ORIGINAL ARTICLE

Composition of Metal in Indoor Dust from University Laboratories

Fazrul Razman Sulaiman, Muhammad Alif Suratmin

Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM) Cawangan Pahang, 26400 Bandar Tun Abdul Razak Jengka, Pahang Malaysia

ABSTRACT

Introduction: This study determines the concentration of selected heavy metals in indoor dust from selected laboratories in UiTM Cawangan Pahang and estimates the potential health risks of metal exposure. **Methods:** Dust samples were collected from the Chemistry lab, Biology lab, and Physics lab based on the frequency used by students. The aluminium (Al), cadmium (Cd), copper (Cu) and lead (Pb) compositions of the dust samples were analysed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). **Results:** The overall concentrations of heavy metals were in the order of Al > Cu > Pb > Cd. The enrichment factor (EF) calculation indicated that the heavy metal determined in indoor dust were influenced by natural and anthropogenic sources. Pb was found to have the highest enrichment (EF>10) in indoor dust collected, which may be contributed by indoor materials and vehicular emissions. The overall hazard index (HI) value suggests a minimal non-carcinogenic risk (HI=$1.01x10^{-3}$). However, there is a slightly high estimated value for the ingestion exposure route of lifetime cancer risk (LCR>$1.0x10\text{-}^{4}$). **Conclusion:** Perhaps a comprehensive monitoring assessment of indoor dust should be considered to ensure the safety of laboratory occupants.

Keywords: Dust, Health risk, Laboratories, Metal, Student's exposure

Corresponding Author:
Fazrul Razman Sulaiman, MPhil
Email: fazrul@uitm.edu.my
Tel: +609-460 2781

INTRODUCTION

Indoor environments regularly have higher levels of air pollutants than outdoor environments (1, 2). Students may stay longer indoors than outdoors (3). The productivity and health status of students may be affected by exposure to poor indoor air quality (1). Indoor sources and activities, as well as outdoor sources such as fuel combustion, influenced the level of indoor air quality (4, 5). Outdoor sources may cause airborne pollutants to adsorb on particulate matter and become deposited as indoor dust (2). Walking activities and ventilation systems could suspend the particles and eventually influence metal concentration in the indoor dust (6). Coarser dust particles have higher deposition velocities than smaller dust particles, indicating the smaller one can remain for a longer time in the air (7). Fine particles, which usually contain hazardous constituents, potentially penetrate deep into the lung, disturbing the human respiration system (8).

Allergies, skin irritation, and respiratory diseases are some common effects of indoor air pollutant exposure (8, 9). Indoor dust might contain metals which is linked to cardio injuries as well as cancer (10). Therefore, measuring indoor dust composition is crucial when assessing the health risks of a building occupant. Limited studies explore the metal composition in indoor dust, especially in university laboratories. An earlier study noted that metal composition in indoor laboratories is more dominant than in other buildings (11). Hence, this study intends to assess the concentration of metals (Al, Cu, Cd, and Pb) in indoor dust from three different laboratories at UiTM Cawangan Pahang, Jengka, Malaysia. A health risk assessment model has been adopted to estimate the non-carcinogenic and carcinogenic risks of metal composition in indoor dust.

MATERIALS AND METHODS

The dust collection approach was adapted from Zhong et al. (1), Latif et al. (2), and Sulaiman et al. (11). A total of 24 dust samples were collected from three laboratories, namely Chemistry Lab 3, Biology Lab 1, and Physics Lab 4 within the same building in UiTM Cawangan Pahang. The Physics and Biology labs are facing each other at the lower level, while the Chemistry lab located at level one. The Physics lab is facing the main road of the campus. Biology and Chemistry labs, however, located on the other side. These sampling locations were chosen based on the frequency used by students, and ventilation systems which trap pollutants inside the building (2, 12).

