

# A REVIEW OF THE OCCUPATIONAL AND ENVIRONMENTAL HEALTH HAZARDS OF BAUXITE MINING IN MALAYSIA

Ahmad Qureshi<sup>1</sup>, Rusli Nordin<sup>2</sup>, Krystal Yiqian<sup>3</sup>, Ho Hua<sup>4</sup>, Tan Hooi<sup>5</sup>, Tham Ying<sup>6</sup>,  
Shum Ling<sup>7</sup>, Thayaparan Ponnudurai<sup>8</sup>

<sup>1-8</sup> *Jeffrey Cheah School of Medicine and Health Sciences, Monash University Malaysia, Clinical School, No. 8, Jalan Masjid Abu Bakar, 80100 Johor Bahru, Johor, Malaysia*

*Email: <sup>1</sup>ahmadmqureshi@gmail.com  
<sup>2</sup>rusli.nordin@monash.edu*

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**Abstract:** This review aims to explore the potential occupational and environmental health hazards on lives of miners and neighbouring communities, in relation to bauxite mining in Malaysia. The mining related environmental issues include air, water and soil pollution due to bauxite dust; its leaching into water sources reduces soil fertility, affects agricultural food produce and aquatic life. Bauxite occupational exposure affects the health of miners, apart from negative health impacts on neighbouring communities; such as frequent respiratory symptoms, and contamination of drinking water. Other potential health effects of bauxite mining include noise-induced hearing loss and mental stress. This review describes the processes of bauxite mining, its components, the residual trace elements, and their impacts on environment and health of exposed workers and communities. It also discusses Malaysian legal requirements and occupational exposure standards for bauxite.

**Keywords:** Bauxite mining, occupational and environmental health hazards, Malaysia

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## Introduction

Aluminium (Al) metal is abundant in earth's outer layer or crust; comprising 7% by weight, which makes it the third most commonly found element after silicon and oxygen. It is highly reactive and exists in oxidized form, with other 250 minerals. Al possesses high chemical reactivity, and not been found in element form (IAI, 2008). Bauxite is the main source of global aluminium, providing 99% of metallic aluminium (IAI, 2008; 2015). Feldspars also contain aluminium; however, extraction is costly as it involves high energy consumption than bauxite (Donoghue *et. al*, 2014).

Bauxite was named after a town (Les Baux) in France where it was first found. It is the main ore of alumina (Al<sub>2</sub>O<sub>3</sub>), a precursor of aluminium production (IAI, 2015). Bauxite has red-brown colour and is a natural heterogeneous substance; comprising aluminium hydroxide (gibbsite, boehmite and diaspore). Other compounds are hematite, goethite, quartz, rutile/anatase, and kaolinite with few impurities (Mitchell *et. al*, 1961). Trace elements comprise arsenic, beryllium, cadmium, chromium, lead, manganese, mercury, nickel with natural radioactive substances (uranium and thorium). However, these substances can still be found in bauxite residue after alumina extraction (IAI, 2015).

Bauxite is a product of iron and silica rock (Mitchell *et. al*, 1961; IAI, 2008), which is formed by exposure of volcanic, sedimentary and metamorphic rocks to tropical or subtropical climate over millions years. That is why most of global bauxite is extracted from tropical regions, after undergoing weathering process in past (IAI, 2015). Main reserves have been found in Brazil, Guinea and Australia (Mitchell *et. al*, 1961; IAI, 2015). In Malaysia, the reserves are present in Sarawak (Bukit Batu, Bukit Gebong, Lundu-Sematan, and Tanjung Seberang), Sabah (Bukit Mengkabau and Labuk Valley), Johor (Sungai Rengit and Teluk Ramunia), and Pahang (Bukit Goh in Kuantan) (Tse, 2015).

Bauxite is mined from earth surface or from underground reserves. Most reserves are found in earth surface with 1 - 2 meter overburden; comprising top soil and vegetation (IAI, 2015). Underground deposits are found below a covering of other substances, which needs underground mining for cheaper extraction (Mitchell *et. al*, 1961; IAI, 2015). Surface mining is more frequent than underground mining as most reserves are near the surface, which are extracted by open-cut mining via open-pit method from the lateritic deposits of 4-6 meter thickness; lying below 10 meter overburden (Gardener and David, 2007). The deposits thickness vary, they are mined and processed via beneficiation process without any treatment to concentrate mineral. However, bauxite from Brazil and Vietnam contains a high proportion of clay which requires to be washed before processing (Donoghue *et. al*, 2014).

In the refinery Bayer process is used to refine bauxite into alumina by dissolving aluminium containing minerals in sodium hydroxide. These solids (bauxite residue, mud and sand) are washed or neutralized by using carbon dioxide or seawater treatment, then are collected in impoundments either by wet or dry disposal methods, providing 15–30% and 50–65% solids respectively (Gardener and David, 2007). Finally Hall-Heroult electrolytic process converts alumina to aluminium. To produce one ton of alumina we require 2-3 tons of bauxite, because it comprises 30-54% alumina (IAI, 2008), whereas 4-6 tons are needed to produce a ton of aluminium metal. Bauxite mining uses lesser energy than refining and electrolytic reduction process.

