ORIGINAL ARTICLE

Respirable Particulate (PM_{10}) and Its Heavy Metals Concentrations from Bauxite Mining in the Vicinity of Urban Kuantan, Malaysia: Inhalation Health Risk Assessment

Intan Nor Lyana Sajali[1], Zailina Hashim[1], Jamal Hisham Hashim[2]

[1] Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Malaysia.

[2] United Nations University-International Institute for Global Health, off UKM Medical Centre, Jalan Yaakob Latif, Bandar Tun Razak, 56000 56000 Kuala Lumpur, Malaysia

ABSTRACT

Introduction: Bauxite ore contain various heavy metals especially aluminum, if exposed excessively is detrimental to the respiratory system. Objective: This study aimed at determining the PM_{10} and its Al, As, Cd, Cr, Ni and Pb content and assessing the inhalation health risk assessment (HRA) among the community. **Method:** This cross-sectional study was conducted in Kuantan on 162 randomly selected respondents in three residential areas; Felda Bukit Goh (FBG), Jalan Besar Bukit Goh (JBBG) and Kuantan Port Consortium Flat (KPCF). Questionnaires were used to obtain the background information and health symptoms. PM_{10} with its heavy metals were subsampled for 24 hours using air sampling pumps in 42 randomly sub-sampled households from the 3 areas. **Results:** PM_{10} exceeded 150 µg/m^3 and the Al, Cd, As, Cr, Ni and Pb levels exceeded the standard limit. The hazard quotient (HQ) of Cd in JBBG (4.13), Cr in FBG (74.06), JBBG (84.41), KPCF (76.87) and Ni in FBG (60.53), JBBG (66.95) and KPCF (58.81) exceeded the HQ value of 1. The lifetime cancer risk (LCR) exceeded the level of 0.0000001 for Cr in FBG (0.0252), JBBG (0.0288) and KPCF (0.0262), as well as for Ni in the FBG (0.000184), JBBG (0.000204), and KPCF (0.000179) areas. **Conclusion:** The PM_{10} levels exceeded the USEPA guidelines while Al, Cd, As, Cr, Ni and Pb exceeded the ATSDR limit. The Cd, Cr and Ni posed non-carcinogenic and carcinogenic health risks. Therefore, health risks from the PM_{10}, Cd, Cr and Ni exposures were found in this study.

Keywords: PM_{10}, Respiratory symptoms, Non-carcinogenic and carcinogenic health risks assessments

Corresponding Author:
Zailina Hashim, PhD
Email: drzhashim@gmail.com
Tel: +60176361367

INTRODUCTION

Bauxite exists in the environment naturally occurred in reddish-brown colour (1). Bauxite occurred from a mixture of minerals such as aluminum hydroxides known as gibbsite, boehmite, diaspore, and compounds: hematite, goethite, quartz, rutile/anatase, kaolinite, trace elements including As, Be, Cd, Cr, Pb, Mn, Hg and Ni as well as uranium and thorium (2). Bauxite is the major component for aluminum production. More than three-fourths of the world's bauxite reserves constitute lateritic bauxites. Australia is the largest producer which made up one 30 percent (125 million metric tons annually) of the world's total production (3).

Bauxite mines have sprung up in Malaysia since 2014, notably in Kuantan, Pahang, since Indonesia suspended its production of bauxite and Ni exports to China. This area supplied 1.27 million tons of bauxite to China in the first nine months of 2014 (4). The mining of bauxite ore in Kuantan, Pahang had started on a small scale in Balok since early 2013, which later expanded to other areas like Bukit Goh and Sungai Karang. Based on a report by The Star newspaper on 19 December 2015, mining activities in Kuantan escalated from 208,770 tons in 2013 to 963,000 tons in 2014, to staggering 20 million tons in 2015 (5).

Bauxite mining is seen as a contributor to the economic growth for the development of Kuantan and the areas endowed with the resource. In mining operations, dust particle is the main environmental hazard produced by the earth excavation. Dust particle tend to disperse to nearby areas affecting natural habitats, residential and agricultural neighbourhoods near the bauxite exploitation sites (6). Mining activities degrade the land surface due to the destruction of land cover by vegetation and topsoil. The primary problem resulting from bauxite mining was the particles in the air. The red dust particles remained suspended in the air and then settled on the surfaces of homes and properties.

This study focused on the environmental health impacts of bauxite on the populations of Felda Bukit Goh, near to the mining sites, and the Kuantan Port Commission flats beside the Kuantan Port area. According to the US EPA, the major health concerns of human exposures to heavy metals particulate were their effects on the respiratory systems, lung tissue impairment, various types of cancer and premature death (7). These environmental and health impacts of the bauxite mining have attracted huge public attention, both locally, nationally and even internationally. Hence, there was a need to address this issue amicably.

The study objective was to determine the PM_{10} and its Al, Cd, As, Cr, Ni and Pb levels in the vicinity of bauxite mining areas as well as to assess the potential non-carcinogenic and carcinogenic health risks associated with bauxite mining activities as proposed by the US EPA (7, 8). Selected heavy metals were known to cause carcinogenic (Cd, As, Cr and Ni) and non-carcinogenic (Al and Zn) (9, 10) health effect to human.

