

**DISTRIBUTION OF POLYCYCLIC AROMATIC
HYDROCARBONS IN AIR AND SURFACE SOIL: CASE
STUDY KUMASI, GHANA.**

BY

NESTA BORTEY-SAM

MAY, 2011

**KWAME NKURUMAH UNIVERSITY OF SCIENCE AND
TECHNOLOGY**

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HYDROCARBONS IN AIR AND SURFACE SOIL: CASE
STUDY KUMASI, GHANA.**

THIS THESIS IS SUBMITTED TO THE DEPARTMENT OF CHEMISTRY, BOARD
OF POSTGRADUATE STUDIES IN PARTIAL FULFILMENT OF THE
REQUIREMENT FOR THE AWARD OF MSc. ENVIRONMENTAL CHEMISTRY.

BY

NESTA BORTEY-SAM

MAY, 2011

DECLARATION

I, Nesta Bortey-Sam, hereby declare that this thesis is a compilation of research results conducted by me in the laboratories of the Chemistry Department, KNUST and the Graduate School of Veterinary Medicine and Toxicology, Hokkaido University, Japan under the supervision of Mr. Osei Akoto and Dr Yoshinori Ikenaka. This work has not been presented to this University or another elsewhere for an award of a degree. Cited literature has been duly acknowledged.

Nesta Bortey-Sam
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(Supervisor) Sign Date

Dr. S. Osafo Acquah
Head, Chemistry Department Sign Date

DEDICATION

I dedicate this thesis to my mother, Mrs. Margaret Adotey-Nyanu, who has been of immense help throughout my education to this level. I am so grateful to her for playing such a role in my life for which God will surely bless her abundantly.

ACKNOWLEDGEMENT

I am so grateful to the Almighty God for enabling me reach a point like this in my career, having bestowed upon me such an abundant grace to go through this programme of study. I am also very much grateful to Mr. Osei Akoto, Prof. Mayumi Ishizuka and Dr. Yoshinori Ikenaka for the opportunity to carry out my research work in Japan. I am so thankful to them especially Mr. Osei Akoto for all the inputs, suggestions, unflinching, dedicated and superlative support throughout this thesis. I would like to express my profound gratitude to Mr. Shouta Nakayama and every member of the Graduate School of Veterinary Medicine and Toxicology, Hokkaido University, Japan for their immense assistance in the research work. Finally, I would like to acknowledge all who endeavored to assist me one way or the other, God bless you all.

ABSTRACT

PAHs are organic compounds connected in ring like forms. Their presences in air and soil matrices deserve attention because they are highly stable, toxic and can produce carcinogenic and mutagenic effects. The objectives of this study are to determine the concentrations, distribution, and the sources of emission of PAHs in air samples and surface soils from the Kumasi metropolis. Concentrations of total and 22 individual PAHs in air and soils samples in Kumasi were determined. In all, 34 air samples were collected from KNUST campus and the Kejetia lorry station and 129 soil samples were also collected from 36 communities in the Kumasi metropolis. These samples were extracted with a 1:2 v/v acetone: hexane mixture for 6 h prior to clean-up and GC-MS analyses. The highest concentration of total PAHs in air samples from KNUST campus and Kejetia lorry station were 16.58 ng/m^3 and 38.72 ng/m^3 respectively. The mean concentration of total PAHs in surface soils ranged from 10.85 ± 4.84 at Ahinsan to $2084.87 \pm 2210.05 \text{ ng/g}$ dry weight at Adum. The Benzo(a)Pyrene concentration in the air samples from KNUST campus and Kejetia lorry station ranged from below detection to 0.08 ng/m^3 and 1.69 to 5.66 ng/m^3 respectively. From the results Adum is the most polluted community with total PAHs concentration with mean value of 2084.87 ng/g dry weight. The diagnostic ratios of the results show that PAHs in the air and surface soil samples are mainly from fuel combustion.

Keywords: PAHs; Diagnostic ratio; Kumasi; Air; Soil

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LIST OF SYMBOLS AND ABBREVIATIONS

- ng/g dw : nano gram per gram dry weight
- ng/m³ : nano gram per cubic metre
- PAH : Polycyclic Aromatic Hydrocarbon
- AFR : Air to fuel ratio
- GPS : Global Positioning System
- GIS : Geographic Information System
- SD : Standard deviation
- IARC : International Agency for Research on Cancer
- US EPA : United States Environmental Protection Agency
- OSHA : Occupational Safety and Health Administration
- PEL : Permissible Exposure Limit
- EPAQS : Expert Panel on Air Quality Standards

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Polycyclic aromatic hydrocarbons (PAHs) refer to a group of compounds made up of varying number of carbon and hydrogen atoms connected in ring like forms. PAHs consist of two or more fused benzene rings in linear, angular or cluster arrangements (Woodard *et al*, 2010). PAHs are environmental pollutants that may be found in air, soil, stream sediment, water and food. They are found naturally in coal, crude oil and in emissions from forest fires and volcanoes. Most PAHs entering the environment are formed unintentionally during burning of fossil fuel, biomass, wood, brushwood etc. (Woodard *et al*, 2010).

Exposure to PAHs occur mainly by inhalation of contaminated air and ingestion of soil, food and drinking contaminated water (Barranco *et al*, 2003; Dissanayake *et al*, 2004). Although food can be contaminated by environmental PAHs (thus PAHs from air, dust and soil), PAHs in food are mainly formed during processing and food preparation, for example smoking, roasting, baking, drying, frying, or grilling (Phillips, 1999). Foods grown in areas with PAHs contaminated soil or air may contain higher levels of PAHs. Water can become contaminated with PAHs from runoff or waste water from industries (e.g. creosote manufacturing, aluminum smelting) (Woodard *et al*, 2010).

PAH exposure to some particular occupations or areas has been explored. Cases include on-duty traffic policemen (Liu *et al*, 2007; Ruchirawat *et al*, 2002), incense smoke in vehicle (Kuo *et al*, 2003), fixed site with heavy traffic (Ho and Lee, 2002), urban site, vegetation area, forest area (Vasconcellos *et al*, 2003), bus station and traffic tunnel (Pereira *et al*, 2002), outdoor air (Velasco *et al*, 2004), roadside air (Marr *et al*, 2004; Chetwittayachan *et al*, 2002), and ambient traffic site (Lodovici *et al*, 2003). These studies have provided many valuable insights on the potential threat of PAHs to human health.

The emission rates of PAHs from vehicle exhausts are dependent upon a large number of factors including; engine type, operating conditions and composition of both fuel and lubricating oil (Candeli *et al*, 1983; Pedersen *et al*, 1980). The effect of engine type is largely determined by the design of the combustion system, the fuel-air mixture, the temperature within the combustion chamber and the manufacturing quality. It has been established that different vehicles operated under the same conditions with the same fuel can emit significantly different amounts of PAHs (Handa *et al*, 1979; Lang *et al*, 1981). The main engine operating parameters that affect exhaust PAHs content are engine load, air to fuel ratio (AFR) and engine coolant temperature. In general larger quantities of PAHs are emitted during acceleration, deceleration or when cruising at high speeds than when driving at steady average speeds (Pedersen *et al*, 1980; Laity *et al*, 1973).

Of the various engine operating parameters, changes in the air to fuel ratio are known to produce the largest effects on PAH emission.

It has been found that the amount of PAH in engine exhaust decreases with increasing air to fuel ratio (Pedersen *et al*, 1980; Laity *et al*, 1973). The aromatic hydrocarbon content of fuel has been the main focus of concern directed at the composition of fuels, since benzene and its derivatives produce more PAHs than aliphatic hydrocarbons (Hoffman *et al*, 1965). A number of investigations have shown that PAH emissions increase as the aromatic content of fuel increases (Candeli *et al*, 1974; Begeman and Colucci, 1970; Gross, 1974; Laity *et al*, 1973).

PAHs are ubiquitous organic pollutants, of great environmental concern because of the documented carcinogenicity in experimental animals (Manoli *et al*, 2000). Due to their ubiquitous occurrence, recalcitrance, and suspected carcinogenicity and mutagenicity, PAHs are included in the US Environmental Protection Agency (EPA), and the European Union priority lists of pollutants. The US EPA has fixed 16 parent PAHs as priority pollutants, (Baumard *et al*, 1997; Mastral and Callén 2000; Magi *et al*, 2002; Szolar *et al*, 2002; Schubert *et al*, 2003). The International Agency for Research on Cancer (IARC), the United States Environmental Protection Agency, and the United States National Toxicology Program has classified some PAHs as probable human carcinogens (IARC, 1983, US National Toxicology Program, US HHS, 2001; US HHS, 1995). Endocrine disrupting activities of PAHs have also been reported (Clemons *et al*, 1998; Brun *et al*, 2004). Four to seven ring members of PAHs are highly mutagenic and carcinogenic, but two or three ring PAHs are less mutagenic but can be highly toxic (Fernandes *et al*, 1997).

As one of the most industrialized and economically significant cities in Ghana, Kumasi has been subject to heavy anthropogenic influences as a result of rapid economic development and urbanization. The human population has drastically increased, the number of vehicles has doubled during the past decade and many fuel filling stations are located in this region leading to greater fuel combustion rate. Some communities in the Kumasi metropolis are densely populated with heavy vehicular movement. This leads to fuel leakages, smoke production from exhaust of automobiles and high levels of PAHs are released into the environment. In addition garbage, paper, cloth, wood are burned in the open in the Kumasi metropolis and all these are potential sources of contamination with PAHs.

1.2. PROBLEM STATEMENT

Kumasi is one of the comprehensively industrial and commercial cities in Ghana. Contamination of air and soils with PAHs from the Kumasi metropolis mainly originates from wood, grass and fuel combustion. PAHs emission from fuel combustion was predominantly from vehicular exhaust. Some of these PAHs have been classified as “carcinogenic to humans” (Group 1), “probably carcinogenic to humans” (Groups 2A), and “possibly carcinogenic to humans” (Group 2B) (IARC, 1983). PAHs are transboundary and settle on soil and food as the ultimate sink, increasing the exposure pathways as a result.

Breathing of contaminated air and ingestion of contaminated soils and food is considered to be an important exposure pathway in humans (Finley and Paustenbach, 1994; Staneck *et al*, 1995).

PAHs in soils may further accumulate in vegetables and other biota via food chains (Kipopoulou *et al*, 1999; Li *et al*, 2008). This accumulation leads to direct or indirect exposure in humans. Moreover, leaching of PAHs from soils are possible sources of groundwater contamination (Bispo *et al*, 1999; Cousins *et al*, 1999).

1.3. OBJECTIVES OF THE STUDY

The objectives of the study are:

- to determine the concentrations of 22 PAHs including the 16 that are listed by the United States Environmental Protection Agency as priority pollutants in the air and surface soil samples from the Kumasi Metropolis.
- to evaluate the extent of pollution of PAHs in surface soil of Kumasi Metropolis.
- to establish the possible sources of PAHs in the air and surface soils from the Kumasi metropolis of Ghana.
- develop a distribution map of PAHs throughout the city using the Geographic Information System (GIS).

