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HEALTH RISK ASSESSMENT ON HEAVY METALS IN DRINKING AND SURFACE WATER OF COMMUNITIES IN BAUXITE MINING AREAS

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ABSTRACT

Background: The mining of bauxite ore in Kuantan, Pahang has been going since early 2013. Bauxite ore contains radionuclides and heavy metals by which uncontrolled bauxite mining, can pollute waterways. These can pose great threat to environment and human health. The study objectives were to determine and compare the concentrations of selected heavy metals; aluminium (Al), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and lead (Pb) in water as well as to evaluate the risk of drinking such water.

Materials and Methods: This study was conducted in residential area of Felda Bukit Goh (FBG), Jalan Besar Bukit Goh (JBBG) and Kuantan Port Flat (KPF). A total of 162 respondents were interviewed using self-construct questionnaire. Seventy-nine samples of drinking water and 6 samples of water from water treatment plant were collected and analysed using the Inductively Coupled Plasma–Mass Spectrometry (ICP-MS).

This cross-sectional study was conducted in Kuantan on 162 randomly selected respondents in three residential areas; FBG, JBBG and KPC. Questionnaires were used to obtain the socio-demographic background information and health symptoms.

Result: Results indicated that there were significant differences in Al, Ni and Cr concentrations between rivers near the bauxite mining activities in Kuantan. The health risk assessment for all heavy metals from drinking water indicated that there was no significant risk of non-carcinogenic adverse health effect for both adults and children. Meanwhile, the lifetime cancer risk (LCR) for carcinogenic heavy metals from drinking the water for adults and children were also within the acceptable limit.

Conclusion: The presence of heavy metals levels in drinking and river water at the beginning of the year, 2016 posed no health risk to the communities.

Keywords: Bauxite mining, heavy metals, inductively coupled plasma–mass spectrometry (ICP-MS), health risk assessment

1.0 Introduction

Bauxite is classified as a ferrous metal in which the production in 2012 is estimated at 117,232 ton, a decrease of 38% from 188,141 ton produced in 2011. All the bauxite produced by Malaysia was exported to Japan, Taiwan and Thailand. However, in 2015, the bauxite was produced at the rate of 1.5 million tons a month or 18 million tons a year to fulfil China massive demand of the bauxite ore to produce aluminium (Al). Malaysian bauxite production was not highly pure bauxite. For example, from ten tons of bauxite, only three tons of highly grades bauxite can be produced. Therefore, washing of the raw bauxite would upgrade the alumina content by eliminating the silica and other impurities (Rajah, 1986). Therefore, washing the bauxite ore will create a massive waste of heavy metal sludge that will have to be disposed locally.

Water pollution from the bauxite mining activity in Bukit Goh Kuantan (FBG) Pahang was a concern since the sources of the drinking water are from the rivers near the bauxite mining activities. The most remarkable impact was its implications on water quality and availability of water resources within the mining area. According to Pengurus Air Pahang Berhad (PAIP), the FBG residential area obtained their water sources from one of the rivers located near the bauxite mining area. The negative impacts of bauxite mining activities lead to environmental degradation, loss in biodiversity and create high environmental rehabilitation cost. Therefore, it is important to determine the heavy metal concentrations in the water consumed, to assess the possible health risk of water consumption. Thus, the findings of this study would answer as to whether the water sources from the rivers are safe for human consumption.

2.0 Materials and Methods

2.1 Sampling Method

2.1.1 Study Background

A cross-sectional study design was conducted in Kuantan district with many bauxite mining activities in January 2016. These areas are presently Felda oil palm plantations. Permission for conducting this study was obtained from the Felda Bukit Goh Management Office. 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).

One hundred and sixty-one households were selected randomly from the list of 400 households obtained from the Felda office. The household selected were more than 25% of the total households in the areas. From each of these households, respondents aged from 18 to 75 years participated in this study. The respondents resided within a radius of 0.5 to 1.0 kilometre from the bauxite mining areas and had volunteered to participate in the study. Face to face interview were carried out on respondents using questionnaires. The questionnaires were divided into several parts including social demographic, health symptoms and socio-psychosocial problem. In this research, the focus was on health symptoms of the respondents during the previous 1 to 6 months and the health risk of consuming the piped water supply to their houses.