The significance of this research would be to assess the health outcome of bauxite mining activities to the surrounding communities since the mining activities in these areas were not controlled and did not abide to a specific standard operating procedure. The bauxite ores transported by lorries were dusty turning road and highways orange in colour. The community in the vicinity complained on respiratory problems, noise and stress due to the high number of lorries on the roads (2). The findings and recommendations from this research would help the authorities to better plan and regulate future bauxite mining activities in Kuantan and maybe elsewhere in Malaysia. Recommendation include to prepare a standard operating procedure adhered by miners in the areas so that the activities are not detrimental to the environment and the community health. Findings would help the authorities to plan appropriate environmental monitoring programme and documentation of health data from government and private clinics in the area, with regard to illnesses.

MATERIALS AND METHODS

Study design, respondent and environmental sampling

This is a cross-sectional study carried out near Kuantan and the neighboring areas with large number of bauxite mining activities in Pahang, Malaysia in January 2016. Bukit Goh is located near Kuantan, Pahang and borders with Terengganu and it is easily accessible to Kuala Terengganu via the new Kuantan bypass highway, as well as to Sungai Lembing, and Jabor Valley Estate. The area is almost exclusively planted with oil palm. Permission for conducting study in this area was obtained from Felda Bukit Goh management office and the KPCF authority. This study was carried out in three different residential areas namely Felda Bukit Goh (FBG), Jalan Besar Bukit Goh (JBBG) and Kuantan Port Consortium Flat (KPCF) (Figure 1). The houses were located within 0.5 to 1 km radius of the bauxite mining area in which these household members might be affected by the mining activities. These areas were close to the South China Sea and upwind from the mines.

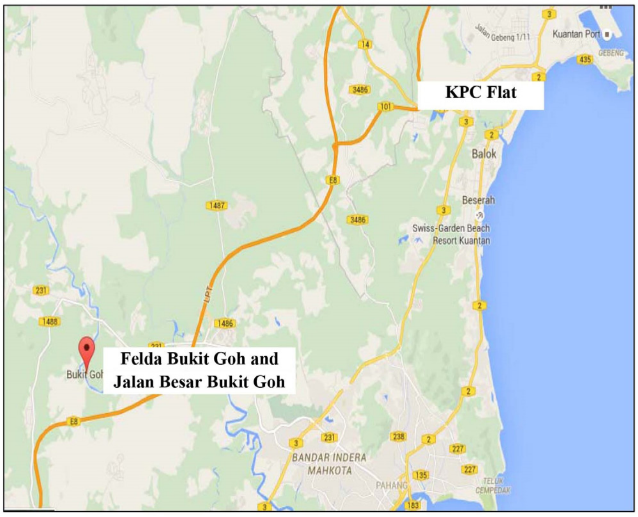

Figure 1: Geographical area of study location in Felda Bukit Goh and viscinity in Kuantan, Pahang

The list of households obtained from the Felda Bukit Goh administrative office. This area consisted of houses located close to the bauxite mining areas (radius of 0.5 to 1.0 km), including those on the main road where bauxites were transported by lorries. Another list of apartments was obtained from the Kuantan Port Consortium Authority, since at the Kuantan Port area, huge piles of bauxite ores were placed near the apartments before being shipped overseas. Therefore, most likely the apartment dwellers would be exposed. There were about 300 houses in the FBG close to the mining sites, 40 houses located on the main road Bukit Goh and only 12 units apartment in the KPCF. From the house lists, 152 were selected randomly to meet the minimal sample size of 152, calculated for the study. From the KPCF, all the 10 apartments in the block were selected as 2 apartments were vacant since the occupants had moved out. Therefore, in total, one hundred and sixty-two houses were selected, with 130 houses in FBG, 22 houses in JBBG and 10 houses from the KPCF.

The sample size was calculated with reference to Lemeshow, et al. (11). The prevalence used in the sample size calculation was 0.9 where 90% of the study respondents complained respiratory problems associated with the dust pollution cause nearby road used for mining activity at Girgaon area (12). Other health symptoms were also reported by the respondents, however, respiratory problem showed the highest reported symptom, which was the main health impact to the community associated with the mining activities.

The respondents who participated, should be adult in the aged range of 20 to 70 years. They should be either the head of the households or their wives or their eldest child (at least 20 years old) who resided in the same households and had agreed to participate in the study.

$$N = \frac{(Z_{1-\alpha})^2 - [P(1-P)]}{d^2} \quad \text{(Equation 1)}$$

Where,

P = estimated proportion (0.9)

d = desired precision (0.05)

$Z_{1-\alpha}$ = Z0.95 = 1.96 for CI of 95%, Z=1.96 (normal distribution table)

$$N = \frac{(Z_{1-\alpha})^2 - [P(1-P)]}{d^2}$$

$$= \frac{(1.96)^2 - [0.9(1-0.9)]}{(0.05)^2}$$

$$= 138$$

Source: (11)

In order to recover any loss of respondents throughout the study, additional 10%, would be added to 138 ~14 respondents. The total sample size of respondents would be 152.

A self-constructed questionnaire was used to obtain the socio-demographic information, economic status, involvement with mining activities, environmental related issues and health symptoms experienced for the present and past 7 days. The face to face interviews were about 20 minutes duration and were carried out by the researchers.