Samples were collected twice a week for four weeks, between 9.00 a.m. and 5.00 p.m, during academic activities for all sampling locations. All sampling locations can be occupied by 30 persons at one time, with a combination of mechanical supply type (fans) and exhaust type (air-conditioned) ventilation systems applied. The dust samples were collected from windows, fans, fume hoods, and air conditioners. For each sampling point and sampling event, a new paintbrush and polyethylene container used and labelled to avoid cross-contamination.

The dust samples were dried in an oven at 105°C for 24 hours. Then, about 0.5-1.0 g of the fine portion of the dust was weighed and digested with a mixture of nitric acid (HNO_3) and perchloric acid ($HClO_4$) at a ratio of 4:1 on a hot plate at 50°C for 1 hour inside a fume hood (11). The solution was cooled before filtering through filter paper into a 100 ml volumetric flask. After that, the filtrate was added with deionized water up to the calibration mark of 100 mL in a volumetric flask. The samples were analysed in triplicate using an Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) to determine the concentration Al, Cd, Cu, and Pb. Topsoil near to sampling location, about <2 m from sampling point building, was collected with a depth of 0.01m as the reference sample. This study adopted the adjacent topsoil concentrations of heavy metals as the earth's crust ratio (11). The soil samples were dried in a furnace at 450°C for 3 hours. Then, about 1g of the reference sample was digested using the same digestion method as a dust sample.

A health risk assessment (HRA) framework considering ingestion, inhalation and skin contact was adopted from the United States Environmental Protection Agency (13). Average daily dose (ADD) is calculated for each heavy metal exposure. Reference dose values were used to determine potential non-cancer and cancer risks, as indicated in Table I. The estimation of health risks was adapted from USEPA (13) and USDOE (14) with the following equations:

$$ADDingest = \frac{C_{dust} \times IngR \times EF \times ED}{BW \times AT} \times CF \quad (1)$$

$$ADDdermal = \frac{C_{dust} \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \times CF \quad (2)$$

$$ADDinhale = \frac{C_{dust} \times InhR \times EF \times ED}{PEF \times BW \times AT} \times CF \quad (3)$$

$$HQ = ADD / RfD \quad (4)$$

$$HI = \sum (HQingest + HQdermal + HQinhale) \quad (5)$$

$$CR = ADD \times SF \quad (6)$$

$$LCR = \sum (CRingest + CRdermal + CRinhale) \quad (7)$$

Table I : Reference values of parameters for estimation of non- cancer and cancer risks via exposure ingestion, dermal contact and inhalation routes

Parameter	Unit	Value*
Cdust - Concentration of metal in dust	µg/kg	
SA -Skin surface area	cm²/event	5700
AF - Skin adherence factor	mg/cm²	7×10^{-2}
ABS - Dermal absorption factor		1×10^{-3}
EF - Exposure frequency	days/year	350
ED -Exposure duration	years	24
CF- Conversion factor	kg/mg	1×10^{-6}
BW-Average body weight	kg	70
AT-Averaging time	days	8760
InhR - Inhalation rate	m³/day	20
IngR- Ingestion rate	mg/day	100
PEF -Particle emission factor	m³/kg	1.36×10^{9}
RfD ingest	mg/kg/day	Cd: 5×10^{-3}
		Cu: 4×10^{-2}
		Pb: 3.5×10^{-3}
RfD dermal		Pb: 3.5×10^{-3}
RfC inhale	mg/m³	Pb: 3.5×10^{-3}
SF- slope factor for ingestion	mg/kg/day	Cd: 6.3
		Pb: 8.5×10^{-3}
SF- slope factor for inhalation	µg/m³	Cd: 1.8×10^{-3}
		Pb: 1.2×10^{-5}

*values are adopted from USEPA and USDOE

The enrichment factor (EF) was calculated to estimate the metal enrichment level in the indoor dust (15). Pearson correlation analysis was used to identify the potential relationships among metal elements in indoor dust. Cluster analysis was adopted to group the potential source of indoor dust. Pearson correlation and cluster analysis were performed using the Statistical Package for Social Science (SPSS) v20.