1.4. JUSTIFICATION

Soil is the primary environmental reservoir for PAHs. Due to their high hydrophobicity and stable chemical structure, PAHs are not very soluble in water and can be adsorbed rapidly onto soil particles, particularly on soil organic matter (Means *et al*, 1980; Xing, 2001). Polycyclic aromatic hydrocarbons are ubiquitously distributed in both air and soil matrices which deserve some attention because they are highly stable and toxic and can produce carcinogenic and mutagenic effects. They cannot be easily remediated and therefore will persist over long period, resulting in their accumulation and long term risk of transport to other environmental matrices such as groundwater (Wild and Jones, 1995). This might therefore contribute to groundwater contamination in areas with high levels of PAHs.

From literature no work has been conducted to address the accumulation and distribution of PAHs in the air and surface soils in the Kumasi metropolis. The results of this study will provide valuable information for the Environmental Protection Agency and other environmental policy makers to develop environmental quality guidelines for the Kumasi metropolis. It will also provide baseline information on the concentration and distribution of PAHs in the air and soil samples in Kumasi.

CHAPTER TWO

2.0. LITERATURE REVIEW

PAHs are ubiquitously distributed in diverse environmental matrices such as air, soil (Fernández *et al*, 2000; Krauss *et al*, 2000; Grimalt *et al*, 2004; Gocht *et al*, 2007a, 2007b), and are introduced into environmental compartments both from natural (forest fires, volcanoes, etc.) and anthropogenic processes (fossil fuel burning, incomplete combustion of organic matter, petroleum, incineration, etc.). However, the anthropogenic contribution usually outweighs the inputs from natural sources (Fernandez *et al*, 2000).

Knowledge of soil contamination with PAHs is needed to avoid any food production risk and to restrict the deleterious effect of these contaminants. Ingestion of contaminated soils is considered to be an important exposure pathway in humans, especially in young children, who are capable of unintentionally swallowing minute amounts of foreign matter. Studies have estimated that up to 1200 mg soil per day can be ingested by young children (Finley and Paustenbach 1994; Staneck *et al*, 1995). Therefore, children who play in and on contaminated grounds are at high risk of exposure (Christensen *et al*, 1997).

PAHs have a wide range of toxic effects, including skin, eye irritation, immuno-toxicity, and developmental toxicity. The most serious toxicity of PAHs is carcinogenicity.

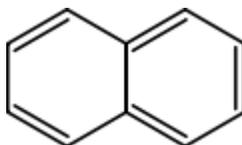
Extensive mechanistic studies have proved that some PAH compounds are complete carcinogens (Flowers *et al*, 2002).

2.1 NATURE AND PROPERTIES OF SOME PAHs

A review on properties and characteristics of the 22 PAHs selected for the studies is presented below.

2.1.1. NAPHTHALENE

Naphthalene is a crystalline, aromatic, white, solid hydrocarbon with molecular formula $C_{10}H_8$ and molecular mass of 128.16 g/mol. It readily sublimates at room temperature, producing a characteristic odor that is detectable at concentrations as low as 0.08 ppm (Amoore *et al*, 1983). This compound has the following structure.



Structure of Naphthalene

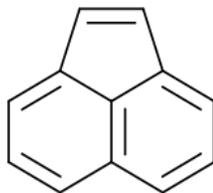
Naphthalene is a natural constituent of coal tar (approximately 11 %). It is present in gasoline and diesel fuels. Naphthalene is used as a moth repellent, though this use is decreasing in favour of p-dichlorobenzene (HSDB, 1995). Exposure to large amounts of naphthalene may damage or destroy red blood cells. Humans, particularly children, have

developed hemolytic anemia, after ingesting deodorant and other products containing naphthalene. Symptoms include fatigue, lack of appetite, restlessness, and pale skin. Exposure to large amounts of naphthalene may cause nausea, vomiting, diarrhea, blood in the urine, and jaundice (NTP, 2005).

Chronic exposure of rats and mice to naphthalene vapor exhibited carcinogenic activity and bronchiolar adenomas of the lung (NTP, 2005). Naphthalene has been classified as possibly carcinogenic to humans and animals [Group 2B], studies also points out that acute exposure causes cataracts in humans, rats, rabbits, and mice; and that hemolytic anemia, described above, can occur in children and infants after oral or inhalation exposure or after maternal exposure during pregnancy (IARC, 2008).

2.1.2. ACENAPHTHYLENE

Acenaphthylene is a PAH consisting of naphthalene with an ethylene bridge. It is a tricyclic aromatic hydrocarbon with a molecular formula of $C_{12}H_8$ and molecular mass of 152.2 g/mol (ATSDR, 1990). The structure of this compound is as presented below.



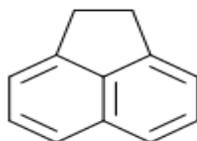
Structure of Acenaphthylene

Acenaphthylene is an environmental pollutant and has been detected in soils, groundwater, and surface waters at hazardous waste sites. It is a constituent of coal tar and is used to make dyes, plastics and pesticides. Acenaphthylene is one of the 16 PAHs characterized by the United States Environmental Protection Agencies (US EPA's) as priority pollutant (ATSDR, 1990).

One of the most common ways acenaphthylene can enter your body is through breathing contaminated air, eating or drinking contaminated food or water, working in hazardous waste site where PAHs are disposed (Lauderdale *et al*, 2003). Animal studies have shown that pulmonary effects such as bronchitis, pneumonia, and desquamation of the bronchial and alveolar epithelium were reported in sub chronic inhalation studies with rats exposed to concentrations ranging from 0.5 to 18 mg/m³ (Reshetyuk *et al.*, 1970; Rotenberg and Mahbits, 1965). Acenaphthylene is irritating to the skin and mucous membranes of rabbits (Knobloch *et al*, 1969).

2.1.3. ACENAPHTHENE

Acenaphthene is a PAH with molecular formula C₁₂H₁₀ and molecular mass of 154.21 g/mol. The structure of the compound is as presented below.



Structure of Acenaphthene

Acenaphthene occurs as a pure substance and also as a component of PAH mixtures. Human population studies have associated acenaphthene as gastrointestinal or liver toxicant. The substance is very toxic (IPCS, CEC, 2005). Acenaphthene is a component of crude oil and coal tar and a product of combustion which may be produced and released to the environment during natural fires. Emissions from petroleum refining, coal tar distillation, coal and diesel combustion are major contributors of acenaphthene to the environment. Acenaphthene may also be released to the environment via manufacturing effluents, landfills, municipal waste water treatment facilities and waste incinerators (ITER, 2005).

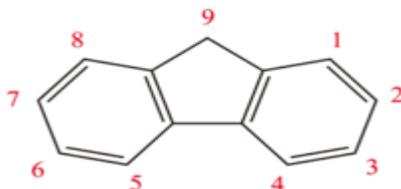
It does not accumulate in the environment because it undergoes photolysis in sunlight. In aquatic systems, acenaphthene can partition from the water column to organic matter contained in sediments and suspended solids (Lauderdale *et al*, 2003). Acenaphthene exist mainly in the gas-phase in ambient air. In the atmosphere it can react with the hydroxyl (OH) and nitrate (NO_3^-) radical, which can lead to the formation of mutagenic nitro-PAH and other nitropolycyclic aromatic compounds, including nitrodibenzopyranones. These atmospheric reactions have a significant effect on ambient mutagenic activity (Atkinson and Arey, 1994).

The most probable human exposure occurs through dermal contact or inhalation at places where acenaphthene is produced or used. The reported biodegradation half-live of acenaphthene in aerobic soil is about 10 to 102 days (Lauderdale *et al*, 2003). However,

acenaphthene may persist under anaerobic conditions or at high concentrations due to toxicity to micro organisms. It is not expected to undergo hydrolysis in soils; yet, should undergo direct photolysis under sunlight in surface soils. Monitoring data also demonstrates that acenaphthene will flow in groundwater when spilled or deposited at high concentrations (Lauderdale *et al*, 2003).

2.1.4. FLUORENE

Fluorene is a PAH with molecular formula $C_{13}H_{10}$ and molecular mass of 166.22 g/mol. It forms white crystals that exhibit a characteristic, aromatic odor similar to that of naphthalene. It has a violet fluorescence, hence its name. It is obtained mainly from coal tar. It is insoluble in water and soluble in benzene and ether (Karl *et al*, 2002). The compound has the following structure.

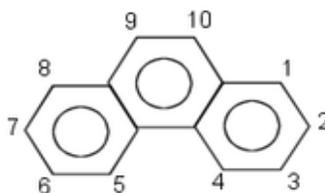


Structure of Fluorene

Fluorene is classified as Group 3 by the IARC, meaning there is no evidence at present that it causes cancer in humans (IARC, 1983), but it has been found to causes skin, eye and respiratory irritation and suspected to be gastrointestinal and liver toxicant. It has been found to show evidence of mutagenic properties in laboratory animals (ATSDR, 2004).

2.1.5. PHENANTHRENE

Phenanthrene is a polycyclic aromatic hydrocarbon composed of three fused benzene rings and has a molecular formula of $C_{14}H_{10}$ and molecular mass of 178.2 g/mol. It is insoluble in water but soluble in most organic solvents such as toluene, carbon tetrachloride, ether, chloroform, acetic acid and benzene (Bardhan *et al*, 1932). The compound has the following structure.

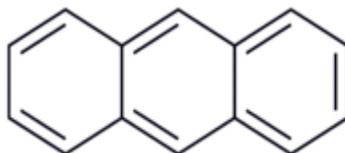


Structure of Phenanthrene

It is commonly found as pollutants in soils, estuarine waters and sediments. Although phenanthrene is not mutagenic or carcinogenic, it has been shown to be toxic to marine diatoms, gastropods, mussels, crustaceans, and fish (Jun, 2008). Phenanthrene can enter the body through breathing contaminated air. Eating or drinking food and water that are contaminated with PAHs, could also be an exposure route. Exposure can also occur if the skin comes into contact with contaminated soil or products like heavy oils, roofing tar or creosote where PAHs have been found. Creosote is an oily liquid found in coal tar and is used to preserve wood. Once in your body, phenanthrene can spread and target fat tissues and other organs including kidneys, liver. It could also be through eating foods that has been grilled. Grilling and charring of food actually increases the amount of phenanthrene in the food (ATSDR, 1990; Faust *et al*, 1993).

2.1.6. ANTRACENE

Anthracene is a solid polycyclic aromatic hydrocarbon consisting of three fused benzene rings and has molecular formula $C_{14}H_{10}$ and molecular weight 178.2 g/mol. It is a component of coal tar and used in the production of the red dye alizarin and other dyes. It is also used in wood preservatives, insecticides, and coating materials (Iglesias *et al*, 2010). The compound has the following structure.



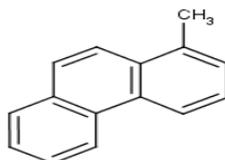
Structure of Anthracene

Unlike other PAHs, anthracene is not carcinogenic but has recently been included in the Substances of Very High Concern list (SVHC) by the European Chemicals Agency (ECHA) (NIST, 2008) because it is considered persistent, bioaccumulative and toxic (Iglesias *et al*, 2010). Anthracene, as many other PAHs is generated during combustion processes. Exposure to human happens mainly through tobacco smoke and ingestion of food contaminated with combustion products (Gerd *et al*, 2006).

2.1.7. 1-METHYL PHENANTHRENE

1-Methylphenanthrene is present as a major component of the total content of polycyclic aromatic compounds in the environment. Human exposure to 1-methylphenanthrene

occurs primarily through the smoking of tobacco, inhalation of polluted air and by ingestion of contaminated food and water. The compound has the structure below.

