg, Mo, and S	Ni and Cr	Mn and Fe	Pb and Se – Coal combustion
Lu <i>et al.</i> (2010)/ Baoji, China	Pb, As, V, and Co	Cu, Mn, Hg, and Zn	Cr and Ni	-
Li and Feng (2012)/ Weinan industrial area, China	-	Ba, Cu, Pb, Cr, Zn	Mn, V, Co, As, and Ni	-

carved tile roof surface area was swept into a plastic bag using a plastic brush. Dustfall sampling was performed according to the method of the ASTM standard D1739-98 (ASTM, 2004). The container used to collect the dustfall was made of a 30 cm long PVC pipe, 15 cm in diameter, with 1 end closed. Each container was placed on top of a 170 cm stand with a ring-shaped windshield surrounding the opening of the container to reduce settling disturbance. This dustfall collection device is installed on the ground in an open area within the administration office's boundary. To prevent interference, the sampling locations were elected so that they were not in the proximity of local sources such as busy streets or biomass burning areas. After 30 days, the settled dust accumulated in the container was measured for its weight and the amount of dustfall was calculated in the unit of milligram per square meter per month. Three dustfall samples were composited at each location to meet the required amount for the HM analysis. All 3 types of sample were oven-dried at 103°C, screened with 250 micron screening, and digested in a microwave device using a mixture of nitric and fluoric acid. The solutions were then analyzed

for Pb, As, Cd, Hg, Cr, Mn, Fe, Cu, and Zn using inductively coupled plasma - mass spectrometry (ICP-MS) equipment (Sandroni *et al.*, 2003; Kulkarni *et al.*, 2007; Joshi *et al.*, 2009).

EFs are used to describe the possibility of chemical contamination by normalizing the concentration of elements found in dust to their respective concentrations in natural soil. (Joshi *et al.*, 2009). The EF of an element x in roof dust, as well as in dustfall, can be calculated using the following equation (Mason, 1966; Buat-Menard and Chesselet, 1979):

$$EF(x) = \frac{\left(\frac{x}{Ref}\right)_{dust}}{\left(\frac{x}{Ref}\right)_{soil}}$$

The numerator and the denominator are the mass ratio of x over the reference element in the dust sample and the soil sample, respectively. The reference element in this study is Fe, which is most commonly used in the literature because it is abundant in soil and relatively less disturbed by human activity (Li and Feng, 2012). In general, the EF values greater than 10 are regarded as having contamination from human activities. A more detailed enrichment classification



Figure 1. The 10 study areas in Nakhon Ratchasima province

of EF values was given by Han *et al.* (2006) as follows: EF < 2: minimal; EF = 2-5: moderate; EF = 5-20: significant; EF = 20-40: very high; and EF = > 40: extremely high.

The PASW Statistics software, version 18 (SPSS Inc., Chicago, IL, USA) was used to perform the multivariate analysis throughout this study. PCA and CA, both widely used statistical techniques, were employed (Townend, 2001). PCA produces scoring systems for the observations – in this case the 10 study areas – so that the concentration variables of each study area can be reduced to only a few variables called principal components (PCs). The values of each PC, called PC scores, are computed using the information from the concentration variables and their corresponding coefficients generated by the analysis. These coefficients are called factor loadings and are the same across the study areas. As a result, the relative magnitudes of the factor loadings in each PC can be used as the indication of the grouping of the HMs. In a similar fashion, the relative magnitudes of the PC scores can help to identify the grouping of

the study areas.

In addition, CA was utilized to gain more insight into the possible grouping of the data set. To classify the study areas, CA first combines 2 areas which are most similar to each other and forms a subgroup – a cluster. The similarity of a pair of areas is measured by the distance between them, which is calculated using all values of their concentration variables simultaneously. Next, the similarity among the remaining areas and the first cluster is considered to form another cluster. This process, called the hierarchical clustering method, continues until all areas and clusters are combined. Likewise, clustering of the concentration variables considers the most highly correlated pair to form the first cluster. Next, the correlation among the remaining variables and the first cluster is considered to form another cluster, and so on. Eventually, CA yielded the grouping of both the study areas and the concentration variables in a graphical format called dendrograms (Townend, 2001).

