UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF ENVIRONMENTAL HEALTH RISK TO RESPIRABLE DUST AND HEAVY METALS IN AIR AND SOIL FROM BAUXITE MINING AREAS IN FELDA BUKIT GOH AND KUANTAN PORT FLAT, PAHANG

INTAN NOR LYANA SAJALI

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BY

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In the name of Allah, the Most Gracious and Most Merciful.

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ABSTRACT

ASSESSMENT OF ENVIRONMENTAL HEALTH RISK TO RESPIRABLE DUST AND HEAVY METALS IN AIR AND SOIL FROM BAUXITE MINING AREAS IN FELDA BUKIT GOH AND KUANTAN PORT FLAT, PAHANG

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Background: Bauxite mining activities in Kuantan, Pahang seems to give harm by releasing hazardous waste such as dust, toxic chemicals and radioactive substances. These environmental and health effect of the mining activities have been a public concern recently, hence, need to be addressed. Therefore, the objectives of this study were: (1) to determine particulate matter (PM_{10}) and heavy metal levels (Al, Cd, As, Cr, Ni and Pb) of red dust in the air and soil sedimentation within the household in the area surrounding the mines and (2) to assess the environmental health risk of bauxite mining activities in Kuantan, Pahang. **Methodology:** Cross-sectional study was conducted on 162 randomly selected households in the three different residential area; Felda Bukit Goh, Jalan Besar Bukit Goh and Kuantan Port Consortium flat. Respondents were interviewed using self-constructed questionnaire to collect information on their background and the health symptoms. For environmental sampling 42 households were sub-sampled and surface soil samples were collected from respondents' households, while PM_{10} and selected heavy metals level in household area were measured by Gillian air sampling pumps that were equipped with filter paper for 24 hours period. **Results:** The results showed that the PM_{10} level exceeded the limit value of 150 $\mu g/m^3$ for 24 hours exposure. Level for Al, Cd, As, Cr, Ni and Pb in ambient air were found exceeding the U.S Department of Health and Human Services (ATSDR) limit value, meanwhile for soil, all heavy metals does not exceeded the value recommended by Standard of Dutch Target. The health risk assessment for the population exposed to bauxite mining activities also indicated that the inhalation exposure did not pose any health hazard except for cadmium in Jalan Besar Bukit Goh (4.1328), chromium; Felda Bukit Goh (74.0560), Jalan Besar Bukit Goh (84.4088), Kuantan Port Consortium Flat (76.8655) and nickel; Felda Bukit Goh (60.5322), Jalan Besar Bukit Goh (66.9509), Kuantan Port Consortium Flat (58.8111). The lifetime cancer risk also did not show any significant hazard as the lifetime excess cancer risk were less than 10^{-6} except for chromium; Felda Bukit Goh (2.5234×10^{-2}), Jalan Besar Bukit Goh (2.8763×10^{-2}), and Kuantan Port Consortium Flat (2.6191×10^{-2}).**Conclusion:** From the findings it can be concluded that the overall PM_{10} levels exceeded the Malaysian Ambient Air Quality Guidelines (MAAQG, 2015). Heavy metal levels in ambient air exceeded the limit value and might have influence on the health symptoms among respondents, meanwhile, heavy metals levels in soil were low and did not exceed the recommended value.

Keywords: Particulate Matter (PM_{10}), Respiratory Symptoms, Dermal Symptoms

ABSTRAK

PENILAIAN RISIKO KESIHATAN PERSEKITARAN TERHADAP PARTIKEL TERNAFAS DAN LOGAM BERAT YANG TERDAPAT DI DALAM TANAH DAN UDARA DI KAWASAN PERLOMBONGAN BAUKSIT DI FELDA BUKIT GOH DAN FLAT PELABUHAN KUANTAN, PAHANG

INTAN NOR LYANA BINTI SAJALI

Latar Belakang: Aktiviti perlombongan bauksit di Kuantan, Pahang dipercayai membahayakan penduduk setempat akibat pelepasan sisa berbahaya seperti debu, bahan kimia toksik dan bahan-bahan radioaktif. Kesan-kesan terhadap alam sekitar dan kesihatan akibat daripada aktiviti perlombongan ini telah menarik perhatian orang ramai dan perlu ditangani. Justeru itu, tujuan kajian ini adalah (1) untuk menentukan tahap partikel ternafas (PM_{10}) dan logam berat yang terpilih (Al, Cd, As, Cr, Ni dan Pb) yang terdapat di udara dan tanah termendap dalam kawasan rumah penduduk di sekitar lombong dan (2) untuk menilai risiko kesihatan alam sekitar daripada bauksit aktiviti perlombongan di Kuantan, Pahang. **Kaedah:** Satu kajian rentas telah dijalankan di 162 rumah yang dipilih secara rawak di tiga kawasan perumahan yang berbeza; Felda Bukit Goh, Jalan Besar Bukit Goh dan perumahan kakitangan Kuantan Port Consortium. Responden telah ditemuramah menggunakan borang soal selidik yang dirangka sendiri meliputi latar belakang responden dan gejala-gejala kesihatan yang dialami. Bagi persampelan alam sekitar, sebanyak 42 sampel permukaan tanah telah diambil dari kawasan rumah responden, manakala kepekatan PM_{10} dan logam berat terpilih di kawasan rumah diukur menggunakan 'Gillian air volume sampler' yang dilengkapi dengan kertas penapis untuk tempoh 24 jam. **Keputusan:** Hasil kajian menunjukkan bahawa tahap PM_{10} melebihi nilai had logam berat di udara melebihi nilai had 150 $\mu g / m^3$ bagi pendedahan 24 jam. Tahap kepekatan untuk Al, Cd, As, Cr, Ni dan Pb dalam udara didapati melebihi piawaian 'U.S Department of Health and Human Services (ATSDR)', sementara untuk tanah, semua logam berat tidak melebihi nilai yang disyorkan oleh Dutch Target. Penilaian risiko kesihatan bagi penduduk yang terdedah kepada aktiviti perlombongan bauksit juga menunjukkan bahawa pendedahan penyedutan tidak menimbulkan apa-apa bahaya kesihatan kecuali untuk kadmium di Jalan Besar Bukit Goh (4.1328), kromium; Felda Bukit Goh (74.0560), Jalan Besar Bukit Goh (84.4088), apartmen pelabuhan Kuantan (76.8655) dan nikel; Felda Bukit Goh (60.5322), Jalan Besar Bukit Goh (66.9509), dan apartmen pelabuhan Kuantan (58.8111). Risiko kanser seumur hidup juga tidak menunjukkan apa-apa bahaya yang ketara kerana semua logam berat kurang daripada 10^{-6} kecuali khromium; Felda Bukit Goh (2.5234 x 10^{-2}), Jalan Besar Bukit Goh (2.8763 x 10^{-2}), dan apartmen pelabuhan Kuantan (2.6191 x 10^{-2}). **Kesimpulan:** Dari hasil kajian dapat disimpulkan bahawa keseluruhan bacaan bagi PM_{10} melebihi Garis Panduan Kualiti Udara Persekitaran Malaysia (MAAQG, 2015). Tahap logam berat terpilih dalam udara melebihi nilai had seperti dalam garis dan mungkin memberikan pengaruh kepada gejala-gejala kesihatan dalam kalangan responden. Sementara itu, bagi tahap logam berat terpilih adalah rendah dan tidak melebihi nilai yang disyorkan.

Kata Kunci: Partikel ternafas (PM_{10}), simptom pernafasan, simptom kulit

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LIST OF ABBREVIATIONS

$\mu g/m^3$	Microgram per meter cubic
mg/m^3	Miligram per meter cubic
ATS	American Thoracic Society
ATSDR	Agency for Toxic Substances in Disease Registry
EPA	Environmental Protection Agency
FBG	Felda Bukit Goh
KPC	Kuantan Port Consortium
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
NAAQS	National Ambient Air Quality Standard
NAM 0600	NIOSH Analytical Method 0600
PM_{10}	Particulate Matter with a diameter of 10 micron
SPSS	Statistical Package for Social Science
UNEP/GPA	United Nations Environmental Protection/Global Program of Action
US EPA	U.S. Environmental Protection Agency
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background of study

Bauxite is an aluminum-rich sedimentary rock (Figure 1). It is the principal ore of aluminum. Aluminum in bauxite is hosted by aluminum hydroxide minerals, mostly gibbsite (Deer *et al.*, 1996). The major impurities are iron oxides and hydroxides (which gave reddish color to most bauxites) and clay minerals. The climate promotes vegetation that provides organic acids, which help to dissolve rocks in percolating water that carries more soluble components away, leaving only aluminum and also often iron as the least mobile common ions behind. This process is known as lateritization (Robb, 2005).

Figure 1.1: Regular shapes of bauxite rock. Width of sample 8 cm
(Source: http://www.sandatlas.org/bauxite/)

Extensive bauxite mostly deposited in Guinea (largest in the world), Australia, Brazil, India, Surinam, and Indonesia are lateritic deposits. Lateritic bauxites constitute more than three-fourths of the world's bauxite resources. The largest producer is Australia, which provides roughly one third (125 million metric tons annually) of the world's total output (Murray *et al.*, 2007). In 2014, Indonesia has suspended production of bauxite and nickel exports to China. As a result, bauxite mines have sprung up in Malaysia since late last year, notably in Pahang's state capital of Kuantan, an area along the east coast facing the South China Sea. Malaysia had been supplied 1.27 million tonnes of bauxite to China in the first nine months of last year, 12 times more than the 105,000 tonnes shipped in the same period for 2013 (Raghu and Burton, 2014).

Figure 1.2: Geographical area of bauxite mining activities of Felda Bukit Goh, Kuantan

(Source: www.google.com.my/maps)

The mining of bauxite ore in Kuantan, Pahang had started in small scale in Balok since early 2013, which later expanded to other areas like Bukit Goh and Sungai Karang. From some point, bauxite mining has been seen as an important economic activity which has the potential of contributing to the development of areas endowed with the resource. On an annual basis, more than 130 million tons of bauxite is extracted globally, and current estimates suggest that we have enough reserves sources for the next 400 years (Leigh, 2010).

Mining activities of bauxite have lots of environmental and health impacts. This has emanated from the methods of operation by the mining companies, its effects on the natural environment as well as the people in the surrounding communities. The health cost of mining operations sometimes outweighs the benefits gained.

The gains from the sector in the form of increased investment are being achieved, but not to the environment, health and social, recording series of public outcry against the mining companies operating in Kuantan, Pahang who themselves are yet to explicitly concede that their investments are inherently a major pollutant and a source of social conflicts around.

1.2 Problem Statement

The bauxite mining activities in Kuantan, Pahang has sudden increase in 2014 followed the ban of bauxite export from Indonesia in January 2014. Based on a report by

The Star on 19 December 2015, mining activities in Kuantan increase from, a mere 208 770 tonnes in 2013 to 963 000 tonnes in 2014, to a staggering 20 million tonnes in 2015.

Few residential areas were located near to the mining sites and thus having the tendency to be exposed with particles and chemical toxic contained, emitted from the mining activities. In mining operation, dust is a primarily environmental problem caused by the earth excavation. Dust absolutely covers very large surrounding areas that affect the habitats, including residential and agricultural neighborhoods of the bauxite exploitation site (Mai, 2009). During mining processes, some metals and toxic chemicals were left behind as tailings scattered in environment and which could in long run become a cause of lung cancer for residents in the surrounding areas (Habashi, 1992).

This study mainly focused on the environmental and health effects of population from residential areas of Felda Bukit Goh, located near to the bauxite mining sites. According to Environmental Protection Agency (EPA, 2002), major concerns for human health from exposure of toxic particulate include effects on breathing and respiratory systems, damage to lung tissue, cancer and premature death. Health effects from the exposure of air pollutants may be experienced soon after exposure or possibly years later (EPA, 2006). Heavy metals contamination in soil may also pose risks and hazards to humans and the ecosystems through direct ingestion or contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal-human), and drinking of contaminated ground water.

These environmental and health effects of mining activities have been attracting public attention recently, hence, need to be addressed. In spite of the above, a thorough research into the current environmental and health impacts of bauxite mining in Kuantan, Pahang, as one of the main areas of bauxite mining in capital of is therefore a necessity. Hence, the aims of this study were to assess the potential carcinogenic and non-carcinogenic health risk due to bauxite mining activities by using Hazard Quotient (HQ) as proposed by U.S. Environmental Protection Agency (2005).

1.3 Justification and Significance of the Study

Kuantan Pahang is currently the largest mining areas for bauxite. Toxic chemicals and particulates matter were derived primarily from suspension or re-suspension of dust, soil and other plant parts. Since the residential areas were located near to the mining sites, there was the possibility for the population to be exposed to the toxic substances.

Acknowledging the economic contributions of bauxite mining, however, several economies lost sight of environmental and health effects associated with these activities. Researches that have been undertaken lately to look into the environmental and health effects of mining, have found mining activities to be more hazardous to economic development than a blessing. Whether some of these researches have or are capable of reducing the negative health impacts of bauxite mining on the environment and surrounding communities is a matter of great concern.

The significance of this research work was to undertake a thorough and broader outlook into the health effects of bauxite mining activities on surrounding communities. Thus, it is a good opportunity to prevent the problems from getting serious and simultaneously avoid negative impacts on the population in term of health and well-being. Findings and recommendations would serve as integrated information on environmental and health effects of bauxite mining.

1.4 Objectives

1.4.1 General Objective

To assess the environmental health risk of bauxite mining in Kuantan, Pahang.

1.4.2 Specific Objectives

1.4.1.1 To determine particulate matter (PM_{10}) levels in the air within the household in the area surrounding the mines.

1.4.1.2 To determine heavy metals level [(aluminum (Al), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni) and lead (Pb)] of red dust in air and soil sedimentation within the household in the area surrounding the mines.

1.4.1.3 To determine the potential health hazard (respiratory and dermal) based on health complaints from the community within 1 km radius of the bauxite mining areas.

1.4.1.4 To compare the number of respiratory and dermal symptoms with different PM_{10} levels in the air.

1.4.1.5 To assess the health risk of exposure to the population within 1 km radius of the bauxite mining areas.

1.5 Study Hypothesis

1.5.1.1 There is significant different between number of respiratory health cases with level of PM_{10} in air.

1.5.1.2 There is significant different between dermal health cases with level of PM_{10} in air.

1.6 Definition of Term

1.6.1 Respirable Particles (PM_{10})

1.6.1.1 Conceptual Definition

Particles with an aerodynamic diameter smaller than 10 µm and can travel deeps into lungs. The lifetime of PM_{10} is from minutes to hours, and its travel distance varies from less than 1 km to 10 km (EPA, 1997).

1.6.1.2 Operational Definition

The PM_{10} level will be measured by Gillian air sampling pump equipped with cyclone. The instruments were left in resident's household area for 24 hours. Weight of filter paper was calculated based on the gravimetric principles in $\mu g/m^3$.

1.6.2 Heavy metal

1.6.2.1 Conceptual Definition

The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations (Lenntech, 2004).

1.6.2.2. Operational Definition

Heavy metal concentration in soil and air will be measured by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis.

1.6.3 Respiratory health symptoms

1.6.3.1 Conceptual Definition

Respiratory health symptoms can be defined as condition resulting from a distributed respiratory symptoms by various factors either internal or external factors. The examples of respiratory symptoms are cough, phlegm, and chest tightness.

1.6.3.2 Operational Definition

Respiratory health symptoms will be measured by using self-constructed questionnaire. Symptoms evaluated are cough, phlegm, and chest tightness.

1.6.4 Dermal health symptoms

1.6.4.1 Conceptual definition

Dermal health symptom is defined as diseases that affecting the skin, either due to an inherent skin defect, direct contact with an irritating substance, or to an allergic reaction. Symptoms of dermal health include redness, itching, and in some cases blistering.

1.6.4.2 Operational Definition

Dermal health symptoms will be measured by using self-constructed questionnaire. In this questionnaire, it covers all dermal symptoms including itchiness, redness, rash and edema.

1.6.5 Health risk

1.6.5.1 Conceptual Definition

Health risk is an outcome of health hazard and exposure to that hazard. A health hazard may be biological, chemical or physical in nature. Health risk assessment is defined as methodological approach in which the toxicities of chemical are identified, characterized, analyzed for dose-response relationship and data generated are applied to a mathematical model to produce a numeric estimate representing guideline or decision concerning, available exposure (James, 1985).

1.6.5.2 Operational Definition

Human health risk assessment includes 4 basic steps which are hazard identification, dose-response assessment, exposure assessment and finally come out with risk characterization.

1.7 Conceptual Framework

The conceptual framework (Figure 1.3) used to shows the environmental and health impacts of mining activities. This study aims to relate environmental impacts of dust and soil from bauxite mining activities to the exposed human health. On environmental perspective, the mining activities degrade the land surface since there was a destruction of the entire forest. The primary problem resulting from bauxite mining was dust. The red dust remained in the air and then settled in soil. Later, the red dust become red sludge and would get into the nearby streams causing water pollution, destroying the aquatic life as well as reduce the quality of water.

Last but not least, on the health perspective, bauxite mining activity caused several health implications to the population. The red dust threatened human health and lives at risk and could cause harm through the air that they breathed and water that they consumed. Direct contact to skin might cause skin irritation, or inflammation of the respiratory system such as blistering of the throat, mouth, or nose. These sometimes lead to incidence of upper respiratory tract infections such as cough or cold and asthma.