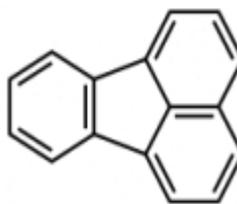


Structure of 1-Methyl Phenanthrene

It may be harmful to the eye when it gets contact. It can also cause skin irritation. When heated to decomposition it emits acrid smoke and toxic fumes of carbon monoxide and carbon dioxide (IARC, 1983).

2.1.8. FLUORANTHENE

Fluoranthene has molecular formula C₁₆H₁₀ and molecular weight 202.26 g/mol. It exists as pale yellow needles or plates. It can be produced by the pyrolysis at high temperatures from materials such as coal and petroleum (RAIS, 2009). The compound has the following structure.



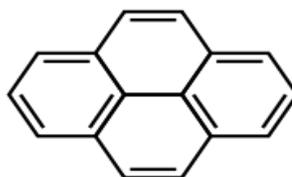
Structure of Fluoranthene

It consists of naphthalene and a benzene unit connected by a five membered ring. It is a member of the class of PAHs known as non-alternant PAHs (that is the hydrogen atoms are immobile compared to the alternate which are mobile and migrate under high temperature conditions along the perimeter of the molecule) because it has rings other than those with six carbon atoms. It is one of the U.S. Environmental Protection Agency's 16 priority pollutant PAHs and is a suspected carcinogen (NPI 2010; Lauderdale *et al*, 2003).

In the atmosphere, fluoranthene is present both as vapour and adsorbed to particles. As vapour it degrades rather rapidly, but it's more stable when adsorbed to particles and can travel long distances before being deposited. Fluoranthene is slightly soluble in water, and therefore rapidly adsorbed to sediment and other particulate matter. In sediments the compound is very stable and can stay for decades. Since it has a high tendency to be adsorbed to organic matter, it has a high bioaccumulation potential. It bioaccumulates in shellfish, making them an excellent bioindicator for fluoranthene pollution (Lauderdale *et al*, 2003). Fluoranthene adsorbs strongly to soil and would be expected to remain in the upper layers of soil for a very long time (half-life of 5 months to 2 years). However, it has been detected in groundwater samples which demonstrates that it can be transported there by some process(es) (Lauderdale *et al*, 2003). Human exposure is from ambient air and ingesting contaminated food. Exposure from drinking water is less common since water treatment processes such as filtration and chlorination removes fluoranthene from water (Lauderdale *et al*, 2003).

2.1.9. PYRENE

Pyrene is a PAH consisting of four fused benzene rings, resulting in a flat aromatic system. It has a molecular formula $C_{16}H_{10}$ and molecular mass of 202.26 g/mol. Pyrene is formed during incomplete combustion of organic compounds.



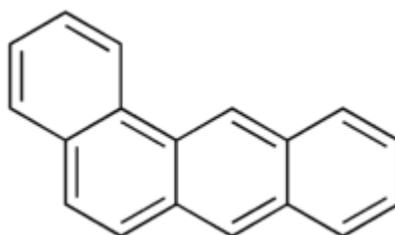
Structure of Pyrene

It was first isolated from coal tar, where it occurs up to 2% by weight (Selim and Marco, 2003). Pyrene and its derivatives are used commercially to make dyes and dye precursors. Animal studies have shown that pyrene is toxic to the kidneys and the liver. One of the most common ways by which pyrene can enter the body is through breathing contaminated air (ATSDR, 1990; Faust *et al*, 1993). Exposure can also occur through the skin. Grilling and charring of food actually increases the amount of PAHs in the food. It has also been found in surface water. Animal studies showed that pyrene has the potential to cause nephropathy, a kidney disease (ATSDR, 1990; Faust *et al*, 1993).

2.1.10. BENZO(a)ANTRACENE

Benzo(a)anthracene is a high molecular weight, 4 ring PAH. It has molecular formula $C_{18}H_{12}$ and molecular mass of 228.3 g/mol. Benzo(a)anthracene is classified a probable human carcinogen by the US EPA (EPA (IRIS), 1996). Because it is formed when

gasoline, garbage, or any animal or plant material burns, it is usually found in smoke and soot. It is carried in the atmosphere by dust particles and is finally deposited into water on soil or crops. Humans can acquire it through breathing of contaminated air, eating contaminated food or drinking contaminated water. Benzo(a)anthracene is also found in creosote (Roy *et al*, 1997).



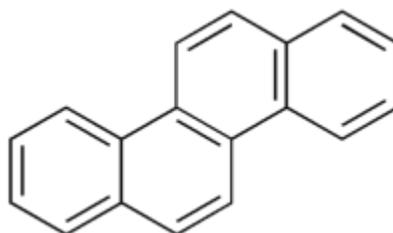
Structure of Benzo(a)anthracene

Benzo(a)anthracene is known to produce tumors in mice exposed by gavage that is feeding through tube (Klein, 1963); intraperitoneal i.e. introduced into the peritoneal cavity (Wislocki *et al*, 1986), subcutaneous or intramuscular injection (Steiner and Faulk, 1951; Steiner and Edgecomb, 1952); and topical application (applied externally). Benzo(a)anthracene is known to produce mutations in bacteria and in mammalian cells, and transformed mammalian cells in culture (US EPA, 1984, 1990; IARC, 1984).

2.1.11. CHRYSENE

Chrysene is a PAH with the molecular formula $C_{18}H_{12}$ and molecular mass of 228.3 g/mol. It is a natural constituent of coal tar, from which it was first isolated and characterized. It is also found in creosote.

Chrysene is used in the manufacture of some dyes. As with other PAHs, chrysene is suspected to be a human carcinogen. It is known to cause cancer in laboratory animals (US HHS, 1995). This compound has the following structure:



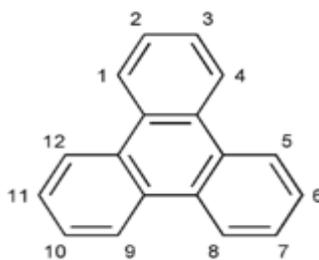
Structure of Chrysene

Chrysene is often produced as a gas during combustion of coal and petroleum products as well as animal and plant material (RAIS, 2000). In pure solid form, chrysene is a colourless, crystalline solid which fluoresces red-blue under ultra-violet light (RAIS, 2000). It is virtually insoluble in water, and only slightly soluble in many other solvents such as alcohol, ether and glacial acetic acid (RAIS, 2000). It is however, moderately soluble in benzene, and readily dissolves at higher temperatures, in benzene and toluene (Harvey, 1991).

Chrysene is a probable human carcinogen. Human exposure occurs through contact with contaminated areas and products such as smoked and grilled meats, and through inhalation of smoke (Harvey, 1991). Chrysene is released into the atmosphere as a by-product of many industrial processes. Once in the air, it is adsorbed to soil and dust particles and is dispersed over large areas, contaminating both soil and water (RAIS, 2000).

2.1.12. TRIPHENYLENE

Triphenylene is a flat PAH consisting of four fused benzene rings with molecular formula $C_{18}H_{12}$ and molecular mass of 228.29 g/mol. It can be isolated from coal tar. Triphenylene is a fully benzenoid PAH, thus its structure is composed of full benzene rings as presented below (NIST, 2008).



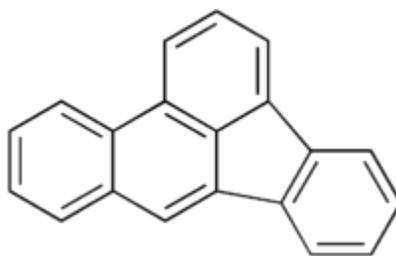
Structure of Triphenylene

Therefore the compound is much more resonance stable than its isomers chrysene, benzo(a)anthracene, benzo(c)phenanthrene and tetracene. This makes it much more difficult to hydrogenate to the saturated hydrocarbon (NIST, 2008).

It is released into the environment mainly through industrial processes including those of coal burning and incinerators. Triphenylene detrimentally effects aquatic and terrestrial ecosystems and may be carcinogenic to humans. Human exposure commonly occurs through cigarette smoking, inhalation of polluted air, and by consumption of contaminated food and water (NSDL, 2009).

2.1.13. BENZO(b)FLUORANTHENE

Benzo(b)fluoranthene is a PAH with the chemical formula $C_{20}H_{12}$ and molecular mass of 252.31 g/mol. It is present as a component of PAHs content in the environment usually resulting from the incomplete combustion or pyrolysis of organic matters, such as fossil fuels and tobacco (IPCS, CEC 2005).

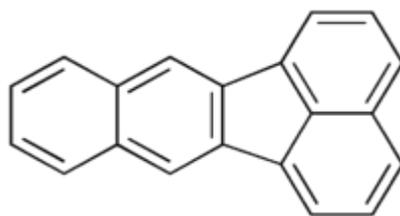


Structure of Benzo(b)fluoranthene

Benzo(b)fluoranthene has been classified category 2B by the IARC which means it is a probably carcinogen to human, and this is based on the fact that there are no human data but there are sufficient data from animal bioassays. Thus benzo(b)fluoranthene produced tumors in mice after lung implantation, intraperitoneal or subcutaneous injection, and skin painting (IARC, 1984). The current Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for benzo(b)fluoranthene (as a coal tar pitch volatile) is 0.2 mgm^{-3} of air as an 8-hour time weighted average (OSHA, 1994).

2.1.14. BENZO(k)FLUORANTHENE

Benzo(k)fluoranthene is a PAH with the molecular formula $C_{20}H_{12}$ and molecular weight 252.31 g/mol. The structure of this is presented below.



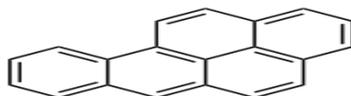
Structure of Benzo(k)fluoranthene

Benzo(k)fluoranthene is released into the environment usually through incomplete combustion or pyrolysis of organic matters, especially fossil fuels and tobacco (IPCS, CEC 2005). Although environmental concentrations are greatest near sources, its presence in distant places indicates that it is reasonably stable in the atmosphere and capable of long distant transport. Atmospheric losses are caused by gravitational settling and rainout. On land it is strongly adsorbed to soil and remains in the upper soil layers and does not leach into groundwater. Biodegradation may occur but it is very slow (Lauderdale *et al*, 2003). In water it is sorbed to sediment and particulate matter in the water column. There is also a potential for sorbed benzo(k)fluoranthene to be slowly desorbed and, therefore, concentration in the water column is usually low (Lauderdale *et al*, 2003).

Human exposure is from smoking, inhalation of polluted air and eating contaminated food. Since water treatment such as filtration, chlorination and ozonolysis removes benzo(k)fluoranthene, exposure from drinking water is minor (Lauderdale *et al*, 2003). Based on bioassay studied benzo(k)fluoranthene is known to produce tumors in mice and is mutagenic in bacteria (IARC, 1984).