2.1.2 Water Sample

Drinking water were sub-sampled from the tap of the selected households in FBG, JBGG and KPF. If the household had filter units, unfiltered and filtered water samples were taken for comparisons. About 78 unfiltered and 51 filtered tap water were sampled from these households. Before the sampling, the tap was fully turned on for water to run freely for 1 to 2 minutes, to ensure the interior of the nozzle was flushed and free from stagnant water. Water samples collected in new pre-cleaned acid rinsed high-density polyethylene (HDPE) bottles.

River water was sampled about 0.5m from the water surface of rivers namely, Sg. Mabok, Sg. Taweh, Sg. Riau, Sg Kuantan, Sg Reman and Sg. Pinang are in the bauxite mining areas. About 5 water samples were collected from the river as well as raw water before and treated water after the Water Treatment Plant.

The collected water was decanted from the collection vessels and immediately filtered through 0.45 pore diameter cellulose acetate (membrane) filters in the laboratory. The samples were then refrigerated at 1- 4^{o}C and cooled in the chiller before the analysis. All water samples were acidified with the nitric acid (HNO_3) for preservation. The heavy metals concentrations (As, Al, Cd, Cr, Pb and Ni elements) in the surface water were determined using Inductive Couple Plasma-Mass Spectrometer (ICP-MS). Analysis were carried out with reference to Method 3005 by EPA.

2.1.3 Health Risk Assessment

The potential health risk on the ingestion of drinking water which came from the river near bauxite mining area were determined. There are two categories of potential chronic health risk; non-carcinogenic and carcinogenic risk. For the non-carcinogenic risk, the exposure below which no adverse effects were observed is known as threshold dose (U.S. EPA 1989). Non-carcinogenic risk can be calculated and indicated by the hazard quotient (HQ). HQ is the ratio of exposure level of non-carcinogenic elements to the reference dose (RfD). According to United States Environmental Protection Agency (US EPA), if the value of HQ is less than one, then there is no significant risk of non-carcinogenic effects.

Carcinogenic health risk estimates the incremental probability that an individual would develop cancer over a lifetime because of a specific exposure to a carcinogenic chemical (US EPA, 1989). It is usually estimated using the lifetime cancer risk (LCR) indicator. LCR lower than 10^{-4} is acceptable.

2.1.4 Water Ingestion Exposure Dose

The water ingestion exposure dose was calculated for drinking water that exceeds the Malaysian Drinking Water Quality Standard (MDWQS). The concentration that exceeds the standard limit was being averaged to get the contaminant concentration (mg/L). Average daily doses (ADD) from ingestion of water can be calculated as follows:

$$ADD = \frac{C \times RW \times ET \times EF \times ED}{BW \times AT}$$

Where;

C = Pollution Concentration (mg/L)
RW = Water Ingestion Rate (L/day)
ET = Exposure time (hour/event)
EF = Exposure Frequency (day/year)
ED = Exposure Duration (year)
BW = Body Weight (kg)
AT = Average Time = ED x 365 days (Source: US EPA 1989)

The default value:

i. Water ingestion rate: Children 0.78 L/day and Adult 2 L/day.
ii. Exposure time to drinking water: Children 0.54 hour/event and Adult 0.71 hour/event.
iii. Exposure Frequency: 365 days/year
iv. Body Weight: Children 30 kgs/Adult 65 kgs
v. Exposure Duration: 2 years

3.0 Result

3.1 Heavy Metal in River

There were 6 rivers near the bauxite mining area of Bukit Goh, Kuantan (Table 1). Based on the results, there were significant differences ($p<0.001$) in Al, Ni and Cr concentrations between rivers near the bauxite mining areas. However, all the mean concentrations for the heavy metal were below the standard limit of Malaysian Interim National Water Quality Standard (INWQS) Standard for Class IIA/IIB.

There were 5 water treatment plant (WTP) in Kuantan namely WTP Bukit Sagu, WTP Sg. Lembing, WTP Bukit Ubi, WTP Semambu and Empangan Sungai Kobalt in which the authority gave access to their raw and treated water for sampling. The raw water from the WTP, were compared with the Malaysian Drinking Water Quality Standard (Recommended

Raw Water Quality) Acceptable Value while, the treated water were compared with the Malaysian Drinking Water Quality Standard (Maximum Acceptable Value). Results from Table 2 shows that there was no significant difference between the heavy metal levels in drinking water before and after the treatments.