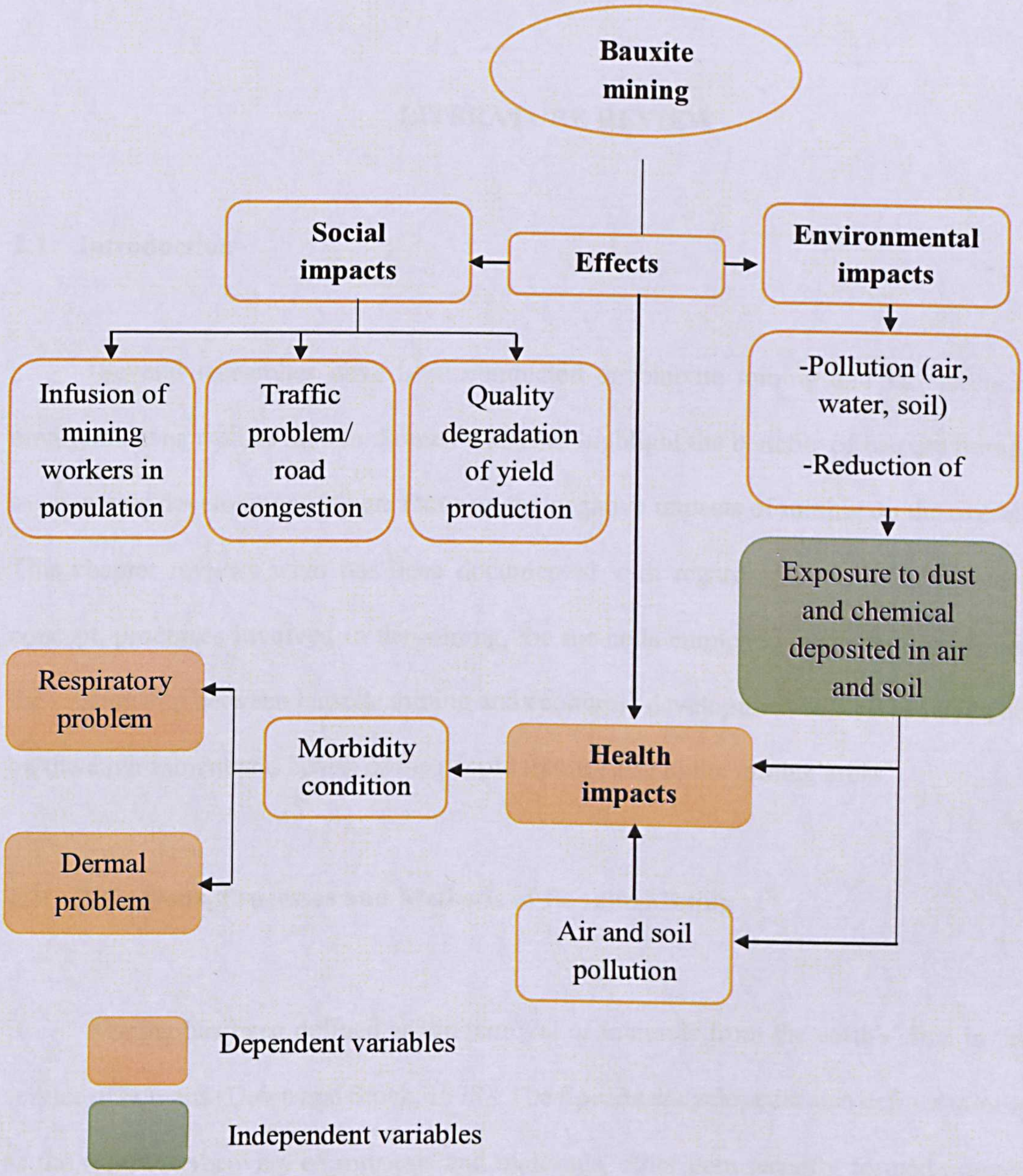

Figure 1.3: Bauxite mining, Environmental and Health Impacts

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Several researches have been conducted on bauxite mining and its effects to environment as well as human. Some researches highlight the benefits of bauxite mining to economic development; others focus on the negative impacts of mining on the overall. This chapter reviews what has been documented with regarding bauxite mining as a concept, processes involved in the mining, the methods employed in ore extraction and the relationship between bauxite mining and economic development as well as its impact on the environment and health of the people living close to the mining areas.

2.2 Definitions, Processes and Methods of Bauxite Mining

Mining has been defined as the removal of minerals from the earth's crust in the service of humans (Down and Stock, 1978). The Encarta encyclopedia also defines mining as the selective recovery of minerals and materials, other than recently formed organic materials from the crust of the earth (Encarta, 2005).

Aluminum in bauxite is hosted by aluminum hydroxide minerals, mostly gibbsite (Deer *et al.*, 1996). Bauxite is usually considered to be a rock type, but considerable amount of poorly consolidated material is often also named that way. Bauxitic or lateritic soil is scientifically known as oxisol (Stow *et al*, 2005). Sometimes "bauxite" has been used as a mineralogical term. In this case it refers to mixed aluminum hydroxide minerals of uncertain identity, analogous to the terms "limonite" and "wad" for iron and manganese hydroxides, respectively (Neese *et al.*, 2011). About 8-14 tons of bauxite is needed to produce one ton of aluminum (Murray *et al.*, 2007). Aluminum is extracted solely from bauxite, but that does not mean that there are no alternatives. Aluminum is the most widespread metal in the crust.

Bauxite mining is a processed in alumina refineries by the Bayer process (Figure 2.1) in which Al-containing minerals are dissolved in hot NaOH. The insoluble solids (bauxite-processing residues) are washed, sometimes partially neutralized, and then deposited in impoundments surrounding the refinery (Cooling, 2007). The thickened mud is spread in beds up to 0.5 m deep over storage areas and perimeter embankments are constructed from residue sand. Once the bed is dried, the process is repeated by depositing a fresh layer of mud. Thus, the storage area is constructed in a progressive stack (termed dry stacking) and periodically the perimeter embankments are built higher with residue sand (Cooling, 2007).

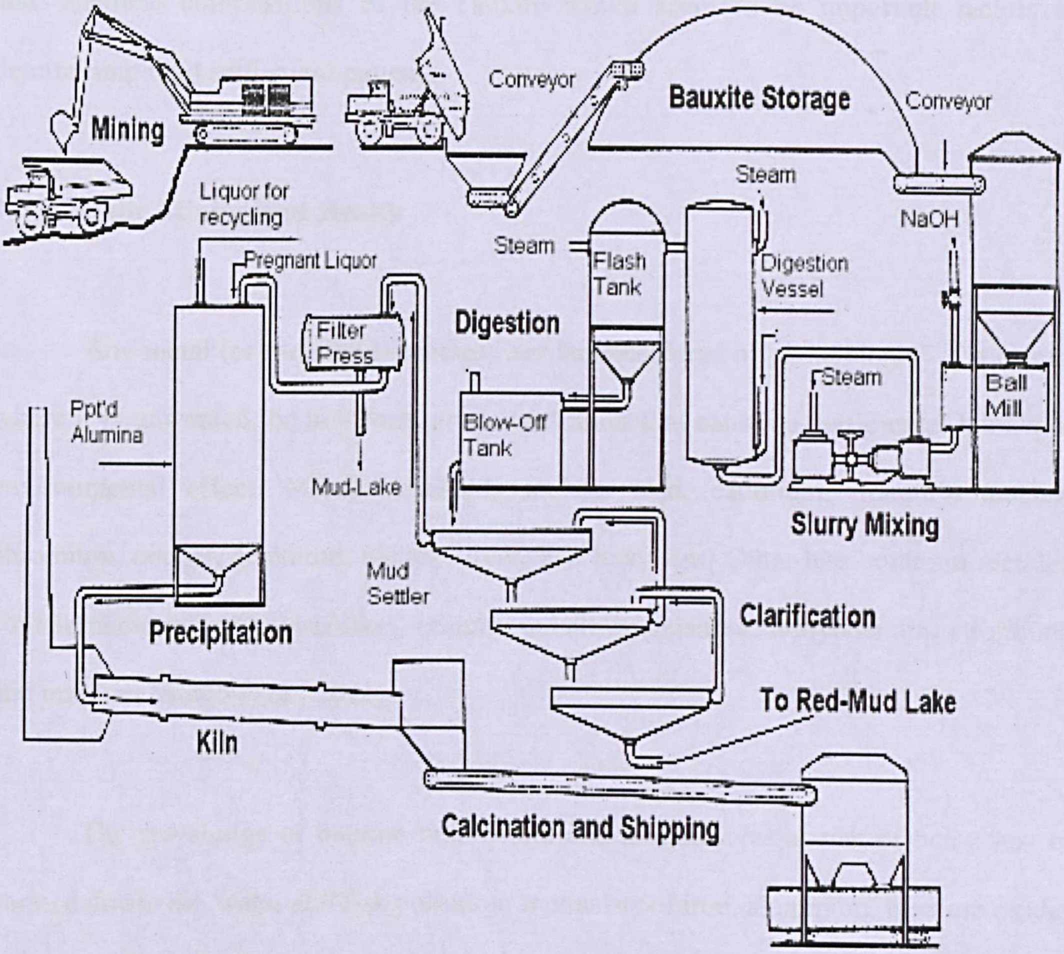

Figure 2.1: Illustrated of Chemistry and Processing of Bauxite Ore
(Source: http://wwwchem.uwimona.edu.jm/lectures/bauxite.html)

In the alumina production process with sodium hydroxide (Bayer process), the ore minerals go into solution and the iron-oxide impurities remain insoluble (red mud tailings). The settling behavior of the tailings is an important economic factor as it controls purity, and an important environmental factor as it controls final liquid content of the red mud tailings for disposal. In the Bayer process (Figure 2.1), the operating factors determining different settling rates are not at all clear. It is known that two bauxites from a few meters apart may produce muds with different settling rates. Thus, the mineralogical and chemical compositions of the bauxite would seem to be important factors in determining mud settlement patterns.

2.3 Bauxite Mining and Health

Any metal (or metalloid) species may be considered a "contaminant" if it occurs where it is unwanted, or in a form or concentration that causes a detrimental human or environmental effect. Metals/metalloids include lead, cadmium, mercury, arsenic, chromium, copper, selenium, nickel, silver, and zinc (Zn). Other less common metallic contaminants include aluminium, cesium, cobalt, manganese, molybdenum, strontium, and uranium (Singh *et al.*, 2011).

The red sludge of bauxite puts health and human lives at risk of being lost or harmed due to air, water and fish pollution. It consists of iron, aluminum, titanium oxides and hydroxides (Burke *et al.*, 2012, Mayes *et al.*, 2011). Chemical analysis shows that it also contains radionuclides (^{226}RA, ^{230}TH and ^{40}K) as well as heavy metals including Arsenic, Chromium, and Nickel (Mayers *et al.*, 2011, Ruyters *et al.*, 2011).

The medical statistics prove that prolonged toxicity may cause encephalopathy, osteoporosis, anemia and possibly Parkinson diseases. An Australian researcher in Australia where bauxite mining is largely developed proved that red sludge causes lung cancer and uterus deformation in rat experiments. The common symptoms of toxicity in human are dizziness, vertigo, nausea, fainting, or comatose if breathing or taking in a large dosage (Mai, 2009).

2.4 Effects of Heavy Metal on Human Health

Heavy metals disrupt metabolic functions in two ways. First, they accumulate and thereby disrupt function in vital organs and glands such as the heart, brain, kidneys, bone, liver, et cetera. Second, they displace the vital nutritional minerals from their original place, hindering their biological function. It is, however, impossible to live in an environment free of heavy metals.

There were many ways by which these toxins can be introduced into the body such as consumption of foods, beverages, skin exposure, and the inhaled air. Center for Hazardous Substance Research of Kansas State University have highlighted the effects of heavy metals on human health. The health effects are as stated below:

2.4.1 Arsenic

Aside from occurring naturally in the environment, arsenic can be released in larger quantities through volcanic activity, erosion of rocks, forest fires, and human activity. Animal feeding operations and certain fertilizers and pesticides can release high amounts of arsenic to the environment as can industry practices such as copper or lead smelting, mining, and coal burning. Inorganic arsenic is a known carcinogen and can cause cancer of the skin, lungs, liver and bladder.

Arsenic had been reported to be a trace element of nutritional importance to humans but its functions in the biological system is not clear (Holum, 1983). Any level of concentration of arsenic in drinking water has been disallowed, both by the World Health Organization (WHO) and National Agency for Food and Drugs Administration and Control (NAFDAC), Nigeria. Lower level exposure can cause nausea and vomiting, decreased production of red and white blood cells, abnormal heart rhythm, damage to blood vessels, and a sensation of "pins and needles" in hands and feet. Ingestion of arsenic in very high levels can possibly result in death while low level exposure in long terms can cause a darkening of the skin and the appearance of small "corns" or "warts" on the palms, soles, and torso.

2.4.2 Cadmium

Cadmium is a very toxic metal. All soils and rocks, including coal and mineral fertilizers, contain some cadmium. Cadmium and cadmium compounds are known human carcinogens. Severe damage to the lungs may occur through breathing high levels of cadmium. Ingesting in very high levels severely irritates the stomach, leading to vomiting and diarrhea, while long-term exposure to lower levels leads to a buildup in the kidneys and possible kidney disease, lung damage, and fragile bones.

Severe exposure may result in pulmonary odema and death. Pulmonary effects (emphysema, bronchiolitis and alveolitis) and renal effects may occur following sub-chronic inhalation exposure to cadmium and its compounds (Young, 2005).

2.4.3 Chromium

Chromium is found in rocks, animals, plants, and soil and can be a liquid, solid, or gas. Chromium compounds bind to soil and are not likely to migrate to ground water but, they are very persistent in sediments in water. Chromium (VI) compounds are toxins and known human carcinogens, whereas Chromium (III) is an essential nutrient.

Breathing high levels of chromium can cause irritation to the lining of the nose, nose ulcers, runny nose, and breathing problems, such as asthma, cough, shortness of breath, or wheezing. Besides, skin contact to chromium can cause skin ulcers. Allergic reactions consisting of severe redness and swelling of the skin have been noted. Exposure to arsenic in long term can cause damage to liver, kidney circulatory and nerve tissues, as well as skin irritation.

2.4.4 Lead

As a result of human activities, such as fossil fuel burning, mining, and manufacturing, lead and lead compounds can be found in all parts of our environment. Lead is a highly toxic metal and, as a result of related health concerns. EPA has determined that lead is a probable human carcinogen. Lead is the most significant toxin of the heavy metals, and the inorganic forms are absorbed through ingestion by food and water, and inhalation (Ferner, 2001).Lead can affect every organ and system in the body. Long-term exposure of adults can result in decreased performance in some tests that measure functions of the nervous system; weakness in fingers, wrists, or ankles; small increases in blood pressure; and anemia (Ogwuebgu and Muhanga, 2005).

2.4.5 Nickel

Exposure to nickel may occur by dermal contact or by inhalation of aerosols, dusts, fumes, or mists containing nickel. The most commonly reported adverse health effect associated with nickel exposure is contact dermatitis. Lung inflammation is the predominant noncancerous respiratory effect. Atrophy of the nasal epithelium has been observed following exposure to soluble nickel compounds. Nickel compounds are considered human carcinogens and metallic nickel is possibly a human carcinogen.

2.4.6 Aluminum

The most sensitive target of aluminum toxicity is the nervous system. Impaired performance on neurobehavioral tests of motor function, sensory function, and cognitive function have been observed in animals. Neurobehavioral alterations have been observed following exposure of adult or weanling animals and in animals exposed during gestation and/or lactation. Apart from that, respiratory effects, such as impaired lung function and fibrosis have been observed in aluminum workers.

2.5 Bauxite Mining and the Environment

Heavy metals can be emitted into the environment by both natural and anthropogenic causes. The major causes of emission are the anthropogenic sources specifically mining operations (Hutton and Symon, 1986). In some cases, even long after mining activities have ceased, the emitted metals continue to persist in the environment. Peplow (1999) reported that hard rock mines operate from 5-15 years until the minerals are depleted, but metal contamination that occurs as a consequence of hard rock mining persist for hundreds of years after the cessation of mining operations. Such a substance has to be present in the environment beyond a set or tolerance limit, which could be either a desirable or acceptable limit.

Apart from mining operations, mercury is introduced into the environment through cosmetic products as well as manufacturing processes like making of sodium hydroxide. Heavy metals are emitted both in elemental and compound (organic and inorganic) forms. Anthropogenic sources of emission are the various industrial point sources including former and present mining sites, foundries and smelters, combustion by-products and traffics (UNEP /GPA, 2004). Cadmium is released as a by- product of zinc (and occasionally lead) refining; lead is emitted during its mining and smelting activities, from automobile exhausts (by combustion of petroleum fuels treated with tetraethyl lead antiknock) and from old lead paints; mercury is emitted by the degassing of the earth's crust.

Generally, metals are emitted during their mining and processing activities (Lenntech, 2004). Environmental pollution by heavy metals is very prominent in areas of mining and old mine sites and pollution reduces with increasing distance away from mining sites (Peplow, 1999). These metals are leached out and in sloppy areas, are carried by acid water downstream or run-off to the sea. Through mining activities, water bodies are most emphatically polluted (Garbarino *et al*., 1995)

The potential for contamination is increased when mining exposes metal-bearing ores rather than natural exposure of ore bodies through erosion (Garbarino *et al.,* 1995), and when mined ores are dumped on the earth surfaces in manual dressing processes. They may then be stored in river bed sediments or seep into the underground water thereby contaminating water from underground sources, particularly wells; and the extent of contamination will depend on the nearness of the well to the mining site. Wells located near mining sites have been reported to contain heavy metals at levels that exceed drinking water criteria (Garbarino *et al*., 1995).

The tolerance limits of some heavy metals in environment defined by United State Environmental Protection Agency (USEPA) were summarized in Table 2.1.

Table 2.1: United State Environmental Protection Agency (USEPA) maximum contamination levels for heavy metal concentration in air, soil and water.

Heavy metal	Maximum concentration in air (mg/m^3)	Maximum concentration in sludge (soil) (mg/kg or ppm)	Maximum concentration in drinking water (mg/l)	Maximum concentration in H_2O supporting aquatic life (mg/l or ppm)
Cd	0.1-0.2	85	0.005	0.008$^{\delta}$
Pb	-	420	0.01$^{\pi}$ (0.0)	0.0058$^{\delta}$
Zn	1, 5*	7500	5.00	0.0766$^{\delta}$
Hg	-	<1	0.002	0.05
Ca	5	Tolerable	50	Tolerable >50
Ag	0.01	-	0.0	0.1
As	-	-	0.01	-

(Value in bracket is the desirable limit; WHO; adapted from U.S. – OSHA; EPA, July 1992; USEPA, 1987; Georgia Code, 1993; Florida Code, 1993; Washington Code, 1992; Texas Code, 1991; North Carolina, 1991; *1 for chloride fume, 5 for oxide fume; - - no guideline available).

