MAEH Journal of Environmental Health eISSN 2637-1359
Jurnal Kesihatan Persekitaran MAEH
Published By Malaysian Association of Environmental Health
http://www.maeh4u.org.my/journal

RESEARCH ARTICLE

Exposure Concentration of Heavy Metals in Indoor Air of FELDA Bukit Goh's Residential Area

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Abstract

Introduction: Bauxite mining activity emits Heavy Metals (HMs) to the ambient air and may subsequently implicate the indoor air of residential area in Felda Bukit Goh, Kuantan, thus raising concern of HMs poisoning from exposure through inhalation. **Objective:** Study was performed to measure the concentration of HMs Al, Cd, Fe, Pb and Zn in indoor air of 25 selected houses in proximity to bauxite mining sites (Sample Location 1) and another 25 selected houses farther from bauxite mining sites (Sample Location 2). Next is to compare between the two areas and lastly to assess the potential health risk effects from exposure through inhalation by estimating health risk assessment. **Methodology:** A total of fifty samples of indoor air inside residential houses in Felda Bukit Goh were collected by using air sampling pumps, were digested appropriately and analyzed by AAS for five elements. **Result:** All five elements were detected in the indoor air of the houses at both Sample Location 1 and 2 with the variation order Fe > Al > Zn > Pb > Cd and Fe > Pb > Al > Zn > Cd respectively, and with mean concentration ranging from 0.0043 to 0.0259 mg/m3 and from 0.0038 to 0.0149 mg/m3 respectively. The p-value for all HMs except for Cd are lesser than 0.05, signifying that there is significant difference of most HMs concentration between the two areas, and Sample Location 1 is generally higher in concentration. The non-carcinogenic health risk of HMs was estimated by hazard quotient (HQ) and hazard index (HI) and the results showed that the HI value for both areas exceed the safe limit (HI>1), indicating non-carcinogenic health effects exist in present condition. Whereas, the carcinogenic health risk of HMs was estimated by cancer risk (CR) and the result showed that Cd is also above the threshold value, thus the carcinogenic health effects exist and likely to be of threat. **Conclusion:** Both non-carcinogenic and carcinogenic negative health effects are currently present at both areas in Felda Bukit Goh and may pose health deterioration to the locals through chronic inhalation exposure.

Keywords: Heavy metals, Health risk assessment, Indoor air, Air sampling pump

INTRODUCTION

Bauxite mining causes plethora of environmental and health impacts by generating pollutants like particulate matter (PM) and chemical compounds like heavy metals (HMs) to the ambient air thus causing air pollution (Abdullah, Mohamed, Sulaiman, Zakaria, & Abdul Rahim, 2016; Al-Khashman, 2004). Concentration of PM and HMs in the ambient air can influence the concentration of the same pollutants in the indoor air from the transfer of pollutants into buildings through various means (WHO, 2016). Järup (2003) and Kurt-Karakus (2012) found that HMs in the indoor air like cadmium and lead may pose negative health complications including carcinogenic and non-carcinogenic effects from exposure through inhalation.

Despite the stop work order and moratorium commencement in Kuantan, Pahang, there were still reports stating that illegal mining is secretly being done by private sectors from unknown agencies (Abdullah et al., 2016). Out of hundreds of bauxite miners, only 21 are licensed and only 7.6 hectare of lands were approved. Moratorium is for the recuperation of the state and for repairing of the infrastructures like roads, houses and more, yet illegal practices are still being done.

METHODOLOGY

This study that was mainly adapted from a research conducted by Yeboah (2008) and Liu et al. (2015) and was performed to measure the concentration of HMs Al, Cd, Fe, Pb and Zn in indoor air of 25 selected houses located in the area that is in proximity to bauxite mining sites, which is approximately 0.5 to 1.5 km away from the mining sites (regarded as Sample Location 1 henceforth) and another 25 selected houses located farther, which is approximately 1.5 km to 3.0 km away from the mining sites (regarded as Sample Location 2 hereafter). A total of fifty samples of indoor air inside residential houses in Felda Bukit Goh were collected by using air sampling pumps, were digested appropriately and analyzed by AAS for the stated five elements.