2.1.15. BENZO(a)PYRENE

Benzo(a)pyrene, (BaP), is a five ring PAH whose metabolites are mutagenic and highly carcinogenic. It has molecular formula $C_{20}H_{12}$ and molecular mass of 252.31 g/mol. BaP is listed as a Group 1 carcinogen by the IARC (Straif, 2005). It belongs to a class of PAHs known as benzopyrenes, which consist of a benzene ring fused to a pyrene molecule. BaP is a product of incomplete combustion at temperatures between 300 and 600 °C. It was determined in 1933 to be the component of coal tar responsible for the first recognized occupation associated cancers, the sooty warts (cancers of the scrotum) suffered by chimney sweeps in 18th century in England. In the 19th century, high incidences of skin cancers were noted among fuel industry workers. By the early 20th century, the toxicity of BaP was demonstrated when malignant skin tumors were produced in laboratory animals by repeatedly painting them with coal tar (Le Marchand *et al*, 2002). The compound has structure,



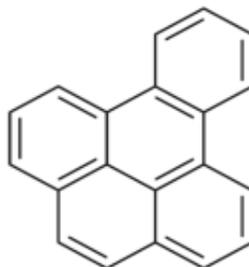
Structure of Benzo(a)pyrene

Benzo(a)pyrene is not manufactured and has no industrial uses. It is ubiquitously distributed throughout the environment as a consequence of its formation during the combustion of organic matter. The principal natural sources of BaP are forest fires and volcanic eruptions (Zedeck, 1980). Anthropogenic emission sources include the combustion of fossil fuels, coke oven emissions and vehicle exhausts (Lee *et al*, 1977; Stoker *et al*, 1975).

Benzo(a)pyrene has been found to be carcinogenic in a variety of species through a number of exposure routes. Tumors have been produced in mice, rats, hamsters, guinea pigs, rabbits, ducks and monkeys following intragastric, subcutaneous, dermal or intratracheal administration of BaP. The preferred target sites appear to be proliferating tissues of the intestinal epithelia, bone marrow, lymphoid organs and testes, which interact with the active metabolite of BaP (Santodonato *et al*, 1981). Benzo(a)pyrene has been shown to cause genotoxic effects in a broad range of prokaryotic and mammalian cell assay systems. In prokaryotes, BaP tested positive in DNA damage assays and in both reverse and forward mutation assays. In mammalian cell culture assays, BaP tested positive in DNA damage assays, forward mutation assays, chromosomal effects assays and cell transformation assays (U.S. EPA, 1991a).

2.1.16. BENZO(e)PYRENE

Benzo(e)pyrene, (BeP), is a high molecular weight PAH with the molecular formula $C_{20}H_{12}$ and molecular weight 252.31 g/mol. The structure of the compound is presented below:

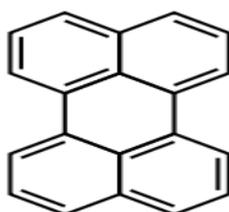


Structure of Benzo(e)Pyrene

It is listed as a Group 3 carcinogen by the IARC. Benzo(*e*)pyrene is present as a major component of the total content of polycyclic aromatic compounds in the environment (IARC, 1983). Human exposure to benzo(*e*)pyrene occurs primarily through the smoking of tobacco, inhalation of polluted air and by ingestion of food and water contaminated by combustion effluents. In rats, pulmonary injection of benzo(*e*)pyrene at various doses resulted in squamous-cell carcinoma of the lung at the highest dose level and pulmonary sarcoma at the mid dose level (IARC, 1983).

2.1.17. PERYLENE

Perylene or perilene is a PAH with the molecular formula $C_{20}H_{12}$ molecular mass of 252.31 g/mol. Perylene has the following structure.



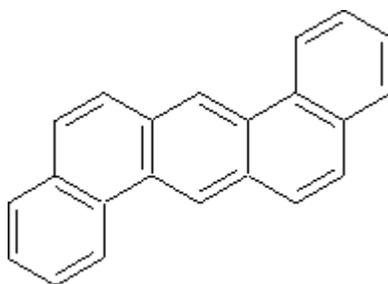
Structure of Perylene

Perylene and its derivatives may be carcinogenic, and is considered to be a hazardous pollutant. In cell membrane cytochemistry, perylene is used as a fluorescent lipid probe (Donaldson *et al*, 1953). Fluorescence liquids probes are used to obtain information about the structure, dynamics, and interactions in biomembranes (Alexander *et al*, 2009). These probes are efficient for studying the microscopic analogs of viscosity, polarity,

and hydration, as well as the molecular order, environment relaxation, and electrostatic potentials at the sites of their location (Alexander *et al*, 2009).

2.1.18. DIBENZO(a,h)ANTHRACENE

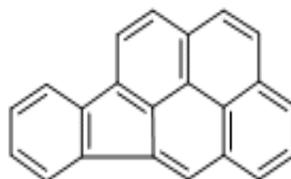
Dibenzo(a,h)anthracene (D(a,h)A) is a PAH with molecular formula $C_{22}H_{14}$ and molecular mass 278.4 g/mol. There is no commercial production or known use of dibenzo(a,h)anthracene. It occurs as a component of coal tars, shale oils, and soots (IARC, 1985) and has been detected in gasoline engine exhaust, coke oven emissions, cigarette smoke, charcoal broiled meats, vegetation near heavily travelled roads, surface water, and soils near hazardous waste sites (ATSDR, 1993; IARC, 1983). Dibenzo(a,h)anthracene is one of a number of PAHs on EPA's priority pollutant list (U.S. EPA, 1991). IARC classes D(a,h)A as a Group 2A i.e. probably carcinogenic to humans. The compound has the structure,



Structure of Dibenzo(a,h)Anthracene

2.1.19. INDENO(1,2,3-c,d)PYRENE

Indeno(1,2,3-c,d)pyrene is a PAH with molecular formula $C_{22}H_{12}$ and molecular mass 276.3 g/mol. It has the structure,

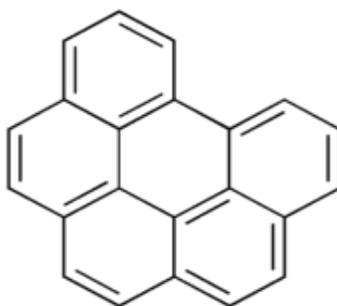


Structure of Indeno(1,2,3-c,d)Pyrene

Based on data from animal bioassays, indeno(1,2,3-c,d)pyrene has been classified category 2B (possibly carcinogen to human) by the IARC. Indeno(1,2,3-c,d)pyrene produced tumors in mice following lung implants, subcutaneous injection and dermal exposure. It tested positive in bacterial gene mutation assays (IARC, 1985).

2.1.20. BENZO(g,h,i)PERYLENE

Benzo(g,h,i)perylene, BghiP, is a PAH with the molecular formula $C_{22}H_{12}$ molecular mass of 276.33 g/mol. It has the structure,



Structure of Benzo(g,h,i)perylene

Benzo(g,h,i)perylene is released to the environment mainly through incomplete combustion of organic substances such as fuel, domestic wood and coal fires. Emissions also arise from industrial effluents, municipal waste water treatment facilities, waste incinerators and aluminum smelting (SEPA, 2006). Benzo(g,h,i)perylene is also released naturally from volcanoes and forest fires, but the amounts are very small compared to those released from man-made combustion sources (SEPA, 2006).

Benzo(g,h,i)perylene can enter the body either by inhalation of contaminated air, ingestion of water, soil or food. The most serious environmental impact of benzo(g,h,i)perylene is its significant accumulation in organisms exposed to it. It is also toxic and a suspected carcinogen (SEPA, 2006; Lauderdale *et al*, 2003; IPCS, CEC, 2001). In water, benzo(g,h,i)perylene attaches strongly to sediments and any other solid matter. Benzo(g,h,i)perylene released to soils tends to bind very strongly to the soils particles, so no major leaching to groundwater or volatilisation to air is likely to take place. It is very stable and can remain in the environment for a long period of time (Lauderdale *et al*, 2003; IPCS, CEC, 2001).

Benzo(g,h,i)perylene is extracted from coal tar and is used in making dyes, plastics, pesticides, explosives and drugs. It is also found (as part of a complex mixture of PAHs) in creosote, tar paints, waterproof membranes and other products (ATSDR, 1990; Faust *et al*, 1994).

CHAPTER THREE

METHODOLOGY

3.1. REAGENTS AND EQUIPMENT USED

3.1.1. Reagents Used

80 % and 96.5 % hexane

99.5 % Acetone

20 % Diethyl ether

99 % n-decane

Silica gel (5% water content)

Anhydrous sodium sulphate

70 % ethanol

1 mg/L PAH Internal standards

3.1.2. Equipment Used

Gas Chromatography-Mass Spectrometer

Soxhlet extractor

Air sampler

Rotary evaporator

Nitrogen gas evaporator

3.2. SAMPLING

3.2.1. Soil sampling

Soil samples were randomly collected from 36 communities in the Kumasi metropolis. Sampling was done in May, 2010. A total of 129 soil samples (0-10 cm top layer) were collected using a stainless steel scoop and stored in labeled centrifuge tubes. The sampling points and their Global Positioning System (GPS) coordinates are shown in Table 9, Appendix.3.

The soil samples obtained were stored at 4 °C in the Department of Chemistry, KNUST, Ghana and later transported to the Graduate School of Veterinary Medicine and Toxicology, Hokkaido University, Japan where they were stored at -30 °C before analysis. A map showing the sampling area is presented in Fig. 3.1

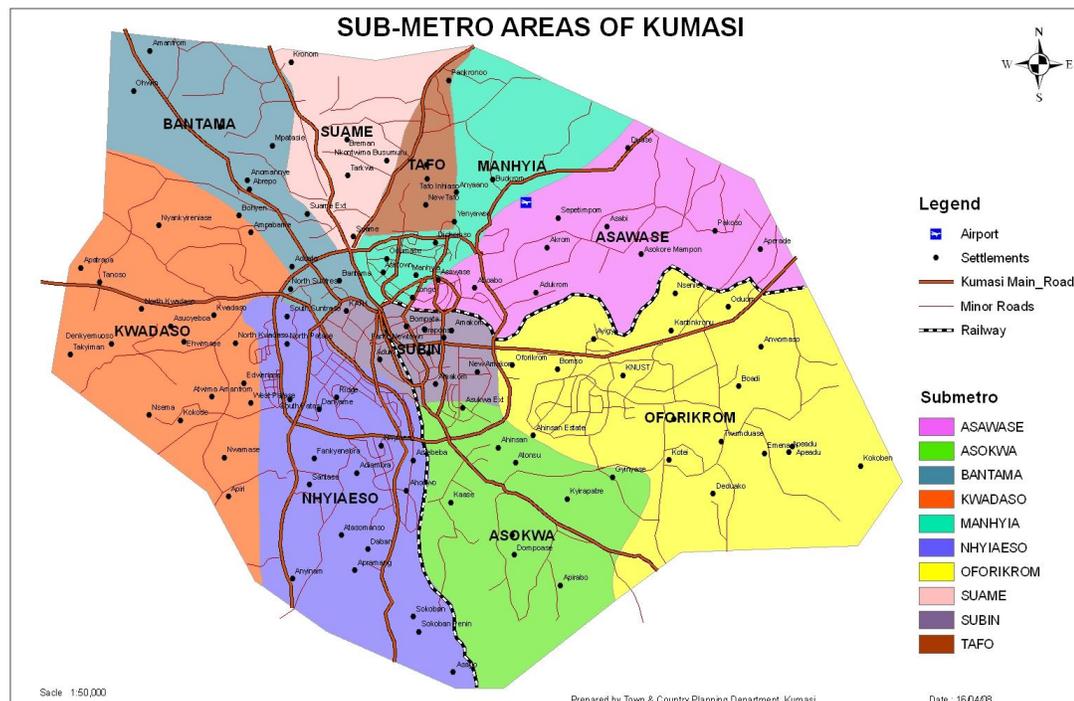


Figure 3.1: Map showing the sampling areas within the Kumasi sub-metro

3.2.2 Air sampling

Two sampling sites were selected for the collection of air samples in the Kumasi metropolis. These sites were located at the KNUST campus and the Kejetia lorry station. Airborne particulate samples were collected on filters using a Sibata Low Volume Pump air sampler. Air sampling was done for 8 hours each day starting from 8:00 am in the morning to 4:00 pm in the evening, at a flow rate of 30 L/min. A total of thirty four (34) air samples were collected from the two sites between the months of May to September, 2010. Approximately 14,400 L of the air passed through each filter during sampling. At both sampling sites, the air inlet was located 1.0 -1.5 m above ground level to simulate the breathing zone.