Key environmental impacts of primary aluminum production are: high energy consumption (in particular for smelting); emissions of greenhouse gases (associated with energy use, and release of small amounts of perfluorocarbons from smelters) and other air pollutants; and solid waste generation (in particular bauxite residue from alumina refineries and spent pot lining from smelters). Using average bauxite grades and current technology, the environmental impact of primary aluminum production has been assessed as having gross energy requirement of 211 MJ/kg aluminum, greenhouse gas emissions of 22.4 kg CO2eq/kg aluminum, acidic air emissions of 0.131 kg/kg aluminum and 4.5 kg solid waste/kg aluminum (Norgate *et al.*, 2006).

High recycling rates have been achieved since commencement of industrial use of aluminum. A recent study estimated that of the 678 million tonnes aluminum produced since 1888 some 75% is still in productive use. Recycling has significant environmental benefits. Per kg of aluminum, recycling can save some 8 kg of bauxite, 4 kg of chemicals and 14 kWh of electricity (Moors, 2006), a 95% saving in energy overall.

The EPA (2006) says that the release of perfluorocarbons during the aluminum smelting process is 9,200 times more harmful than carbon dioxide in terms of their effect on global warming. When bauxite is extracted from the earth, the strip-mining process removes all native vegetation in the mining region, resulting in a loss of habitat and food for local wildlife as well as significant soil erosion.

The caustic red sludge and toxic mine tailings that remain are commonly deposited into excavated mine pits where they ultimately seep into aquifers, contaminating local water sources. Greenhouse gas emissions released during smelting and processing (which have been found to blanket surrounding regions with toxic vapors) include carbon dioxide, perfluorocarbons, sodium fluoride, sulfur dioxide, polycyclic aromatic hydrocarbon and a vast list of other problematic elements.

The opencast mining activity is known to be environmentally destructive as it has important negative impacts on air, water, land, wildlife and other biological resources as well as it has a significant social impact too (Saxena *et a.l*, 2000) . According to Chauhan (2010) mining operations necessarily involves deforestation, habitat destruction and biodiversity erosion. Unscientific mining of minerals poses a severe threat to the environment, which results into reduction of forest cover, soil erosion at a greater scale, pollution of air, water and land and decline in biodiversity (Singh *et al.*, 2011).

Shaikh and Dongare (2010) reported that environmental impacts due to mining manifest as water pollution, land degradation, loss of biodiversity, air pollution, and increase in health related problems. According to Singh (2007) one of the major environmental challenges of bauxite mining is to manage the huge volume of overburden generated in these opencast mines which is associated with the problems of landslides, loss of top soil, soil erosion, ecological disruption, aesthetics, visual impacts social problems, safety, risk and health. Zobrist *et al.,* (2009) reported high impact of mining activities on Certej River and found that the respondent's perceptions to pollution were to a large extent consistent with the measured results.

CHAPTER 3

METHODOLOGY

3.1 Study Location

Felda Bukit Goh, Kuantan and the neighboring area with large number of bauxite mining activities was identified as the study area. Bukit Goh, lies in the neighborhood of Kuantan in the states of Pahang and Terengganu (Figure 3.1). It is easily accessible via the highway to Kuala Terengganu, the new Kuantan bypass, and roads to Sungai Lembing, Bukit Goh Estate 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 (Appendix 1). The figures below (Figure 3.1) show the bauxite mining area, as well as population settlement area that may be affected by the bauxite mining activities within 1 km radius.

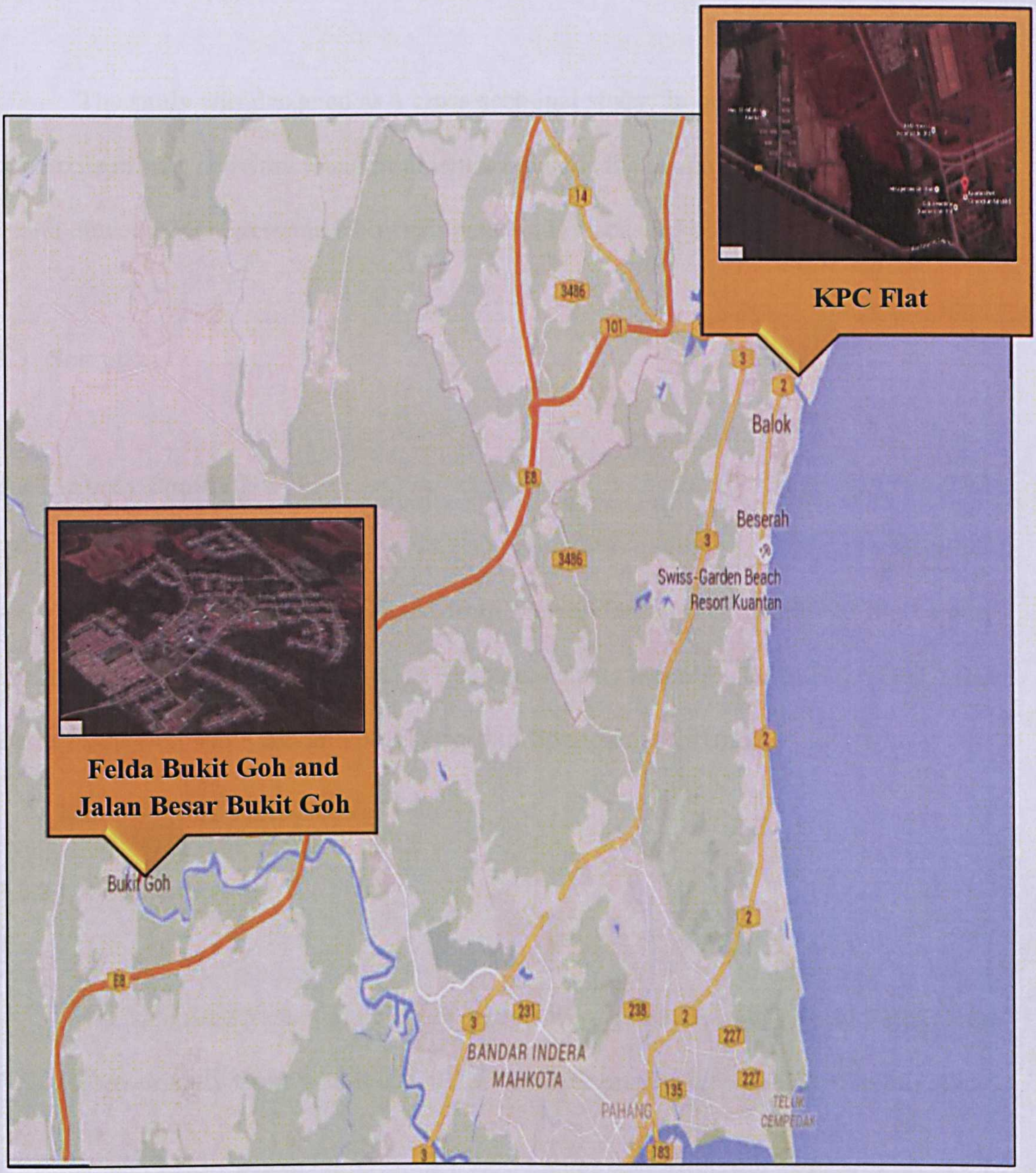

Figure 3.1: Geographical area of study location in Felda Bukit Goh and viscinity in Kuantan, Pahang

(Source: www.google.com.my/)

3.2 Study Design

The study was designed as a cross-sectional study. In order to identify the result of bauxite mining activities to environment and health, the health hazards and the potential health outcome were determined by using methods discussed below:

3.3 Sampling

3.3.1 Study Population

The respondents were selected from the residential area nearest to the bauxite mining area (500 meter-1 kilometer) in Kuantan, Pahang including Felda Bukit Goh, Jalan Besar Bukit Goh and Kuantan Port Consortium apartment (N=162).

3.3.2 Sample Frame

The sampling frame (name list of settler) were gathered from Pejabat Felda Bukit Goh. However, only those who fulfilled the inclusion criteria were included in this study.

3.3.3 Sample Unit

Sampling unit for this study involved only those respondents who fulfilled the inclusion criteria such those who lived near the bauxite mining activities (500 meter to 1 kilometer radius) for more than five years.

3.3.4 Sampling Method

In this study, the main sampling method used was simple random sampling. The respondents were only selected when fulfilled the inclusive criteria and gave consent to participate in the study. However, snowball sampling method was also used in gathering respondents in Kuantan Consortium apartment and Jalan Besar Bukit Goh as there was no sampling frame available.

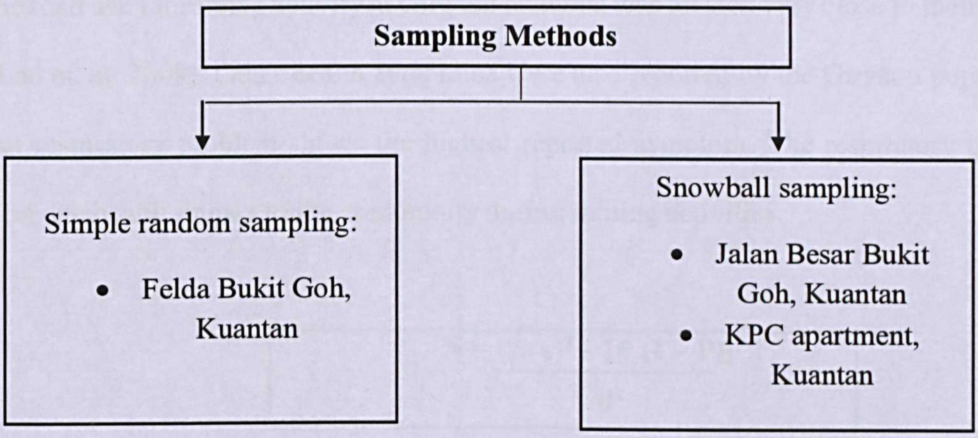

Figure 3.2 Types of sampling method used in study

Environmental sampling were also used in this study, which meets the inclusion criteria; soil sediments and air quality near to the bauxite mining area. Forty two samples of air and 42 samples of soil were collected from the residence to represent the whole study. Each sample represents the block available in the study area and was duplicated to obtain the average reading. Both sampling locations for soil and air were sub-sampled from the 162 randomly sampled household and were selected purposively based on their close proximity to the mining activities.

3.3.5 Sample Size

The sample size in this study consist of 162 respondents living near to the bauxite mining activities. The sample size was calculated by using Lemeshow, Klar, & Lawanga, 1990. The prevalence used to compare the sample size is 0.9 where 90% of Girgaon respondents complained respiratory problems associated with the dust pollution cause by the road use for mining activity at Girgaon area that was located very close to their houses (Lad et. al, 2009). Other health symptoms were also reported by the Girgaon population, yet respiratory problem shows the highest reported symptom. The respiratory problem was one health impact to the community during mining activities.

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

(Equation 3.1)

Where,

P = estimated proportion (0.9)
d = desired precision (0.05)
$Z_{1-\alpha} = Z_{0.95} = 1.96$ for CI of 95%, Z=1.96 (normal distribution table)

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

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

$$= \mathbf{138}$$

Lemeshow, Klar, & Lawanga (1991)

In order to recover the loss of respondents throughout the study, the minimum sample size will be rounded up to 20%.

20% of 138

=27.6

The total sample size population will be **166**.

3.4 Instrumentation and Data Collection Techniques

3.4.1 Approval Letter

Respondents Information and Consent Form (Appendix 2) were distributed among the respondents. Prior the study conducted, consent from respondents was obtained and they were fully informed about the procedures and objectives of the study.

3.4.2 Questionnaire

Face-to-face interviewed were conducted using a self- construct questionnaire (Appendix 3) was distributed to the respondents. The questionnaire was translated into Malay version to ease respondents in understanding the question. Pre-test was conducted on 10% of the total respondents to ensure the reliability and validity of the questionnaire ($\alpha = 0.797$). The questionnaire determined the socio-demographic information, health problems reported by respondents and associated environmental problems created by the bauxite mining.

For health problem, respondents were asked whether they have health symptoms such as asthma, difficulties of breathing, chest problem, eye irritation, and dermal irritation for the past 1 week, 1 month and 6 months.

3.4.3 Sample Collection in Field

3.4.3.1 Surface soil samples

Heavy metals from anthropogenic sources are believed to be easily accumulated in the top soil (0-20 cm) (Khairiah et al, 2009). Thus, 42 surface samples (0-20 cm depth, 30x30 cm^2 surface) was collected from the household located about 1 km radius from the bauxite mining area using shovel. Each of the sampling point consisted of duplicate samples which were analyzed to obtain the average of the concentration means of selected heavy metals.

All soil samples were kept in sealed plastic bag prior to shipment to the laboratory. The soil samples were then dried at 105°C for 2 hours to remove all the moisture content. After drying, the samples were repeatedly crushed with clean mortar and pestle and sieved through a 2-mm sieve to fineness. This study focused on the total heavy metal concentration, therefore, the basic soil characteristics like ion exchange capacity, texture, and color were not determined.

3.4.3.2 Ambient Air Quality Measurement

Forty two various locations for ambient air quality were chosen from the houses of respondents within 500 m to 1 km radius of the mining areas. Each sample represents the block available in the study area. Ambient air quality measurements included total particulate matter (PM_{10}) monitoring and the selected heavy metal (aluminum (Al), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni) and lead (Pb)) concentration.

The total particulate matter (PM_{10}) and selected heavy metals were measured by using Gillian personal high volume air sampler with a flow rate at 1.7 L/min. Cyclone was used to separate large particles from the respirable particles (PM_{10}), where PM_{10} were collected on the filter type cellulose acetate membrane with diameter 47 mm 0.45 µm air pore size. The measurement was for 24h period. Details on sampling were summarized as below.

3.4.3.2.1 Preparation before sampling

a) First, the cassette were washed with Decon® detergent and rinsed thoroughly under running water. After that, the cassette were soaked in 50% nitric acid for 24 hours and rinsed again with distilled water before left for drying process.
b) Next, the filter paper were dried in oven at 40° C for two hours to remove excess moisture. After drying, the filter paper were weighted on micro-scale device to obtain the initial weight (W_1). Subsequently, the filter paper were put in the cassette together with support pad and left in desiccator for 24 hours to remove any moisture.

3.4.3.2.2 During sampling

a) Each sampling pump was calibrated to the flow rate of 1.7 L/min.
b) The sampling pump was turned on and placed in the house of respondents with the filter cassette attached near the window about breathing zone height for 24 hours. The cassette inlet was always facing downwards vertical position to avoid gross contamination.

3.4.3.2.3 Post sampling

a) The final flow rate at the end of sampling period was checked to ensure the rotameter ball was still at the calibrated mark. If not, the final flow rate reading was recorded to obtain the average flow rate.

b) Then, the sampling pump was turn off and the cassette was removed from the pump and sealed in the plastic bag prior to the shipment to laboratory.
c) Next, the filter paper was weighted again and recorded as final weight (W_2).

3.4.4 Sample Analysis in Laboratory

3.4.4.1 Heavy metal analysis in soil surface

The preparation of soil samples were based on Aqua Regia method by Miroslav (1998).

a) First, 130 mL of HCl was diluted with 120 mL distilled water. After that, 150 mL of diluted HCl was added with 50 mL HNO_3 to prepare the aqua regia solution.
b) Next, 0.5 g soil sample (dried and sieved) was mixed with 15 mL aqua regia solution in the crucible and stored overnight in the fume cupboard.
c) After overnight, the crucibles were left in oven (120°C) for two hours and cooled for a few minutes before filtered with 0.45 μm filter membrane. The samples were then analyzed using ICP-MS.

Further information regarding the heavy metals analysis in soil can be referred in appendix section. The concentration of heavy metal in soil was determined by using the following equation.

$$\boxed{C = \left[\frac{(\ {}^{*}ppb\ metal) \times Dilution\ (ml) \times Mark\ up\ (ml)}{Sample\ weight\ (g)} \right] \div 1000}$$

(Equation 3.2)

Where,

C = Total concentration (mg/kg)
*ppb metal = Metal concentration determined from ICP-MS
Dilution volume = Total sample extraction from extraction procedure (mL)
Mark up volume = Aqua regia volume (mL)

3.4.4.2 Heavy metal analysis in ambient air

For assessing heavy metal concentration in ambient air, hot acid digestion method by US EPA (2005) was used.

a) First, exposed filter strips were cut into pieces and placed in 250 mL quartz beaker. After that, 30 mL of 10% HNO_3 was added into the beaker and refluxed for 30 minutes at 95°C. When the filter strips were fully digested, 10 mL clean deionized was added and extracted sample was allowed to cool for 30 minutes.
b) The sample was then filtered using Whatmann 541 filter paper and transferred into polypropylene bottle to be analyzed using ICP-MS.

Further information regarding the heavy metals analysis in air can be referred in appendix section. Next, the concentration of heavy metal in ambient air was determined by using the following formula.

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

(Equation 3.3)

Where:

C = Concentration, g metal/m^3

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

Digestion volume = Total sample extraction volume from extraction procedure

V_{std} = standard air volume pulled through the filter, m3

Source: Office of Air Quality Planning and Standards, U.S. EPA (2005)

3.4.4.3 Total particulate matter (PM_{10}) measurement

Total suspended particulate is measured by making comparison between the original weight of filter paper and the final weight of the filter paper after sampling. The PM_{10} level was determined by using gravimetric method and calculated using the following formula.

$$\text{Concentration of } PM_{10}\ (\mu g/m^3) = \frac{[W_2 - W_1] - [B_2 - B_1]}{\text{Flow rate (L/min)} \times \text{Time (min)}} \times 1000$$

(Equation 3.4)

Where,

W_1 = Initial weight (mg)
W_2 = Final weight (mg)
B_1 = Initial weight (mg)
B_2 = Final weight (mg)

Source: Niosh Analytycal Method (NAM) 0600

3.5 Quality Control

To ensure data collection was reliable and valid, quality control on the instruments and procedures were taken as followed.

3.5.1 Pre-test study

Prior to the actual data collection from the study, a pre-test study was conducted on 10% of sample size. Respondents were tested on the self-constructed questionnaire to ensure the reliability and validity of the questionnaire. From the pre-test, the questionnaire was found to be reliable (60 items; α=0.797).