RESULTS

The average concentrations of metal (Al, Cd, Cu, Pb) in indoor laboratories' dust are shown in Fig. 1. The concentrations were dominated by Al followed by Cu, Pb and Cd. Cu and Pb concentration are the highest at the Physics lab. Al is the highest (>4 µg/g), meanwhile, Cd is the lowest (< 0.1 µg/g) in all sampling laboratories. The EF values of the metal were estimated based on EF = $Xi/R_{(dust)} / Xi/R_{(background)}$, where Xi_{dust} is the concentration of the metal in indoor dust, $Xi_{background}$ is the concentration of metal in reference sample, R_{dust} and $R_{background}$ are the Al concentration in dust sample and reference sample respectively. The enrichment levels ranking of metal is as follows: Pb (very high) > Cu (minimal to moderate) > Cd (minimal), as seen in Table II.

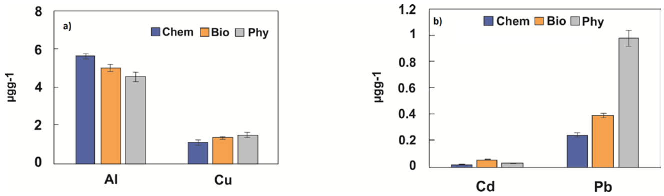

Fig. 1 : Concentration of (a) Al and Cu, (b) Cd and Pb in indoor laboratories' dust (error bars show the standard deviation)

Table II : Enrichment factor (EF) value of metal concentrations in indoor laboratories' dust

Lab	Al	Cd	Cu	Pb
Chemsitry	1	0.44	1.23	7.07
Biology	1	1.69	1.72	12.96
Physics	1	0.95	2.14	35.94

Table III : Correlation matrix between metal in indoor laboratories' dust

	Al	Cd	Cu	Pb
Al	1	-0.36	-0.81**	-0.83**
Cd		1	0.38	-0.33
Cu			1	0.73**
Pb				1

**correlation is significant at the level of 0.01 (two-tailed)

Table III shows the Pearson correlation analysis output for the metal in indoor laboratories' dust. Element pairs of Cu–Pb had a strong positive correlation (*r = 0.73*) at a significance level of 0.01. Pairs of Cu-Al (*r = -0.81*) and Pb-Al (*r = -0.83*) showed strong significant negative correlations. A similar source may imply the significant correlation coefficients between variables. Cu, Pb, and Al are related to dust deposition from various human activities (16).

Euclidean distances for similarities were computed in cluster analysis. Fig. 2 shows the dendrogram from cluster analysis of metals composition in indoor laboratories' dust. Two groups were identified: Cluster 1 (Cd, Cu, Pb), and Cluster 2 (Al).

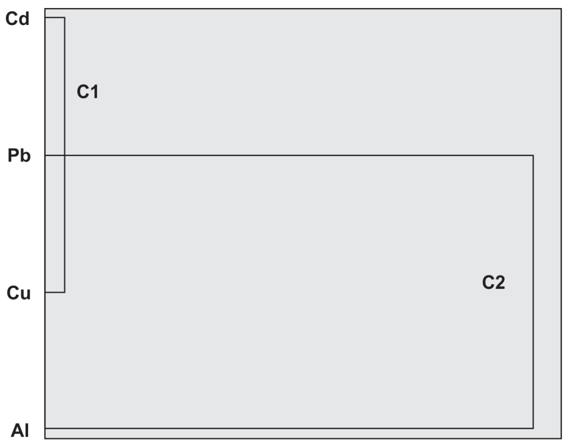

Fig. 2 : Cluster analysis dendrogram for indoor laboratories' dust

Table IV : Potential non-carcinogenic health risks of indoor laboratories' dust exposure