The sampling location was marked using the GPS. The GPS coordinates at the KNUST site were N06°40'24.7", W001°34'04.8" and that of the Kejetia lorry station were N06°41'51.6", W001°37'23.6". Air sampling on KNUST campus was done from 18th May to 30th of June, 2010. A total of 22 samples were collected and labeled as S₁ to S₂₂ whilst that from the Kejetia lorry station was done from 12th August to 18th September, 2010. A total of 12 samples were collected and labeled as C₁ to C₁₂.

3.3. EXTRACTION OF PAHs FROM AIR AND SOIL SAMPLES

3.3.1. Extraction of PAHs from soil samples

Soil samples were air dried at room temperature for 48 h. The samples were then passed through a 2 mm sieve to remove the coarse soil fraction. 10 g of the soil samples were weighed into extraction thimbles. The soil samples were covered completely with glass wool for thermal insulation. Extraction of PAHs from soil samples was done by soxhlet extractor (Soxtherm Gerhardt Variostat; Soxtherm V7.5) using 170 ml of 1:2; v/v acetone-hexane mixture. Extraction was done continuously for 6 h. The extracts were dehydrated by filtering through anhydrous sodium sulphate. The dehydrated extracts were collected into a round bottom flask. 25 µL of 1 mg/L PAH internal standard was added to the dehydrated extract. It was then concentrated to about 1.5 mL on a rotary evaporator. The concentrated sample was transferred into a test tube. The dehydrated extract in the test tube was further concentrated to 0.3 mL under a gentle N₂ stream.

3.3.1.1. Clean-up of soil extracts

This was done to remove other contaminants such as lipids and pigments that may have been extracted with PAHs. Clean-up was done using column packed with 5% water content silica gel. The column was packed as follows; first filled with anhydrous Na_2SO_4 , then packed with the 3 g of silica gel presoaked in hexane. About 25 mm length of anhydrous Na_2SO_4 added. The extracts were transferred onto the prepared column. It was then eluted with 100 mL of diethyl ether and hexane mixture in the ratio 1:4. The eluate was further concentrated using a rotary evaporator to 2 mL. 300 μL of n-decane was added to the extract to prevent evaporation of PAHs. It was further concentrated to 0.3 mL using a gentle N_2 stream.

3.3.2. Extraction of PAHs from air samples

For extraction of air samples, the filter paper was put into an extraction thimble. It was then extracted for PAHs using the same procedure described for the extraction of PAHs in soil samples. 50 μL of n-decane was added to extracts to prevent evaporation of PAHs. It was then concentrated to 0.3 mL under a gentle N_2 stream.

3.4. ANALYSIS OF PAHs USING GC-MS

PAHs analyses were carried out using AS3000 Gas Chromatograph (GC) coupled with a Thermo scientific Mass Selective Detector operating in the electron impact mode (GC-MS). The selective ion monitoring mode was used for quantification.

An ENV-8 MS, 30 m, 0.25 mm inner diameter, 0.25 μm film thickness capillary column was used for separation. Helium gas was used as the carrier gas at a constant flow rate of 1.2 ml/min. 8% Polycarborane-Siloxane was used as the stationary phases. Injection temperature for the GC-MS analysis was 280 $^{\circ}\text{C}$. Temperature programming for the column was as follows, initial temperature of 90 $^{\circ}\text{C}$ then held for 1 min, temperature was ramped to 280 $^{\circ}\text{C}$ at 10 $^{\circ}\text{C}/\text{min}$ and finally to 320 $^{\circ}\text{C}$ at a ramp rate of 5 $^{\circ}\text{C}/\text{min}$ and held for 10 min.

The PAHs that were measured in the samples were Naphthalene (Nap), Acenaphthylene (Acl), Acenaphthene (Ace), Fluorene (Fle), Phenanthrene (Phe), Anthracene (Ant), Fluoranthene (Flu), Pyrene (Pyr), Benz(a)anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Indeno(1,2,3-cd)pyrene (IDP), Dibenzo(a,h)anthracene (DBahA), Benzo(ghi)perylene (BghiP), Perylene (Peryl), Benzo(e)pyrene (BeP), Triphenylene (Trip), Methylene phenanthrene (Methyl-Phe), 1-methyl phenanthrene (Me-Phe) and Retene (Ret).

3.5. QUALITY CONTROL

A surrogate standard is a compound that is chemically similar to the analyte group but not expected to occur in an environmental sample, an example is Acenaphthene_{d10}, with molecular formula, $\text{C}_{12}\text{D}_{10}$, obtained by replacing all the hydrogen atoms of acenaphthene, $\text{C}_{12}\text{H}_{10}$, with deuterium. A surrogate standard was added to each sample

and blank prior to extraction. The recovery of the surrogate standard was used to monitor sample extraction errors, method or procedural recoveries etc. Surrogate recovery is evaluated by comparing the measured concentration with the amount added to the sample.

10 g of air dried and sieved soil sample from the KNUST Botanical Gardens was spiked with 25 μ L of 1 mg/L PAH internal standard. It was extracted and cleaned-up using the methods described earlier. Recoveries of four surrogate standards were analysed using the GC-MS under the same conditions of PAHs analysis (PAH internal standard was added before extraction). Similarly another 10 g of air dried and sieved soil sample from the KNUST Botanical Gardens was weighed. It was extracted, cleaned-up and analysed for four surrogate standards (but in this case the 25 μ L of 1 mg/L PAH internal standard was added after extraction).

Surrogate recoveries in soil samples were as follows Acenaphthene_d10, 93.3%, Phenanthrene_d10, 85.9%, Chrysene_d12, 93.1% and Perylene_d12, 99.3%. Air sample recoveries were carried out by the same method described for soil recoveries and percentage recoveries were as follows, Acenaphthene_d10, 90.1%, Phenanthrene_d10, 88.5%, Chrysene_d12, 92.6% and Perylene_d12, 91.1%.

Blanks prepared under the same conditions exhibited no detectable amount of PAHs.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Concentrations of Total PAHs in Air Samples from KNUST Campus

The results of total PAHs concentrations in the air samples from KNUST campus is presented in Fig. 4.1. The total concentrations ranged from 0.66 to 16.58 ng/m³ with a mean value of 3.71±3.52 ng/m³, this shows that there is a significant variation in the concentrations of total PAHs in air samples from KNUST campus. S₁₃ and S₁₅ recorded the lowest and highest concentrations of total PAHs in the air samples from KNUST campus respectively (Fig. 4.1). These samples were taken on the 18th of May, 2010 and 21st June, 2010 respectively. A similar work conducted at the Tunghai University Campus (THUC), in Taiwan recorded a mean concentration of total PAHs of 609.7±356.3 ng/m³ (Guor-Cheng *et al*, 2003). This shows that the concentration of total PAH from THUC is over 100 times greater than those from KNUST campus.

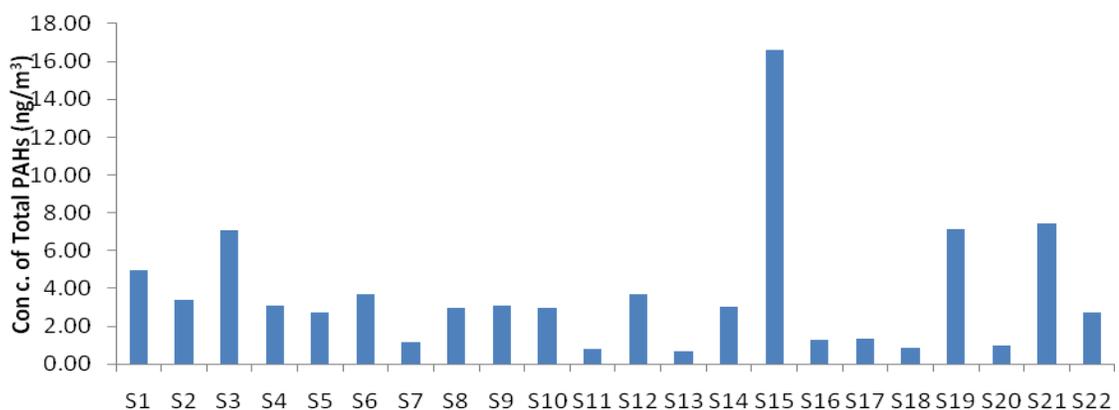


Figure 4.1: Concentrations of total PAHs in air from KNUST campus

The sum of concentrations of total PAHs in the air samples from KNUST campus was 81.67 ng/m³. Lower concentrations of total PAHs were recorded in the air samples from KNUST campus because the sampling site was located within an area with very low vehicular movement, low industrial and human activity, and therefore PAHs from point sources are very negligible. Based on the lower concentrations of total PAHs in the air samples, the air quality from KNUST campus is considered good and safe from the harmful effects of PAHs inhalation.

Each air sample from KNUST campus was analysed for individual PAHs. In each sample, concentrations of 22 individual PAHs were measured. S₁₅ which recorded the highest concentration of total PAHs in the air samples from KNUST campus was examined for individual PAH concentrations (Fig. 4.1). The individual concentrations of PAHs in S₁₅ were below detection limit for naphthalene, acenaphthene, 1-methyl phenanthrene and benzo(a)pyrene to 4.54 ng/m³ for benzo(g,h,i)perylene. The mean concentration of the individual PAHs in S₁₅ was 0.83±1.25 ng/m³ which indicates that there was a significant variation in the concentrations of individual PAHs in the air sample.

4.1.1. Concentrations of Benzo(a)Pyrene in the Air Samples from KNUST campus

Concentrations of BaP which is the most potent carcinogenic PAH in the individual samples were below detection in S₇, S₉, S₁₃, S₁₄, S₁₅, S₁₈. Sample S₂ recorded the highest

concentration of BaP (0.08 ng/m^3) in the air samples from KNUST campus. The mean concentration was $0.02 \pm 0.03 \text{ ng/m}^3$. The mean concentrations of benzo(a)pyrene in air samples from KNUST campus was low and this can be attributed to the fact that BaP is a typical marker for coke oven in a steel work (Smith, 1984) and there are no steel works on KNUST campus. Fig.4.2 shows the distribution of benzo(a)pyrene in the air samples from KNUST campus.