3.5.2 Calibration

Instruments used in this study were calibrated before the actual data collection were made to ensure that the instruments were in good condition when collecting the samples, eliminate any possible error of data and give an accurate results during the sampling. Each instruments used was calibrated based on the standard operating procedures provided.

3.5.3 Standard Operating Procedure (SOP)

All procedures were carried out by following the standard operating procedures.

3.6 Data Analysis

All data obtained from this study were analyzed statistically by using Statistical Package for Social Sciences (SPSS) version 22 software. The significant levels in this study was set at $p<0.05$. The types of data analysis used in this study are shown in the following Table 3.1.

Table 3.1: Types of Data Analysis

Objectives	Statistical Analysis
• To assess the environmental health risk of bauxite mining in Felda Bukit Goh, Kuantan.	Descriptive Analysis
• To determine the heavy metals [(aluminum (Al), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni) and lead (Pb)] levels of red dust in air and soil sedimentation within the household in the area surrounding the mines.	Descriptive Analysis
• To determine particulate matter (PM10) in the air within the household in the area surrounding the mines.	Descriptive Analysis
• To determine the potential health hazard (respiratory and dermal) based on health complaint from the community within 1 km radius of the bauxite mining areas.	Descriptive Analysis
• To compare the number of respiratory health symptoms with different level of PM_{10} (high and very high) in air.	Chi-square test
• To compare the number dermal health symptoms with different level of PM_{10} (high and very high) in air.	Chi-square test
• To assess the health risk of exposure to the population within 1 km radius of the bauxite mining areas.	Descriptive Analysis

3.7 Health Risk Assessment

The risk was quantified under the present of environmental condition at residential area in study areas for the selected exposure scenario. The risk characterization was considered separately as carcinogenic and non-carcinogenic effects.

3.7.1 Non-carcinogenic risk

Hazard Quotient (HQ) which was ratio of exposure dose to the compounds-specified reference dose (RfD) was used as standard EPA method to determine the non-carcinogenic risk. US EPA (2001) stated that if value of HQ is less than one, there was no significant risk of non-carcinogenic effects. Whereas, when the value of HQ exceed one, then there was significant non-carcinogenic risk.

Dermal exposure to some air contaminants could also result in absorption through the skin. However, data are not likely to be available to quantitatively estimate exposures from this pathway. Nevertheless, potential exposure pathway for air contaminants that can be readily absorbed through the skin should be acknowledge.

The HQ for inhalation route was defined as following equation:

$$\boxed{HQ = ADD/RfDi}$$

(Equation 3.5)

Where,

HQ = Hazard Quotient (unitless)
ADD = Average daily dose (mg/kg-day)
RfDi = Inhalation reference dose (mg/kg-day)

RfD_i is an estimate of a continuous inhalation exposure dose to people (including sensitive subgroups) that is likely to be without risk of deleterious effects during a lifetime. An RfD_i is reported in milligrams of pollutant per kilogram per day (mg/kg/day).

Table 3.2: The inhalation reference concentration (RfC) for selected heavy metals

Elements (heavy metals)	RfC(mg/m^3)
Aluminum (Al)	N/A
Arsenic (As)	3.0×10^{-5}
Cadmium (Cd)	1.0×10^{-5}
Chromium (Cr)	1.0×10^{-4}
Lead (Pb)	N/A
Nickel (Ni)	5.0×10^{-5}

RfC derived from California Environmental Protection Agency
N/A = Not available

RfD_i for each elements (heavy metal) were derived using the following equation.

$$\boxed{RfD_i \text{ (mg/kg/day)} = \frac{\text{RfC (mg/m}^3\text{) x Inhalation rate (15.2 m}^3\text{/day)}}{\text{Body weight (65 kg)}}}$$

(Equation 3.6)

Table 3.3: The inhalation reference dose (RfD_i) for selected heavy metals

Elements (heavy metals)	RfD_i(mg/kg/day)
Aluminum (Al)	N/A
Arsenic (As)	7.0154×10^{-6}
Cadmium (Cd)	2.3385×10^{-6}
Chromium (Cr)	2.3385×10^{-5}
Lead (Pb)	N/A
Nickel (Ni)	1.1692×10^{-5}

N/A = Not available

ADD was defined by the following equation.

$$\boxed{ADD = \frac{C \times IR \times EF \times ED}{W_B \times AT}}$$

(Equation 3.7)

Where,

ADD = Average daily dose (mg/kg-day)
C = Mean concentration of air pollutant (mg/m^3)
IR = Inhalation rate (m^3/day) = 15.2 m^3/day
EF =Exposure frequency (days/year) = 350 days/year
ED = Exposure duration (year)
W_B = Body weight (kg) = 65 kg (adjusted for Malaysians)
AT = Averaging time (days); for chronic non-carcinogenic effects
= 2 years x 365 days = 730 days

The inhalation rate of 15.2 m^3/day used is as recommended by the USEPA (1997) for chronic exposure for an average adult male).

3.7.2 Carcinogenic risk

Inhalation cancer risk was estimated as the incremental probability of an individual developing cancer over a lifetime as a result of exposure to a potential carcinogenic substances. 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 are given below:

$$\boxed{\mathbf{LCR = LADD \times CSF_{inh}}}$$

(Equation 3.8)

Where,

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

Table 3.4: The inhalation slope factor (mg/kg-day) for selected heavy metals

Elements (heavy metals)	Inhalation Slope Factor (mg/kg-day)
Aluminum (Al)	N/A
Arsenic (As)	1.2×10^{1}
Cadmium (Cd)	1.5
Chromium (Cr)	5.1×10^{2}
Lead (Pb)	4.2×10^{-2}
Nickel (Ni)	9.1×10^{-1}

Adapted from OEHHA Cancer Potency Values
N/A= Not available

LADD was defined by the following equation.

$$\boxed{\mathbf{LADD = \frac{C \times IR \times EF \times ED}{W_B \times AT}}}$$

(Equation 3.9)

Where,

LADD = Lifetime verage daily dose (mg/kg-day)
C = Mean concentration of air pollutant (mg/m^3)
IR = Inhalation rate (m^3/day) = 15.2 m^3/day
EF =Exposure frequency (days/year) = 350 days/year
ED = Exposure duration (year)
W_B = Body weight (kg) = 65 kg (adjusted for Malaysians)
AT = Averaging time (days); for chronic non-carcinogenic effects
= 70 years x 365 days = 25 550 days

3.8 Ethical Consideration

This study was approved by Ethics Committee for Research involving Human Subjects of Universiti Putra Malaysia (JKEUPM), reference number FPSK(EXP15-OSH)U007 (Appendix 4). A written consent form of participants was given to the respondents and they were well explained about the entire process along the research. The identities of respondents including their personal information were remained confidential and were not stated in any parts of the study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Socio-demographic Data of Respondents

This study was carried out in 3 different residential area which are Felda Bukit Goh, Jalan Besar Bukit Goh and Kuantan Port Consortium flat. A total of 162 respondents participated in this study. Information on the socio-demographic, economic status and involvement with mining activities were obtained from self-constructed questionnaire.

Result showed that all respondents are Malaysian Malay, which include 62 males and 108 females, aged from 18 to 100 years old. Percentage of female respondents in the sample was more than male as they housewives and easily available for interview.

Most respondents have resided in the study area for more than 30 years (66.7%). The literacy level in study area was low with over half of the respondents (87%) had only up to primary (33.3%) and secondary (40.1%) level education, with 13.6% respondents without formal education. About 73.5% of respondent were non-smokers while the rest were smokers. Majority of the respondent were housewives (48.1%) with an average income of RM 1 000-RM 3 000 (57.4%) as they had to relied on subsistence agriculture income. Only some (9.2%) had their monthly income between RM 3 000 to RM 5000 as which came from the bauxite mining activities. It was observed that some (30.2%) of respondents from the study areas involved in mining activities whether directly or indirectly involved. The detail of background information of the respondents are presented in Table 4.1.

Table 4.1: Socio-demographic of respondents who participated in the study

Variables	Frequency (n)	Percentage (%)
Gender		
Male	62	38.3
Female	108	61.7
Age group (years)		
<25	15	9.3
25-55	74	45.7
>55	73	45.1
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
Others	78	48.1

Duration of stay (years)		
<5	15	9.3
5-30	39	24.1
>30	108	66.7
Involvement in mining activity		
Yes	49	30.2
No	113	69.8

N=162

4.2 Level of Particulate Matter (PM_{10}) within the Mining Areas

The distribution of sampling points and time weighted average concentration (24 hours) for PM_{10} was illustrated in Table 4.2. The data for PM_{10} levels were normally distributed. Hence, the statistical analysis were obtained by using parametric test (one sample t-test) to compare mean of PM_{10} level with standard value. From Table 4.3, it 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 $\mu g/m^3$) as stated in Malaysian Ambient Air Quality Guidelines (MAAQG 2015) which is 150 $\mu g/m^3$ for 24 hours exposure ($p<0.001$).

In terms of study location, Jalan Besar Bukit Goh shows the highest reading of PM_{10} (292.08 $\mu g/m^3$) followed by KPC flat (266.89 $\mu g/m^3$) and Felda Bukit Goh (238.14 $\mu g/m^3$). Jalan Besar Bukit Goh was identified as the main road used in transporting bauxite ore from mining sites to be exported through Kuantan Port. The road used in transporting the bauxite ore became dusty and thus continuous movement of hundreds of heavy vehicles generates large amount of dust in air which settled on the surrounding vegetation. Even during the moratorium, the settled dust could be re-suspended again into the air by passing vehicles. Particularly in summer months, due to heat, water scarcity and winds the problem of dust pollution becomes more acute (Lad and Samanth, 2013).

According to a study conducted by Chauhan (2010), dust pollution is a major problem occurred in any opencast mining activity including bauxite. Ghose (2010) found high level of dust pollution in work zone as well as ambient air in open cast coal mining areas. Mining activities including drilling, blasting and transportation increase the suspended particulate matter in air which is harmful to the workers as well as locals exposed to the mine environment. The main transportation road became dusty and thus continuous movement of hundreds of heavy vehicles generates large amount of dust in air which settles on the surrounding vegetation (Lard and Samanth, 2013)

PM_{10} emitted from bauxite mining areas was first dispersed downwind in the near-field in high concentration plumes and then dispersed in lower concentrations further downwind in the far-field for more than 1 km (Wang et al, 2010). According to Maynard & Howard (1999), PM_{10} is not as long-lived as $PM_{2.5}$, with a life-time 7±30 days, as the latter is less efficient removal by gravitational settling or scavenging in rain. Since the residential areas distance from the mining areas were less than 1 kilometer, the concentration of PM_{10} also increased.

Table 4.2: Level of particulate matter (PM$_{10}$), (µg/m^3) within mining areas and comparison with Malaysian Ambient Air Quality Guidelines 2015.

Location	Mean (µg/m^3)	Std. Deviation	Range value (µg/m^3)	MAAQG 2015 guideline for PM$_{10}$
Felda Bukit Goh	238.14	53.92	161.86 - 364.93	150 µg/m^3
Jln Besar Bukit Goh	292.08	52.43	243.62 - 363.92	
KPC flat	266.89	21.76	242.86 - 284.88	

N= 42

Table 4.3: Comparison of PM$_{10}$ Levels with standard value (µg/m^3)

Variables	Observed value (µg/m^3)	Standard Value (µg/m^3)	t	P
	Mean			
PM$_{10}$ Levels	249.35	150.0	12.254	<0.001*

N=42

t = One sample t-test

**Significant at $p < 0.001$*

4.3 Level of Heavy Metal within the Mining Areas

Environmental pollution by heavy metals is very prominent in areas of mining and old mine sites and pollution reduces with increasing distance away from mining sites (Peplow, 1999). Numerous reports showed that water, soil, vegetables and dust have been polluted by lead (Pb), arsenic (As), copper (Cu), chromium (Cr), zinc (Zn) and cadmium (Cd) near the mining areas (Liu *et al.*, 2005). Pb, As, Cu, Cr and Cd are important toxic heavy metals, and have been identified as health risks by World Health Organization (WHO, 1993).

The distribution of sampling points and concentration of selected heavy metals concentrations (µg/m^3) in ambient air and soil are shown in Table 4.4 and Table 4.5 respectively. The highest concentration value of heavy metals present in ambient air of study location was Al followed by Cr > Ni > Pb > Cd >As. The heavy metals concentration (µg/m^3) obtained from the study were compared with air quality standard derived by U.S Department of Health and Human Services, (ATSDR) (Table 4.4). Overall findings showed that the median of selected heavy metals concentration present in ambient air was high and exceeded the standard limit derived by ATSDR.

In terms of study location, Jalan Besar Bukit Goh shows the highest reading for most of the selected heavy metals concentration followed by Felda Bukit Goh and KPC flat. The heavy metals remain suspended in air for long period especially when there was continuous movement of heavy vehicles which generates large amount of dust in air.

The finding of this study also found that mean concentration of selected heavy metals present in the soil in respondents' household area were low. The present in soil was below the standard limit derived from Dutch Target and Intervention Values and still considered as safe. The highest concentration of heavy metals present in the soil in study areas was Al, followed by Cr > Ni > As > Pb > Cd. The median of selected heavy metals concentration in soil (mg/kg) in different sampling point and the comparison with available standards were summarized in Table 4.5.

Table 4.4: Concentration of selected heavy metals in ambient air, (µg/m^3) in different sampling point and comparison with available standard.

Variables	Study Location	Median (IQR) (µg/m^3)	Range value (µg/m^3)	Air Quality Standard (µg/m^3)
Al	FBG	1.7673 (1.08)	0.58 - 4.97	**0.005 - 0.018**
	Jln Besar BG	2.5288 (4.54)	2.22 – 7.63	
	KPC flat	4.0894 (0.98)	2.95 – 4.32	
As	FBG	0.0060 (0.00)	0.00 – 0.03	**0.02 – 0.1**
	Jln Besar BG	0.0120 (0.01)	0.01 – 0.03	
	KPC flat	N/D	N/D	
Cd	FBG	0.0074 (0.02)	0.00 – 0.03	**0.0001 – 0.005**
	Jln Besar BG	0.0431 (0.04)	0.01 – 0.07	
	KPC flat	N/D	N/D	
Cr	FBG	7.7229 (2.03)	4.70 – 10.04	**0.02**
	Jln Besar BG	8.8032 (1.19)	8.23 – 9.78	
	KPC flat	8.0159 (3.80)	2.16 – 8.57	
Ni	FBG	3.1562 (1.38)	2.06 0 19.04	**0.0022**
	Jln Besar BG	3.4909 (2.03)	3.14 – 7.00	
	KPC flat	3.0665 (2.83)	1.11 – 6.54	
Pb	FBG	0.1841 (0.10)	0.07 – 0.54	**0.05**
	Jln Besar BG	0.1827 (0.38)	0.15 – 0.87	
	KPC flat	0.1651 (0.06)	0.13 – 0.22	

Adapted from air quality guideline by U.S Department of Health and Human Services, ATSDR
N/D= Not detectable
N= 42

Table 4.5: Concentration of selected heavy metals in soil, (mg/kg) in different sampling point and the comparison with available standards

Variables	Study Location	Median (IQR) (mg/kg)	Range value (mg/kg)	Soil Standard (mg/kg)
Al	FBG	4722.79 (4849.32)	1437.12 – 9991.14	N/A
	Jln Besar BG	6311.52 (5189.91)	1378.27 – 9604.36	
	KPC flat	661.98 (374.29)	350.60 – 977.56	
	Stockpile	199887.46*		
As	FBG	2.56 (3.35)	0.44 – 102.45	**29.0**
	Jln Besar BG	1.764(1.92)	0.99 – 4.21	
	KPC flat	0.73 (0.66)	0.27 – 1.22	
	Stockpile	7.0403*		
Cd	FBG	N/D	N/D	**0.8**
	Jln Besar BG	N/D	N/D	
	KPC flat	N/D	N/D	
	Stockpile	0.1733*		
Cr	FBG	27.80 (23.40)	1.84 – 75.25	**100.0**
	Jln Besar BG	8.02 (3.80)	2.16 – 8.57	
	KPC flat	2.39 (2.00)	0.42 – 3.83	
	Stockpile	96.006*		
Ni	FBG	12.64 (5.41)	2.91 – 32.21	**35.0**
	Jln Besar BG	16.54 (14.88)	5.99 – 27.22	
	KPC flat	1.33 (1.83)	0.70 – 3.33	
	Stockpile	43.68*		
Pb	FBG	4.65 (5.49)	N/D – 16.53	**85.0**
	Jln Besar BG	3.51 (4.76)	0.19 – 5.79	
	KPC flat	0.38 (1.51)	N/D – 1.23	
	Stockpile	16.3538*		

Standard limit derived from Dutch Target, 2009
N/D= Not detectable
*Mean value

4.4 Health Complaints among Respondents

For health complaints among respondents, there were eight parameters of respiratory health symptoms and dermal health symptoms evaluated in this study which were identified through interview using self-constructed questionnaire as mentioned in Chapter 3. Table 4.6 represent the number of health complaints among respodents exposed to bauxite mining activities within six months. The highest number of complaints was depression due to nuisances (39.5%) followed by itchiness (35.8%) and dry cough (30.9%). Meanwhile, bronchitis (0.6%) was the health symptoms were also reported.

Besides, the respiratory and dermal symptoms which include dry cough, phlegm cough, asthma, difficulties in breathing, bronchitis, rashes, redness, and edema also had been evaluated among respondents exposed to high level and very high level of particulate matter. The statistical analysis showed that prevalence of reported health symptoms were higher among respondents with very high exposure compared to high exposure. A study by Lad and Samant (2013) showed 90% of the respondents from Girgaon complained respiratory problems associated with the dust pollution due to the proximity of roads leading to mine sites which were very close to their houses.

The findings in Table 4.7 also shows the significant difference between the respondents exposed to high level and very high level PM_{10} for itchiness ($\chi^2 = 4.257$, $p = 0.039$). Figure 4.1 shows the graph of reported respiratory and dermal symptoms among study groups. Based on the finding on the graph, it clearly shows that respondents exposed to very high level of PM_{10} had higher reported symptoms.

Heavy metal exposure also occurs significantly by occupational exposure. Ogwuegbu and Muhanga, (2005) reported that workers of the mining and production of cadmium, chromium, lead, mercury, gold and silver, also inhabitants around industrial sites of heavy metal mining and processing, are exposed through air by suspended particulate matters (SPM).