Air sampling

Air sampling is done by utilizing air sampling equipment Sensidyne's GilAir-3 and GilAir-5 Air Sampling System. To collect the suspended dusts in the air, the media used is Mixed Cellulose Ester (MCE) membrane filter with pore size of 0.8 µm, specific to sample HMs-carrying dusts. The air sampling pump is placed indoor of the selected houses, 130cm above floor, in the middle of an area like living room, at least 2m away from windows and doors and 1m away from wall, with flow rate of 1 to 3 L/min (Hassanvand et al., 2014). Sampling is adopted based on Method 7013 from NIOSH Manual of Analytical Methods (NMAM), Fourth Edition. The sampling time inside the house is 8 hours (typically from 8am to 4pm). The cassettes are labeled according to sampling points (selected houses) and stored in an airtight and re-sealable laboratory plastic bag to prevent contamination during storage and transport.

Acid digestion and Heavy Metals Analysis

The cassettes are brought back to Environmental Instrumentation Laboratory in Faculty of Health Sciences, UiTM Puncak Alam. Acid digestion is based on Method 7300 and 7013 of NIOSH Manual of Analytical Methods (NMAM) and adapted from the work by Latif, Abidin, & Praveena (2015). MCEs are weighed for final weight (MCE + HMs), digested on hot plate in mixture of concentrated nitric acid (HNO3 and H2O2 in a ratio of 4:1) and diluted with deionised water up to 100 mL, then filtered through a 0.45-lm Millipore filter paper (Whatman 41) to obtain a clear solution. Solution samples are labeled accordingly and stored in a chiller of temperature 0-4oC before HMs analysis. The samples are then tested for Al, Cd, Fe, Pb and Znc concentrations by using Atomic Absorption Spectrophotometer (AAS) Perkin-Elmer Model AAnalyst 900.

Estimation of Health Risk Assessment for Adults via Inhalation Route

The Estimation is accomplished by calculating the chemical daily intake via inhalation route (CDIinh) then calculating hazard quotient (HQ) for non-carcinogens (Al, Fe and Zn) and lastly calculating the hazard index (HI) to characterize the non-carcinogenic health effects of the non-carcinogens. Similar to HQ and HI, Cancer Risk (CR) is calculated for carcinogens (Cd and Pb) to characterize the carcinogenic health effects of the carcinogens. CDIinh (mg/kg/day) can be computed through a formula developed by USEPA:

$$\mathrm{CDI_{inh}(mg/kg/day)} = \mathrm{C} \times \frac{\mathrm{Rinh \times Fexp \times Texp}}{\mathrm{ABW \times Tavrg}}$$

Equation (1)

Where C is the mean concentration of indoor air HMs (mg/m3); Rinh is the inhalation rate, that is 20m3 day-1 for adults (Van den Berg, 1994); Fexp is the exposure frequency, that is 350 day year-1 (Lina Thabethe, Engelbrecht, Wright, & Oosthuizen, 2014); Texp is the exposure duration, that is 24 years for adults (USEPA, 2001); ABW is the average body weight, that is 70 kg for adults (USEPA, 2001); Tavrg is the averaging time in days, that is 22,550 for carcinogenic elements and Texp x 365 for non-carcinogenic elements (Abbasi & Tufail, 2013; Kurt-Karakus, 2012).

Next, by substituting values from Table 1 into the following equations, HQ, HI and CR are quantified.

$$\textbf{Hazard Quotient (HQ)} = \frac{CDIinh}{RfD}$$

Equation (2)

$$\textbf{Cancer Risk (CR)} = CDIinh \times CSFinh$$

Equation (3)

$$\textbf{Hazard Index (HI)} = \sum_{1}^{n} HQal + HQcd + HQfe + HQpb + HQzn$$

Equation (4)

Table 1 Recommended values in equation according to appropriate references.