The environmental air sampling were carried out in households subsampled from the total households. A total of 37 residences were randomly subsampled from the 150 households (approximately 9%) to represent the high risks households located in a proximity of the mining areas (30 houses) and close to the transportation activities (7 houses). Another 5 apartment were subsampled randomly from the KPCF housing near the port. The outdoor air was very similar to the indoor air of the 42 houses because none of the houses were air conditioned. Only 42 households were environmentally monitored due to the limited number of available pumps, time and the cooperation of the house owners. Three sampling pumps were used to sample the air for 24 hours. The house owners had to switch off the 1st pump and start the 2nd and 3rd pumps after 8 hours, giving a total of 24 hours monitoring.

The PM_{10} and selected heavy metals were sampled using the Gillian personal air sampling pumps. The flow rate was 1.7 L/minutes and cyclones were used to separate the respirable particles (PM_{10}) from the larger ones and were collected over 24 hours. Cellulose acetate membrane filters with a pore size of 0.45 µm and diameter of 47 mm were used. The pumps were placed on the windows of their living rooms where most dwellers spend time sitting and watching television.

Analysis of air samples

PM_{10} measurement

Gravimetrically respirable particulate (PM_{10}) was measured by subtracting the original weight from its final weight after sampling, for both the sampled filter as well as the blank filter. The PM_{10} concentration was then determined using the following formula (13):

Concentration of PM_{10}(µg/m^3)

$$= \frac{[W_2-W_1]-[B_2-B_1] \times 1000}{\text{Flow rate (L/min)} \times \text{Time (min)}} \quad \text{(Equation 2)}$$

Where;

W_1 = Initial weight of filter (mg)

W_2 = Final weight of filter (mg)

B_1 = Initial weight of blank filter (mg)

B_2 = Final weight of blank filter (mg)

Source: [13]

Heavy metal analysis

For analysis of the heavy metal levels in respirable particles, the hot acid digestion method by US EPA [9] was used. The sample was filtered using a Whatman 541 filter paper and the filtrate transferred into a polypropylene bottle to be analyzed using inductively coupled plasma mass spectrometry (ICP-MS). The heavy metal levels were determined using the following formula:

$$C = \frac{(\text{*g metal/L}) \times \text{Digestion volume (L/filter)}}{V_{std}} \quad \text{(Equation 3)}$$

Where;

C = Concentration in g metal/m^3

*g metal/L = Metal concentration determined from ICP-MS

Digestion vol = Total sample extraction volume from extraction procedure (L/filter)

Vstd = Standard air volume pulled through the filter in m^3

Source: [9]

Health risk assessment

The risk was quantified under the existing environmental condition at the residential locations in study areas for the selected exposure scenario. The risk characterization for carcinogenic and non-carcinogenic risks were carried out separately

Non-carcinogenic risk

The hazard quotient (HQ), which is the ratio of the exposed dose to the compound-specific reference dose (RfD) was used as a Standard US EPA Method to determine the non-carcinogenic risk. US EPA (14) stated that, when the value of HQ is more than 1, there is a significant non-carcinogenic risk. The HQ calculation for the inhalation route is as follow:

$$HQ = \frac{ADD}{RfDi} \quad \text{(Equation 4)}$$

Where;
HQ = Hazard quotient (no unit)
ADD= Average daily dose (mg/kg-day)
RfDi = Inhalation reference dose (mg/kg-day)

RfDi is an estimate of a inhalation dose to humans during a lifetime without the risk of deleterious effects. RfDi is reported in milligrams of pollutant per kilogram of body weight in a day (mg/kg/day). RfDi for each element (heavy metal) were derived using the following equation.

$$RfDi\ (mg/kg/day) = \frac{RfC(mg/m^3) \times \text{Inhalation rate } (15.2\ m^3/day)}{\text{Body weight } (65\ kg)} \quad \text{(Equation 5)}$$

ADD was defined by the following equation.

$$ADD = \frac{CxIRxEFxED}{W_BxAT} \quad \text{(Equation 6)}$$

Where;
ADD= Average dose per day (mg/kg-day)
C = Level of air pollutant (mg/m^3)
IR = Inhalation daily rate (m^3/day) = 15.2 m^3/day
EF = Frequency per year (days/year) (350 days/year)
ED = Duration of exposure (year)
WB = Weight (kg) = 65 kg (adjusted for Malaysian body weight)
AT = Average time (days); for chronic non-carcinogenicity
(Eg. 2 years x 365 days = 730 days)
Source: [14]

The inhalation rate of 15.2 m^3/day was used for chronic exposure for an average adult male (15). Table I shows the RfC, RfDi and inhalation slope factor of the studied heavy metals obtained from previous literatures.