Table 4.6: Number of health complaints among community exposed to bauxite mining activities within six months

Types of Health Symptoms	Frequency (n)	Percentage (%)
General problem		
Depression due to the nuisances	64	39.5
Headache	21	13.0
Vomit	2	1.23
Diarrhoea	2	1.23
Muscle cramps	5	3.1
Respiratory Problem		
Dry cough	50	30.9
Phlegm cough	49	30.2
Shortness of breath	27	16.7
Asthma	12	7.4
Bronchitis	1	0.6
Dermal Problem		
Itchiness	58	35.8
Redness/rash	46	28.4
Swollen /edema	3	1.9

N=162

Table 4.7: Number of Reported Respiratory and Dermal Symptoms among Study Group with Different Level of PM_{10}.

Variables	Very High n (%)	High n (%)	OR	95% CI	χ^2	*p*
Dry cough						
Yes	16 (43.2)	3 (60.0)	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)	0.813	0.120-5.499	0.045	0.831
No	24 (64.9)	3 (60.0)				
Shortness of breath						
Yes	8 (21.6)	1 (20.0)	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)	1.057	0.979-1.142	0.284	0.594
No	35 (94.6)	5 (100.0)				
Bronchitis						
Yes	1 (2.7)	0 (0.0)	1.028	0.974-1.084	0.138	0.710
No	36 (97.3)	5 (100.0)				
Itchiness						
Yes	18 (48.6)	0 (0.0)	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)	1.103	0.108-11.306	0.007	0.934
No	29 (78.4)	4 (80.0)				
Swollen /edema						
Yes	3 (8.1)	0 (0.0)	1.088	0.989-1.198	0.437	0.509
No	34 (91.9)	5 (100.0)				

N= 42
χ^2= Chi-Square Test
**Significant at $p < 0.05$*

Key:

High : PM_{10} level between 150-200 µg/m³
Very High : PM_{10} level more than 200 µg/m³

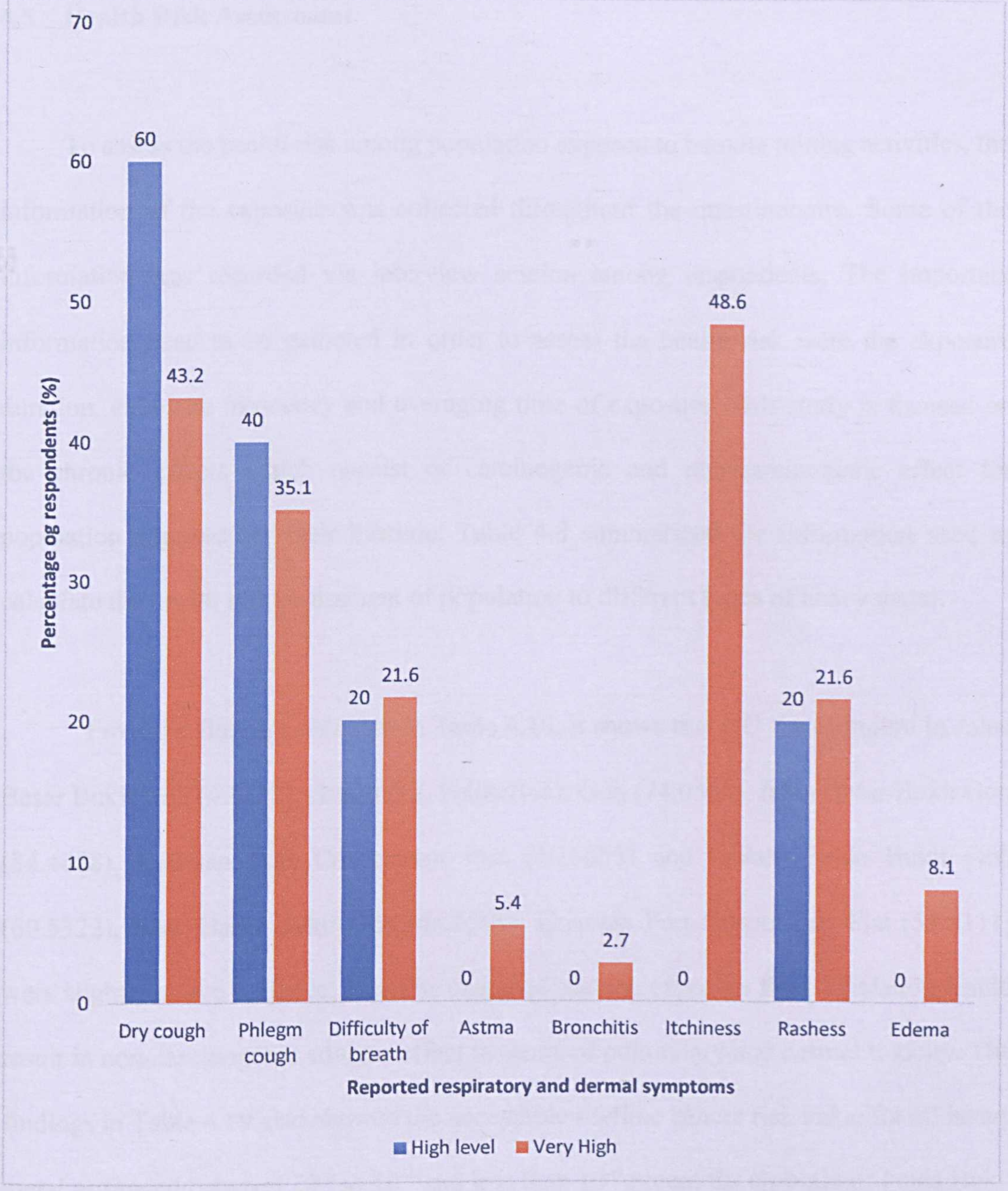

Figure 4.1: Reported respiratory and dermal symptoms among respondents

Key:

High : PM_{10} level between 150-200 µg/m³
Very High : PM_{10} level more than 200 µg/m³

4.5 Health Risk Assessment

To assess the health risk among population exposed to bauxite mining activities, the information of the exposure was collected throughout the questionnaire. Some of the information was recorded via interview session among respondents. The important information need to be gathered in order to assess the health risk were the exposure duration, exposure frequency and averaging time of exposure. This study is focused on the chronic effects which consist of carcinogenic and non-carcinogenic effect for population exposed for their lifetime. Table 4.8 summarized the information used to calculate the health risk assessment of population to different types of heavy metal.

From the findings obtained in Table 4.10, it shows that HQ for cadmium in Jalan Besar Bukit Goh (4.1328), chromium; Felda Bukit Goh (74.0560), Jalan Besar Bukit Goh (84.4088), Kuantan Port Consortium Flat (76.8655) and nickel; Felda Bukit Goh (60.5322), Jalan Besar Bukit Goh (66.9509), Kuantan Port Consortium Flat (58.8111) were slightly above 1. Hence, it can be deducted that the exposure from inhalation would result in non-carcinogenic adverse effect in terms of pulmonary and dermal toxicity. The findings in Table 4.10 also showed the acceptable lifetime cancer risk value for all heavy metal as ranged between 10^{-6} to 10^{-4} and less than 10^{-6} except for chromium; Felda Bukit Goh (2.5234×10^{-2}), Jalan Besar Bukit Goh (2.8763×10^{-2}), and Kuantan Port Consortium Flat (2.6191×10^{-2}).

The finding for chromium indicates about 20 000 cancer developed in every 1000 000 of exposed population over a lifetime duration of 70 years. Center for Hazardous

Substances Research of Kansas State University had classified chromium as carcinogens where breathing high levels of chromium can cause irritation to the lining of the nose, nose ulcers, runny nose, and breathing problems, such as asthma, cough, shortness of breath, or wheezing. Besides, skin contact to chromium can cause skin ulcers. Exposure to arsenic in long term can cause damage to liver, kidney circulatory and nerve tissues, as well as skin irritation.

Table 4.8 Information of population exposure to bauxite mining activities

Parameters	Average
Inhalation rate (m^3/day)	15.2
Exposure frequency (days/year)	350
Exposure duration (years)	2
Body weight (kg)	65
AT (days)	Non-carcinogenic: 730 Carcinogenic: 25 550

Table 4.9: Average Daily Dose (ADD) and Lifetime Average Daily Dose (LADD) for each elements

Elements (heavy metals)	Location	Average Daily Dose (mg/kg-day)	Lifetime Average Daily Dose (mg/kg/day)
Al	FBG	3.9629×10^{-4}	1.1323×10^{-5}
	Jln. Besar BG	5.6705×10^{-4}	1.6201×10^{-5}
	KPC Flat	9.1699×10^{-4}	2.6199×10^{-5}
As	FBG	1.3454×10^{-6}	3.8440×10^{-8}
	Jln. Besar BG	2.6908×10^{-6}	7.6881×10^{-8}
	KPC Flat	N/D	N/D
Cd	FBG	1.6593×10^{-6}	4.7410×10^{-8}
	Jln. Besar BG	9.6646×10^{-6}	2.7613×10^{-7}
	KPC Flat	N/D	N/D
Cr	FBG	1.7318×10^{-3}	4.9479×10^{-5}
	Jln. Besar BG	1.9739×10^{-3}	5.6399×10^{-5}
	KPC Flat	1.7975×10^{-3}	5.1356×10^{-5}
Ni	FBG	7.0773×10^{-4}	2.0221×10^{-5}
	Jln. Besar BG	7.8279×10^{-4}	2.2365×10^{-5}
	KPC Flat	6.8762×10^{-4}	1.9646×10^{-5}
Pb	FBG	1.8410×10^{-4}	1.1795×10^{-6}
	Jln. Besar BG	1.8270×10^{-4}	1.1705×10^{-6}
	KPC Flat	1.6510×10^{-4}	1.0578×10^{-6}

N/D = Not detectable

Table 4.10: The health risk assessment (value for Hazard Quotient and Lifetime Cancer Risk) on population in study areas

Elements (heavy metals)	Location	HQ	LCR
Al	FBG	N/A	N/A
	Jln. Besar BG	N/A	N/A
	KPC Flat	N/A	N/A
As	FBG	0.1918	4.6128×10^{-7}
	Jln. Besar BG	0.3836	9.2257×10^{-7}
	KPC Flat	N/D	N/D
Cd	FBG	0.7100	7.1115×10^{-8}
	Jln. Besar BG	4.1328	4.1420×10^{-7}
	KPC Flat	N/D	N/D
Cr	FBG	74.0560	2.5234×10^{-2}
	Jln. Besar BG	84.4088	2.8763×10^{-2}
	KPC Flat	76.8655	2.6191×10^{-2}
Ni	FBG	60.5322	1.8401×10^{-5}
	Jln. Besar BG	66.9509	2.0352×10^{-5}
	KPC Flat	58.8111	1.7878×10^{-5}
Pb	FBG	N/A	4.9539×10^{-8}
	Jln. Besar BG	N/A	4.9161×10^{-8}
	KPC Flat	N/A	4.44276×10^{-8}

N/A = Not available
N/D = Not detectable

Key:

HQ<1 indicates no significant non-carcinogenic risk.
HQ>1 indicates significant non-carcinogenic risk.
LCR<10^{-6} indicates no significant lifetime cancer risk
LCR>10^{-6} indicates significant lifetime cancer risk

CHAPTER 5

CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

5.1 Conclusion

From the findings, it could be concluded that level of selected heavy metals (aluminum (Al), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni) and lead (Pb)) in ambient air exceeded the limit value as in air quality guideline by U.S Department of Health and Human Services (ATSDR). Meanwhile, for level of selected heavy metals (aluminum (Al), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni) and lead (Pb)) in soil, the levels were low and did not exceeded the value recommended by Standard of Dutch Target.

The overall results of PM_{10} showed the concentration in each sampling points exceeded the Malaysian Ambient Air Quality Guidelines (MAAQG 2015) limit which is 150 $\mu g/m^3$ for 24 hours exposure ($p<0.001$). High PM_{10} sources come from the mining activities which contributed to air pollution and led to health symptoms. For health complaints from the community nearby the mining areas, itchiness shows the highest reported symptoms (35.8%), followed by dry cough (30.9%), phlegm cough (30.2%) and redness/rash (28.4%) while bronchitis (0.6%) shows the least reported symptoms. Very high level of PM_{10} exposure (>200 µg/m^3) showed significantly higher in number of reported itchiness among respondents (χ^2=4.257, p=0.039).

The health risk assessment for the population exposed to bauxite mining activities also indicated that the inhalation exposure did not pose any health hazard except for cadmium in Jalan Besar Bukit Goh (4.1328), chromium; Felda Bukit Goh (74.0560), Jalan Besar Bukit Goh (84.4088), Kuantan Port Consortium Flat (76.8655) and nickel; Felda Bukit Goh (60.5322), Jalan Besar Bukit Goh (66.9509), Kuantan Port Consortium Flat (58.8111). The lifetime cancer risk also did not show any significant hazard as the lifetime excess cancer risk were less than 10^{-6} except for chromium; Felda Bukit Goh (2.5234×10^{-2}), Jalan Besar Bukit Goh (2.8763×10^{-2}), and Kuantan Port Consortium Flat (2.6191×10^{-2}).

5.2 Study Limitation

This study was designed as cross-sectional study and thus it has some limitation as the factor and outcome can be determined at the same specific period of time. Besides, the information bias can happened when the respondents could not remember some important information related to the study or their answer given and not reflecting their actual situation. This scenario can give effect to the outcome of this study as well. There were also difficulties in getting cooperation from respondents as some of them were directly involved with the mining activities. Other than that, changing of weather might also influenced the data collection. Some of sampling happened were carried out during rainy day.

5.3 Recommendation

From the study, the exposure of PM_{10} exceed the available guideline and increase the number of respiratory health symptoms among residents near the bauxite mining areas. The lifetime cancer risk also indicates probability of cancer developments for some type of heavy metals to the exposed population for a lifetime duration.. Thus, it is suggested that bauxite mining company take proactive actions to reduce the emission of particulate from mining activities. There was no proper standard operating procedures and regulations and thus mining companies simply exploit the earth's mineral rather than taking proactive and preventive measures to protect the public. Local authorities should enforce laws and regulations regarding the illegal mining to ensure mining activities did not cause harm to any parties.

Apart from that, further study can be done for ambient air quality using standard operating methods and equipment such as high volume air sampler that more accurate for environmental sampling compared to personal air volume sampler. Besides that, to strengthen the study, different measurement to identify the sources of air pollutant should be done to reduce the confounding. Other than that, further study should be conducted with two different group; control group and exposed group to identify the association between bauxite mining activities with the health related symptoms.

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Appendix 1

Felda Bukit Goh Approval Letter

Appendix 2

Respondent's Information and Consent Form (Bahasa Melayu)

JAWATANKUASA ETIKA UNIVERSITI UNTUK
PENYELIDIKAN MELIBATKAN MANUSIA (JKEUPM)
UNIVERSITI PUTRA MALAYSIA, 43400 UPM SERDANG,

BORANG B1: PENERANGAN DAN PERSETUJUAN RESPONDEN

Sila baca maklumat berikut dengan teliti. Sekiranya anda mempunyai sebarang pertanyaan, sila kemukakan kepada penyelidik.

1. TAJUK KAJIAN

Penilaian Risiko Kesihatan Alam Sekitar untuk Logam Berat dalam Tanah dan Udara di Kawasan Aktiviti Perlombongan Bauksit di Felda Bukit Goh, Kuantan.

2. PENGENALAN

Tujuan kajian ini adalah:

i. Untuk menilai risiko kesihatan daripada perlombongan bauksit di Felda Bukit Goh, Kuantan.
ii. Untuk menentukan tahap logam berat ((aluminium (Al), kadmium (Cd), arsenik (As), kromium (Cr), nikel (Ni) dan plumbum (Pb)) debu merah di udara dan endapan tanah di kawasan sekitar perlombongan bauksit.
iii. Untuk menentukan risiko kesihatan yang berpotensi berdasarkan aduan kesihatan dari masyarakat dalam jarak 1km radius kawasan perlombongan bauksit.
iv. Untuk menentukan hubungan antara masalah kesihatan (pernafasan dan kulit) dengan tahap PM10 yang berbeza dalam udara.
v. Untuk menilai risiko kesihatan pendedahan kepada penduduk dalam jarak 1 km radius kawasan perlombongan bauksit.

3. APA YANG PERLU ANDA LAKUKAN?

Responden hanya perlu menjawab borang soal selidik yang diajukan oleh penyelidik dengan memenuhi setiap ruang maklumat yang diperlukan dan memberi kerjasama untuk ditemubual.

4. SIAPA YANG TIDAK BOLEH MENYERTAI KAJIAN INI?

Responden yang tidak mempunyai ciri-ciri yang diperlukan dalam kajian ini seperti tidak terdedah di dalam kawasan yang dikaji dan duduk melebihi dari keluasan 1km radius dari kawasan kajian.

5. APAKAH FAEDAH MENYERTAI KAJIAN INI?

a) KEPADA ANDA SEBAGAI PESERTA?

Dapat membantu penyelidikan masa akan datang dengan memudahkan pengumpulan maklumat yang diperlukan serta membantu memberi kesedaran terhadap masalah kesihatan yang hadapi akibat aktiviti perlombongan ini.