	RfD for $\mathrm{CDI_{inh}}$ (mg/kg/day)	Reference	$\mathrm{CSF_{inh}}$ for CR (mg/kg/day)	Reference
Al[a]	4.0E–4	IRIS USEPA (1987)	-	-
Cd	1.0E–3	Kurt-Karakus (2012) and USEPA (2010)	1.5E+1	OEHHA (2009)
Fe[b]	7.0E–1	Hu et al. (2011)	-	-
Pb	3.5E–3	Kurt-Karakus (2012) and USEPA (2010)	4.2E–2	OEHHA (2009)
Zn	3.0E–1	Kurt-Karakus (2012) and USEPA (2010)	-	-

[a] RfD value of Al is substituted with Aluminum phosphide due to unavailability.
[b] RfD value of Fe is adopted from a different literature as compared to other RfD values.

RESULTS AND DISCUSSION

Interpretation and Comparison of Heavy Metals Concentration in Indoor Air of Residential Houses between Sample Location 1 and Sample Location 2

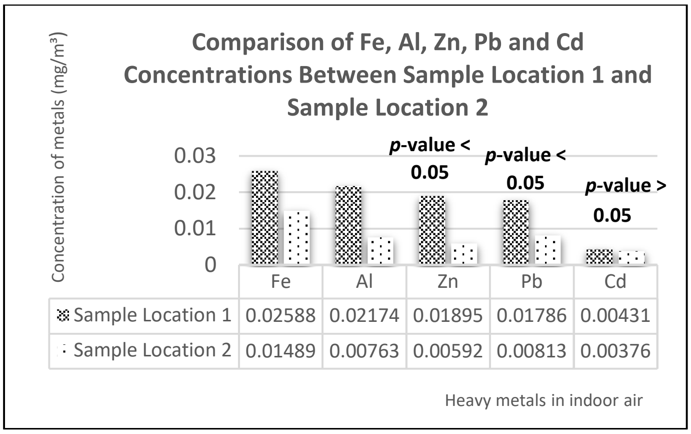

Fig.1 Mean Concentration in Sample Location 1 and Sample Location 2

Referring to Figure 1, all five elements were detected at both Sample Location 1 and Sample Location 2. At Sample Location 1, the order of elements detected according to concentration is Fe > Al > Zn > Pb > Cd. Sample Location 2 follows the variation order of Fe > Pb > Al > Zn > Cd. In general, the mean concentration of all the selected HMs in indoor air of Sample Location 1 is higher than Sample Location 2. Referring to Figure 1, The HM that dominates both sample locations is Iron (Fe), with the mean concentration of 0.0259 mg/m3 and 0.0149 mg/m3 respectively. A similar is result attained from Ntziachristos et al. (2007) and Shah & Shaheen (2007). The huge amount of Fe is hardly shocking because Fe is known for its abundance in the crust of the earth (Feng & Wang, 2012; Mohd Talib Latif et al., 2014). For Sample Location 1, second to Fe is Aluminum (Al) with the mean concentration of 0.0217 mg/m3 whereas for Sample Location 2, Fe is followed by Lead (Pb) with mean of 0.0081 mg/m3. Al-Khashman (2004) mentioned that contiguous to Fe, Al is also a naturally ample element in the soil and it can be float up into the air due natural or anthropogenic activities (Yap, Chew, & Tan, 2012). Due to the farther distance between Sample Location 2 and mining area, Aluminum that is copious in the bauxite mine only come in third after Pb. Pb which is second for Sample Location 2 and fourth for Sample Location 1 but still higher in the latter (0.0179 mg/m3), may be due to anthropogenic sources in indoor and outdoor environment (Fergusson & Ryan, 1984). The fourth most concentrated HM at Sample Location 2 is Zinc (Zn), found to be 0.0059 mg/m3 and third at Sample Location 1, found to be 0.0189 mg/m3. Zn at the latter is higher because according to Nriagu (1988), Zn is also one of the HM emitted from anthropogenic mining like smelting and refining. Furthermore, Zn is also a widely known as a function of emission from indoor wall paints (Mohd Talib Latif et al., 2014). The most cancerous and fortunately the least highly concentrated HM is Cadmium (Cd) with 0.0043 mg/m3 and 0.0038 mg/m3 in Sample Location 1 and 2 respectively. According to the investigation by Fergusson & Ryan (1984), Cd, Pb and several other HM are extremely concentrated in households and are of anthropogenic origin from both indoor and outdoor atmosphere. Furthermore, Al-rajhl & Madany (1996) assert that Cd in particular could be due to vehicular emission and so forth.