Carcinogenic risk

Inhalation cancer risk is an estimate of an individual incremental probability of developing cancer over a lifetime because of the exposure to a carcinogenic substance. For inhalation, the lifetime cancer risk (LCR) was estimated by the product of lifetime average daily dose (LADD) and the inhalation cancer slope factor (CSF_{inh}). The formula is given below:

$$LCR = LADD \times CSF_{inh} \quad \text{(Equation 7)}$$

Where;
LCR = Lifetime cancer risk (unitless)
LADD = Lifetime average dose per day (mg/kg-day)
CSF_{inh} = Inhalation slope factor for cancer (mg/kg-day)

LADD is defined by the following equation;

$$LADD = \frac{CxIRxEFxED}{(W_BxAT)} \quad \text{(Equation 8)}$$

Where;
LADD = Lifetime average dose per day (mg/kg-day)
C = Mean level of air pollutant (mg/m^3)
IR = Inhalation rate per day (m^3/day) (15.2 m^3/day)
EF = Exposure frequency (days/year) (350 days/year)
ED = Exposure duration (year)
WB = Body weight (kg) = 65 kg (adjusted for Malaysians)
AT = Average time (days); for chronic non-carcinogenic effects
(70 years x 365 days = 25,550 days)
Source: (14)

Table I. The inhalation reference concentration (RfC) and reference dose (RfD_i) for selected heavy metals

Elements (heavy metals)	[a] RfC (mg/m^3)	RfD_i (mg/kg/day)	[b] Inhalation Slope Factor (mg/kg-day)
Aluminum (Al)	N/A	N/A	N/A
Arsenic (As)	3.0×10^{-5}	7.0154×10^{-6}	12.0
Cadmium (Cd)	1.0×10^{-5}	2.3385×10^{-6}	1.5
Chromium (Cr)[c]	1.0×10^{-4}	2.3385×10^{-5}	5.1×10^{2}
Lead (Pb)	N/A	N/A	4.2×10^{-2}
Nickel (Ni)	5.0×10^{-5}	1.1692×10^{-5}	9.1×10^{-1}

[a] RfC derived from Geiger A. and Cooper J., (2010)
[b] Adapted from OEHHA Cancer Potency Values
[c] Only applicable for Cr (VI) through inhalation route
N/A= Not available

RESULTS

Socio-demographic data of respondents

Table II shows that all respondents were of Malay ethnicity, consisted of 62 males and 100 females, aged from 18 to 100 years. Most respondents have resided in the study area for more than 30 years (66.7%). The literacy rate was high with over half of the respondents (87%) had only up to primary (33.3%) and secondary (40.1%) level education and 13.6% was without formal education. About 73.5% of respondents were non-smokers. Majority were housewives (48.1%) with an average income of RM 1000 to RM 3000 (57.4%) thus, they had to rely on their subsistence agriculture income. Only 9.2% had their monthly income between RM 3000 to RM 5000, which partly came from the bauxite mining activities. It was observed that some (30.2%) of respondents from the study areas were involved in mining activities whether directly or indirectly.

PM_{10} level in the mining areas

The distribution of sampling areas and time weighted average concentrations (24 hours) for PM_{10} are shown in Table III. The PM_{10} levels were normally distributed. This table shows that the overall mean of PM_{10} obtained from the study (249.35 $\mu g/m^3$) were higher than the standard value (150 $\mu g/m^3$ for 24 hours exposure) in the MAAQG by the Malaysian DOE (16) and National Ambient Air Quality Standards guideline by US EPA (17). In terms of study location, JBBG shows the highest reading of PM_{10} (292.08 $\mu g/m^3$) followed by KPCF (266.89 $\mu g/m^3$) and

Table II: Socio-demographic of the respondents

Variables	Frequency (n)	Percentage (%)
Gender		
Male	62	38.3
Female	100	61.7
Age group (years)		
<25	15	9.3
25-55	74	45.7
>55	73	45.0
Smoking status		
Yes	43	26.5
No	119	73.5
Education		
No formal education	22	13.6
Primary school	54	33.3
Secondary school	65	40.1
Higher education	21	13.0
Income (RM)		
<1000	52	32.1
1000-3000	93	57.4
3000-5000	8	4.9
>5000	7	4.3
Employment		
Government	4	2.5
Private	5	3.1
Self-employed	56	34.6
Retirees	19	9.9
Housewives	78	48.1
Duration of stay (years)		
<5	15	9.3
5-30	39	24.1
>30	108	66.7
Involvement in the mining activity		
Yes	49	30.2
No	113	69.8

N=162

Table III: PM_{10} and heavy metals levels in ambient air at residences in the three selected areas

Variables	Study Location	Mean (STD) / Median (IQR) (µg/m³)	Range value (µg/m³)	Air Quality Standard (µg/m³)
	FBG	[c]238.14 (53.92)	161.86 - 364.93	
PM_{10}	JBBG	[c]292.08 (52.43)	243.62 - 363.92	[a]150
	KPCF	[c]266.89(21.76)	242.86 - 284.88	
	FBG	1.77 (1.08)	0.58 - 4.97	
Al	JBBG	2.53 (4.54)	2.22 – 7.63	[b] 0.005 - 0.018
	KPCF	4.09 (0.98)	2.95 – 4.32	
	FBG	0.01 (0.01)	0.00 – 0.03	
As	JBBG	0.01 (0.01)	0.01 – 0.03	[b] 0.02 – 0.1
	KPCF	N/D	N/D	
	FBG	0.01 (0.02)	0.00 - 0.03	
Cd	JBBG	0.04 (0.04)	0.01 - 0.07	[b] 0.002-0.015
	KPCF	N/D	N/D	
	FBG	7.72 (2.03)	4.70 - 10.04	
Cr	JBBG	8.80 (1.19)	8.23 - 9.78	[d] median <0.02
	KPCF	8.02 (3.80)	2.16 – 8.57	
	FBG	3.16 (1.38)	2.06 - 19.04	
Ni	JBBG	3.49 (2.03)	3.14 - 7.00	0.0022
	KPCF	3.07 (2.83)	1.11 - 6.54	
	FBG	0.18 (0.10)	0.07 - 0.54	
Pb	JBBG	0.18 (0.38)	0.15 - 0.87	0.05
	KPCF	0.17 (0.06)	0.13 - 0.22	