A total of 78 samples of drinking water were collected which consist of 66 samples from FBG, 5 samples from the bauxite route JBBG and 7 samples from the KPCF. From 162 questionnaire responses, 146 (90.1%) used tap water as their major source of drinking water and 51 (66%) of the household sampled used water filter in their homes. Only Al showed significantly high concentrations in unfiltered drinking water (Table 3).

Table 1: The distribution in heavy metals concentrations from 6 rivers in the bauxite mining areas of Felda Bukit Goh

Rivers name	Mean					
	Al	As	Cd	Ni	Cr	Pb
Sg. Mabok	0.0118	0.0009	0.0009	0.0026	0.0013	0.0008
Sg. Riau	0.0594	0.0004	0.0047	0.0016	0.0005	0.0017
Sg Taweh and Sg. Riau intersection	0.0356	0.0005	0.0013	0.0012	0.0005	0.0018
Sg. Taweh (after bauxite washing site)	0.0677	0.0008	0.0003	0.0015	0.0007	0.0014
Sg Kuantan and Sg Reman intersection	0.0475	0.0061	0.0013	0.0004	0.0005	0.0233
Sg Reman	0.0552	0.0080	0.0005	0.0012	0.0011	0.0018
Sg. Kuantan	0.0207	0.0002	0.0011	0.0012	0.0017	0.0023
Sg. Pinang	0.2309	0.0002	0.0010	0.0013	0.0013	0.0030
Standard Deviation (SD)	±0.2036	±0.0020	±0.0014	±0.0007	±0.0005	±0.0076
Interim National Water Quality Standard (INWQS) Malaysia for River-Class IIA/IIB (mg/L)	-	0.05	0.01	0.05	0.05	-

3.2 Heavy Metal in Water Treatment Plant

Table 2: Comparison between level of heavy metals before and after the water treatment plant

Heavy Metals	[1] MDWQS Raw Water Acceptable Value (mg/L)	[2]MDWQS Maximum Acceptable Value (mg/L)	Median (IQR)		Mean Rank	Z	*p*
			Raw	Treated			
Al	-	0.2	0.5649 (0.0441)	0.0267 (0.070)	3.00, 2.00	-0.365	0.715
As	0.01	0.01	0.0004 (0.0006)	0.0003 (0.0003)	2.67, 2.00	-1.095	0.273
Cd	0.003	0.003	0.00001(0.00008)	0.0001 (0.0001)	1.00, 2.00	-0.447	0.655
Ni	-	0.005	0.0006 (0.0014)	0.0005 (0.0018)	2.00, 3.00	-0.365	0.715
Cr	0.05	0.05	0.0012 (0.0017)	0.0010 (0.0030)	1.00, 3.00	-1.461	0.144
Pb	0.05	0.01	0.0017 (0.0021)	0.0008(0.0016)	2.20, 0.00	-1.826	0.068

[1]MDWQS- Malaysian Drinking Water Quality Standard (Recommended Raw Water Quality) Acceptable Value
[2]MDWQS- Malaysian Drinking Water Quality Standard (Maximum Acceptable Value)

3.3 Heavy Metal in Drinking Water

Table 3: Comparison of heavy metal concentration in filter drinking water and unfiltered drinking water

Heavy Metals	MDWQS Maximum Acceptable Value (mg/L)	Median (IQR)		Mean Rank	Z	*p*
		Filter[a]	Unfiltered[b]			
Al	0.20	0.0293 (0.071)	0.1056 (0.0983)	14.64, 14.00	-2.710	0.007*
As	0.003	0.0003 (0.0012)	0.0002 (0.0003)	12.88, 15.04	-0.517	0.605
Cd	0.02	0.00003 (0.00004)	0.00005 (0.0001)	12.10, 11.81	-1.325	0.185
Ni	0.05	0.0013 (0.0023)	0.0013 (0.0028)	18.88, 15.24	-0.384	0.701
Cr	0.05	0.0012 (0.0014)	0.0009 (0.0012)	12.68, 16.32	-0.581	0.561
Pb	0.01	0.0009 (0.0042)	0.0011 (0.0029)	13.28, 15.44	-1.201	0.230