It can be statistically described that the levels of Fe, Al, Zn and Pb contamination in indoor air in Sample Location 1 is proven to be greater than the level of contamination of the same elements in Sample Location 2 (p-value less than 0.05 for all the four HMs). Also, the difference in means of Cd between Sample Location 1 and Sample Location 2 is statistically not significant by p-values more than 0.05.

Results from this study is in agreement with Yeboah (2008), who once proved his similar hypothesis where the associated respiratory diseases, cold, cough and skin diseases from exposure to airborne particulate matters and chemical compounds among population is directly proportional to the distance from the active mine sites. Another research is also consistent where the associated respiratory diseases such as asthma and rhinoconjuctivitis are prevalent in children in a community that is 2.1 km apart from the gold and copper mining site compared to a population that is 2.0 km away from the site (Herrera et al., 2016). Although not quite the same source of air pollution, but both Jabeen et al. (2001) from Pakistan and Puett et al. (2014) from United States verified that the concentration of certain HM in indoor and the associated incidence of lung cancer is connected to the factor of proximity of the houses to sources of air pollutants arising from busy road occupied with traffic emissions and industrial activity releases. Findings by Al-rajhl & Madany (1996) demonstrated that the households nearby to industrial area and heavy motorcar traffic showed a considerably high concentration of toxic trace metals.

The overall higher concentration at Sample Location 1 could be due to indoor contributions like residents are practicing domestic fuel burning cooking, tobacco smoking and cleaning activities. Furthermore, Li et al. (2016) stressed that high levels of Cd, Pb and Zn can arise from wall paints. Indoor environment that contain carpet and clothing fibers, microbes and garden soil also give rise trace HMs (Fergusson & Ryan, 1984). Jabeen et al. (2001) also conclude that HM concentration inside houses they investigated depend on the natural or mechanical ventilation system of the house, which in turn is affected by loading of HMs into the house. Illegal mining operation is also a contributor to the concentration (Abdullah et al., 2016). Movement of illegal transportation trucks carrying bauxite ores heading out of the area is causing the roadways and ambient air to be tainted with red dust. Houses that are located along the streets are affected when wind carry the dusts into the indoor air (Holmes & Eisner, 2003; Lina Thabethe et al., 2014).

Indoor Air Heavy Metal Concentration in Comparison with Established International Air Quality Standards

The HMs concentration obtained were first compared with local occupational USECHH Regulations 2000 and all the HM concentrations are within the recommended permissible exposure limits range. The maximum allowed concentration (in mg/m3) according to USECHH is Al: 10; Fe: 5, Pb: 0.05; Zn: 10; Cd: 0.01. Since USECHH is an occupational standard and the study location is a community area, another comparison is made for element Cd and Pb with international two standards from 'Community Metals Concentration of Concern. Referring to Table 2, both elements at both Sample Locations are not within compliance of these two standards. The basis of EPA to making these standards as strict and low as they are now is because these HMs (Pb and Cd) in rural and urban zones are of exceptional concern due to the great number of citizens. However, the mean concentration alone does not infer that the same concentration is being exposed to the human population (USEPA, 2005). Hence, measurement is coupled with HRA to associate the mean concentration with the exposure towards human beings and ultimately characterize the human health status (Smolders & Degryse, 2002).

Table 2 Heavy Metals Mean Concentration at Sample Location 1 and Sample Location 2 vs Community Metals Concentration of Concern and Compliancy Status.