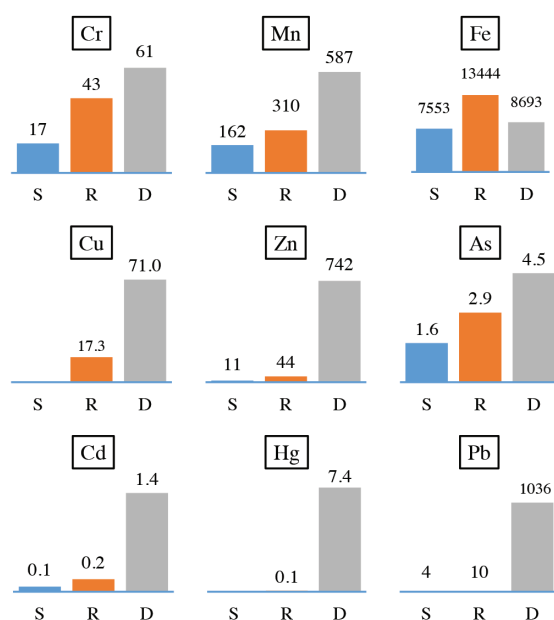


Figure 2. Median values (mg/kg) of heavy metal concentrations in 3 types of samples (S = soil, R = roof dust, D = dustfall)

Results and Discussion

Eight out of 9 HMs were detected in the soil samples. All Hg concentrations were below detection limits, as well as most of the Cu concentrations. Fe had the highest concentration values of the group, followed by Mn, indicating their abundance in natural soil. When compared with the results of Zarcinas *et al.* (2004) which studied HMs in soils and crops in Thailand, the concentrations in this study are similar but generally lower. The median values of 5 elements, As, Cd, Cr, Pb, and Zn, in both studies are similar. Descriptive statistics of the HM concentrations in the dust samples are shown in Table 2. The sample size for each element was

10 – 1 composite sample for each sampling location. Based on the median values, the prevalent elements of roof dust were Fe>Mn>Zn>Cr>Cu, and those of dustfall were Fe>Pb>Zn>Mn>Cu. When compared with the concentrations of HMs in urban dust and soil found in other cities, these results appear to be within the range of values reported in the relevant literature.

A comparison of the HM concentrations among the 3 types of samples is illustrated in Figure 2. Overall, the concentrations in the soil were the smallest, followed by those in roof dust and dustfall. Note that certain concentration values in the dustfall samples were much higher

Table 2. Summary statistics of heavy metal concentrations in the dust samples

Element	Type	Concentration (mg/kg) ^a			S.D.	COV.
		Mean	Median	Reference ^b		
Cr	Roof Dust	113.50	43.47	11 – 263	240.66	2.12
	Dustfall	78.56	61.08		64.50	0.82
Mn	Roof Dust	262.44	310.13	-	144.40	0.55
	Dustfall	620.96	586.65		200.94	0.32
Fe	Roof Dust	13058.89	13444.34	-	7622.07	0.58
	Dustfall	11528.47	8693.18		6480.57	0.56
Cu	Roof Dust	30.51	17.33	26 – 143	47.24	1.55
	Dustfall	96.99	71.04		57.01	0.59
Zn	Roof Dust	124.63	43.99	112 – 1,883	145.68	1.17
	Dustfall	781.93	741.67		294.21	0.38
As	Roof Dust	2.46	2.86	-	1.15	0.47
	Dustfall	4.52	4.48		0.68	0.15
Cd	Roof Dust	0.24	0.17	1 – 7	0.23	0.96
	Dustfall	1.42	1.35		0.68	0.48
Hg	Roof Dust	0.08	0.08	-	-	-
	Dustfall	8.80	7.36		6.51	0.74
Pb	Roof Dust	15.95	9.81	36 – 544	15.95	1.00
	Dustfall	1126.62	1036.46		470.70	0.42

^aThe detection limit was 0.5 mg/kg for Fe and 0.05 mg/kg for the rest of the HMs.