Appendix 3

Questionnaire (Bahasa Melayu)

Kod Responden: ☐☐☐

JABATAN KESIHATAN PERSEKITARAN DAN PEKERJAAN

FAKULTI PERUBATAN DAN SAINS KESIHATAN

UNIVERSITI PUTRA MALAYSIA

PENILAIAN RISIKO KESIHATAN PERSEKITARAN TERHADAP LOGAM BERAT YANG TERDAPAT DI DALAM TANAH DAN UDARA DI KAWASAN PERLOMBONGAN BAUKSIT DI FELDA BUKIT GOH DAN PANGSAPURI PELABUHAN KUANTAN, PAHANG

ARAHAN SOALAN:

1. Borang soal selidik ini mengandungi **DUA (2)** bahagian iaitu:

   Bahagian A : Maklumat Diri

   Bahagian B : Masalah Kesihatan Akibat Pendedahan Aktiviti Perlombongan

2. Anda dikehendaki **menjawab semua soalan** yang ada dalam borang soal selidik ini

BAHAGIAN A: MAKLUMAT DIRI

1. Nama: ....

2. Alamat: ....
....

3. No. Telefon: ....

4. Umur: .... tahun

5. Jantina:
☐ Lelaki
☐ Perempuan

6. Bangsa:
☐ Melayu
☐ Cina
☐ India
☐ Lain-lain (Sila nyatakan): ....

7. Berat: .... kg

8. Tinggi: .... m

9. Adakah anda merokok?

☐ Ya, merokok sekarang. (jumlah tahun:....................; jumlah batang/hari:..................)
☐ Pernah merokok (bila berhenti:..................................)
☐ Tidak pernah

10. Tahap Pendidikan:

☐ Sekolah Rendah

☐ Sekolah Menengah

☐ Sijil

☐ Ijazah

☐ Lain-lain (sila nyatakan): ....

11. Pendapatan Seisi Rumah Sebulan:

☐ < 1000 ☐ 1000-3000 ☐ 3000 – 5000 ☐ >5000

12. Tempoh tinggal di tempat ini: .... tahun

13. Pekerjaan sekarang: ....

14. Tempoh bekerja di tempat sekarang: .... bulan/tahun

15. Tempat bekerja sekarang: ....

16. Adakah anda terlibat dengan aktiviti perlombongan? Ya ☐ Tidak ☐

17. **Sila jawab soalan ini sekiranya anda menjawab Ya di soalan 16.**

Jika Ya:

a. Membenarkan tanah milik sendiri dilombong ☐
b. Bekerja di kawasan perlombongan ☐
c. Ahli keluarga bekerja dilombong ☐
d. Lain-lain (Sila nyatakan): .... ☐

18. Adakah anda mempunyai anak yang masih bersekolah rendah? Ya ☐ Tidak ☐

19. **Sila jawab soalan ini sekiranya anda menjawab Ya di soalan 18.**

Jika Ya :

a. Berapa orang: ....
b. Umur: ....

20. Tempat anak anda bersekolah : ....

BAHAGIAN B: MASALAH KESIHATAN AKIBAT PENDEDAHAN AKTIVITI PERLOMBONGAN

21. Tandakan **(√)** pada gejala-gejala masalah kesihatan yang dihadapi selepas wujudnya aktiviti perlombongan untuk jangka masa **1 minggu, 1 bulan & 6 bulan** yang lepas. (Boleh tanda lebih dari satu)

a. Masalah Umum

Jenis Gejala Kesihatan	**1 Minggu**	**1 Bulan**	**6 Bulan**	**Punca**
Tekanan akibat bunyi bising				
Sakit kepala				
Muntah-muntah				
Cirit-birit				
Kekejangan otot				

b. Masalah Saluran Pernafasan

Jenis Gejala Kesihatan	**1 Minggu**	**1 Bulan**	**6 Bulan**	**Punca**
Batuk kering				
Batuk berkahak				
Masalah pernafasan /sesak nafas				
Asma				
Bronkitis				

c. Masalah Kulit

Jenis Gejala Kesihatan	**1 Minggu**	**1 Bulan**	**6 Bulan**	**Punca**
Kulit gatal				
Kulit gatal dan berbintat				

Kulit merah-merah/ruam				
Kulit bengkak /edema				

22. Adakah anda batuk 4 hingga 6 kali dalam sehari atau lebih dalam seminggu?

Ya ☐ Tidak ☐

23. Adakah anda batuk sepanjang hari di waktu siang atau malam?

Ya ☐ Tidak ☐

24. Adakah anda batuk ketika bangun dari tidur pada pagi hari?

Ya ☐ Tidak ☐

-Soalan Tamat-

Appendix 4

Ethical Clearance

JKEUPM Ref No. **: FPSK(EXP15-OSH)U007**

a) Members of the JKEUPM who reviewed the documents:
Dr Salmiah Md Said

b) Date of approval:
13 Mei 2016

Appendix 5

Work Schedule (Gannt Chart)

Activity	Sept 2015	Oct 2015	Nov 2015	Dec 2015	Jan 2016	Feb 2016	Mar 2016	Apr 2016	May 2016
Library research/Literature review	🟥								
Select topic	🟥								
Drafting proposal	🟥	🟥							
Submit proposal to be reviewed by supervisor		🟥							
Revised draft		🟥							
Submit proposal			🟥						
Feedback on proposal				🟥					
Develop schedule for data collection				🟥					
Data collection					🟥	🟥			
Data analysis						🟥	🟥		
Report writing						🟥	🟥	🟥	
Submitting final report									🟥

Appendix 6

ICP-MS Calibration Curve

Quantitative Analysis Calibration Report

File Name:
File Path:
Calibration Type: External Calibration

Analyte	Mass	Curve Type	Slope	Intercept	Corr. Coeff.
Al	26.982	Simple Linear	25096.43	-27957.79	0.999804
As	74.922	Simple Linear	1702.51	-189.19	0.999958
Cd	113.904	Simple Linear	8127.62	-122.82	0.999984
Ni	57.935	Simple Linear	7562.56	279.08	0.999954
Cr	51.941	Simple Linear	12760.57	-362.62	0.999980
Pb	207.977	Simple Linear	19796.19	2800.45	0.999975

Report Date/Time: Thursday, February 18, 2016 14:42:28

QC Calculated Values

IS	Analyte	Mass	QC Std % Recovery	Int Std % Recovery	Spike % Recovery	Dilution % Diff	Duplicate Rel. % Diff
	Al	27	112.93				
	As	75	102.36				
	Cd	114	102.01				
	Ni	58	101.68				
	Cr	52	104.01				
	Pb	208	101.12				

QC Out of Limits

Measurement Type	Analyte	Mass	Out of Limits Message

Appendix 7

ICP-MS Analysis for Heavy Metals

ERG No.: 0143.04.005
EPA Contract No.: 68-D-00-264

Standard Operating Procedure for the Determination of Metals In Ambient Particulate Matter Analyzed By Inductively Coupled Plasma/Mass Spectrometry (ICP/MS)

Work Assignment 5-03

Prepared for:
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC

September 2005

DISCLAIMER

Through its Office of Air Quality Planning and Standards, the U.S. Environmental Protection Agency funded and managed the research described in this procedure under EPA contract No. 68-D-00-264 to Eastern Research Group, Inc. Mention of trade names or commercial products in this procedure does not constitute endorsement or recommendation for their use. This procedure has not been subjected to the EPA's review and is not an EPA approved document.

1.0 IDENTIFICATION AND PURPOSE

This standard operating procedure (SOP) provides the sample preparation procedures for Teflon, PM10, or TSP filters and analysis for metals by Inductively Coupled Plasma - Mass Spectrometer (ICP-MS).

2.0 MATRIX OR MATRICES

This procedure applies to the preparation and analysis of metals on Teflon, PM10, or TSP filters obtained by low-volume sampling.

3.0 METHOD DETECTION LIMIT

3.1 Method Detection Limits (MDL)

3.1.1 The method detection limit (MDL) for each isotope is calculated according to 40 CFR, Vol. 49, No. 209, Appendix B to Part 136. At least 7 replicates are prepared and analyzed for this study. An example of MDL attainable by this method is shown in Table 24.1.

3.1.2 The y-intercept for each linear calibration must be set to zero.

3.1.3 Use the same internal standards and instrument settings (sweeps and dwell) for MDL and field sample analysis.

3.1.4 The MDL determination should be reported in ng/mL and ng/m^3 (assuming 20 m^3 for Teflon filters and 1700 m^3 for PM10 or TSP filters).

3.1.5 The MDLs should be repeated once per year.

3.2 Instrument Detection Limits (IDL)

The IDL is used to compare instrument performance over time or to verify performance to manufacturer's specifications. Although the IDL is not used in data QC evaluations, the IDL can be useful in comparing instrument performance over time.

3.2.1 To determine an IDL, use settings for sweeps and dwell time that yield the most outstanding results.

3.2.2 Run at least 7 replicates of a blank solution and a concentration 3.5 times the MDL. Use the standard deviation value appropriate for the degrees of freedom in the Federal Register's equation listed in Section 3.1.1.

4.0 SCOPE AND APPLICATION

This procedure describes the acid extraction and trace elemental analysis of ambient air samples using an inductively coupled plasma-mass spectrometer (ICP-MS). The extraction procedures are suitable for low-volume ambient air samples collected on exposed Teflon, and high-volume ambient air sampling collected on PM10 or TSP filters.

5.0 METHOD SUMMARY

This SOP covers the preparation and analysis of metals on Teflon, PM10, or TSP filters exposed to ambient air and submitted to the laboratory. The filters are extracted in 4% nitric acid via sonication for 3 hours. The extract is analyzed by ICP-MS. The ICP-MS analysis is completed using the manufacturer software following conditions established during calibration and quality control checks of instrument performance.

6.0 DEFINITIONS

CCB	Continuing Calibration Blank
CCV	Continuing Calibration Verification
DI water	Deionized water
DQO	Data Quality Objective
HSV	High Standard Verification
IC	Initial Calibration
ICB	Initial Calibration Blank
ICP-MS	Inductively Coupled Plasma - Mass Spectrometry
ICS	Interference Check Standard
ICV	Initial Calibration Verification
LCS	Laboratory Calibration Spikes
MB	Method Blank
MDL	Method Detection Limit
mL	milliliter(s)
mm	millimeter(s)
MS	Matrix Spike
ng/m^3	nanogram(s) per cubic meter
NIST	National Institute of Standards and Technology
QCS	Quality Control Sample
RSD	Relative Standard Deviation
RPD	Relative Percent Deviation
SD	Standard Deviation
• g/mL	microgram(s) per milliliter(s)

7.0 INTERFERENCES

The background level of metals on a given lot of quartz filters can vary. Any background levels found on blanks should be documented for all the filters from the corresponding lot.

7.1 Laboratory Interferences

7.1.1 Wear talc-free gloves when handling unexposed or exposed filters.

7.1.2 Clean all equipment used in the sample preparation and analysis following standard dishwashing procedures followed by acid washing filters in 10 or 50% HNO_3 acid.

7.1.3 Use Type I deionized (DI) water, with a resistivity of greater than 17.3 megaohms or greater, for sample extraction and standard preparation. Record the water resistivity prior to use.

7.2 Chemical Interferences

Pay close attention to the nature of solutions introduced to the ICP-MS.

7.2.1 Nitric acid must be less than 2% for ICP-MS analysis to minimize the damage to the interface and to minimize isobaric molecular interferences.

7.2.2 If higher acid extraction concentrations are required, dilute to 2%.

7.2.3 The final dilutions of sample extracts must equal the acid content of the calibration standards in order to compensate for potential interferences.

7.2.4 The concentrations of dissolved solids in analysis solutions should be less than 2% to protect the sample interface on the instrument. Higher concentrations may plug the sample cone orifice.

7.2.5 Protect the channel electron multiplier from high chemical concentrations (high ion currents). The channel electron multiplier suffers from fatigue after being exposed to high ion currents. This fatigue can last from several seconds to hours depending on the extent of exposure. During this period, response factors are constantly changing, which causes instrument instability that invalidates the calibration curve, and thereby, invalidates all associated sample results. A sodium bicarbonate (NaHCO3) sample matrix is known to cause this problem.

7.3 Instrument Interferences

7.3.1 Isobaric molecular and doubly charged ion interferences are caused by more than one atom (example, the contribution of ArCl on the 75As signal) or more than one charge (example, MoO+ ions on Cd isotopes).

7.3.2 Spectral interferences result from the presence of other isotopes or ions that have the same atomic weight or mass number as the analyte.

7.3.3 Transport interferences are a specific physical interference associated with the sample nebulization and transport process through the instrument. These usually result from sample matrix components that influence the aerosol formation or cause a change in the surface tension or viscosity. Changes in the matrix composition can cause observed signal suppression or enhancement.

7.3.4 Matrix interferences are caused by elemental properties of the samples in solution. For matrices of known composition, match the composition of the standards to that of the samples. For matrices of unknown composition, use an internal standard that has been matched to the analyte(s) so that the two elements are similarly affected by matrix changes.

7.3.5 Memory interferences can occur when there are large concentration differences between samples or standards that are analyzed sequentially. Sample deposition on the sampler and skimmer cones, spray chamber design, and the type of nebulizer all affect the extent of the memory interferences that are observed. The rinse period between samples must be long enough to eliminate significant memory interferences.

8.0 SAFETY

8.1 Personal protection should be used for all work used in the inorganic laboratory, (e.g., gloves, safety glasses, laboratory coats, etc.).

8.2 The compressed gas cylinders must be stored and handled according to relevant safety codes outlined in the corporate health and safety manual. In use, the cylinders must be secured to an immovable structure and moved using a gas cylinder cart.

8.3 Make sure that sample vials are kept in racks to prevent spills.

8.4 All personnel should be trained in the exaction and analysis of acid samples for inorganic analysis.

8.5 Strong acids must not be stored with organic solvents or samples.

8.6 Follow applicable laboratory safety procedures and Health and Safety Manuals.

9.0 EQUIPMENT

Inductively Coupled Plasma-Mass Spectrometer - consists of an inductively coupled plasma source, ion optics, a quadrupole spectrometer, a computer that controls the instrument, data acquisition, and data handling, a printer, an autosampler and a recirculator. The quadrupole mass spectrometer has a mass range of 2 to 270 atomic mass units (amu).

9.1 <u>Typical Operating Conditions</u>

Plasma forward power	1.6 kW
Coolant flow rate	13.5 Lpm
Auxiliary flow rate	0.6 Lpm
Nebulizer flow rate	0.78 Lpm
Solution uptake rate	0.6 mL/min
Spray chamber temperature	15 •C

Detector mode	Pulse counting
Replicate integrations	3
Mass range	8 - 240 amu
Dwell time	320 microsecond
Number of MCA channels	2048
Number of scan sweeps	85
Total acquisition time	3 min/sample

10.0 MATERIALS

10.1 Polypropylene sample vials with screw caps.

10.2 Sonication bath with the heating capability to 69 degrees Celsius (°C).

10.3 Micro-pipettes with disposable tips, 100 microliter (• L) to 10 milliliter (mL).

10.4 Repeating pipeter, 20 mL.

10.5 Volumetric flasks, 50 mL.

10.6 Polypropylene funnels and Whatman 541 filter paper, or Environmental Express "FilterMate".

10.7 Miscellaneous: talc-free gloves; disposable laboratory wipes; self adhesive labels.

11.0 CHEMICALS, REAGENTS, AND STANDARDS

11.1 Nitric Acid, ultrapure and concentrated.

11.1.1 To prepare the 0.5% Nitric Acid Solution, dilute 0.5 mL of nitric acid in 100 mL of DI water.

11.2 De-ionized water, filtered with a resistivity of greater than 17.3 megaohms.

11.3 Argon gas, high purity.

11.4 Calibration Standards: National Institute of Standards and Technology (NIST) traceable material, 10 • g/mL stock in one percent nitric acid.

11.5 Secondary Source Control Standard: secondary source of the intermediate range calibration standard is run as a check of the precision of the instrument and calibration.

12.0 COLLECTION, PRESERVATION, SHIPMENT, AND STORAGE

12.1 Preparation and Handling of Filters

Whenever the filter is handled, clean Teflon® coated or plastic tweezers are used with disposable PVC gloves.

12.2 Preservation and Storage of Filters

Samples can be stored for up to 180 days in ambient conditions.
A unique identification number is placed on the outside of the envelope.

13.0 CALIBRATION AND STANDARDIZATION

13.1 Tuning Solution

The tuning solution contains elements representing all of the mass regions of interest, thereby verifying that the resolution and mass calibration of the instrument are within the required specifications. The solution is also used to verify that the instrument has reached thermal stability. The tuning solution should include 10 ng/mL of Be, Mg, Co, In, and Pb. If needed other elements can be added, such as Cu, Rh, Cd, Ba, Ce, U.

13.2 Calibration

13.2.1 Allow a period of not less than 30 minutes for instrument warm up. During this process, conduct mass calibration and resolution checks using the tuning solution. Resolution at low mass is indicated by magnesium isotopes 24, 25, and 26. Resolution at high mass is indicated by lead isotopes 206, 207, and 208. For good performance, adjust spectrometer resolution to produce a peak width of approximately 0.75 amu at 5% peak height. Adjust mass calibration if it has shifted by more than 0.1 amu from unit mass.

13.2.2 Instrument stability must be demonstrated by running the tuning solution a minimum of five times with resulting relative standard deviations of absolute signals for all analytes of less than 5%.

13.2.3 Prior to initial calibration, set up proper instrument software routines for quantitative analysis. The instrument must be calibrated, using a minimum of 4 calibration points, for the analytes to be determined using the calibration blank and calibration standards prepared at one or more calibration levels. A minimum of three replicate integrations are required for data acquisition. Use the average of the integrations for instrument calibration and data reporting.

13.2.4 The rinse blank should flush the system between solution changes for blanks, standards, and samples. Allow sufficient rinse time to remove traces of the previous sample or a minimum of 1 min. Solutions should aspirate for at least 30 seconds prior to the acquisition of data to establish equilibrium.

13.2.5 All quality control requirements presented in Table 24-2 must be met.

13.3 Internal Standardization

Selecting the proper internal standard, at ideal concentrations, can eliminate the need for correction equations.

13.3.1 Internal standards for this method are Sc, ^{89}Y, ^{115}In, Tb, and ^{209}Bi for analytes beginning with Mass 6 and ending with Mass 238. If needed other elements can be added, such as ^{6}Li, and ^{69}Ga.

13.3.2 Concentrations of the internal standards for this method should be 10 nanogram per milliliter (ng/mL).

13.3.3 The concentration of the internal standard must be added equally to the reagent blank, calibration standards, and samples.

13.3.4 Internal standardization must be used in all analyses to correct for instrument drift and physical interferences.

13.4 Instrument Performance

13.4.1 After establishing calibration, verify all analytes by analyzing the Initial Calibration Verification Sample (ICV), which should be obtained from a second source outside the laboratory. If measurements exceed ± 10% of the established ICV value, terminate the analysis, identify and correct the problem, and re-analyze the ICV before continuing analysis.