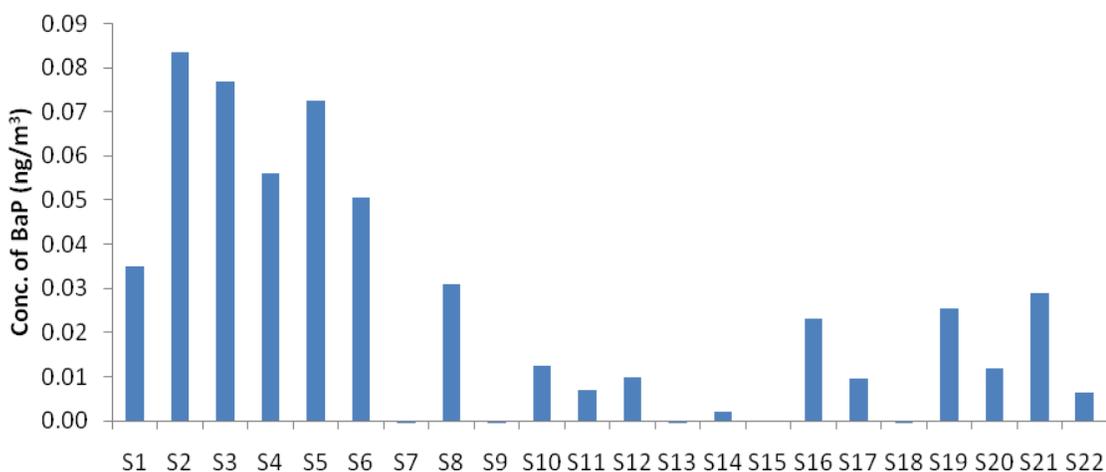


Figure 4.2: Concentrations of BaP in air samples from KNUST campus

The mean concentration of BaP from KNUST campus was compared to similar work done from the Tunghai University Campus (THUC), in Taiwan which recorded mean BaP concentration of $3.0 \pm 5.9 \text{ ng/m}^3$. The results from THUC were found to be 150 times higher than that from KNUST campus. Since no corresponding standard is available for Ghana, this study adopted the UK and Swedish standards as the basis for determining the quality of BaP in the air samples from KNUST campus. The United Kingdom Air Quality Standards (EPAQS) has recommended BaP value of 0.25 ng/m^3 (Dimashki *et al*,

2001) and the Swedish guideline value for BaP in the air is 0.1 ng/m^3 (Bostrom *et al*, 2002). The mean BaP concentration in the air samples from KNUST campus ($0.02 \pm 0.03 \text{ ng/m}^3$), was 12.5 times lesser than the standard set by the United Kingdom and 5 times lesser than the Swedish standard for BaP in the air. The individual concentrations of BaP in the air samples from KNUST campus were all below the Swedish and United Kingdom standards (Fig. 4.2). Based on this criterion air from KNUST campus is of good quality and inhabitants of KNUST campus are safe from the deleterious effects of BaP since the concentrations in the air samples were all below the UK and Swedish standards (Fig. 4.2).

4.1.2. Concentrations of Most Abundant PAHs in Air Samples from KNUST Campus

The sums of individual PAHs in air samples from KNUST campus were calculated. The most abundant PAHs found in the air samples were phenanthrene, benzo(g,h,i)perylene retene, and pyrene (Fig. 4.3). The relative abundances for these PAHs were 18.8%, 14.3%, 12.9%, and 10.5% respectively. Chrysene and triphenylene were the least abundant PAH in the air samples from KNUST campus with concentration below the detection limit in all the samples (Fig. 4.3). Air samples from the KNUST campus were dominated by 3 member ring PAHs (46.0%), followed by the 6 member rings (21.3%), the 4 member ring PAHs (19.2%), the 5 member ring (10.0%) then naphthalene, a 2 member ring PAH (3.4%). During combustion at low temperatures (wood combustion), the low molecular weight PAH compounds (< 4 rings) are abundant (Lake *et al*, 1979).

Similarly at high temperature combustion (that is during vehicular emissions) the high molecular weight PAH compounds (≥ 4 rings) are dominant (Laflamme and Hites 1978). This shows that 50.5% of air samples from KNUST campus were dominated by high molecular weight PAHs suggesting vehicular emissions and 49.5% dominated by low molecular weight PAHs which suggests wood or grass combustion sources.

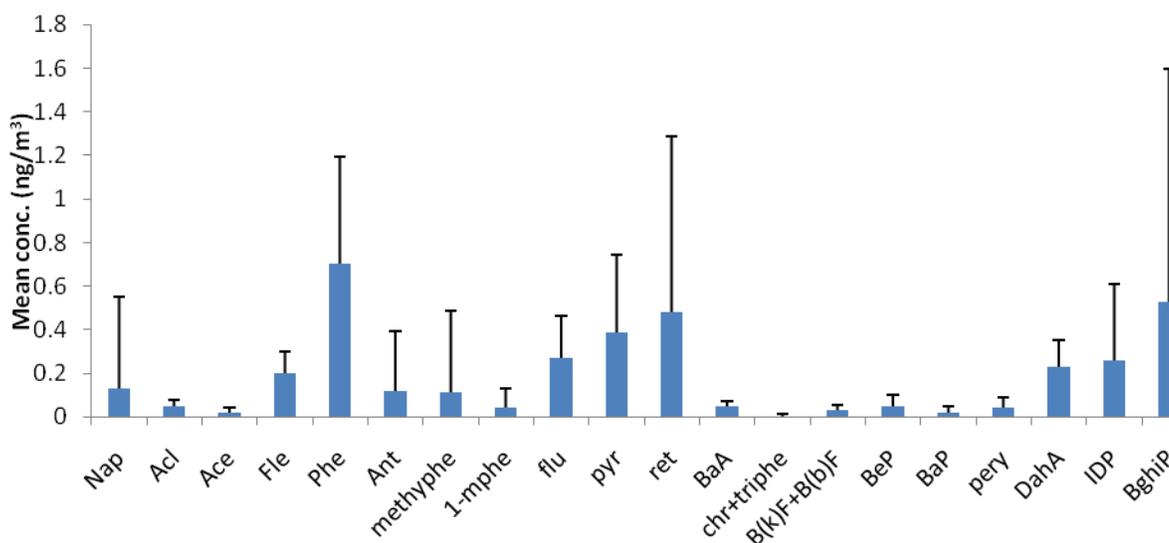


Figure 4.3: Concentrations of mean PAHs in air samples from KNUST campus

The most abundant individual PAH in the air samples from KNUST campus was phenanthrene (Fig. 4.3). The lowest and highest concentrations of phenanthrene in the air samples from KNUST campus were 0.08 and 1.88 ng/m³ recorded in S₁₁ and S₃ respectively. The mean concentration of phenanthrene in the air samples (S₁-S₂₂) was

$0.70 \pm 0.49 \text{ ng/m}^3$ and this shows the variation in the concentrations of phenanthrene in the air samples from KNUST campus is insignificant.

S₃ which recorded the highest concentration of phenanthrene (Fig. 4.4) was sampled on the 9th of June, 2010. The concentrations of the individual PAHs in S₃ ranged from below detection for naphthalene, anthracene, benzo(a)anthracene, chrysene and triphenylene to 2.01 ng/m^3 for retene. The mean concentration of the 22 PAHs in S₃ was $0.35 \pm 0.58 \text{ ng/m}^3$ and this shows that there is a significant variation in the concentrations individual PAHs in S₃. Fig. 4.4 shows the distribution of phenanthrene in the air samples from KNUST campus.

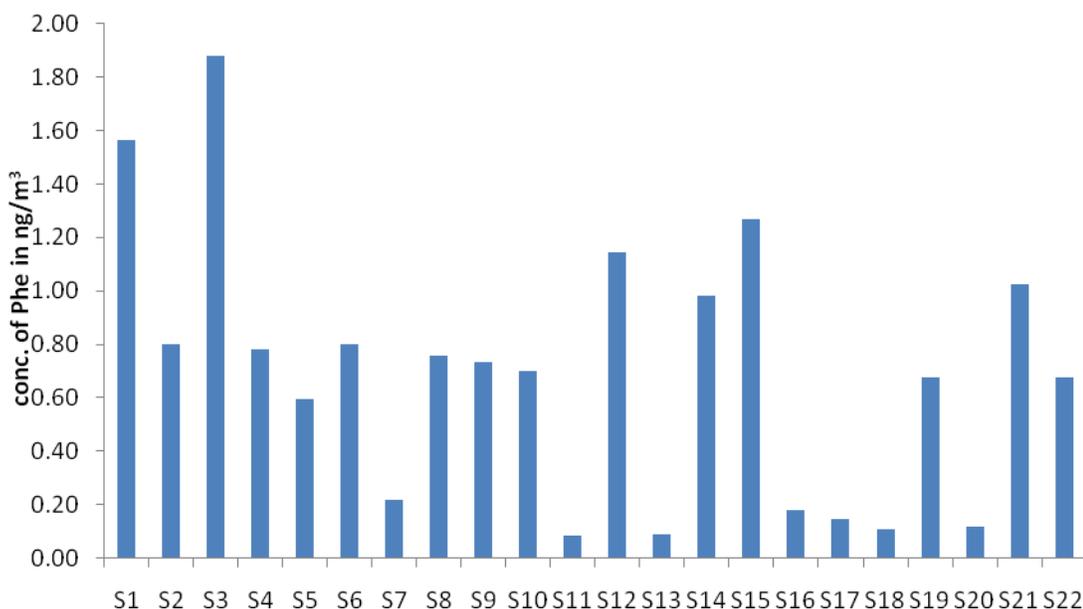


Figure 4.4: Concentrations of Phenanthrene in the air samples from KNUST campus

Benzo(g,h,i)perylene was the second most abundant PAH in the air samples from KNUST campus (Fig. 4.3). BghiP recorded minimum and maximum concentrations of 0.03 and 4.54 ng/m³ in S₁₈ and S₁₅ respectively. The mean concentration of BghiP in air samples from KNUST campus was 0.53±1.07 ng/m³. Fig. 4.5 shows the distribution of BghiP in the air samples from KNUST campus.

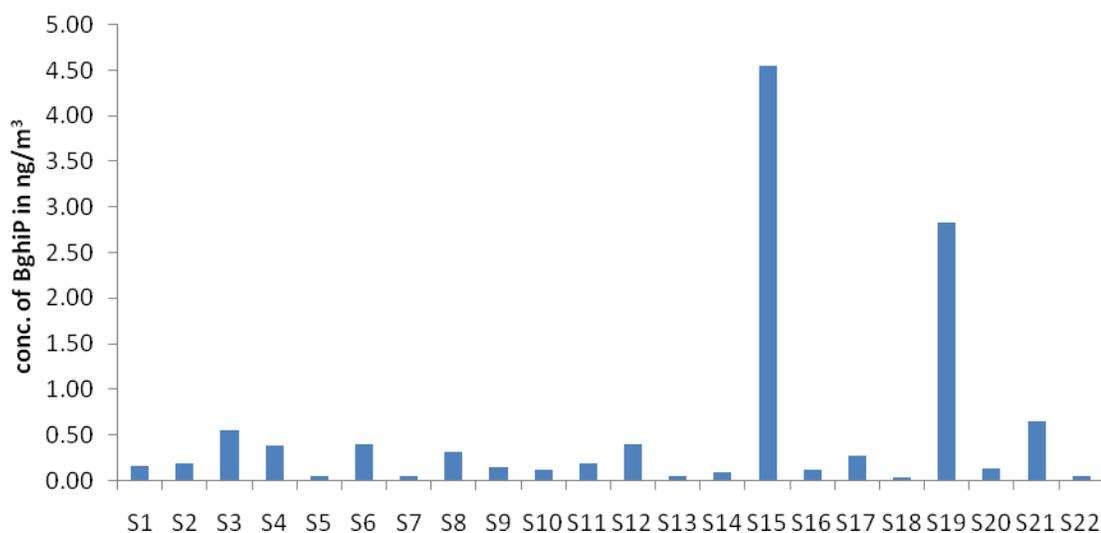


Figure 4.5: Concentrations of BghiP in the air samples on KNUST campus

The concentration of retene, the third most abundant PAH in the air samples from KNUST campus, ranged from below detection in S₇, S₁₁, S₁₃, S₁₆, S₁₇, S₁₈, and S₂₀ to 3.49 ng/m³ in S₁₅ (Fig. 4.6). The mean value of retene in air samples from the KNUST campus was 0.48±0.81 ng/m³. There was a significant variation in the concentrations of retene in the air samples (S₁ – S₂₂).