[a] Malaysian Ambient Air Quality Guideline (MAAQG) 2015
[b]Adapted from air quality guideline by U.S Department of Health and Human Services, ATSDR (2018)
[c] Mean (STD)
[d] Only applicable for Cr (VI)
FBG=Felda Bukit Goh, n=30; JBBG=Jalan Besar Bukit Goh, n=7;
KPCF=Kuantan Port Consortium Flat, n=5
Total N = 42
N/D= Not detectable

FBG (238.14 µg/m³).

Heavy metal levels within the mining areas

The distribution of sampling points and selected heavy metals concentrations (µg/m) in ambient air obtained from this study were compared with air quality standard derived by U.S Department of Health and Human Services (18,19) as shown in Table III. The highest concentration of heavy metals present in ambient air of study location was Al followed by Cr >Ni>Pb>Cd>As. Overall findings stated that the median of selected heavy metals levels present in ambient air was high and exceeded the ATSDR standard limit. In terms of study location, JBBG showed the highest reading for most of the selected heavy metals concentration followed by FBG and KPCF.

Health complaints among respondents

Reported health symptoms among respondents were divided into three types; general health, respiratory and dermal symptoms which were gathered using self-constructed questionnaire. Reported symptoms such as stress due to nuisances of dust, noise or heavy traffic, headache, vomit, diarrhea and muscle cramp were included under general health symptoms. Symptoms such as dry cough, phlegm cough, asthma, dyspnea (shortness of breath) and bronchitis were listed under respiratory symptoms, while itchiness, redness/rashes, and edema were included under dermal health symptoms. These symptoms were reported by the respondents exposed to high level (PM_{10} between 150-200 µg/m³) as well as very high level (PM_{10} > 200 µg/m³) of PM_{10}.

Table IV represents the number of health complaints reported by respondents exposed to bauxite mining activities within six months. The highest number of complaints were stress due to nuisances (39.5%) followed by itchiness (35.8%) and dry cough (30.9%). Meanwhile, bronchitis (0.6%) was also reported.

Table V also shows the reported respiratory and dermal symptoms among the study respondents. There were significant association between those exposed to high level and very high level PM_{10} with itchiness (χ^2 =4.257, p=0.039). it clearly showed that the respondents who were exposed to very high level of PM_{10} had almost twice (1.947) higher risk as indicated by the Odd Ratio

Table IV: Reported health symptoms among community exposed to bauxite mining activities within six months

Types of Health Symptoms	Frequency (n)	Percentage (%)
General Health Symptoms		
Stress due to the nuisances (dust, noise or heavy traffic)	64	39.5
Headache	21	13.0
Vomit	2	1.2
Diarrhea	2	1.2
Muscle cramps	5	3.1
Respiratory Symptoms		
Dry cough	50	30.9
Phlegm cough	49	30.2
Dyspnea (shortness of breath)	27	16.7
Asthma	12	7.4
Bronchitis	1	0.6
Dermal Symptoms		
Itchiness	58	35.8
Redness/rash	46	28.4
Swollen/edema	3	1.9

N= 162

and more than twice (2,667) higher risk as indicated by the Prevalent Ratio. reported symptoms.

Health risk assessment

To assess the health risk assessment, the information of exposure duration, exposure frequency and averaging time of exposure were collected throughout the questionnaire interview. The health effects of carcinogenic and non-carcinogenic effect for population exposed for their lifetime were shown in Table VI. The exposure in term of the ADD and the LADD for each element were also listed in Table VI.

Table VI presents that the HQ were above 1, for Cd in JBBG (4.13), Cr in FBG (74.06), JBBG (84.41), KPCF (76.87) and Ni in FBG (60.53), JBBG (66.95), KPCF (58.81). Hence, it can be concluded that the exposure from inhalation would result in non-carcinogenic adverse effect in terms of pulmonary and dermal toxicity. Carcinogenic adverse effect shows the LCR value for all heavy metals; Cr in FBG (0.025), JBBG (2.88×10^{-2}), and KPCF (2.62×10^{-2}) and for Ni in the FBG (1.84×10^{-5}), JBBG (2.04×10^{-5}), and KPCF (1.79×10^{-5}).