The current estimated global reserves stand over 70 billion tons; with Guinea leading the group with 25 billion tons (Donoghue *et. al*, 2014). There are ample aluminium reserves which at current demand can sustain another 100 years. With an increasing need of aluminium products, bauxite is in high demand, which compels new explorations to maintain the economic viability (IAI, 2008).

Apart from bauxite, the other known sources of aluminium comprise kaolin clay, shale oil, coal waste and mineral anorthosite (Gardener and David 2007), but current bauxite deposits are sufficient and economically feasible than the alternatives, so it is predicted that the methods of converting alternatives into aluminium will not go past the current levels (Mitchell *et. al*, 1961).

Recently many quarters in Malaysia have raised concerns about the negative effects of bauxite mining on environment and resident's health around Kuantan, Pahang, because of proximity of mines to the residential areas, and have created a scare among general public about its harms. Environmental pollution related to bauxite mining is a serious concern because of its direct effects along with the short and long term harms. We have noted that not enough research has been performed in this area, particularly in Malaysia; which stresses a detailed enquiry on bauxite mining to incorporate the impacts, standards of exposure and laws related to its mining. The purpose of this review is to add scientific information about the impacts of bauxite mining and its components on the environment and peoples' health, to initiate in depth reviews.

## **Materials and Methods**

### ***Search Strategy***

For the literature we searched Google Scholar and British Medical Journal (BMJ) to find the basic information about bauxite mining and its effects, while for the details and quality papers Cochrane Library was explored. The key words entered in Google Scholar were Bauxite Malaysia Review and search was restricted to Where My Words Occur.

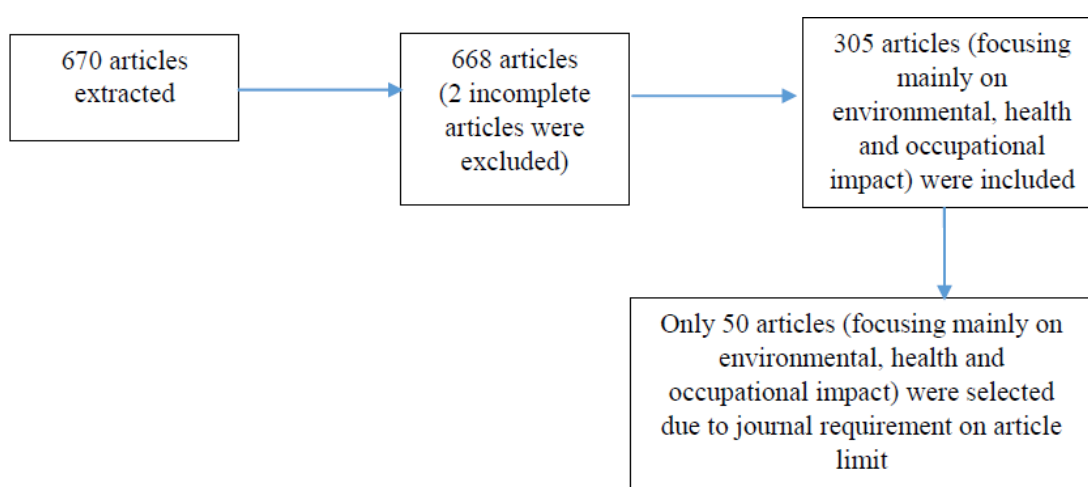
Ovid Medline and PubMed were explored to expand the search on environmental and occupational health impacts of bauxite mining; broad search terms were used to ensure inclusion of maximum studies. The key words entered in PubMed were Bauxite, Health Impact, Aluminium Oxide, Bauxite Refining, Bauxite Mining Respiratory and Bauxite Mining Occupational. However, our main search source was Ovid Medline due to extensive listing of articles, we applied Medical Subject Headings (MeSH) and Additional Limits for the

search. There was no Language restriction, and we reviewed all the studies published before 31<sup>st</sup> August, 2016.

### ***Selection Criteria***

For in depth review, studies were selected according to type of Ores mined and refined, while those under Kaolinite, Vermiculite Mining, Asbestos and Aluminium Nanoparticles were removed from the list. We also rejected articles or formal documents about meeting proceedings, strategic policy reports, new mining sites and studies on extraction process along with neutralization of bauxite and social issues of its mining.

Data from Western Australia, India, Mozambique, Surinam and other similar areas was incorporated, because of lack of Malaysian data. Our review included the articles on environmental impacts of bauxite mining; eg studies of microbial life, plant growth and soil contents.



*Figure 1, Illustration of articles selection criteria.*

### **Results**

According to the literature search, Australia was the main producer of global bauxite, contributing 29% in 2015 (80,000 tons) (Bray, 2016), followed by China (60,000 tons, 22%) and Brazil (35,000 tons, 13%); which is depicted in Figure 1. It is worth mentioning that Malaysian bauxite production showed a spike over one year period; from 3,260 tons in 2014 to 21,200 tons in 2015 (6.5 fold increase) which resulted from high Chinese demand after Indonesia banned its exports to promote local processing industry.