Metal	Concentration of Heavy Metals in Indoor Air of FELDA Bukit Goh ($\mu g/m^3$)		U.S National Ambient Air Concentrations for Rural Area[a] ($\mu g/m^3$)	European Union Air Quality Standard ($\mu g/m^3$)	Compliance
	Sample Location 1	Sample Location 2			
Cd	4.3	3.8	0.001	0.005	Not comply
Pb	17.9	8.1	0.02	0.5	Not comply

Health Risk Assessment (HRA) of Exposure to Heavy Metals via Inhalation

The HQ values for non-carcinogenic effects of non-carcinogens, Sample Location 1 was in the order of Al > Zn > Fe. Whereas for Sample Location 2, the order goes Al > Fe > Zn. HQ is calculated by applying Equation 2 and by using the recommended RfD values listed in Table 1. By referring to note from Table 1, usually, in the event of absence of RfD of a certain element, the HQ value is not calculated at all and is disregarded. Therefore, the peculiar order of HQ for both sample locations are due to this reason. If Al and Fe is neglected due to their absence of RfD, no HQ can be calculated since there is no non-carcinogenic HMs left that is applicable for estimation of HQ.

Table 3 HQ and HI for Non-Carcinogens Al, Fe and Zn and CDIinh and CR for carcinogens Cd and Pb

Element	Route of Exposure	Sample Location 1		Sample Location 2		Sample Location 1	Sample Location 2
		HQ	HI	HQ	HI	CR	CR
Al	Inhalation	5.095	14.89	1.785	5.22	N/A	
Fe		3.476×10^{-3}		1.999×10^{-3}			
Zn		5.917×10^{-3}		1.847×10^{-3}			
Cd		N/A				6.059×10^{-3}	5.355×10^{-3}
Pb						7.060×10^{-5}	3.196×10^{-5}

Referring to Table 3, HI values for both Sample Location 1 and Sample Location 2 showed to be greater than 1, that is 14.89 and 5.22 respectively, which indicates that there shall be concern for potential non-carcinogenic chronic effects of the HMs to human health (Liu et al., 2015). The HI value that is less or equal to 1 is acknowledged as a safe limit of exposure in which there is zero adverse health effects due to the exposure concentration (USEPA, 2001). Similarly, Lemly (1996) and Lina Thabethe et al., (2014) have established a guideline for interpreting and characterizing HI. The following is the guideline: HI <0.1: no hazard exists; HI 0.1-1.0: low hazard; HI 1.1-10: moderate hazard; and HI >10: high hazard. The HI for Sample Location 1 which is 14.89 was above 10, which means the population there was at high risk of negative health effects from chronic exposure to the HMs. Meanwhile, the HI for Sample Location 2 is 5.22; above 1.1 yet below 10; which indicates that the residents were at low moderate risk and it is likely that they may have experienced some of the negative symptoms (Lina Thabethe et al., 2014).

The cancer risk (CR) for Pb and Cd were calculated using Equation 3. Table 3 depicts the CR value where the order is Cd > Pb for both sample locations. The upsetting result of 6.059 x 10-3 and 5.355 x 10-3 of Cd for Sample Location 1 and 2 respectively are worrying as they both exceed the range that has been deemed acceptable by corresponding regulatory authorities. This suggest that chronic carcinogenic risks of Cd from exposure to the indoor air are present and are of concern, thus cannot be neglected (Liu et al., 2015).

CONCLUSION

Indoor air of Felda Bukit Goh, Kuantan, Pahang were selected to determine the concentration of heavy elements and to assess the potential carcinogenic (only from Pb and Cd) and non-carcinogenic health risk effects. The health risk of HMs in indoor air was measured by calculating the HI and CR values of HMs which indicated the presence of both non-carcinogenic and carcinogenic negative health effects at both Sample Locations in Felda Bukit Goh and may pose health deterioration to the locals through chronic inhalation exposure. The limitations of this study are that should be understood that the estimated risk is affected by a substantial degree of uncertainties. Nonetheless, exposure health risk assessment has proved in hundreds of previous literary works to be a powerful tool to estimate the health risks from HMs exposure (Du et al., 2013). Furthermore, the absence of reference dose (RfD) or reference concentration (RfC) for certain heavy metals like Fe and Al forces the estimation to advance but by employing values from other references. These facts shall act as the prerequisite of using the results from this study. Instead, the results presented here should be regarded as preliminary, thus call for the need of further research.

ACKNOWLEDGEMENT

The authors would like to thank the residents of Felda Bukit Goh for their support to the study.

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