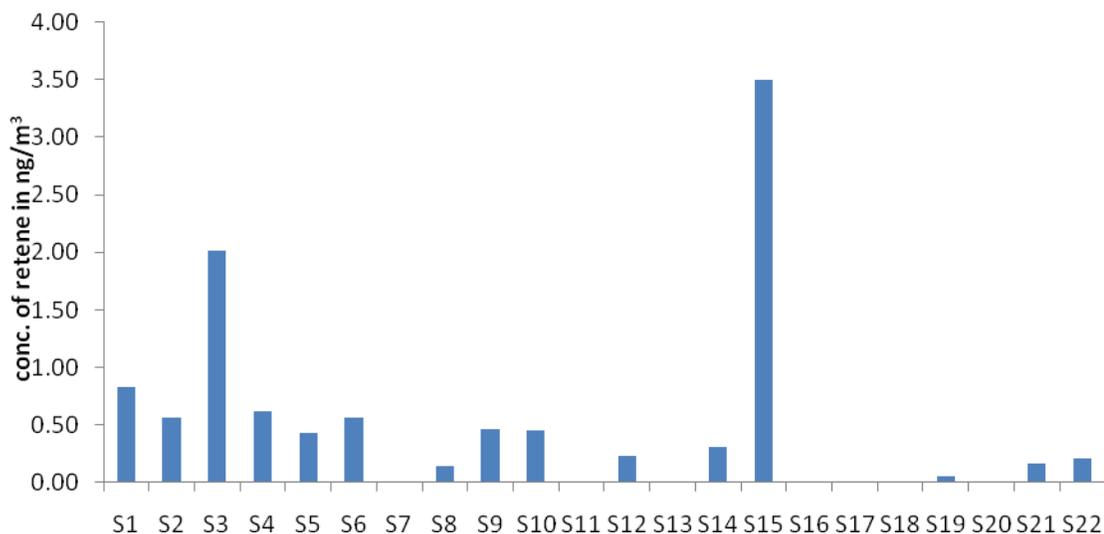


Figure 4.6: Concentrations of Retene in the air samples from KNUST campus

Pyrene was the fourth most abundant PAH in the air samples from KNUST campus (Fig. 4.3). The concentrations ranged from 0.04 in S₁₃ to 1.61 ng/m³ in S₂₁ (Fig. 4.7). The mean concentration of pyrene in the air samples from KNUST campus was 0.39±0.35 ng/m³ and this indicates that there was a significant variation in the concentrations of pyrene in the air samples (S₁–S₂₂). PAHs profile developed by Harrison *et al*, 1996, on the types of emission sources suggests that phenanthrene and pyrene which are the 1st and 4th most abundant PAHs in the air samples from KNUST campus are typical diesel vehicles markers whereas benzo(g,h,i)pyrene (BghiP), the 2nd most abundant, is a typical gasoline vehicle marker. Fig. 4.7 shows the distribution of pyrene in the air samples from KNUST campus.

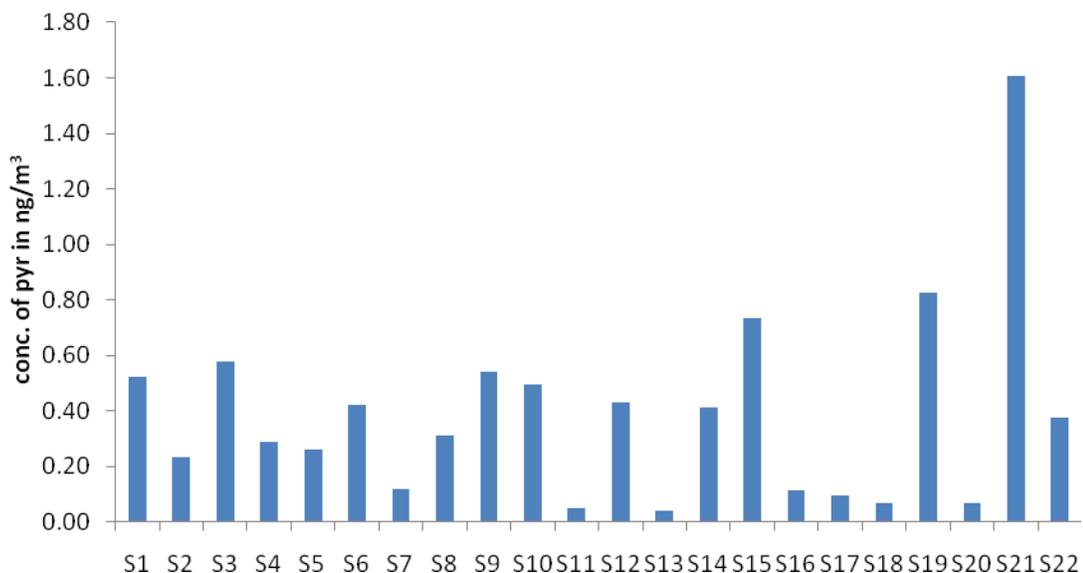


Figure 4.7: Concentrations of Pyrene in the air samples from KNUST campus

4.2. Concentrations of Total PAHs in the Air Samples from the Kejetia Lorry Station

Concentration of total PAH in the air samples from the Kejetia lorry station is presented in Fig. 4.8. The concentrations ranged from 19.95 in C₁₂ to 38.72 ng/m³ in C₁. The mean concentration of total PAHs in air samples from the Kejetia lorry station was 30.23±4.96 ng/m³. The mean concentration of total PAH from the Kejetia lorry station (30.23 ng/m³) was 8 times greater than from KNUST campus (3.71 ng/m³). This may be attributed to the fact that the sampling site at Kejetia was located within an area with heavy vehicular movement, where there were high exhaust fumes emissions and also oil seeps from vehicles was possible.

There were also high emissions of PAHs from manufacturing or small scale industrial activities (e.g. Exhausts from corn milling plants) from the sampling site.

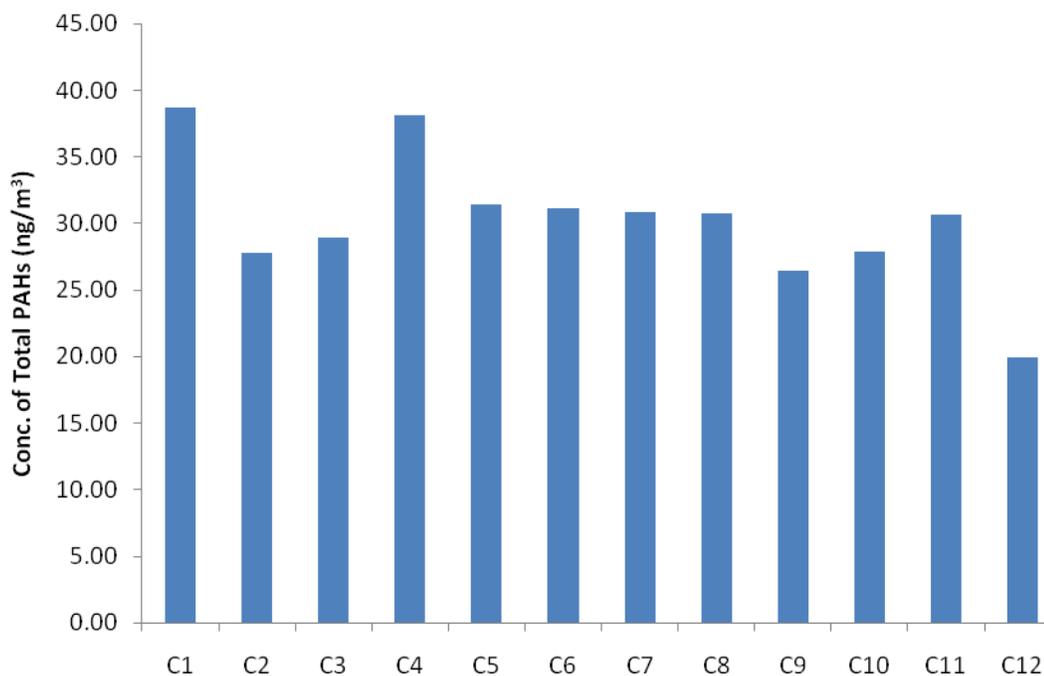


Figure 4.8: Concentration of total PAHs in the air samples from Kejetia lorry station

Meanwhile concentration of total PAHs at the Taichung Industrial Park (TIP), Taiwan was 1233.8 ± 963.6 ng/m³. From this, mean concentration of total PAHs from TIP was 41 times greater than from the Kejetia lorry station. The lowest and highest concentrations of total PAHs in air samples from the Kejetia lorry station were sampled on the 28th August and 1st September, 2010 respectively.

4.2.1. Concentrations of Most Abundant PAHs in Air Samples from Kejetia Lorry Station

The sum of individual PAHs in air samples from the Kejetia lorry station was calculated and is presented in Fig. 4.9. The most abundant PAH from the Kejetia lorry station was BghiP (Fig. 4.9) with mean concentration of $8.62 \pm 2.26 \text{ ng/m}^3$. 1-methyl phenanthrene on the other hand was the least abundant PAH in the air samples from the Kejetia lorry station with mean value of $0.01 \pm 0.04 \text{ ng/m}^3$. High concentrations of BghiP from the Kejetia lorry station can be attributed to the fact that most BghiP is released from vehicular exhausts and wood fires (SEPA, 2006) and these are the predominant sources of PAHs from the sample site at the Kejetia lorry station.

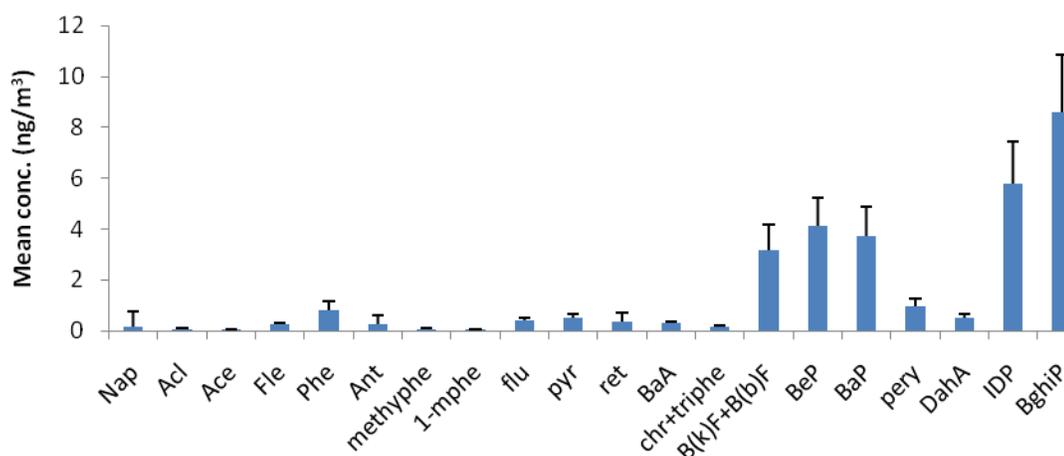


Figure 4.9: Concentrations of mean PAHs in air samples from the Kejetia lorry station

The most abundant PAHs from the Kejetia lorry station were BghiP, IDP, BeP and BaP (Fig. 4.9). These are all high molecular weight PAHs. Their relative abundances were

28.5%, 19.1%, 13.6%, 12.4% respectively. Based on the PAHs profile developed by Harrison *et al*, 1996, BghiP and IDP the 1st and 2nd most abundant PAHs in air samples from the Kejetia lorry station are mainly from vehicular emissions since they are typical markers for gasoline combustion.