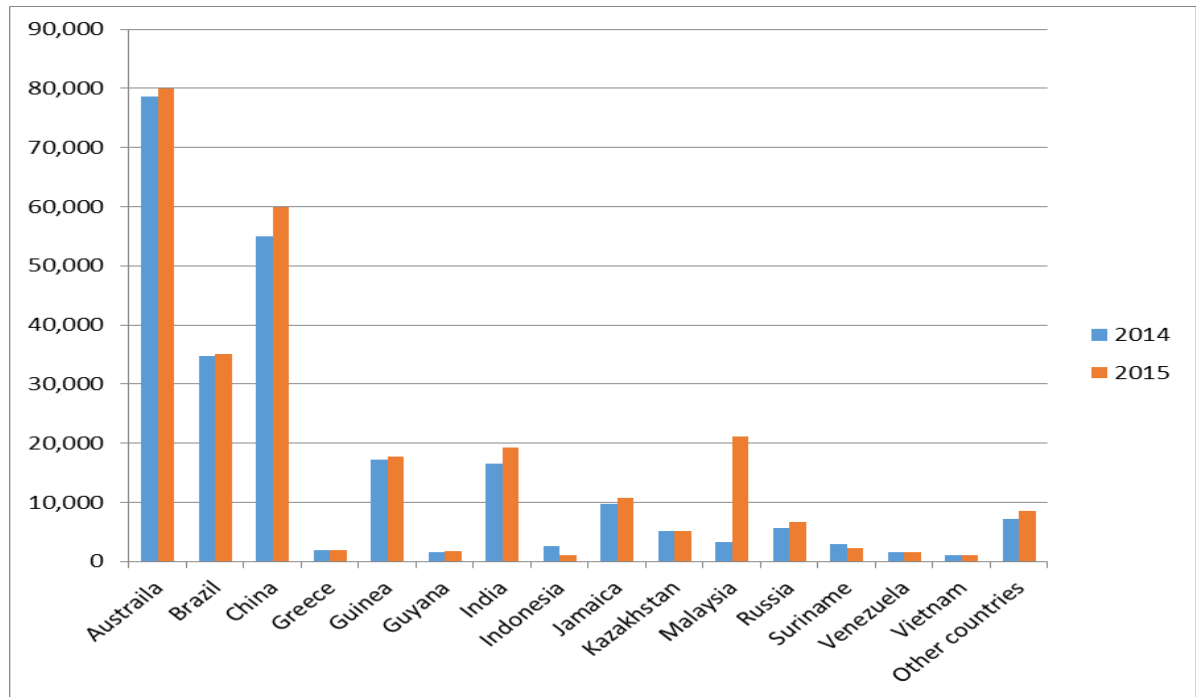


Figure 2, Bauxite amount produced by each country in 2014 and 2015 (in tons) (Bray, 2016)

Considering the bauxite reserves, largest deposits are found in Guinea (7,400,000 tons), followed by Australia (6,200,000 tons), Brazil (2,600,000 tons), Vietnam (2,100,000 tons), Jamaica (2,000,000 tons) and Indonesia (1,000,000 tons) (Bray, 2016). According to below figure, Malaysia holds about 40,000 tons of reserves, compared to other states.

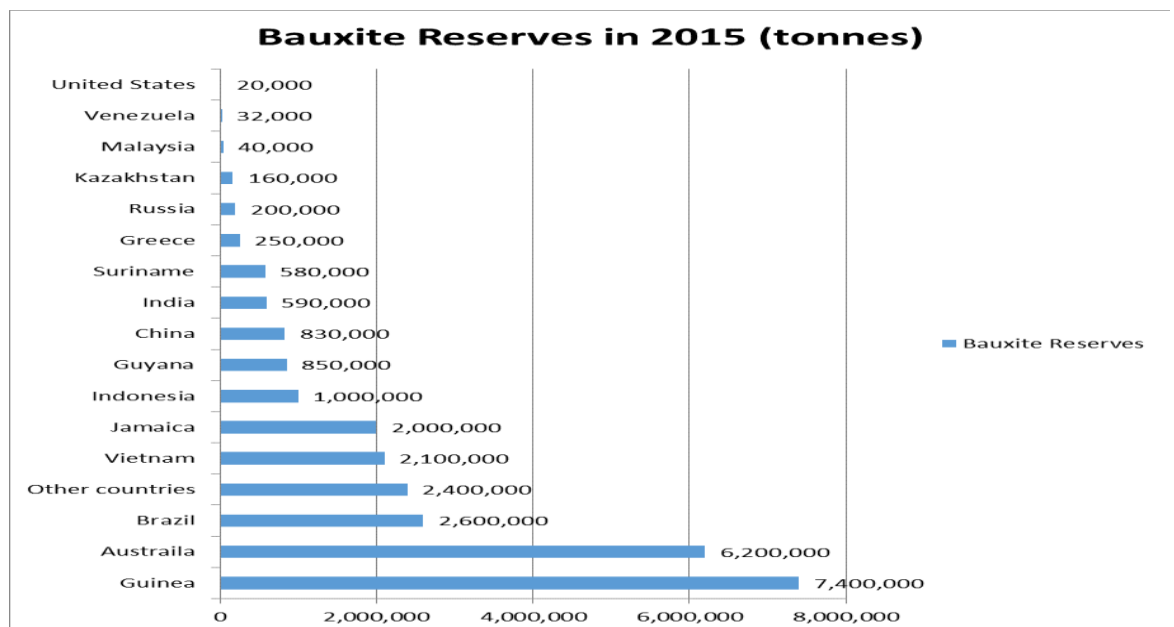


Figure 3, Bauxite reserves of each country in 2015 (Bray, 2016)

## **Environmental Impacts of Bauxite and its Mining**

The direct impacts of bauxite mining on environment include air, water and soil pollution, while indirect effects of environmental pollution are observed on the health of miners and surrounding communities.