Metal	Lab	HQingest	HQinhale	HQdermal	HI
Cu	Chemistry	3.57×10^{-5}			
	Biology	4.46×10^{-5}			
	Physics	4.98×10^{-5}			
Cd	Chemistry	4.10×10^{-5}	3.02×10^{-7}		
	Biology	1.39×10^{-3}	1.02×10^{-6}		
	Physics	7.08×10^{-5}	5.21×10^{-7}		
Pb	Chemistry	9.44×10^{-5}	1.38×10^{-8}	3.76×10^{-7}	
	Biology	1.51×10^{-3}	2.23×10^{-8}	6.05×10^{-7}	
	Physics	3.83×10^{-4}	5.63×10^{-8}	1.52×10^{-6}	
					1.01×10^{-3}

The potential non-carcinogenic risks of metal in indoor laboratories' dust are shown in Table IV. Generally, the HQ and HI values were less than unity (< 1), implying a low non-carcinogenic risk for occupants. However, HQ values for Pb and Cd were the highest, especially for the Biology lab.

Table V shows that the potential cancer risk of Cd and Pb exposure from dust via ingestion and inhalation pathways. All sampling locations show low cancer risk, except for Cd exposure.

Table V : Potential carcinogenic risks of indoor laboratories' dust exposure

Metal	Lab	CRingest	CRinhale	LCRingest	LCRinhale
Cd	Chemistry	2.58×10^{-4}	5.43×10^{-10}		
	Biology	8.80×10^{-4}	1.84×10^{-9}		
	Physics	4.46×10^{-4}	9.38×10^{-10}		
Pb	Chemistry	8.03×10^{-7}	1.67×10^{-13}		
	Biology	1.29×10^{-6}	2.68×10^{-13}		
	Physics	3.26×10^{-6}	6.76×10^{-13}		
	Chemistry			2.58×10^{-4}	8.05×10^{-7}
Cd + Pb	Biology			8.80×10^{-4}	1.29×10^{-6}
	Physics			4.46×10^{-4}	3.25×10^{-6}

DISCUSSION

Overall, the metal concentrations in indoor laboratories' dust were higher compared to those in the surface soils collected around the laboratory building compound. Perhaps the metal concentrations in indoor dust influenced by the building location and the activities around the building. All laboratories have different nature of chemical usage, where Biology and Chemistry laboratories use more chemicals. It is expected the metal concentrations in indoor dust from both laboratories higher than the Physics lab. Surprisingly, that is not true as seen in Fig. 1.

The EF results indicate a higher level of Pb (EF>10) in indoor dust than other metals. The EF value less than 1 (EF<1) suggests natural source of metal origin, while value above 1 (EF>1) indicates metal enrichment related to anthropogenic inputs (11). Pb concentration in indoor dust from all laboratories showed EF values much higher than 1, suggesting very high enrichment contributed by anthropogenic factors. Road dust as a result of its emission from vehicles (tires, brakes, oil) may contribute to the accumulation of Pb (17). Perhaps this factor increases the Pb level in laboratory indoor dust, especially the Physics lab, as this site located very close to a major road and has a combined open mechanical type and closed ventilation systems. Suspended dust remained in the enclosed room and resuspended as a result of building ventilation (1). Buildings with open ventilation systems influence the movement of outdoor air pollutants to the indoor environment (2). A previous study suggested a correlation between meteorological factors and dust entering the indoor environment, thus increase the building's dust composition (5).

Hassan (18) and Mummullage et al. (19) suggested that automobile emissions are the major Pb contributor. The use of Pb–based paint might be another potential anthropogenic source of Pb (20). Cu and Pb concentrations, especially from the Physics lab, had the highest level apart from Al concentration. The Physics lab located at the ground level and exposed directly nearby to a roadside; hence, a higher concentration of metal in indoor dust is expected. Perhaps the nature of the ventilation system, as well as laboratory activities, have influenced the composition of these elements in the indoor dust sample. During the sampling, the Physics lab has the highest number of occupants with many outdoor to indoor movement activities observed. Most likely the suspension and re-suspension of settled dust are brought in by students and staff's footwear (2). Hence, induce soil dust entering the building.