MDWQS- Malaysian Drinking Water Quality Standard (Maximum Acceptable Value)
Wilcoxcon Signed Rank Test
* Significant at *p*-value <0.01
a= N was 51
b= N was 78

3.4 Exposure Doses from Ingestion of Water

Based on Table 4, HQ for all heavy metals were < 1, indicating that there was no significant non-carcinogenic risk for both adult and children. There were about 14 houses which showed the Al levels of over the MDWQ Standard. One house showed As level exceeding the MDWQ standard, while 6 houses showed Pb levels exceeding the standard.

Table 4: Non-carcinogenic risk of water ingestion

Heavy Metals	Mean concentration (mg/L)	Exposure to Adult (mg/kg/day)	HQ	Exposure to children (mg/kg/day)	HQ
Al	0.552**	9.40×10^{-3}	1.34×10^{-3}	1.49×10^{-2}	2.12×10^{-3}
As	0.014**	6.64×10^{-6}	2.21 x 10-2	1.05×10^{-5}	3.5 x 10-2
Ni	0.0356	2.72×10^{-5}	2.25 x 10-2	2.74×10^{-5}	2.28 x 10-2
Pb	0.0335**	1.63×10^{-5}	4.66 x 10-3	2.58×10^{-5}	7.37 x 10-3

* HQ, hazard quotient < 1 indicates a not significant non-carcinogenic health effect.
**Exceeding the MDWQS (Malaysian Drinking Water Quality Standard-Maximum Acceptable Value)

The LCR for carcinogenic elements such as As, Ni, and Pb were lower than 10^{-4} for both adults and children (Table 5). Therefore, the LCR for water ingestion were regarded as acceptable.

Table 5: Lifetime cancer risk for water ingestion

Heavy Metals	Mean concentration (mg/L)	Exposure to Adult (mg/kg/day)	LCR	Exposure to children (mg/kg/day)	LCR
Al	0.552	-	-	-	-
As	0.014	6.64×10^{-6}	1.04×10^{-5}	1.05×10^{-5}	1.63×10^{-5}
Ni	0.0356	2.72×10^{-5}	7.07×10^{-6}	2.74×10^{-5}	1.83×10^{-7}
Pb	0.0335	1.63×10^{-5}	1.38×10^{-7}	2.58×10^{-5}	2.19×10^{-7}

**LCR > 1×10^{-6} indicates risk of developing cancer for an individual in a 1,000,000 population
**LCR > 1×10^{-4} indicates risk of developing cancer for an individual in a 10,000 population

3.5 Reported Health Symptoms.

Reported health symptoms among respondents were divided into 3 sections; general health, respiratory and dermal symptoms which were gathered using a questionnaire. Symptoms such as stress due to nuisances of dust, noise or heavy traffic, headache, vomit, diarrhoea and muscle cramp were included under general health symptoms. Symptoms such as dry cough, phlegm cough, asthma, dyspnoea (shortness of breath) and bronchitis were listed under respiratory symptoms, while itchiness, redness/rashes, and oedema were included under dermal health symptoms. Table 6 represents the number of health complaints reported by respondents exposed to bauxite mining activities within the last 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 6: 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	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)

4.0 Discussion

4.1 Heavy Metal Concentrations in Raw River and Treated Drinking Water

When rainfalls, the water droplet collected impurities from the air which reach the ground, streams and rivers with impurities in the surface run off. All of these elements from the bauxite dust were carried from the atmosphere to the rivers, lakes or reservoirs which supply drinking water for human residing in the area (Skeat, 1969). There was a high concern on the heavy metal contamination in river bodies among residences who also complaint of frequent interruption of water supply to residences at that time. Rivers was important not only to the community as a source of water supply but also to the fishing. This study showed there were significant difference in Al, Ni and Cr concentrations between the rivers near the bauxite mining activities ($p<0.001$). If the contamination continued, these toxic metals will accumulate in sediment which will further contaminate the surface water as well as the aquatic life. However, presently, the heavy metal concentrations in all the rivers studied were below the Malaysian Drinking Water Quality (MDWQ) Standard.