13.4.2 To verify that the instrument is properly calibrated on a continuing basis, run the calibration blank and calibration standards as surrogate samples after every 10 analyses. The results of the analyses of the standards will indicate whether the calibration remains valid. If the indicated concentration of any analyte deviates from the true concentration by more than 10%, re-analyze the standard. If the analyte is again outside the 10% limit, the instrument must be re-calibrated and the previous ten samples re-analyzed. The instrument responses from the calibration check may be used for re-calibration purposes. If the sample matrix is responsible for the calibration drift, the previous 10 samples should be re-analyzed in groups of five between calibration checks to prevent a similar drift induced error from reoccurring.

14.0 PROCEDURE

14.1 Filter Extraction

Sonication Preparation - applicable to Teflon, TSP, and PM10 filters.

14.1.1 If preparing a TSP or PM10 filter, cut a 1 x 8 " strip from the exposed filter.

14.1.2 Place filter strip or Teflon filter in an extraction tube as far down as possible.

14.1.3 Pour 20 mL of the 4% nitric acid into the extraction tube with the filter.

14.1.4 To recover mercury for ICP-MS analysis, spike 1 ppm of gold into extraction tube. Cap the tube.

14.1.5 Sonicate for 3 hours using a heated (69 •C) sonication bath.

14.1.6 Check the filter occasionally during sonication. If it floats out of the acid, use a clean pyrex or quartz glass rod to adjust the filter to the bottom of the tube.

14.1.7 After sonication, allow the sample to cool to room temperature.

14.1.8 Set up a filter funnel, Whatman 541 filter paper (or equivalent), and 50 mL volumetric for each sample or use a FilterMate devise.

14.1.9 Filter sample and dilute to 50 mL with clean DI water.

14.1.10Transfer the sample extract to a polypropylene bottle or leave in FilterMate. The sample extract is ready to be analyzed.

Hot Acid Digestion - applicable to TSP and PM10 filters.

14.1.1 If preparing a TSP or PM10 filter, cut a 1 x 8 " strip from the exposed filter.

14.1.2 Place filter strip or Teflon filter in 250mL quartz beaker.

14.1.3 Pour 30 mL of the 10% nitric acid onto the filter.

14.1.4 To recover mercury for ICP-MS analysis, spike 1 ppm of gold into extraction tube. Cap the tube.

14.1.5 Reflux gently for 30 minutes at 95 •C.

14.1.6 After refluxing, add 10 mL of clean DI water and allow the extract to cool for 30 minutes.

14.1.7 Filter the extract using Whatman 541 filter paper (or equivalent), syringe filter, or "FilterMate".

14.1.8 Dilute to 20 mL with clean DI water.

14.1.9 Transfer the extract to a polypropylene bottle. The sample extract is ready to be analyzed.

14.2 Filter Analysis

14.2.1 To tune the ICP-MS, a tuning solution is analyzed prior to analyzing samples with at least five replicates with a RSD of ± 5%.

14.2.2 After the initial calibration is completed, a calibration check is required at the beginning and end of each analysis period and at intervals of ten samples to verify the calibration. The RPD must be within ± 10%. The calibration check does not meet this criteria, the check, and any bracketed samples, should be re-analyzed. If the calibration check does not meet criteria a second time, the instrument should be re-calibrated.

14.2.3 Analyze a continuing calibration blank after the continuing calibration check. The blank must not contain any target metal above the MDLs.

14.2.4 Samples with analyte concentrations above the calibration range must be diluted and re-analyzed.

15.0 CALCULATIONS

15.1 Analyte Concentration

Metal concentration in the air sample should be calculated as follows:

C = [(• g metal/L) x (Digestion volume (i.e., 0.050 L) L/filter)/V_{std}

Where:

C = concentration, • g metal/m^3

• g metal/L = metal concentration determined from Section 14.2.

Filter extract volume (L/filter) = total sample extraction volume from extraction procedure (i.e., 0.05 L).

V_{std} = standard air volume pulled through the filter, m^3

15.2 Relative Percent Difference (RPD)

The RPD is calculated as follows:

$$RPD = (R_1 - R_2)/[(R_1 + R_2)/2] \times 100$$

Where:

R_1, R_2 = values that are being compared (i.e., response factors in calibration verification)

15.3 Percent Recovery

Percent Recovery is calculated as follows:

Percent Recovery = (Analytical result/Theoretical result) x 100

15.4 If an element has more than 1 monitored isotope, examine the concentration calculated for each isotope, or isotope ratios, to detect a possible spectral interference. Consider both primary and secondary isotopes when evaluating the element concentration. In some cases, secondary isotopes may be less sensitive or more prone to interferences that the primary recommended isotopes; therefore, differences between the results do not necessarily indicate a problem with data calculated for the primary isotopes.

15.5 Correct data values for instrument drift or sample matrix induced interferences by applying internal standardization correction factors. Corrections for characterized spectral interferences should also be applied to the data.

16.0 QUALITY CONTROL

Method Quality Objectives (MQO) and data assessment criteria, are determined from the results of the quality control samples. The MQO criteria is presented in Table 24-2.

16.1 Sample Collection Quality Control

16.1.1 Filters which are dropped or become contaminated with any foreign matter (i.e., dirt, finger marks, ink, liquids, etc.) are invalid.

16.1.2 Filters with tears or pinholes, which occurred before or during sampling, are invalid.

16.1.3 A power failure during a sample analysis invalidates the sample collected during that run.

16.2 Initial Calibration

Analyze at least four calibration levels with an correlation factor (R) greater than or equal to 0.995. If calibration fails this criteria, repeat the analysis. If criteria is still not met, reprepare the standards and perform the calibration again.

16.3 Initial Calibration Verification

Analyze the initial calibration verification (ICV) immediately after the initial calibration. If the recovery criteria, 90-110%, is not met, repeat the analysis.

16.4 Initial Calibration Blank

Analyze the initial calibration blank (ICB) immediately after the ICV and prior to analysis of the high standard verification. The analytes must be at levels below the MDL. If not, locate and resolve the contamination problem before continuing. Any sample result for analytes less than 5 times the amount of the blank must be flagged or analysis must be repeated.

16.5 Interference Check Standard

Analyze the interference check standard (ICS) immediately after the analysis of the HSV, and prior to the analysis of the samples. The ICS must be analyzed every 8 hours of continuous operation and again at the end of the analysis batch. If the recovery criteria, 80-120%, is not met, repeat the analysis. If the recovery criteria is not met again, re-prepare the ICS and analyze. Samples containing levels of the interferences above the levels in the ICS should be considered for dilution.

16.7 Continuing Calibration Verification (CCV)

Analyze a mid-range calibration standard after every 10 sample analyses to verify the initial calibration. If the recovery criteria, 90-110%, is not met, repeat the analysis. If the recovery criteria is not met again, the instrument must be re-calibrated and samples must be re-analyzed.

16.8 Continuing Calibration Blanks

Analyze a continuing calibration blank (CCB) immediately following each CCV. The analytes must be at levels below the MDL. If not, locate and resolve the contamination problem before continuing. Any sample result for analytes less than 5 times the amount of the blank must be flagged or analysis must be repeated.

16.9 Method Spikes and Method Spike Duplicates

Analyze one method spike and one method spike duplicate per batch of samples to determine that the matrix effects from the filters at a frequency of one per batch of samples prepped. The method spikes and method spike duplicates should be within ±20% RPD of the target values. If the spikes are outside of these limits, check the calibration and extraction procedures.

16.10 Method Blanks

Analyze a method blank (MB) for every 20 sample analyses. The MB contains all the reagents in the sample preparation procedure and must be prepared and analyzed as a sample to determine the background levels from the instrument. The analytes must be at levels below the MDL. Any sample result for analytes less than 5 times the amount of the blank must be flagged or analysis must be repeated.

16.11 Matrix Spikes

Analyze one matrix spike (MS) per batch of samples at a minimum, or 1 per 20 samples, to determine the matrix effects from the filter. If the recovery criteria, 75-125%, is not met, re-prepare the batch.

16.12 Laboratory Control Spike (LCS)

A laboratory control spike must be prepared from a secondary source of calibration standards and analyzed with each sample batch. If the recovery criteria, 80-120% (exception of Ag and Sb), is not met, re-prepare the sample batch.

16.13 Internal Standards

The intensities of all internal standards must be monitored for every analysis. When the intensity of any internal standard fails to register between 60 to 125% of the intensity of that internal standard in the initial calibration standard, the following procedure is implemented:

16.13.1 If the intensities are too high, the sample must be diluted and reanalyzed with the addition of appropriate amounts of internal standards.

16.13.2 Repeat dilution until the internal standard intensities fall within the prescribed window.

16.13.3 Check that the intensity levels of the internal standards for the calibration blank and interference check standard agree within 20% of the intensity level of the internal standard of the original calibration solution. If they do not agree, stop the analysis, find and correct the problem, re-calibrate if needed and re-analyze the affected samples.

16.14 Serial Dilution

The ICP serial dilution analysis must be performed on one sample per batch. After a fivefold serial dilution, the analyte concentration must be within 90 and 110% of the undiluted sample results. If it does not agree within these limitations, re-prepare and analyze the dilution. If it fails a second time, an interference effect must be suspected and the data must be flagged.

16.15 Rinse Blank

Flush the system between standards and samples with 2% nitric acid in DI water.

17.0 PREVENTION

When possible, minimize the amount of chemicals used in the preparation and analysis of the metals filters to reduce waste.

18.0 CORRECTIVE ACTION

Corrective action for any analyses data quality issues should be developed by each laboratory. Table 24.2 gives the data quality guidelines and the associated recommended corrective actions.

19.0 WASTE MANAGEMENT

The ICP-MS analyst is responsible for ensuring the safe storage and disposal of all chemical standards and reagents associated with this method.

19.1 Ordering Chemicals

19.1.1 Storage of excess chemicals takes up valuable lab space. Prior to ordering chemicals, assess needs carefully. Order only amounts that will be utilized within the following year.

19.1.2 Purchase smaller volumes whenever possible to minimize disposal costs of unused portions.

19.2 Disposing of Chemicals

19.2.1 The ICP-MS analyst is responsible for notifying the hazardous waste coordinator of disposal needs.

19.2.2 The ICP-MS analyst is responsible for keeping chemicals and reagents separate and in their original containers.

20.0 MAINTENANCE

A service contract would provide for preventive maintenance on a semiannual basis and for repair services for the instrumentation as required. All maintenance activities should be documented in instrument maintenance logs. Experienced analysts can perform routine maintenance.

20.1 The following maintenance procedures need to be addressed daily.

20.1.1 Check sample waste container level.

20.1.2 Inspect argon tank supply and its pressure to the instrument.

20.1.3 Inspect chiller connections for possible leaks.

20.1.4 Inspect torch and aerosol injector tubes.

20.1.5 Inspect nebulizer for clogs.

20.1.6 Inspect sample capillary tubing to be sure it is clean and in good condition.

20.1.7 Check peristaltic pump tubing before operation.

20.1.8 At the end of the day, flush system for 5 minutes with the plasma on with a maximum of 2% nitric acid, followed by deionized water.

20.2 The following maintenance procedures need to be addressed quarterly.

20.2.1 Clean touch components and replace any worn O-rings on the torch assembly.

20.2.2 Inspect and clean the RF coil.

20.2.3 Clean nebulizer spray pattern. Clean and replace tip as necessary.

20.2.4 Check nebulizer components and replace worn O-ring on the transducer face.

20.2.5 Clean drain fitting for leaks.

20.2.6 Check that pump rollers are clean and remove and clean pump head as necessary.

21.0 SHORTHAND PROCEDURE

The flow chart shown in Figure 24-1 shows the procedural steps for analysis of filter samples for metals.

22.0 DOCUMENTATION AND DOCUMENT CONTROL

22.1 All information concerning sample preparation, standard preparation, instrument conditions, etc., must be written in the analyst's notebook.

22.2 The instrument calibration values, i.e., DI water conductance readings must be written in the project notebook. A list of the analyses must be recorded in addition to the following information: system number, date of analysis.

22.3 All calculations and the type of method for determining concentration must be recorded in the analyst's notebook. Any unusual problems or conditions must also be noted.

22.4 Record all maintenance performed on the instrument in the maintenance logbook for this particular instrument.

22.5 Record all analyses including quality control samples, performed by the instrument in the logbook for this particular instrument.

22.6 Reviewer must sign laboratory notebook weekly.

23.0 REFERENCES

ICP-MS Operator Manual.

EPA Compendium Method IO-3.5A for the Determination of Metals in Ambient Particulate Matter using Inductively Coupled Plasma/Mass Spectrometry (ICP/MS).

Standard Operating Procedure (S.O.P.) For The Trace Elemental Analysis of Low-Volume Samples Using Inductively Coupled Plasma - Mass Spectrometry (ICP-MS) (SOP MLD 061), California Air Resources Board, May 2002.

Standard Operating Procedure (S.O.P.) For Metals Analysis by Atomic Absorption Spectrophotometry (SOP MLD 005), California Air Resources Board, October 2003

24.0 TABLES, DIAGRAMS, FLOWCHARTS, VALIDATION DATA

Table 24-1. MDLs for Metals

Compound	(ng/filter)	Assuming a 1600 m^3 volume (ng/m^3)
Antimony	15.7	0.785
Arsenic	3.11	0.155
Beryllium	2.01	0.101
Cadmium	2.24	0.112
Chromium (total)	18.7	0.934
Cobalt	7.42	0.371
Lead	9.16	0.458
Manganese	2.56	0.128
Mercury	7.07	0.354
Nickel	20.7	1.03
Selenium	3.49	0.174

Figure 24-1. Flow Diagram for ICPMS Preparation and Analysis for PM10 or TSP Filters

Parameter	Frequency	Acceptance Criteria	Corrective Action
Initial Calibration (IC)	Daily, at least 4 calibration points	Correlation coefficient ?0.995	1) Repeat analysis of calibration standards. 2) Re-prepare calibration standards and reanalyze.
Initial Calibration Blank (ICB)	Immediately after ICV	Analytes below MDL	1) Locate and resolve contamination problems before continuing. 2) Reanalyze
High Standard Verification (HSV)	Following the ICB	Recovery 95-105%	1) Repeat analysis of HSV. 2) Re-prepare HSV.
Initial Calibration Verification (ICV)	Immediately after calibration	Recovery 90-110%	1) Repeat analysis of calibration check standard. 2) Repeat analysis of calibration standards. 3) Re-prepare calibration standards and reanalyze.
Interference Check Standard (ICS)	Following the HSV, every 8 hours and at the end of each run	Recovery 80-120%	1) Repeat analysis of ICS. 2) Re-prepare ICS.
Continuing Calibration Verification (CCV)	Analyze before the 1st sample, after every 10 samples, and at the end of the run	Recovery 90-110%	1) Repeat analysis of continuing calibration verification sample. 2) Re-prepare continuing calibration. 3) Reanalyze samples since last acceptable continuing calibration verification.
Continuing Calibration Blanks (CCB)	Analyzed after each CCV	Must be below MDL	1) Locate and resolve contamination problems before continuing. 2) Reanalyze samples since last acceptable continuing calibration verification.
Method Blanks (MB)	1 per 20 samples, a minimum of 1 per batch	Analytes below MDL	1) Reanalyze. 2) Re-prepare blank and reanalyze. 3) Repeat analyses of all samples since last clean blank.
Method Spike/Method Spike Duplicate	1 per 20 samples, a minimum of 1 per batch	Recovery 80-120%	1) Re-prepare sample batch. 2) Reanalyze.
Laboratory Control Sample (LCS)	1 per 20 samples, a minimum of 1 per batch	Recovery 80-120%, with the exception of Ag and Sb	1) Re-prepare sample batch. 2) Reanalyze.
Matrix Spike (MS)	1 per 20 samples per sample batch	Recovery 75-125%, with the exception of Ag and Sb	1) Re-prepare sample batch. 2) Reanalyze.
Duplicate Samples	1 per batch	RPD < 20%	1) Repeat analysis. 2) Re-prepare.
Serial Dilution	1 per batch	Recovery 90-110% of undiluted sample	1) Re-prepare dilution 2) Flag data.