### **Air Pollution**

The main problem related to bauxite is production of airborne particles due to mining activities. The International Standardization Organization (ISO) and British Standard Institute describe dust as; small solid particles below 75 µm diameter which settle due to own weight after brief suspension in air (Petavratzi and Lowndes, 2005). Other activities such as site clearance, road works, open-pit drilling, blasting, loading, haulage, vehicles movement, ore and waste rock handling also produce dust (Donoghue *et. al.*, 2014).

These particles are divided into coarse and fine categories. The coarse ones have a diameter of 1-10 µm, while fine category has a diameter of 0.1-1 µm. The coarse particles are generated from erosion, road dust, soil dispersion by wind and due to human activities; eg vehicle emissions (Gelencser *et. al.*, 2011), these pose fewer problems and are mostly deposited in larger airways to be coughed out. Whereas fine particles can reach alveoli to cause respiratory and cardiovascular diseases (Petavratzi and Lowndes, 2005; Abdullah *et. al.*, 2016). Bauxite dust may interact chemically with atmospheric air; affecting soil, plants, local climate and depending on their size can enter vegetation. It may get dissolved in water, flows down the food chain to be ingested by humans or aquatic animals (Petavratzi and Lowndes, 2005).

The dust is of red colour and can be seen due to its iron oxide; contaminating clothes, properties, plants, food and water sources (Hashim, 2016). From the occupational health perspective it is categorized as nuisance dust or particles not otherwise specified. The coarse particles harm environment quality, affect machinery, reduce visibility and are irritant (Petavratzi and Lowndes, 2005; Donoghue *et. al.*, 2014). Bauxite dust is harmful due to environmental changes and reduced visibility, it is deposited on machines and affects their life and productivity (Petavratzi and Lowndes, 2005).

Bauxite dust is inhaled as less than 10µm diameter particles, and is called Respirable Dust or Particulate Matter 10 (PM<sub>10</sub>) and PM<sub>2.5</sub>. In Kuantan, Pahang, during December 2015, 24-hour PM<sub>10</sub> levels hovered between 167 to 277 µg/m<sup>3</sup>, crossing the Malaysian National Ambient Air Quality Standards 2015 (Abdullah *et. al.*, 2016). According to World Health Organization, there is 'no safe level' for PM<sub>10</sub> and PM<sub>2.5</sub>, during breathing these particles deposit in alveoli and lead to rise in hospital admissions from respiratory and cardiovascular diseases (Petavratzi and Lowndes, 2005; Abdullah *et. al.*, 2016). Along with lung, nose and throat problems, eyes and exposed skin are also affected, as well as gastrointestinal tract. In some persons, dust can trigger allergic reactions such as asthma or eczema (Petavratzi and Lowndes, 2005).

### **Impact on Water Sources**

The main sources of world surface water comprise streams, rivers, springs, ponds and lakes, which interact with soil and rocks of their surfaces; with environmental temperature and pH affecting adsorption and desorption of inorganic and organic substances (Bradl, 2005). Bauxite mining contaminates water sources, especially drinking water, which become harmful due presence of iron, aluminium and traces of toxic heavy metals (arsenic, cadmium, lead, nickel, manganese and mercury) (Petavratzi and Lowndes, 2005). This is an outcome of heavy and aggressive mining activities.

The main impact of heavy metals is observed on river sediments, aquatic life, and water. Heavy metals are not degradable they get deposited in river sediments and are finally consumed by plants, animals or benthic life. A study conducted on river sediments affected by mining found that the concentration of heavy metals was 1000-100,000 times of water, whereas the concentration in fish and benthic animals was 10-1000 times higher. Heavy metals enter fish from water, food chain and by breathing (Yi and Zhang, 2011). After mobilization in water they reach downstream and get deposited in clay minerals or enter algae at lower food

chain (Bradl, 2005). When heavy metal accumulation reaches a critical level it affects the life in higher food chain, and aggravates the problem.

Mining activities produce acidic water which increases heavy metals solubility and causes harm to marine ecosystem, particularly at pH5 and below. Heavy metals affect ground water due to agricultural and industrial activities, whereas mining and land filling can pollute drinking and irrigation water. After leaching into soil and water, these metals affect air by surface erosion (Bradl, 2005).

The river near Kuantan bauxite mine is the main source of water for neighbouring residents with many water treatment plants located closeby (Abdullah *et. al*, 2016). The mining related river pollution has shut several down water treatment plants. The aluminium and mercury levels in nearby communities' water were 0.20mg/L and 0.0093mg/L, respectively, which is nine times higher than Health Ministry's recommended level. In contrary, Pahang State Health Department checks of drinking water noted that aluminium and iron levels were within the National Drinking Water Quality Standards (Hashim, 2016).

### **Impact on Soil**

Soil is the key element of ecosystem; it supplies plant nutrients, causes degradation and transference of biomass. In solid phase it consists of minerals and organic substances, while in the fluid phase it interacts with water (Bradl, 2005). In these phases ions interact and enter the soil, a higher concentration of heavy metals in soil is harmful, which suppresses these processes and biodegradation of organic matter, with lowering of the soil fertility that can affect agriculture by decreasing food quality and produce (Raymond, 2011).