^bNg *et al.* (2003), Thornton (1991), Varrica *et al.* (2003), Tokalioglu and Kartal (2006), Meza-Figueroa *et al.* (2007).

than those in the soil and roof dust, namely Cu, Zn, Cd, Hg, and Pb. The difference found between the 2 types of dust could be due to the representativeness of each dust type. The roof dust samples come from the dust accumulated on specific, uncontrolled surfaces during a short period of time – hours or a few days. The dustfall samples, on the other hand, come from the dust accumulated in the pre-designed vessels for a relatively long period of time – 1 month. Therefore, the former can be considered as “grab” samples, while the latter can represent “composite” samples of settleable dust in the environment. The use of both sampling methods in this study, hence, benefited the comprehensiveness in the discussion and interpretation.

EFs were calculated for 7 elements in the roof dust samples (Table 3). Fe was used as the reference element. The Hg concentrations in the soil samples were below detection limits so it was not possible to calculate the EFs. Nevertheless, the fact that Hg existed in the dust samples could imply a human origin for this element. Overall, relatively high EF values were found for Cu, Zn, and Cd. Their values also showed high spatial variation. The other group of HMs – Mn, Pb, and Cr – displayed moderate to significant enrichment

in certain locations. For Cr, an extremely high enrichment value was found at 1 location, M1, while the other locations had minimal enrichment. The element with very small EF values in all every location was As.

As for spatial evaluation, locations M1 and M6 had more types and higher levels of HM enrichment than other areas. It is likely that Cr, Cu, and Cd in M1's dust were caused by human activities. High Cr levels could be linked to metal industries such as metal plating and metal welding, and car painting shops (Meza-Figueroa *et al.*, 2007). Considerable numbers of these sources can be found in a city. Common sources of Cu, Cd, and Zn include gasoline, oil lubricants, and mechanical abrasion of vehicles (Meza-Figueroa *et al.*, 2007). Thus, high EF values of these 3 elements found in a big city municipality like M1 and its surrounding communities, M2 to M5, could be the consequence of their relatively heavy traffic. Likewise, high EF values of Cu, Zn, Cd, and Pb in M6's dust could also come from traffic, with a possible influence from industrial-related sources. A few large industrial enterprises situated within the location's area could contribute to the contamination. Lastly, it should be noted that

Table 3. Enrichment Factors of heavy metals in the roof dust samples^a

Study Area	Enrichment Factor						
	Cr	Mn	Cu	Zn	As	Cd	Pb
NRCM ^b (M1)	<u>105.82</u>	0.47	11.21	<u>3.09</u>	< 0.01	4.19	1.08
Nongbuasala (M2)	0.59	0.68	1.75	5.62	< 0.01	0.80	1.81
Bankor (M3)	1.90	1.78	6.55	6.04	< 0.01	1.48	1.46
Nongkratoom (M4)	1.76	1.25	<u>3.78</u>	1.67	< 0.01	<u>2.34</u>	1.04
Suranaree (M5)	0.86	<u>2.57</u>	0.83	0.75	< 0.01	0.55	0.75
Pimai (M6)	0.90	<u>2.12</u>	<u>54.16</u>	16.14	< 0.01	9.55	4.55
Pakchong (M7)	1.85	0.79	<u>4.06</u>	<u>2.79</u>	< 0.01	<u>2.79</u>	1.83
Dankoontod (M8)	1.01	1.00	-	2.71	< 0.01	1.62	<u>2.18</u>
Jorakehin (M9)	0.59	0.40	<u>2.41</u>	13.93	< 0.01	0.54	0.96
Thaisamakee (M10)	1.33	0.86	6.63	1.19	< 0.01	2.42	0.99

^a EF < 2: minimal; EF = 2-5: moderate (underlined); EF = 5-20: significant (bold); EF = 20-40: very high; and EF = > 40: extremely high (bold & underlined) (Han *et al.*, 2006)

^b Nakhon Ratchasima City Municipality

all locations had at least 1 element which is at moderate enrichment level or above.

Correlation analysis using the Pearson correlation coefficient revealed that, in most cases, significant HM correlations existed in roof dust more than in dustfall. Fe, Mn, and As in the roof dust samples were positively correlated, as well as Cu, Cd, and Pb. The correlation found in the dustfall samples include Fe and Mn, Pb and Cr, and Hg and Cd. Notice that the EF analysis yielded small values for Mn and As which indicates near-background concentration levels. Moreover, Mn is the element that is commonly linked to a natural soil origin (Lee *et al.*, 2006; Li and Feng, 2012). Hence, the apparent relationship of Fe, Mn, and As suggested that they could all come from natural sources. On the other hand, the correlation of Cu, Cd, and Pb might imply common anthropogenic sources since relatively high EF values for Cu and Cd were obtained earlier.