The results of this study also indicated that there was no significant difference in the water sampled before and after the Water Treatment Plant. The raw water was free from the heavy metal contaminants; therefore, the quality was maintained before and after the treatment plant. This was probably due to the moratorium which was enforced at the beginning of 2016.

Limitation of the study was the water sampling which was just grab sampling method. Ideally, it should be a continuous sampling to detect any fluctuation in the heavy metal content. Some parts of the rivers were also not accessible for sampling.

4.2 Heavy Metal in Drinking Water and Risk Assessment

Heavy metals which are taken into the body via drinking water, inhalation, ingestion, and skin absorption will accumulate in body tissue faster than the body's detoxification pathways to excrete them. As a result a gradual build-up of these toxins will occur in our organ (Schafer et al., 1985).

Some of the houses have filter unit in the kitchen. The filter helped to reduce the heavy metal content which were within the acceptable concentrations. However, the piped water which had high Al were not removed completely by the filter because out of the 6 elements only Al showed a significantly higher concentration in the unfiltered than the filtered tap water samples. The nervous systems were the target for Al toxicity. Al impairs the neurobehavioral of motor, sensory and cognitive function of human. These effects have been observed and recorded in animal studies (ATSDR 2011). Studies by ATSDR (1999) and Andia (2000) showed that Al can pose significant risk to the central nervous, skeletal and haematopoietic systems in animals as well as humans. Chronic exposure to Al in low concentrations and for a prolonged time, could contributed in Alzheimer‘s disease and related disorders.

From the risk assessment model, we found no significant risk of non-carcinogenic and carcinogenic adverse health effect of these toxic heavy metals (Pb, As, Cr) from water ingestion for both adult and children.

The limitation of the health risk assessment in this study included the exposure concentration which was taken from just grab sampling and not the mean of a continuous monitoring. The exposure to the heavy metals were the values of total element and not by the species or valency with assumption that the elements are soluble in water, thus can be absorbed by the stomach or intestinal linings.

4.3 Heavy Metals and Health Effects

The questionnaire responses were from 162 respondents, only 0.6% of them experienced health symptoms which they believed were caused by the mining activities near their house. The outcome of reported health symptoms among respondents found about 1% of them experienced health disturbance during the past 6 months.

The most sensitive target of Al toxicity is the nervous system. Impaired performance on neurobehavioral tests of motor function, sensory function, and cognitive function have been noticed in animals. Neurobehavioral alterations have been observed following exposure to adult and animals that exposed during gestation and or lactation. Children who are exposed to high levels of Al exhibit symptoms similar to those seen in adults, including neurological effects and skeletal effects (ATSDR, 2008)

Long term exposure to Pb for example, can contribute to acute or chronic damage to the nervous system on human especially children. It causes plumbism-tiredness, lassitude, abdominal discomfort, irritability, anaemia, bio-accumulation, impaired neurological and motor development, and damage to kidneys. Lead exposure either in womb, during infancy, or during childhood may result in delays or impairment of neurological development, neurobehavioral deficits including IQ deficits, low birth weight, and low gestational age, growth retardation, and delayed sexual maturation in girls (ATSDR, 2007). Other element such as Cd in human on long-term exposure is highly toxic; causes 'itai-itai' disease, painful rheumatic condition, cardio vascular system affected, gastro intestinal upsets and hyper tension following oral exposure.

Acute high dose oral exposure to inorganic As may cause nausea, vomiting, diarrhoea, cardiovascular effects and encephalopathy. Long term oral exposure to even low levels of inorganic As can cause dermal effects such as hyperpigmentation and hyperkeratosis, corns and warts and peripheral neuropathy, characterized as a numbness in the hands and feet that may progress to a painful “pins and needles” sensation. Children who are exposed to high levels of As exhibit symptoms similar to those seen in adult. However, there is some evidences that metabolism of inorganic arsenic in children were less efficient than in adults (ATSDR, 2007)

Chromium is used in metal alloys and pigments for paints, cement, paper, rubber, and others materials is known as carcinogenic and causes respiratory problems. Low-level exposure can irritate the skin and cause ulceration while long-term exposure can cause kidney and liver damage as well as damage to circulatory and nerve tissue.