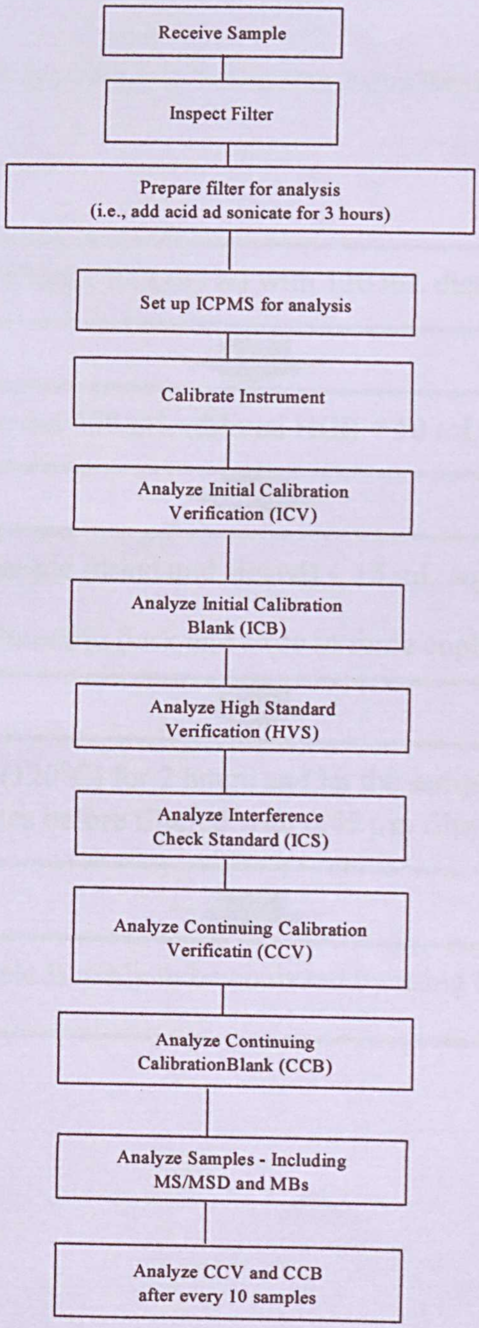
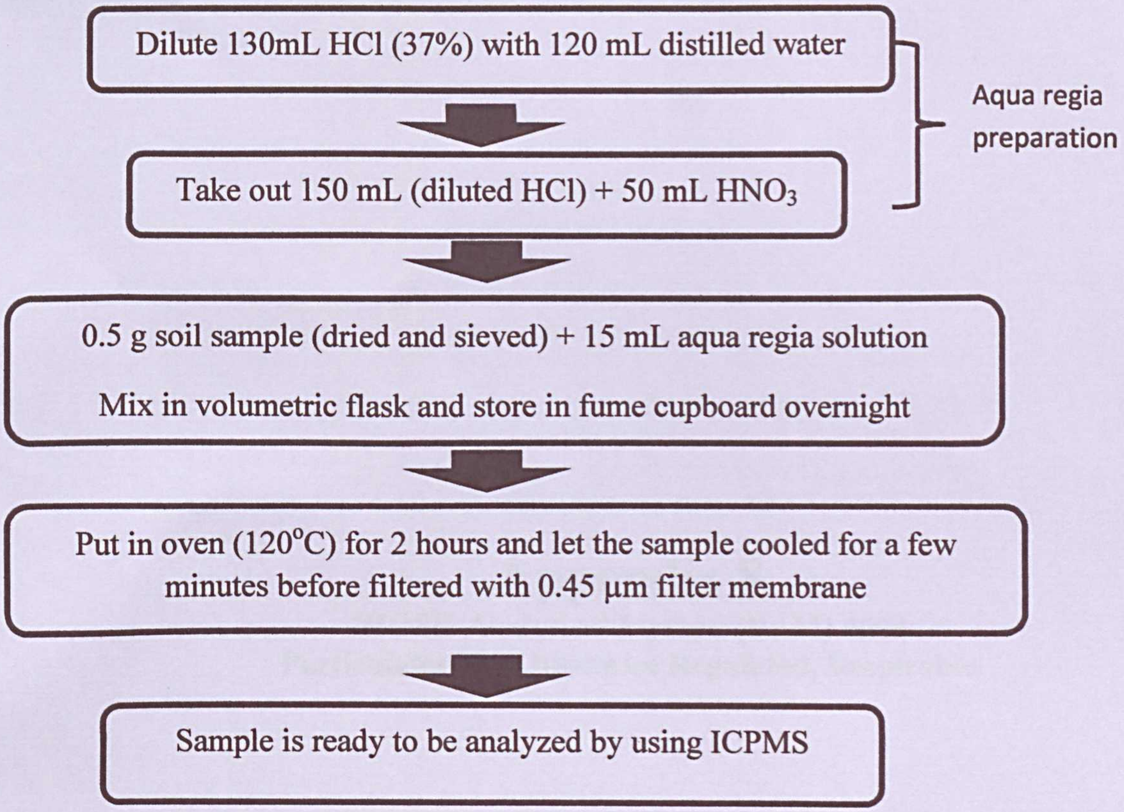


Figure 24-1. Summary of Quality Control Procedures for Metals Analysis

Determination of Heavy Metal in Soil Using Aqua Regia Method (Miroslav, 1998)



Dilute 130mL HCl (37%) with 120 mL distilled water

Take out 150 mL (diluted HCl) + 50 mL HNO_3

0.5 g soil sample (dried and sieved) + 15 mL aqua regia solution

Mix in volumetric flask and store in fume cupboard overnight

Put in oven (120°C) for 2 hours and let the sample cooled for a few minutes before filtered with 0.45 μm filter membrane

Sample is ready to be analyzed by using ICPMS

Appendix 8

NIOSH Analytical Method (NAM) 0600
Particulates Not Otherwise Regulated, Respirable

PARTICULATES NOT OTHERWISE REGULATED, RESPIRABLE 0600

DEFINITION: aerosol collected by sampler with 4-µm median cut point CAS: None RTECS: None

METHOD: 0600, Issue 3 **EVALUATION: FULL** **Issue 1: 15 February 1984**
Issue 3: 15 January 1998

OSHA : 5 mg/m³
NIOSH: no REL
ACGIH: 3 mg/m³

PROPERTIES: contains no asbestos and quartz less than 1%; penetrates non-ciliated portions of respiratory system

SYNONYMS: nuisance dusts; particulates not otherwise classified

SAMPLING

SAMPLER:	CYCLONE + FILTER (10-mm nylon cyclone, Higgins-Dewell [HD] cyclone, or Aluminum cyclone + tared 5-µm PVC membrane)
FLOW RATE:	nylon cyclone: 1.7 L/min HD cyclone: 2.2 L/min Al cyclone: 2.5 L/min
VOL-MIN:	20 L @ 5 mg/m³
-MAX:	400 L
SHIPMENT:	routine
SAMPLE STABILITY:	stable
BLANKS:	2 to 10 field blanks per set

ACCURACY

RANGE STUDIED	0.5 to 10 mg/m³ (lab and field)
BIAS:	dependent on dust size distribution [1]
OVERALL PRECISION ($\hat{S}_{rT}$):	dependent on size distribution [1,2]
ACCURACY:	dependent on size distribution [1]

MEASUREMENT

TECHNIQUE:	GRAVIMETRIC (FILTER WEIGHT)
ANALYTE:	mass of respirable dust fraction
BALANCE:	0.001 mg sensitivity; use same balance before and after sample collection
CALIBRATION:	National Institute of Standards and Technology Class S-1.1 or ASTM Class 1 weights
RANGE:	0.1 to 2 mg per sample
ESTIMATED LOD:	0.03 mg per sample
PRECISION:	<10 µg with 0.001 mg sensitivity balance; <70 µg with 0.01 mg sensitivity balance [3]

APPLICABILITY: The working range is 0.5 to 10 mg/m³ for a 200-L air sample. The method measures the mass concentration of any non-volatile respirable dust. In addition to inert dusts [4], the method has been recommended for respirable coal dust. The method is biased in light of the recently adopted international definition of respirable dust, e.g., ≈ +7% bias for non-diesel, coal mine dust [5].

INTERFERENCES: Larger than respirable particles (over 10 µm) have been found in some cases by microscopic analysis of cyclone filters. Over-sized particles in samples are known to be caused by inverting the cyclone assembly. Heavy dust loadings, fibers, and water-saturated dusts also interfere with the cyclone's size-selective properties. The use of conductive samplers is recommended to minimize particle charge effects.

OTHER METHODS: This method is based on and replaces Sampling Data Sheet #29.02 [6].

EQUIPMENT:

1. Sampler:
   a. Filter: 5.0-µm pore size, polyvinyl chloride filter or equivalent hydrophobic membrane filter supported by a cassette filter holder (preferably conductive).
   b. Cyclone: 10-mm nylon(Mine Safety Appliance Co., Instrument Division, P. O. Box 427, Pittsburgh, PA 15230), Higgins-Dewell(BGI Inc., 58 Guinan St., Waltham, MA 02154)[7], aluminum cyclone (SKC Inc., 863 Valley View Road, Eighty Four, PA 15330), or equivalent.
2. Personal sampling pump, 1.7 L/min ± 5% for nylon cyclone, 2.2 L/min ± 5% for HD cyclone, or 2.5 L/min ± 5% for the Al cyclone with flexible connecting tubing.
   NOTE: Pulsation in the pump flow must be within ± 20% of the mean flow.
3. Balance, analytical, with sensitivity of 0.001 mg.
4. Weights, NIST Class S-1.1, or ASTM Class 1.
5. Static neutralizer, e.g., Po-210; replace nine months after the production date.
6. Forceps (preferably nylon).
7. Environmental chamber or room for balance, e.g., 20°C ± 1 °C and 50% ± 5% RH.

SPECIAL PRECAUTIONS: None.

PREPARATION OF SAMPLERS BEFORE SAMPLING:

1. Equilibrate the filters in an environmentally controlled weighing area or chamber for at least 2 h.
2. Weigh the filters in an environmentally controlled area or chamber. Record the filter tare weight, W_1 (mg).
   a. Zero the balance before each weighing.
   b. Handle the filter with forceps (nylon forceps if further analyses will be done).
   c. Pass the filter over an anti-static radiation source. Repeat this step if filter does not release easily from the forceps or if filter attracts balance pan. Static electricity can cause erroneous weight readings.
3. Assemble the filters in the filter cassettes and close firmly so that leakage around the filter will not occur. Place a plug in each opening of the filter cassette.
4. Remove the cyclone's grit cap before use and inspect the cyclone interior. If the inside is visibly scored, discard this cyclone since the dust separation characteristics of the cyclone may be altered. Clean the interior of the cyclone to prevent reentrainment of large particles.
5. Assemble the sampler head. Check alignment of filter holder and cyclone in the sampling head to prevent leakage.

SAMPLING:

6. Calibrate each personal sampling pump to the appropriate flow rate with a representative sampler in line.
   NOTE 1: Because of their inlet designs, nylon and aluminum cyclones are calibrated within a large vessel with inlet and outlet ports. The inlet is connected to a calibrator (e.g., a bubble meter). The cyclone outlet is connected to the outlet port within the vessel, and the vessel outlet is attached to the pump. See APPENDIX for alternate calibration procedure. (The calibrator can be connected directly to the HD cyclone.)
   NOTE 2: Even if the flowrate shifts by a known amount between calibration and use, the nominal flowrates are used for concentration calculation because of a self-correction feature of the cyclones.
7. Sample 45 min to 8 h. Do not exceed 2 mg dust loading on the filter. Take 2 to 4 replicate samples for each batch of field samples for quality assurance on the sampling procedure (see Step 10).
   NOTE : Do not allow the sampler assembly to be inverted at any time. Turning the cyclone to anything more than a horizontal orientation may deposit oversized material from the cyclone body onto the filter.

SAMPLE PREPARATION:

8. Remove the top and bottom plugs from the filter cassette. Equilibrate for at least 2 h in an environmentally controlled area or chamber.

CALIBRATION AND QUALITY CONTROL:

9. Zero the microbalance before all weighings. Use the same microbalance for weighing filters before and after sample collection. Calibrate the balance with National Institute of Standards and Technology Class S-1.1 or ASTM Class 1 weights.
10. The set of replicate field samples should be exposed to the same dust environment, either in a laboratory dust chamber [8] or in the field [9]. The quality control samples must be taken with the same equipment, procedures, and personnel used in the routine field samples. Calculate precision from these replicates and record relative standard deviation (S_r on control charts. Take corrective action when the precision is out of control [8].

MEASUREMENT:

11. Weigh each filter, including field blanks. Record this post-sampling weight, W_2(mg), beside its corresponding tare weight. Record anything remarkable about a filter (e.g., visible particles, overloading, leakage, wet, torn, etc.).

CALCULATIONS:

12. Calculate the concentration of respirable particulate, C (mg/m^3), in the air volume sampled, V (L):

$$C = \frac{(W_2 - W_1) - (B_2 - B_1)}{V} . 10^3, mg/m^3$$

where: W_1 = tare weight of filter before sampling (mg)
W_2 = post-sampling weight of sample-containing filter (mg)
B_1 = mean tare weight of blank filters (mg).
B_2 = mean post-sampling weight of blank filters (mg)
V = volume as sampled at the nominal flowrate (i.e., 1.7 L/min or 2.2 L/min)

EVALUATION OF METHOD:

1. Bias: In respirable dust measurements, the bias in a sample is calculated relative to the appropriate respirable dust convention. The theory for calculating bias was developed by Bartley and Breuer [10]. For this method, the bias, therefore, depends on the international convention for respirable dust, the cyclones' penetration curves, and the size distribution of the ambient dust. Based on measured penetration curves for non-pulsating flow [1], the bias in this method is shown in Figure 1.

   For dust size distributions in the shaded region, the bias in this method lies within the ± 0.10 criterion established by NIOSH for method validation. Bias larger than ± 0.10 would, therefore, be expected for some workplace aerosols. However, bias within ± 0.20 would be expected for dusts with geometric standard deviations greater than 2.0, which is the case in most workplaces.

   Bias can also be caused in a cyclone by the pulsation of the personal sampling pump. Bartley, et al. [12] showed that cyclone samples with pulsating flow can have negative bias as large as0.22 relative to samples with steady flow. The magnitude of the bias depends on the amplitude of the pulsation at the cyclone aperture and the dust size distribution. For pumps with instantaneous flow rates within 20% of the mean, the pulsation bias magnitude is less than 0.02 for most dust size distributions encountered in the workplace.

   Electric charges on the dust and the cyclone will also cause bias. Briant and Moss [13] have found electrostatic biases as large as -50%, and show that cyclones made with graphite-filled nylon eliminate the problem. Use of conductive samplers and filter cassettes(Omega Specialty Instrument Co., 4 Kidder Road, Chelmsford, MA 01824) is recommended.

2. Precision: The figure 0.068 mg quoted above for the precision is based on a study [3] of weighing procedures employed in the past by the Mine Safety and Health Administration (MSHA) in which filters are pre-weighed by the filter manufacturer and post-weighed by MSHA using balances readable to 0.010 mg. MSHA [14] has recently completed a study using a 0.001 mg balance for the post-weighing, indicating imprecision equal to 0.006 mg.

   Imprecision equal to 0.010 mg was used for estimating the LODand is based on specific suggestions [8] regarding filter weighing using a single 0.001 mg balance. This value is consistent with another study [15] of repeat filter weighings, although the actual attainable precision may depend strongly on the specific environment to which the filters are exposed between the two weighings.

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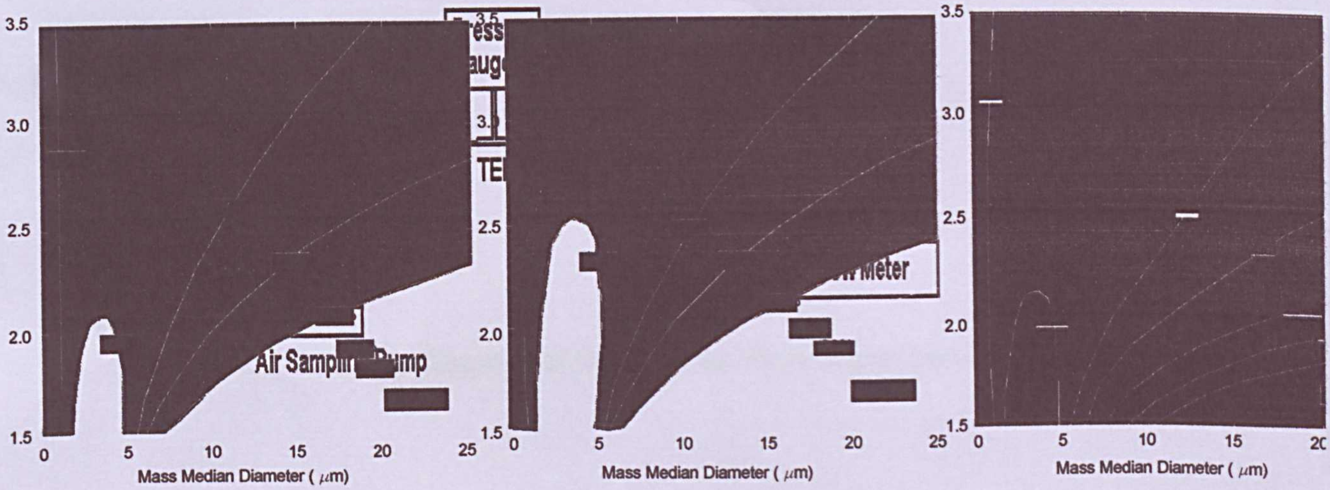
METHOD REVISED BY: David L. Bartley, Ph.D., NIOSH/DPSE/ARDB and Ray Feldman, OSHA.



10-mm nylon cyclone at 1.7 L/min

Higgins-Dewell cyclone at 2.2 L/min

Aluminum cyclone at 2.5 L/m

Figure 1. Bias of three cyclone types relative to the international respirable dust samp convention.

APPENDIX: Jarless Method for Calibration of Cyclone Assemblies

This procedure may be used in the field to calibrate an air sampling pump and a cyclone assembly without using the one-liter “calibration jar”.

(1) Connect the pump to a pressure gauge or water manometer and a light load (adjustable valve or 5-µm filter) equal to 2" to 5" H_2O with a “TEE” connector and flexible tubing. Connect other end of valve to an electronic bubble meter or standard bubble tube with flexible tubing (See Fig. 2.1).
NOTE: A light load can be a 5-µm filter and/or an adjustable valve. A heavy load can be several 0.8-µm filters and/or adjustable valve.

(2) Adjust the pump to 1.7 L/min, as indicated on the bubble meter/tube, under the light load conditions (2" to 5" H_2O) as indicated on the pressure gauge or manometer.

(3) Increase the load until the pressure gauge or water manometer indicates between 25" and 35" H_2O. Check the flow rate of the pump again. The flow rate should remain at 1.7 L/min ± 5%.

(4) Replace the pressure gauge or water manometer and the electronic bubble meter or standard bubble tube with the cyclone having a clean filter installed (Fig. 2.2). If the loading caused by the cyclone assembly is between 2" and 5" H_2O, the calibration is complete and the pump and cyclone are ready for sampling.

Figure 2.1 Block Diagram of Pump/Load/Flow Meter Set-up.

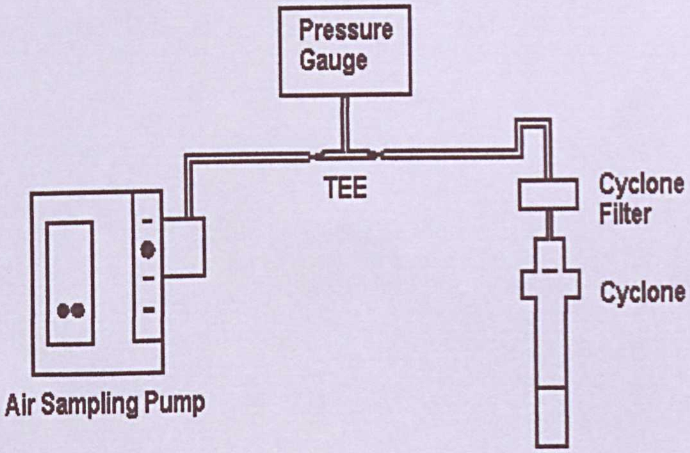


Figure 2.2. Block Diagram with Cyclone as the Test Load.