For the PCA results, Table 4 shows the factor loadings and the variance explained for

each principle component. For the analysis, the correlation matrix method was employed to better suit the different concentration ranges of the elements. In addition, the Varimax rotation method was used to minimize the number of variables that have high loadings on each factor and assist the interpretation. For the roof dust data, 3 PCs satisfactorily explained a large proportion of the variations, approximately 92%. Based on the factor loading values, the dominating variables for each PC were as follows: PC1 = Cu/Cd; PC2 = Zn/Fe; and PC3 = Cr/Mn. Total variation in the dustfall data, on the other hand, was explained, at close to 71%, by 3 PCs. Hence, it appeared that the PCA results of the dustfall data had significantly less ability to describe the variation of the data. The more influential variables found in this analysis for PC1, PC2, and PC3 were Cr/Pb, Fe/Mn, and As/Zn, respectively. The grouping of the elements was illustrated when the factor loadings were plotted in 3-D diagrams as shown in Figure 3. For both dust types, 2 groups of

Table 4. Factor loadings and proportion of variance explained for each component^a

Element	Factor Loadings					
	Roof Dust			Dustfall		
	Component			Component		
	PC1	PC2	PC3	PC1	PC2	PC3
Cr	0.005	0.313	-0.651	0.384	0.096	-0.161
Mn	0.031	0.017	0.341	0.080	0.365	0.063
Fe	-0.148	0.453	-0.051	0.032	0.405	0.096
Cu	0.403	-0.202	0.080	0.301	-0.108	-0.010
Zn	-0.035	0.534	-0.310	-0.009	0.076	0.486
As	-0.060	0.134	0.286	-0.172	-0.002	0.535
Cd	0.385	-0.115	-0.007	0.298	-0.116	0.048
Hg	-	-	-	-0.008	-0.281	0.264
Pb	0.275	0.115	-0.107	0.354	0.185	-0.104
Initial Eigenvalues	2.89	2.48	1.99	2.34	2.28	1.72
% of Variance	36.13	31.02	24.81	26.01	25.38	19.15
Cumulative %	36.13	67.15	91.96	26.01	51.39	70.53

^a The 2 highest loadings in each PC are shown in bold numbers

HMs were conceivable: Cu/Cd/Pb and Fe/Mn. These 2 groups were fairly consistent with the tentative classification discussed above in the EF and the correlation analyses.

Further analyses using the hierarchical clustering technique yielded the dendrograms in Figure 4. Different clustering and interval measurement methods were tried to find the best representation of clusters. Subsequently, the centroid clustering method and Pearson correlation measurement were selected to

represent the outcomes. The results broadly agreed with the PCA grouping mentioned above. Here the closeness of Mn with Fe or with As was obvious, and the separation of this set of elements from the rest was perceived more clearly. However, the Figure also showed the stark difference of the Cr grouping in the 2 types of dust. It seemed to be isolated from the others in the roof dust but easily grouped with Pb/Cd in the dustfall data. Such a difference was foreseeable to some degree due to the

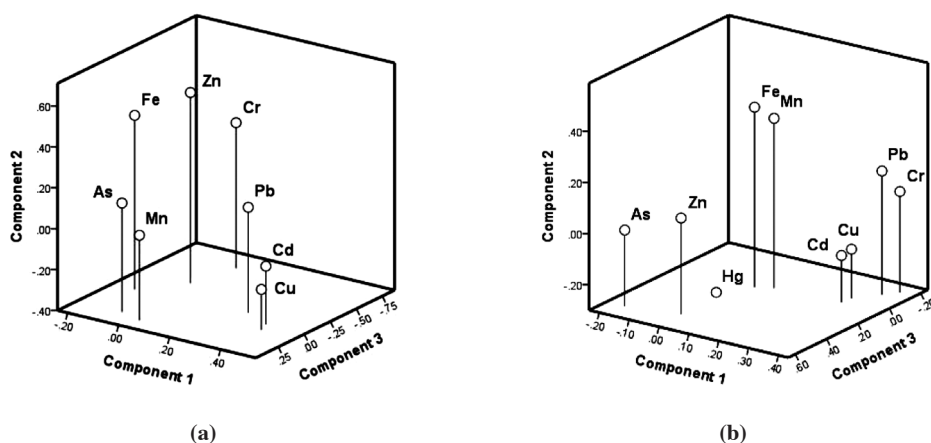


Figure 3. The 3-D plots of factor loadings of heavy metal variables: (a) roof dust data and (b) dustfall data