Based on Fig. 2, Cluster 1 may attribute to anthropogenic sources, and this finding is similar to Zhong et al. (1). Perhaps Cluster 2 contributed by natural sources (soil). As expected, Al is known as one of the most abundances of Earth's crust elements. Soil dust containing Al may be entering the indoor environment via student movement and activity, as well as wind blowing from outdoors (2).

Hazard quotient (HQ) and hazard index (HI) were calculated to evaluate the non-carcinogenic health risks from single metal and combined metals (Cu, Cd, and Pb). The ingestion route shows higher HQ values of Cd and Pb of indoor dust exposure than the HQ values of Cu. Pb was found to be enriched in indoor dust as estimated in the EF calculation, perhaps due to the accumulation of Pb coated indoor materials (20) as well as the suspended particle from outdoor vehicle emission (15). Although Pb has been banned in Malaysia in the past 20 years, the residue can still be found in road dust (21). Perhaps this is due to the exhaust, tire, and brake wear residuals occur around the area enhancing the soil Pb concentration (17).

The total lifetime cancer risk (LCR) values of Cd and Pb have exceeded the safe lifetime level of 1.0×10^{-5}, particularly via the ingestion route. With these LCR values, the probability of cancer cases among adults may increase. Both non-carcinogenic (HI) and carcinogenic risks (LCR) values are quite alarming. In the long term, the concentrations of metal in indoor dust may increase due to the increment of lab activities as well as traffic density. If the metal level in indoor dust increases, the potential health risk to occupant increases too. Some uncertainties such as variation of metal concentration in indoor dust, actual exposure duration, the ingestion and inhalation rates affecting the accuracy of HRA output (11). Thus, comprehensive analysis is still required to assess the health risk in the sampling area. Perhaps bioavailability metal form analysis could be applied (22).

CONCLUSION

Laboratories' indoor dust showed metal concentrations in decreasing order of Al > Cu > Pb > Cd. Activities in the laboratory and the suspended dust from the outdoor environment contribute to the high concentration of Al and Cu. The EF analysis suggests that the same anthropogenic activities influence the concentration of the metals in indoor dust. Moreover, the cluster analysis supports Cd, Cu, and Pb perhaps contributed by the same sources. Two groups distinguished from cluster analysis showing several connections among these heavy metals in indoor dust samples. Low non-carcinogenic risks (HI < 1) for adults are predicted for metal exposure from indoor dust. However, the total LCR values for Cd and Pb were slightly high, indicating an increased likelihood of cancer in long-term exposure. This study proposes that regular monitoring should be conducted to safeguard lower risks to health. Perhaps a comprehensive study integrating the bioavailability metal form analysis could assist in an accurate risk assessment.

ACKNOWLEDGEMENT

We appreciate Mr. Mohd Fauzie Idrus and Mr. Nik Mohd Zamani Nik Ismail for their assistance in the ICP-OES analysis.

REFERENCES

1. Zhong JNM, Latif MT, Mohamad N, Abd-Wahid NB, Dominick D, Juahir, H. Source apportionment of particulate matter (PM10) and indoor dust in a university building. Environ Forensics. 2014; 15(1): 8–16.
2. Latif MT, Yong SM, Saad A, Mohamad N, Baharudin NH, Mokhtar MB, et al. Composition of heavy metals in indoor dust and their possible exposure: a case study of preschool children in Malaysia. Air