Table V: The Associations between reported respiratory and dermal symptoms of respondents with two different levels of PM_{10} measured

Variables	Very High n (%)	High n (%)	PR	OR	95% CI	aχ^2	*p*
Respiratory Symptoms							
Dry cough							
Yes	16 (43.2)	3 (60.0)	**0.922**	0.508	0.076-3.409	0.499	0.480
No	21 (56.8)	2 (40.0)					
Phlegm cough							
Yes	13 (35.1)	2 (40.0)	**0.975**	0.813	0.120-5.499	0.045	0.831
No	24 (64.9)	3 (60.0)					
Dyspnea (shortness of breath)							
Yes	8 (21.6)	1 (20.0)	**1.103**	1.103	0.108-11.306	0.007	0.934
No	29 (78.4)	4 (80.0)					
Asthma							
Yes	2 (5.4)	0 (0.0)	**1.143**	1.057	0.979-1.142	0.284	0.594
No	35 (94.6)	5 (100.0)					
Bronchitis							
Yes	1 (2.7)	0 (0.0)	**1.139**	1.028	0.974-1.084	0.138	0.710
No	36 (97.3)	5 (100.0)					
Dermal Symptoms							
Itchiness							
Yes	18 (48.6)	0 (0.0)	**2.667**	1.947	1.423-2.665	4.257	0.039*
No	19 (51.4)	5 (100.0)					
Redness/rash							
Yes	8 (21.6)	1 (20.0)	**1.042**	1.103	0.108-11.306	0.007	0.934
No	29 (78.4)	4 (80.0)					
Swollen /edema							
Yes	3 (8.1)	0 (0.0)	**1.147**	1.088	0.989-1.198	0.437	0.509
No	34 (91.9)	5 (100.0)					

N = 42 PR = Prevalence Ratio OR = Odd Ratio a=Fisher Exact Test *Significant at $p < 0.05$

Table VI: The Average Daily Dose (ADD), Lifetime Average Daily Dose (LADD) for each element and the Related Hazard Quotient and Lifetime Cancer Risk at Various Locations

Heavy metals	Location	Average Daily Dose (mg/kg-day)	Lifetime Average Daily Dose (mg/kg/day)	HQ	LCR
Al	FBG	3.9629×10^{-4}	1.1323×10^{-5}	N/A	N/A
	JBBG	5.6705×10^{-4}	1.6201×10^{-5}	N/A	N/A
	KPC Flat	9.1699×10^{-4}	2.6199×10^{-5}	N/A	N/A
As	FBG	1.3454×10^{-6}	3.8440×10^{-8}	0.1918	4.6128×10^{-7}
	JBBG	2.6908×10^{-6}	7.6881×10^{-8}	0.3836	9.2257×10^{-7}
	KPC Flat	N/D	N/D	N/D	N/D
Cd	FBG	1.6593×10^{-6}	4.7410×10^{-8}	0.7100	7.1115×10^{-8}
	JBBG	9.6646×10^{-6}	2.7613×10^{-7}	**4.1328**	4.1420×10^{-7}
	KPC Flat	N/D	N/D	N/D	N/D
Cr	FBG	1.7318×10^{-3}	4.9479×10^{-5}	**74.0560**	**2.5234×10^{-2}**
	JBBG	1.9739×10^{-3}	5.6399×10^{-5}	**84.4088**	**2.8763×10^{-2}**
	KPC Flat	1.7975×10^{-3}	5.1356×10^{-5}	**76.8655**	**2.6191×10^{-2}**
Ni	FBG	7.0773×10^{-4}	2.0221×10^{-5}	**60.5322**	**1.8401×10^{-5}**
	JBBG	7.8279×10^{-4}	2.2365×10^{-5}	**66.9509**	**2.0352×10^{-5}**
	KPC Flat	6.8762×10^{-4}	1.9646×10^{-5}	**58.8111**	**1.7878×10^{-5}**
Pb	FBG	1.8410×10^{-4}	1.1795×10^{-6}	N/A	4.9539×10^{-8}
	JBBG	1.8270×10^{-4}	1.1705×10^{-6}	N/A	4.9161×10^{-8}
	KPC Flat	1.6510×10^{-4}	1.0578×10^{-6}	N/A	4.4428×10^{-8}

N/A = Not available N/D = Not detectable
HQ>1 indicates significant non-carcinogenic risk.
LCR>10^{-6} indicates significant lifetime cancer risk (bold)

DISCUSSION

Socio-demographic data of respondents

Most of the respondents have resided in the same areas for more than 30 years. More than half were females, non-smokers with a high literacy rate and earned an average income. Less than half of the respondents were involved in mining activities.

PM_{10} level in the mining areas

JBBG was identified as the main road used in transporting bauxite ore from mining sites to the Kuantan Port. The road used in transporting the bauxite ore became dusty with the continuous movement of hundreds of heavy vehicles generating large amount of bauxite dust in the air which settled on the surrounding surfaces (20). Even during the moratorium, the settled bauxite dust could be re-suspended again into the air by the passing vehicles. Particularly in the hot months, due to the heat, water scarcity and winds, the problem of bauxite dust pollution became more acute (20).

PM_{10} emitted from bauxite mining areas was first dispersed as high level plume downwind in the near-field and then dispersed in the lower level further downwind in the far-field for more than 1 km (21). According to previous study (22, 23), PM_{10} does not have long lifetime in comparison with PM2.5, as the latter is less efficiently removed by gravitational force or scavenging in rain. (PM2.5 lifetime 7±30 days), since the residential areas distance from the mining areas were less than 1 kilometer, the PM_{10} levels increased. Numerous studies reported that the air quality degradation due to dust production is a major problem occurred in any open cast mining activity (24-26). A study found high level of dust pollution in work zone as well as ambient air in open cast coal mining areas (27). Mining activities including drilling, blasting and transportation increased the suspension of the particulate matter which was harmful to the workers as well as the communities who resided near to the mines.