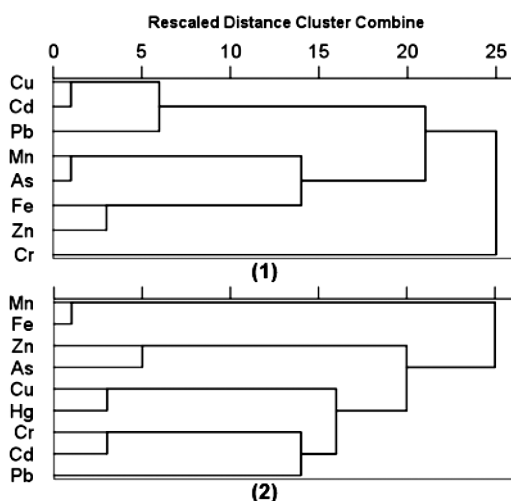


Figure 4. Dendrograms obtained from clustering of heavy metal variables: (1) roof dust data and (2) dustfall data

difference in sampling methods and relevant factors, as discussed earlier.

With respect to the groupings of the study areas, the 10 communities, the 3-D diagram of the factor scores obtained from the PCA analysis showed less obvious groupings than those of the HMs. Based on the roof dust results, most communities appeared to flock around the corner where the PC1 and PC2 are low and the PC3 is high. On the contrary, M1 and M6 were isolated which suggested their unique pollutant sources. This corresponded to the EF analysis findings that both areas were relatively more contaminated than others, as discussed earlier. The plot of the dustfall showed no apparent grouping. The corresponding dendrograms also classified M1 and M6 in the same subgroup with M8 and M10. Even though some communities were selected to represent certain characteristics or locations, e.g. M9 and M10, they did not appear to stand apart from the others. The limited interpretation regarding the community groupings may imply that most areas are not substantially different in terms of types of pollutants and emission sources.

Conclusions

Fe, Mn, Zn, Cr, Cu, and Pb were found to be predominant elements in the dust samples from 10 communities in Nakhon Ratchasima province, Thailand. Human contamination, as indicated by the EF values, existed at various levels in the study areas. Cu, Zn, and Cd had relatively large EF values, while Mn, Pb, and Cr showed moderate to significant enrichment in certain locations. Every community had at least 1 element significantly elevated compared with the natural level. Two relatively populated communities, Nakhon Ratchasima city municipality (M1) and Pimai (M6), had more types and higher levels of enrichment which were attributable to traffic and industrial sources. Two groups of elements emerged from the PCA and CA analysis – Cu/Cd/Pb in 1 group and Fe/Mn in another – both of which were in agreement with the results in earlier steps. The analogous analyses used to categorize the 10 study locations led to less distinct

groupings which could be attributable to the similarity in terms of pollutants and emission sources in the locations. Nevertheless, the analysis did imply that M1 and M6 had characteristics separated from the others. Although the implication made is bound by the scope of the research, the insights can lead to further in-depth studies which focus on the potentially high HM contamination, element-wise or community-wise, and consequently the reduction or prevention of the problems in urban areas.

Acknowledgement

This work was funded by Suranaree University of Technology.