5.0 Conclusion and recommendation

The river and drinking water had low heavy metals concentrations when compared to the Malaysian Interim National Water Quality Standard (MINWQS), Malaysian Drinking Water Standard and Food Act 1983 & Food Regulation 1985. As far as the bauxite mining activity was concerned, the presence of heavy metals levels were acceptable. These might be due to the time of sampling of the river and drinking water at the time when moratorium on bauxite was already enforced and the sampling were by grab sampling. In addition, heavy metals do not exist in soluble forms for a long time in waters, as they are present mainly as suspended colloids or are fixed by organic and mineral substances and due to their higher density, they will settle on sediment at the lower part of the river. It is recommended to analyse the sediment samples in order to confirm that these metals accumulate in sediments.

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Declaration

The authors declare no conflict of interest.

Authors’ contribution

Author 1: wrote the proposal, collected and analysed the data and wrote the manuscript, Author 2: is the principal investigator, wrote the proposal, designed the study, interpreted the results and drafted the manuscript, Author 3: collected the data and assisted the laboratory analysis and Author 4: participated in statistical analysis, risk assessment calculation and review the manuscript.

References

ATSDR. (2012). Agency for Toxic Subtances and Disease Registry Public Health Statement for Cadmium. Retrieved from http://www.atsdr.cdc.gov/PHS/PHS.asp?id=46&tid=15. Accessed online on 26 May 2016

ATSDR. (2012). Agency for Toxic Subtances and Disease Registry Public Health Statement for Chromium. Atlanta, GA.: U.S Department of Health and Human Services, Public Health Service.

ATSDR. (2008). Agency for Toxic Subtances and Disease Registry Toxicological Profile for Aluminum. Atlanta, GA.: U.S Department of Health and Human Services, Public Health Service.

ATSDR. (2007). Agency for Toxic Subtances and Disease Registry Toxicological Profile for Arsenic. Atlanta, GA.: U.S Department of Health and Human Services, Public Health Service.

ATSDR. (2007). Agency for Toxic Substances and Disease Registry Toxicological Profile for Lead. Retrieved from Atlanta, GA.: U.S Department of Health and Human Services, Public Health Service.

ATSDR. (2005). Agency for Toxic Substances and Disease Registry Toxicological Profile for Nickel. Atlanta, GA.: U.S Department of Health and Human Services, Public Health Service.

ATSDR (1999). Agency for Toxic Substances and Disease Registry. A Toxicological Profile for Aluminium. Atlanta, GA.: U.S Department of Health and Human Services, Public Health Service.

Clean Malaysia.com. (2015). Bauxite in Malaysia. Retrieve from http://cleanmalaysia.com/tag/bauxite-mining-in-malaysia. Accessed online on 26 May 2016

Andía, J. B. C. (2000). A dynamic Bone and Chronic Renal Failure: An overview. *The American Journal of the Medical Sciences*, *320*(2), 81-84.

EPA. (1989). Risk Assessment Guidance for Superfund Vol.1 Human Evaluation Manual (Part A) Interim Final. Environmental Protection Association. EPA/540/1-89/002.

Kabata-Pendias, A., & Pendias, H. (2001). Trace elements in Soils and Plants, 3rd ed. CRC Press. *Boca Raton, FL, USA.*

Malaysian Minerals.Com. (2015). The Gateway to Malaysian's Mineral Resource. Industry. Mineral Resources. Retrieved from http://malaysianminerals.com/index.php?option=com_content&task=view&id=21&Itemid=45. Accessed online on 10 October 2016

Malaysian Food Act (MFA). (1983). Malaysian Food and Drug. MDC Publishers Printer Sdn. Bhd. *Kuala Lumpur.*

Rajah, S. S (1986) Bauxite in the Kuantan Area, Peninsular Malaysia. *GEOSEA V Proceedings, Geological Society of Malaysia*. 1(19), 315-325

Schafer, S. G. (1985). The Interaction between Cadmium and Iron: A Review of the Literature. *Trace Elements in Medicine, 2*, 158-162.

Skeat, W., O., (1969). Manual of British Water Engineering Practice, Vol. B: Water Quality and Treatment. *The Institution of Water Engineers, London, England.*