Heavy metal levels within the mining areas

In terms of study location, JBBG showed the highest reading for most of the selected heavy metal concentrations followed by FBG and KPCF (Table III). The highest reading for most of the selected heavy metals concentration in JBBG may be explained by the fact that the JBBG area being used as a major main road for transporting bauxite ore from the mining sites. Hence, the particulate heavy metals from the bauxite dust remain suspended in air for long period especially when there was continuous movement of heavy vehicles which generated large amount of dust in air. Heavy metals pollution is very prominent in areas of mining and old mine. The levels are reduced with increasing distance away from the mining sites. Numerous reports showed that soil, water and vegetables have been contaminated with As, Pb, Cu, Cr, Zn and Cd near the mining areas (1, 28, 29). Heavy metals elements are known as toxic and have been identified as health risks to human by World

Health Organization (30).

Health complaints among respondents
Based on the findings, the prevalence of reported health symptoms was higher among respondents with very high exposure (PM_{10} > 200 µg/m^3) compared to high exposure (PM_{10} between 150-200 µg/m^3). The results showed a significant association between those exposed to high level and very high level PM_{10} with itchiness ($p<0.05$). These results also found that 90% of the respondents complained on respiratory problems associated with the dust pollution due to the proximity of their houses to the roads leading to mining sites (22). According to Ogwuegbu and Muhanga (31), heavy metal exposures also occur through the workplace where mining workers and the inhabitants around the heavy metal mining and processing industrial sites, were exposed to the suspended particulate matters (SPM) during the production of Cd, Cr, Pb, Hg, Au and Ag.

Health risk assessment
The finding for Cr indicates in every 1000 of exposed population over a lifetime duration of 70 years will develop about 25 cancer cases for FBG, 29 cancer cases for JBBG and 26 cancer cases for KPCF. ATSDR (16) had classified Cr particularly Cr (VI) as carcinogens where inhalation of high Cr levels can cause irritation to the lining of the nose and breathing problems, such as asthma, shortness of breath, wheezing and cough. Besides, dermal contact to Cr can cause dermal itchiness and ulcers. Long term exposure to Ni can cause damage to the liver, kidney, circulatory system and nerve tissues, as well as dermal irritation. For Ni, it indicates in every 1,000,000 of exposed population over a lifetime duration of 70 years would develop about 18 cancer cases for FBG, 20 cancer cases for JBBG and 18 cancer cases for KPCF respectively.

CONCLUSION

The findings showed that the PM_{10} concentrations in the studied areas exceeded the Malaysian and USA standards. Based on the findings, Al, Cd, As, Cr, Ni and Pb levels in the respirable particulate (PM_{10}) were high and above the acceptable values.

For reported health complaints, itchiness showed the highest reported symptoms, followed by dry cough, phlegm cough and redness/rash while bronchitis showed the least. The very high PM_{10} levels (>200 µg/m^3) were significantly related the high number of reported itchiness by respondents.

The HQ values of greater than 1, indicated non-carcinogenic risks of Cd in JBBG, Cr in FBG, JBBG, and KPCF as well as Ni in FBG and KPCF. The LCR values showed carcinogenic health risks of Cr in FBG, JBBG and KPCF and Ni in FBG, JBBG and KPCF for communities exposed to the bauxite mining.

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REFERENCES

1. Kusin FM, Rahman MS, Madzin Z, Jusop S, Mohamat-Yusuff F, Ariffin M. The occurrence and potential ecological risk assessment of bauxite mine-impacted water and sediments in Kuantan, Pahang, Malaysia. Environmental Science and Pollution Research. 2017 Jan 1;24(2):1306-21. doi.org/10.1007/s11356-016-7814-7
2. Lee KY, Ho LY, Tan KH, Tham YY, Ling SP, Qureshi AM, Ponnudurai T, Nordin R. Environmental and occupational health impact of bauxite mining in Malaysia: A Review. International Medical Journal Malaysia. 2017 Dec 1;16(2).
3. Murray HH. Bauxite. In: McGraw-Hill. 10th ed. McGraw Hill Encyclopedia of Science & Technology. New York: McGraw-Hill; 2007. pp. 654
4. Raghu A & Burton M. Soaring Malaysian bauxite exports a "game changer" for China supply. Available at: http://www.reuters.com/article/malaysia-bauxite-idUSL6N0T90NH20141121. Accessed on 21/11/2014.
5. Ahmad A. Pahang bauxite fast running out. Available at: http://www.thestar.com. Accessed on 13/01/2016.
6. Mai TT. Environmental and social impacts of bauxite exploitation in central highlands of Vietnam. Available at: http://www.vlink.com. Accessed on 25/05/2014
7. US Environmental Protection Agency. A review of reference dose and reference concentration processes. Available at: https://www.epa.gov/sites/production/files/2014-12/documents/rfd-final.pdf. Accessed on 21/11/2014.
8. US Environmental Protection Agency. Exposure Factors Handbook: 2011 Edition. Available at: http://www.epa.gov/ncea/efh/report.html. Accessed on 16/08/2016.
9. US Environmental Protection Agency. Determination of metals in ambient particulate