Organic carbon is the indicator of soil quality, a research carried out on the soil of bauxite mines noted deficiency of plant nutrients (carbon, nitrogen, phosphorus, potassium, calcium and magnesium) which are important for normal growth. Also this soil contains high levels of Al, which limits microbial growth in soil. Under these conditions nutrients are not released into soil, suppressing plant growth in acidic medium and preventing land reclamation after mining (Lad, 2015). When soil contacts limestone during bauxite refining it turns into alkaline (Coke and Hill, 1987).

When reclaimed and un-mined lands were compared, the later showed a deeper soil depth and could grow deep-rooted trees and crops. Whereas the reclaimed soil depth was 15cm or less which could only grow a few crops. Studies proved that vegetables, root crops and legumes need at least a depth of 30cm, which was missing in reclaimed land (Coke and Hill, 1987).

Artificial pits formed during open cast mining contain large amounts of calcareous debris, which disturbs environmental balance by interrupting geo-morphological processes. Pre mining land clearance, deforestation and new road works affect the habitat; cause soil erosion and aggravate bio-diversity loss, with water pollution and increased turbidity. These impacts can be temporary or permanent; the temporary impacts need time and resources to reverse damage, whereas permanent impacts cannot be reversed (Mertzanis, 2011).

### **Impact of Bauxite Contaminated Soil on Food Produce**

Bauxite contaminated soil is harmful for health, because its components affect the quality of soil and agricultural water. In humans food is the main source of heavy metal exposure, than inhalation of particles, skin contact and drinking water. Heavy metals get absorbed through vegetable roots and are concentrated in edible parts however capacity to absorb and accumulate these metals varies across different vegetables (Zhou *et. al*, 2016). The accumulated heavy metals include lead, cadmium and arsenic.

Cadmium in soil gets mobilized and is taken up by plants and crops. This was supported by a study which noted that the crops grown on reclaimed bauxite mine land showed high level of cadmium. Apart from plant absorption, cadmium leaches into water sources and was discovered in aquatic animals which were consumed by humans. Long term cadmium intake causes kidney and bone problems, cancers, low birth weight and abortion. This highlights the dangers of crops grown on reclaimed bauxite mines. Other crops affected by leaching and accumulation of heavy metals include sweet potatoes, with lead levels exceeding CODEX safety margin (0.1mg/kg). Lead poisoning is deadly; it harms the nervous and reproductive systems, and affects child intelligence (Wright and Omoruyi, 2012).

### ***Occupational Exposures of Bauxite Mining***

#### **Physical Hazards**

The physical hazards of bauxite mining include noise, heat, humidity, and ergonomic issues, along with vibration, ultraviolet radiation and radioactive substances (Donoghue *et. al*, 2014; Wesdock and Arnold, 2014). Studies have observed traumas, but their incidence in bauxite mining is lower than coal and metals mining. Apart from blasting, drilling, excavating and crushing, mining machinery is the cause of noise (producing 85 to 106 dB) (Donoghue *et. al*, 2014).

Research has confirmed that noise is harmful to hearing at 10m distance. Many mines operate on 24-hours/day schedule exposing miners to continuous noise (Donoghue *et. al*, 2014; Wesdock and Arnold, 2014; Nanda, 2012), beyond permissible noise level (<85dB) and exposure duration (101 - 106 dB; 4 - 15 minutes) (Dangerous Decibels, 2016), which lists noise-induced hearing loss as the main hazard of bauxite mining (Donoghue *et. al*, 2014).

Many researchers have agreed that the amount of vibration exposure of a worker at workplace reflects the work conditions and types of machines used (Vanerkar *et. al*, 2008). Due to different machinery types used in bauxite mining (excavators, drilling rigs, scrapers and haulage trucks), the most common vibration hazard is whole-body vibration rather than hand-arm vibration (Donoghue *et. al*, 2014), but this can be minimized with proper maintenance of machines.

Most of bauxite mining is done in tropics, exposing workers to ultraviolet radiations that may cause skin cancers (Fritschi *et. al*, 2008; Donoghue *et. al*, 2014). One of surveys found a high incidence of melanoma among miners, but it was not significance (Fritschi *et. al*, 2008). Another study stated that outdoor work was not responsible for high melanoma risk. While heat and humidity cause heat-related illnesses; heat exhaustion and miliaria rubra (Donoghue *et. al*, 2014).

Bauxite contains traces of radioactive materials (uranium, thorium and potassium), but very few researchers have explored this aspect. Only one study has detected minimal radiations, which was below detection level and exposure risk (Carvalho *et. al*, 2013). A similar research from Australia reported that personal dose levels among workers performing various tasks were below the exposure limit (1.0 mSv/year). Though radioactivity does not have much impact on human health, but does require regular monitoring (Donoghue *et. al*, 2014).

#### **Chemical Hazards**

Bauxite is biologically inert with minimal chemical hazards. From occupational health perspective it is categorized as Nuisance Dust or Particle Not Otherwise Specified. Bauxite miners demonstrate frequent respiratory symptoms such as cough, wheeze and rhinitis, with self-reported symptoms ranging from 1.5% to 11.8% (Townsend *et. al*, 1985; Beach *et. al*, 2001; Donoghue *et. al*, 2014). These conditions are linked to bauxite dust that is generated by breaking and blasting of crust as well as digging and loading of ore on trucks.