References

- Al-Khashman, O.A. (2004). Heavy metal distribution in dust, street dust, and soils from the work place in Karak Industrial Estate, Jordan. *Atmos. Environ.*, 38:6803-6812.
- ASTM. (2004). Standard Test Method for Collection and Measurement of Dustfall. ASTM: D1739-98. ASTM International, Conshohocken, PA, USA.
- Buat-Menard, P. and Chesselet, R. (1979). Variable influence of the atmospheric flux on the trace metal chemistry of oceanic suspended matter. *Earth Planet. Sci. Lett.*, 42:398-411.
- Han, Y.M., Du, P.X., Cao, J.J., and Posmentier, E. S. (2006). Multivariate analysis of heavy metal contamination in urban dusts of Xi'an, Central China. *Sci. Total Environ.*, 355:176-186.
- Huang, S., Jun, T., Liu, H., Hua, M., Liao, Q., Feng, J., Weng, Z., and Huang, G. (2009). Multivariate analysis of trace element concentrations in atmospheric deposition in the Yangtze River Delta, East China. *Atmos. Environ.*, 43:5781-5790.
- Joshi, M.U., Vijayaraghavan, K., and Balasubramanian, R. (2009). Elemental composition of urban street dusts and their dissolution characteristics in various aqueous media. *Chemosphere*, 77:526-533.
- Kulkarni, P., Chellam, S., Flanagan, J.B., and Jayanty, R.K.M. (2007). Microwave digestion – ICP-MS for elemental analysis in ambient airborne fine particulate matter: Rare earth elements and validation using a filter borne fine particle certified reference material. *Anal. Chim. Acta*, 599:170-176.

- Lee, C., Li, X., Shi, W., Cheung, S., and Thornton, I. (2006). Metal contamination in urban, suburban, and country park soils of Hong Kong: a study based on GIS and multivariate statistics. *Sci. Total Environ.*, 356:45-61.
- Li, X. and Feng, L. (2012). Multivariate and geostatistical analyses of metals in urban soil of Weinan industrial areas, Northwest of China. *Atmos. Environ.*, 47:58-65.
- Li, X., Lee, S.L., Wong, S.C., Shi, W., and Thornton, I. (2004). The study of metal contamination in urban soils of Hong Kong using a GIS-based approach. *Environ. Pollut.*, 129:113-124.
- Lu, X., Wang, L., Li, L.Y., Lei, K., Huang, L., and Kang, D. (2010). Multivariate statistical analysis of heavy metals in street dust of Baoji, NW China. *J. Hazard. Mater.*, 173:744-749.
- Mason, B. (1966). *Principles of Geochemistry*. John Wiley & Sons, New York, NY, USA, 346p.
- Meza-Figueroa, D., De la O-Villanueva, M., and De la Parra, M.L. (2007). Heavy metal distribution in dust from elementary schools in Hermosillo, Sonora, Mexico. *Atmos. Environ.*, 41:276-288.
- Ng, S.L., Chan, L.S., Lam, K.C., and Chan, W.K. (2003). Heavy metal contents and magnetic properties of playground dust in Hong Kong. *Environ. Monit. Assess.*, 89:221-232.
- Reutergardh, L.B. and Yen, N.T. (1997). The Thai environment: prospering or suffering from development. *TrAC-Trend. Anal. Chem.*, 16(8):436-450.
- Sandroni, V., Smith, C.M.M., and Donovan, A. (2003). Microwave digestion of sediment, soils and urban particulate matter for trace metal analysis. *Talanta*, 60:715-723.
- Shah, M.H. and Shaheen, N. (2007). Statistical analysis of atmospheric trace metals and particulate fractions in Islamabad, Pakistan. *J. Hazard. Mater.*, 147:759-767.
- Thornton, I. (1991). Metal contamination of soils in urban areas. In: *Soils in the Urban Environment*. Bullock, P. and Gregory, P.J., (eds). Blackwell Scientific Publications, Oxford, UK, p. 47-75.
- Tokalioglu S. and Kartal S. (2006). Multivariate analysis of the data and speciation of heavy metals in street dust samples from the Organized Industrial District in Kayseri (Turkey). *Atmos. Environ.*, 40:2797-2805.
- Townend, J. (2001). *Practical Statistics for Environmental and Biological Scientists*. John Wiley & Sons, Chichester, UK, 288p.
- Varrica, D., Dongarra, G., Sabatino, G., and Monna, F. (2003). Inorganic geochemistry of roadway dust from the metropolitan area of Palermo, Italy. *Environ. Geol.*, 44:222-230.
- Wilcke, W., Muller, S., Kanchanakool, N., and Zech, W. (1998). Urban soil contamination in Bangkok: heavy metal and aluminum partitioning in topsoils. *Geoderma*, 86:211-228.
- Zarcinas, B.A., Pongsakul, P., McLaughlin, M.J., and Cozens, G. (2004). Heavy metals in soils and crops in Southeast Asia. 2. Thailand. *Environ. Geochem. Hlth.*, 26:359-371.