Qual Atmos Health. 2014; 7(2): 181–193.
3. Raysoni AU, Stock TH, Sarnat JA, Sosa TM, Sarnat SE, Holguin F, et al. Characterization of traffic-related air pollutant metrics at four schools in El Paso, Texas, USA: Implications for exposure assessment and siting schools in urban areas. Atmos Environ. 2013; 80:140–151.
4. Latif MT, Othman MR, Kim CL, Murayadi SA, Sahaimi KNA. Composition of household dust in semi-urban areas in Malaysia. Indoor Built Environ. 2009; 18:155–161.
5. Yang Razali NY, Latif MT, Dominick D, Mohamad N, Sulaiman FR, Srithawirat T. Concentration of particulate matter, CO and CO2 in selected schools in Malaysia. Build Environ. 2015; 87:108–116.
6. Brani's M, Rezacova P, Domasova M. The effect of outdoor air and indoor human activity on mass concentrations of PM10, PM2.5, and PM1 in a classroom. Environ Res. 2005; 99:143–149.
7. Matson U. Indoor and outdoor concentrations of ultrafine particles in some Scandinavian rural and urban areas. Sci Total Environ. 2005; 343:169–176.
8. Sloan CD, Andrew AS, Gruber JF, Mwenda KM, Moore JH, Onega T, et al. Indoor and outdoor air pollution and lung cancer in New Hampshire and Vermont. Toxicol Environ Chem. 2012; 94: 605–615.
9. Young, S-H, Cox-Ganser JM, Shogren ES, Wolfarth MG, Li S, Antonini JM, et al. Pulmonary inflammation induced by office dust and the relation to 1-3 β-glucan using different extraction techniques. Toxicol Environ Chem. 2011; 93: 806–823.
10. Massey D, Kulshrestha A, Taneja A. Particulate matter concentrations and their related metal toxicity in rural residential environment of semi-arid region of India. Atmos Environ. 2013; 67: 278–286.
11. Sulaiman FR, Bakri NIF, Nazmi N, Latif MT. Assessment of heavy metal in indoor dust of a university in tropical environment. Environ Forensics. 2017; 18 (1): 74-82
12. Latif MT, Na TS, Baharudin NH, Srithawirat T, Mohamad N, Khan MF, Sulaiman FR. Composition of trace metals in indoor dust during and after building renovation. Environ Eng Manag J. 2018; 17(8): 1781-1790.
13. USEPA (United States Environmental Protection Agency). Supplemental guidance for developing soil screening levels for superfund sites. Office of Emergency and Remedial Response, Washington. 2002 [retrieved on 2020 January 17]. Available from: https://semspub.epa.gov/work/HQ/175878.pdf
14. USDOE (United States Department of Energy). The Risk Assessment Information System (RAIS), U.S. Department of Energy, Washington. 2011 [retrieved on 2020 January 17]. Available from: https://rais.ornl.gov/tools/tox_profiles.html
15. Wan D, Han Z, Yang J, Yang G, Liu X. Heavy metal pollution in settled dust associated with different urban functional areas in a heavily air-polluted city in North China. Int J Environ Res Pub Health. 2016; 13(11): 119.
16. Lu SG, Bai SQ, Xue QF. Magnetic properties as indicators of heavy metals pollution in urban topsoils: A case study from the city of Luoyang, China. Geophys J Int. 2007; 171(2): 568–580.
17. Sulaiman FR, Mohd Ghazali F, Ismail I. Health Risks Assessment of Metal Exposure from a Tropical Semi-urban Soil. Soil Sediment Contam. 2020; 29(1): 14-25.
18. Hassan SKM. Metal concentrations and distribution in the household, stairs and entryway dust of some Egyptian homes. Atmos Environ. 2012; 54: 207–215.
19. Mummullage S, Egodawatta P, Ayoko GA, Goonetilleke A. Use of physicochemical signatures to assess the sources of metals in urban road dust. Sci Total Environ. 2016; 541: 1303-1309.
20. Sulaiman FR, Brimblecombe P, Grossi CM. Mobilisation of trace elements on roofing tiles. Indoor Built Environ. 2016; 25(2): 329–339.
21. Sulaiman FR, Hamzah HA. Heavy metals accumulation in suburban roadside plants in a tropical area (Jengka, Malaysia). Ecol Processes. 2018; 7(1): 28.
22. Praveena SM, Pradhan B, Ismail SNS. Spatial assessment of heavy metals in surface soil from Klang District (Malaysia): An example from a tropical environment. Human Ecol Risk Assess. 2015; 21(7): 1980–2003.