Research on miners exposed to bauxite and silica found atypical airway responses; cough, increased mucous and reduced forced expiratory volume in 1 second (FEV<sub>1</sub>) (Townsend *et. al*, 1985). Another enquiry observed reduced FEV<sub>1</sub> (7.3mL/year), which was related to work duration (Beach *et. al*, 2001). The employment duration and FEV<sub>1</sub> had no relation with bauxite exposure. Other researchers stated that bauxite exposure did not cause lung symptoms or functions variations (Beach *et. al*, 2001; Dennekamp *et. al*, 2015). A single case of pulmonary fibrosis was found among workers exposed to bauxite crushing and transport with bauxite particles in affected area (Bellot *et. al*, 1984). Current research on bauxite exposure concluded that it does not result in pneumoconiosis (Friesen *et. al*, 2009; Donoghue *et. al*, 2014).

### **Cancer Incidence and Mortality**

An Australian research among bauxite and aluminium workers for cancer rate and death could not relate exposure with increased cancer death (Fritschi *et. al*, 2008). Many other enquiries support this finding and report that ultraviolet exposure did not result in frequent squamous or basal cell carcinoma. Another study found that melanomas and pleural mesotheliomas had no environmental or occupational link to aluminium industry (Fritschi *et. al*, 2008; Donoghue *et. al*, 2014). However one group of researchers noted the association between bauxite exposure and risk of non-cancerous respiratory sickness (Friesen *et. al*, 2009).

### **Biological Risks**

Salient biological risks among bauxite miners include communicable diseases such as malaria, dengue, human immunodeficiency virus (HIV) and tuberculosis which require prevention and treatment. Hence mitigation of these biological risks need mining companies investment for education, screening, diagnosis and treatment along with travel medicine consultations for the workers (Donoghue *et. al*, 2014).

### **Ergonomic Risks**

Recent bauxite mining with modern equipment requires minimal manual handling and poses few ergonomic risks (Donoghue *et. al*, 2014). However, due to long shifts and extended work hours fatigue is an issue. Workplace control measures have been placed for monitoring purpose and for cutting fatigue risk, along with solution of worker issues and roster modifications to control fatigue.

### **Impact on Surrounding Communities' Health**

As most of bauxite mines operate in remote areas with proper boundary, so only a few researchers could study their effects on neighbouring communities. One research has listed the acute and chronic effects; acute were related to short term dust exposure, vehicle accidents, vector related diseases and work stress and can turn into chronic effects. Chronic effects arise from air, water and soil pollution (Hashim, 2016).

### **Health Impact of Dust Particles**

A research has focussed on open cut mining and large particles release in environment; contaminating property, water, food and clothes and affecting individuals comfort. These particles irritate eyes, nose and throat (WHO, 2004), they collect on plants and render them unfit for human and animal consumption (Hashim, 2016). Fine bauxite particles (10 and 2.5 micron diameter) go deep in respiratory tract and cause frequent hospital visits due to cardiovascular and respiratory conditions along with early death (WHO, 2004). This is more harmful for kids as they have smaller lungs than adults, and end up with higher dust dose (Schuepp and Sly, 2012), which has led to frequent asthma and upper respiratory infections in Kuantan area. Local clinics data associated this to high PM<sub>10</sub> levels (164 to 277µg/m<sup>3</sup>); violating Malaysian National Ambient Air Quality Standards 2015 (Hashim, 2016).

### **Health Impact of Bauxite and Heavy Metals Contamination**

Bauxite mining pollutes water (especially drinking water), which causes harm due to aluminium hydroxide, iron oxide and heavy metal intake (Hashim, 2016). Aluminium is nerve poison and has been associated with



Alzheimer's disease; though evidence is weak. High aluminium exposure in children has been associated with bone disease due to low phosphate absorption (Flaten, 2001; Hashim, 2016). Continuous intake of iron oxide from bauxite result in iron overload with gastrointestinal and liver disease, cardio-myopathy, diabetes, joint and skin problems (increased pigmentation) (IDI, 2009).

Long term intake of these metals causes organ toxicity and increases cancer risk (Barceloux, 1999; Ratnaïke, 2003; Nawrot *et. al.*, 2006; Hashim, 2016). Heavy metals collect in food items and drinking water, affecting whole food chain. They appear in seafood and are consumed by people. These comprise lead, arsenic, mercury, cadmium, chromium, manganese and nickel and cause central and peripheral nerve harm. They affect nervous and cognitive functions, increases renal toxicity, with hypertension, cardiovascular problems, skin sensitivity and high mortality (Barceloux, 1999; Satoh, 2000; Lustberg and Silbergeld, 2002; Ratnaïke, 2003; Crossgrove, 2004; Nawrot *et. al.*, 2006; Das *et. al.*, 2008; Flora *et. al.*, 2012; Bernhoft, 2012; Bernhoft, 2013). In children, heavy metals are linked to high death risk, delayed nerve development, intellectual and behavioural problems, as well as peripheral nerve damage and hearing loss (Satoh, 2000; Crossgrove, 2004; Flora *et. al.*, 2012).