matter analysis by Inductively Coupled Plasma/ Mass Spectrometry (ICP/MS). Available at: https://www3.epa.gov/ttnamti1/files/ambient/inorganic/mthd-3-5.pdf. Accessed on 16/08/2016.
10. Ismail SN, Abidin EZ, Praveena SM, Rasdi I, Mohamad S, Ismail W, Isharman WM. Heavy metals in soil of the tropical climate bauxite mining area in Malaysia. Journal of Physical Science. 2018 Sep 2;29. doi.org/10.21315/jps2018.29.s3.2
11. Lemeshow S, Homser DW Jr, Klar J, Lwanga SK 1990: Adequacy of sample size in health studies. Chichester: John Wiley & Sons for WHO.
12. Lard, R.J, and Samant, J.S. (2013). Environmental Effects of Bauxite Mining in the Western Ghats in South Maharashtra India. International Journal of Recent Scientific Research. Vol. 4(8):1275-1281.
13. National Institute for Occupational Safety and Health. Particulates not otherwise regulated, respirable 0600, Issue 3. In NIOSH Manual of Analytical Methods (NMAM) 4th Edition. Cincinnati Ohio: National Institute for Occupational Safety and Health; 1998. pp 1-6.
14. United States Environmental Protection Agency. Supplemental guidance for developing soil screening levels for superfund sites. Available at: http://www.epa.gov/superfund/health/conmedia/soil/index.htm. Accessed on 16/08/2016.
15. United States Environmental Protection Agency. Exposure factors handbook. Available at: https://www.nrc.gov/docs/ML1015/ML101590178.pdf. Accessed on 16/08/2016.
16. Department of Environment. New Malaysia ambient air quality standard. Available at: https://www.doe.gov.my/portalv1/wp-content/uploads/2013/01/Air-Quality-Standard-BI.pdf. Accessed on 10/01/2017.
17. United States Environmental Protection Agency. National ambient air quality standards (NAAQS) Table. Available at: https://www.epa.gov/criteria-air-pollutants/naaqs-table. Accessed on 13/02/2019
18. Agency for Toxic Substances and Disease Registry (ATSDR). ATSDR Toxic substances portal. Available at: https://www.atsdr.cdc.gov/substances/index.asp. Accessed on 13/02/2019
19. Agency for Toxic Substances and Disease Registry (ATSDR). Minimal Risk Levels (MRLs) for hazardous substances. Available at: https://www.atsdr.cdc.gov/minimalrisklevels/. Accessed on 13/02/2019.
20. Lard RJ, Samant JS. (2013). Environmental impact of bauxite mining in the Western Ghats in South Maharashtra India. International Journal of Recent Scientific Research. 2013. 4(8): 1275-81. doi: 10.24327/ijrsr.
21. Wang J, Sammis TW, Miller DR, Hiscox AL, Granucci D, Holmйn B, Kasumba J, Shukla MK, Dennis SO, Zhang X. Simulated regional PM_{10} dispersion from agricultural tilling operations using HYSPLIT. Transactions of the American Society of Agricultural and Biological Engineers. 2011;54(5):1659-67. doi: 10.13031/2013.39855
22. Maynard RL, Howard CV. Particulate Matter: Properties and Effects on Health Richmond Texas: Garland Science. 1999
23. Patra AK, Gautam S, Kumar P. Emissions and human health impact of particulate matter from surface mining operation—A review. Environmental Technology & Innovation. 2016 Apr 1;5:233-49. doi.org/10.1016/j.eti.2016.04.002
24. Chauhan SS. Mining, development and environment: A case study of Bijolia mining area in Rajasthan, India. Journal of Human Ecology. 2010 Jul 1;31(1):65-72. doi: 10.1080/09709274.2010.11906299
25. Zhang X, Chen W, Ma C, Zhan S. Modeling particulate matter emissions during mineral loading process under weak wind simulation. Science of the Total Environment. 2013 Apr 1;449:168-73. doi.org/10.1016/j.scitotenv.2013.01.050
26. Pandey B, Agrawal M, Singh S. Assessment of air pollution around coal mining area: emphasizing on spatial distributions, seasonal variations and heavy metals, using cluster and principal component analysis. Atmospheric Pollution Research. 2014 Jan 1;5(1):79-86. doi.org/10.5094/APR.2014.010
27. Ghose MK, Kundu NK. Deterioration of soil quality due to stockpiling in coal mining areas. International Journal of Environmental Studies. 2004 Jun 1;61(3):327-35. doi.org/10.1080/0020723032000093991
28. Liu H, Probst A, Liao B. Metal contamination of soils and crops affected by the Chenzhou lead/zinc mine spill (Hunan, China). Science of the Total Environment. 2005 Mar 1;339(1-3):153-66. doi.org/10.1016/j.scitotenv.2004.07.030
29. de la Campa AM, Jesъs D, Fernбndez-Caliani JC, Gonzбlez-Castanedo Y. Impact of abandoned mine waste on atmospheric respirable particulate matter in the historic mining district of Rio Tinto (Iberian Pyrite Belt). Environmental research. 2011 Nov 1;111(8): 1018-23.doi. org/10.1016/j.envres.2011.07.001.
30. World Health Organization. Evaluation of certain food additives and contaminants: sixty-seventh report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization Technical. Report Series. Available at: https://www.who.int/ipcs/publications/jecfa/reports/trs940.pdf. Accessed on 02/01/2016
31. Ogwuegbu MO, Muhanga W. Investigation of lead concentration in the blood of people in the copper belt province of Zambia. Journal of Environment. 2005;1:66-75.