Mercury and cadmium toxicity is dangerous. Long term mercury poisoning causes Minamata disease due to intake of methyl mercury containing seafood, or from workplace exposure. Mercury passes through blood-brain barrier, affects the brain and causes neurological problems; such as weakness, tiredness, tremors and loss of motor control, with ataxia and sensory loss affecting sight, hearing and speech (Satoh, 2000; Bernhoft, 2012). Long term cadmium exposure causes renal and bone toxicity and manifest as Itai-Itai disease with fractures, osteoporosis, osteomalacia and renal tubular malfunction (Bernhoft, 2013). Cadmium has been linked to lung cancer and emphysema (Nawrot *et. al.*, 2006).

### **Health Impact of Noise**

One research teams has noted that noise affects the bauxite miners and nearby residents due to 24/7 mining operations. The observed health effects include noise-induced hearing loss, reduced hearing sensitivity and sleep problems; noise also exerts cardiovascular, physiological, behavioural and cognitive impacts. While people living close to mines feels mental stress (Hashim, 2016), bauxite also turns the surroundings into dark red due to iron oxide; this poor visibility can lead to mental stress. The detrimental health impacts of bauxite dust are observed on persons, water and food sources.

### **Discussion**

#### ***Environmental Impacts of Bauxite Mining***

The environmental impacts of bauxite mining are mainly seen on air, water and soil. As air pollutant bauxite dust interferes the visibility (Petavratzi and Lowndes, 2005; Donoghue *et. al.*, 2014), it settles on plants, food, and airways and causes chronic cardio respiratory problems (Petavratzi and Lowndes, 2005; Hashim, 2016).

We lack information about bauxite related water pollution and its effects on humans as little research has been done on this. Bauxite and heavy metals present in river sediments can be taken up by aquatic animals or plants, that affects different food chain levels (Yi and Zhang, 2011).

Agricultural activities cause soil pollution by affecting the fertile topsoil; and even the restoration methods could not reverse barren soil to its original fertile status (Coke and Hill, 1987). The plants absorb heavy metals from soil, which triggers consumer food safety issues (Wright and Omoruyi, 2012). The destruction of habitat affects the diversity of flora and fauna, which is a distinct feature of Malaysia as a tropical forest country.

## **Occupational Health Hazards**

Noise-induced hearing loss is among the salient occupational hazards of bauxite mining. Chronic noise exposure reduces hearing sensitivity, affects sleep with cardiovascular, physiological and mental health problems; chronic noise also affects behavioural and cognitive performance (Hashim, 2016). Hearing protection can help to control these issues (Donoghue *et. al*, 2014; Donoghue *et. al*, 2016).

Vibration is another mining equipment related hazard; particularly whole-body vibration and can lead to spinal problems (Donoghue *et. al*, 2014). Heat and humidity can result in heat exhaustion and miliaria, while ultraviolet and other radiations in bauxite mines have not been shown to increase the risk of skin malignancy or other health issues (Fritschi *et. al*, 2008; Carvalho *et. al*, 2013; Donoghue *et. al*, 2014).

Many studies have supported an association between respiratory features (cough, wheeze and rhinitis) and bauxite mining (Donoghue *et. al*, 2014). Despite previous proofs of relation between increased bauxite exposure and reduced FEV<sub>1</sub>; the latest research could not corroborate this relationship (Townsend *et. al*, 1985; Beach *et. al*, 2001; Dennekamp *et. al*, 2015). Clinicians have found a case of lung fibrosis among exposed workers, but it was not due to bauxite pneumoconiosis. Also, bauxite mining is not a cause of skin cancers, pleural mesothelioma and high cancer deaths (Fritschi *et. al*, 2008; Friesen, 2009; Donoghue *et. al*, 2014).

## **Impact on Neighbouring Communities**

As discussed earlier, only a few papers have explored the bauxite mining effects on neighbouring populations, because mines usually operate in remote areas with proper boundaries. In contrary, Kuantan mines are dispersed widely, lack demarcations and are close to the populations, thus exerting negative health effects on neighbouring residents (Hashim, 2016).

The short term effects of bauxite mining are associated with dust exposure and vector borne diseases, whereas chronic effects are due to dust particles which contaminate food and water; and result in lung infections or ailments (Hashim, 2016). The other hazard is leaching of heavy metals and bauxite products into water; exerting chronic effects on adults and children, such as nerve and renal toxicity, cardiovascular conditions and delayed nerve development with high risk of cancer and death (Barceloux, 1999; Ratnaike, 2003; Nawrot *et. al*, 2006; Hashim, 2016). Noise affects the health of populations living close to bauxite mines, with lowered hearing sensitivity and increased noise induced hearing loss (Hashim, 2016). All these impacts cause mental stress among neighbouring communities.

## **Permissible Exposure Limits and Biological Exposure Indices of Bauxite**

### ***Permissible Exposure Limits (PELs) of Bauxite***

During 1970s, U.S. Occupational Safety and Health Administration (OSHA) established permissible exposure limits (PELs) for hazardous substance, which from worker protection point are now deemed obsolete; but has remained unchanged. However OSHA's Z-1 Table for PELs is still valid and utilized for Occupational Exposure Limits (OELs), while exposures exceeding these levels are considered harmful despite PELs compliance (OSHA, 1970).

In many countries OELs are the criteria for airborne vapours, particles and gases; while for airborne chemical concentrations, American Conference of Governmental Industrial Hygienists (ACGIH) has devised Threshold Limit Values (TLVs), assuming a situation where majority of workers are frequently exposed without adverse event (OSHA, 1970). Malaysia uses PELs mentioned under Occupational Safety and Health Act 1994 - Schedule 1: Use and Standards of Exposure to Chemicals Hazardous to Health Regulations 2000 (ILO, 2016;

USECHH, 2000). However, OELs have been established and frequently updated for chemicals listed in OSHA Z-1 Table and are referred for latest values and notations (OSHA, 1970).

### **Biological Exposure Indices (BEIs) for Bauxite**

Chemicals levels detected in biological specimens (exhaled air, blood and urine) of healthy workers having chemical exposures which are equal to workers with inhalation TLVs are called Biological Exposure Indices (BEIs) (ACGIH, 2012). BEIs are considered biological monitoring guide to assess worker exposure and health risks. The chemical exposure dose of a worker is measured via biological monitoring.

BEIs are the concentrations below which majority of workers do not feel negative health effects. A chemical, its metabolite levels or biochemical transformations provide BEIs, but fails to measure negative effects to diagnose occupational disease, or to differentiate hazardous from non-hazardous exposures. Excess health risks are not observed even after chemical levels violate the BEIs. Investigations are recommended after workers' samples remain higher than BEIs or most of the staff from same work area or shift show levels above BEIs.

BEIs and TLVs reflect uptake of chemicals and inhalation exposure of person or group respectively, by air monitoring. There might be differences between biological and air monitoring data due to difference in individual's physiology or health status, such as habit, diet, metabolism, age, gender, body fluid composition, medicines consumption, pregnancy and illnesses; or due to person's occupational exposure including rate, intensity and duration of work, temperature and humidity, exposure to irritants, skin exposure and other work routines; or from non-occupational exposures that include water, food, personal hygiene, home air pollution, alcohol and drug consumption, smoking or exposure to domestic products or hobby chemicals.

The variations may result from method related causes such as contamination of specimen or analysis method bias, or due to placement of air monitoring device with reference to person's breathing zone, or due to particle size and its bioavailability or from variations in effectiveness of personal protective devices.

### **Malaysian Legal Requirements and Standards of Exposure to Bauxite**

In 2012, Malaysian Department of Environment (DOE) finalized the policy to site and zone industrial and residential areas, its purpose was to provide a reference for project developers, federal, state and local governments, about feasibility of a site for specific industrial or non-industrial use which might exert negative environmental impacts (DOE, 2012).

The prime objective of this guideline is to assist in proper selection of a site, to reduce or eliminate the environmental impacts that may occur due to mismatch between a project, process and nearby localities (DOE, 2012). The main purpose of environmental planning is to prevent problems by judicious siting, to achieve long term project sustainability and to the cut cost of pollution control measures to improve project's perception among public. These principles also apply to the extraction and production of other natural sources, such as minerals and rocks.

According to Environmental Quality Act 1974 (EQA 1974), any process or activity which releases, discharges or emits pollutants and may impact the environment, must obtain comment, consent or approval of Director General of Environmental Quality, about suitability assessment of site, Environmental Impact Assessment (EIA), written permission, approval and licensing etc. EQA 1974 is associated with prevention, reduction and control of pollution and environmental quality improvement that may arise due to industrial and non-industrial activity and might produce waste or pollutants which may affect the quality of environment (DOE, 2012).

According to Mineral Development Act 1994 (Act 525); to mine is to intentionally mine minerals and includes any operation directly or indirectly and necessary therefore or incidental thereto, and mining shall be

construed accordingly. Mineral is a naturally occurring element or chemical compound that is formed as a result of geologic processes.

Under Environmental Quality Order 1987, mining is regulated as a prescribed activity and includes mineral mining in new locations where lease covers over 250 hectares area; ore processing including concentrations of aluminium, copper, gold or tantalum; and sand dredging over an area of 50 hectares or more.

Process of mining is initiated with discovery and exploration of minerals, it proceeds with extraction, processing and finally culminates in workplace closure and remedial measures. According to the guidelines, buffer zone is area of separation between two or more areas to control hazards and to protect environment (DOE, 2012). Buffer zones are for the safety and protection of humans, property and ecology.

Buffer zone determines a site's suitability for a specific industry or activities keeping in mind its short term use, the neighbouring land use along with features of receptors around that area. In buffer zone area incompatible land use is not allowed and specific procedures are employed to minimize the effects of such activities (DOE, 2012). In fact, buffer zone cannot replace prevention and control at source or management standards for activities having environmental impact; rather it provides extra protection to control offsite impacts of residues that exist despite preventive procedures; at least one km distance is recommended as primary buffer.

Bauxite mining discharges large amounts of waste water along with residual contaminants, and according to industrial classification and polluting hazardous activities is deemed a high risk activity that is almost untreatable (DOE, 2012).

## Conclusion

This literature review has discussed the environmental effects of bauxite mining that occur by eco system destruction; impacting air, water, food, soil along with flora and fauna of the mining sites. Bauxite mining activities has impacts on health of miners and nearby residents, apart from environmental pollution (which was noted in Kuantan), as mines lack proper boundaries and are located close to nearby communities. We noted a knowledge vacuum about chronic health effects of bauxite mining, as these diseases take a long time to appear; during late stages of life. Therefore, an in-depth enquiry is suggested on areas which need management and control measures to minimize environmental impacts of bauxite mining, apart from negative health effects on humans.

## Conflict of Interest

The authors declare no conflict of interest.

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