Air samples from the Kejetia lorry station were dominated by 6 member ring PAHs (47.7%), followed by the 5 member rings (41.2%), the 3 member ring PAHs (6.2%) , the 4 member ring (4.4%) then the 2 member ring PAH (0.6%). During wood combustion (i.e. combustion at low temperatures) low molecular weight PAH compounds (< 4 rings) are abundant (Lake *et al*, 1979), similarly during vehicular emissions (i.e. combustion at high temperatures) the high molecular weight PAH compounds (≥ 4 rings) are dominant (Laflamme and Hites, 1978). The results show that air samples from the Kejetia lorry station were dominated by high molecular weight PAHs which suggests that most of the PAHs from the sample area at Kejetia were from vehicular emissions. Fig. 4.10 shows the distribution of the most abundant individual PAHs in air samples from the Kejetia lorry station.

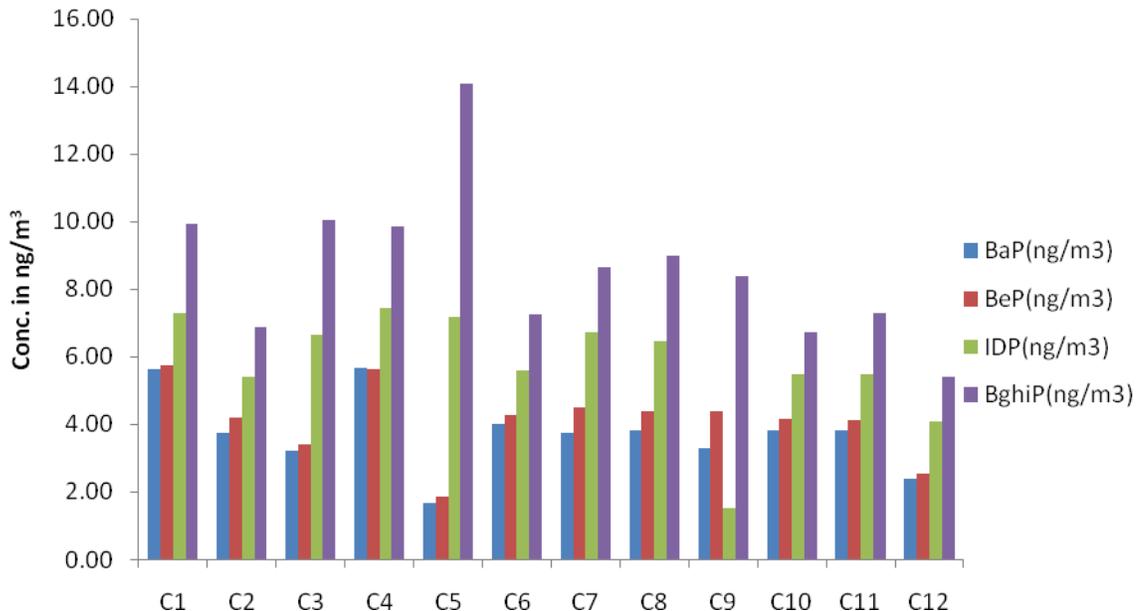


Figure 4.10: Concentration of individual PAHs in air samples from Kejetia lorry station

BghiP was the most abundant PAH from Kejetia lorry station (Fig. 4.9). The concentrations of BghiP ranged from 5.40 in C₁₂ to 14.09 ng/m³ in C₅ (Fig. 4.10) with a mean value of 8.62 ± 2.26 ng/m³ and this shows that the variation in the concentrations of BghiP in the air samples from Kejetia lorry station was insignificant.

The concentration of IDP, the second most abundant PAH in the air samples from the Kejetia lorry station ranged from 1.52 in C₉ to 7.44 ng/m³ in C₄ (Fig. 4.9) with a mean value of 5.78 ± 1.44 ng/m³. The mean concentration of IDP from Kejetia lorry station was 22 times higher than that from KNUST campus.

BeP was the third most abundant PAH in the air samples from the Kejetia lorry station (Fig. 4.9). The concentrations of BeP in air samples from the Kejetia lorry station ranged from 1.85 to 5.76 ng/m³ with mean concentration of 4.11±1.1 ng/m³. The mean BeP concentration from Kejetia lorry station (4.11 ng/m³) was 82 times higher than the mean BeP concentration from KNUST campus (0.05 ng/m³).

Benzo(a)pyrene (BaP), a human carcinogen, was the fourth most abundant PAH in the air samples from the Kejetia lorry station (Fig. 4.9). The concentration of BaP in the air samples from Kejetia lorry station ranged from 1.69 (C₅) to 5.66 ng/m³ (C₄) (Fig. 4.10) with mean concentration of 3.74±1.12 ng/m³. The mean concentration of BaP in air samples from Taichung Industrial Park (TIP), Taiwan was 9.0±25.4 ng/m³ (Guor-Cheng *et al*, 2003). This was 2.4 times higher than that from the Kejetia lorry station. The mean concentration of BaP in air samples from the Kejetia lorry station was 14.69 and 37.4 times higher than air quality standard for BaP concentration in the United Kingdom (0.25 ng/m³) and Sweden (0.1 ng/m³) respectively. The mean concentration of BaP from the Kejetia lorry station (3.74±1.12 ng/m³) was again 187 times higher than the mean concentration of BaP from KNUST campus (0.02±0.03 ng/m³). The air from the Kejetia lorry station can be classified as highly polluted with BaP.

The sum of the concentration of total PAHs in the air samples from the Kejetia lorry station was 362.71 ng/m³. This was 4.4 times higher than that from KNUST campus (81.67 ng/m³). Again the concentrations of individual PAHs were also higher in air

samples from the Kejetia lorry station than from KNUST campus. This may be due to the fact that the sampling site at Kejetia was located within an area with heavy vehicular movement, where exhaust fumes may contain high levels of PAHs.

4.3. Concentrations of Total PAHs in the Surface Soils from the Kumasi Metropolis

The mean concentrations of total PAHs in the soil samples from 36 communities in the Kumasi metropolis ranged from 10.85 ± 4.84 at Ahinsan to 2084.87 ± 2210.05 ng/g dw at Adum (Fig. 4.11). This recorded a mean value of 415.61 ± 525.52 ng/g dw which shows that there was a significant variation in the concentrations of total PAHs in surface soils from the communities. The results show that the concentrations of total PAHs in the soil samples from the communities in the Kumasi metropolis were lower than those from other cities like Dalian which recorded total concentration range of 219–18727 ng/g (Zhen *et al*, 2007). Again when the results from the Kumasi metropolis were compared to similar studies from Estonia, it showed that the concentrations of total PAHs from Estonia were higher, ranging from 2200 to 12300 ng/g (Trapido, 1999). Fig. 4.11 shows the mean concentrations of total PAHs in some communities in the Kumasi metropolis.

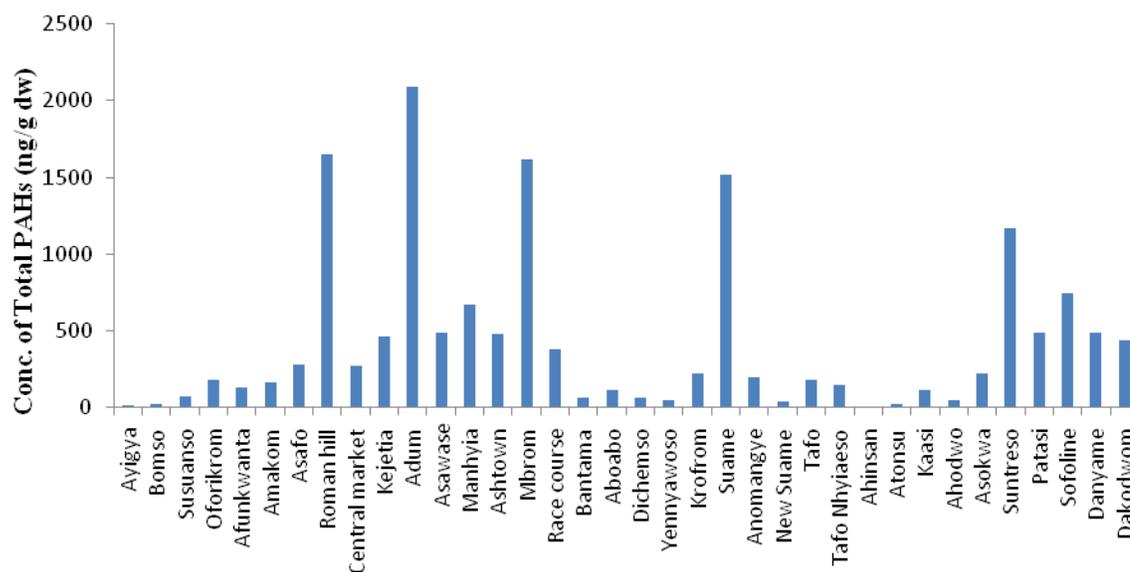


Figure 4.11: Mean concentrations of total PAHs in surface soils from Some Communities in Kumasi

According to the classification established by Maliszewska-Kordybach, the PAHs pollution levels of soil were divided into 4 categories namely unpolluted (concentrations less than 200 ng/g), weakly polluted (concentrations ranging from 200–600 ng/g), polluted (concentrations ranging from 600–1,000 ng/g) and severely polluted (concentrations greater than 1000 ng/g) (Maliszewska-Kordybach 1996). By this classification 51.4% of the communities in this study are considered unpolluted with PAHs (<200 ng/g). The least polluted community was Ahinsan with a total PAHs concentration of 10.85 ng/g dw. 29.7% of the communities were weakly polluted with PAHs and 5.4%, moderately polluted. The most heavily polluted communities representing 13.5% were Adum, Romanhill, Mbrom, Suame and Suntreso (Fig. 4.11).

They recorded mean concentrations of total PAHs of 2084 ± 2210.05 , 1647 ± 784.32 , 1620 ± 1924.03 , 1515 ± 1992.01 and 1170 ± 1048.26 ng/g dw respectively. The high levels of PAHs in the soil samples from these communities may come from the high vehicular traffic and the high human population who may use firewood or charcoal for domestic heating. As a result, the surrounding soils were contaminated with PAHs from these activities.

4.3.1. Concentrations of Most Abundant PAHs in Surface Soil Samples from the Kumasi Metropolis

The mean concentrations of individual PAHs in surface soils from the Kumasi metropolis are presented in Fig. 4.12. The most abundant PAH in the surface soils from the Kumasi metropolis was fluoranthene. On the other hand the least abundant was acenaphthene (Fig. 4.12). The average concentration of acenaphthene from the surface soils was 1.39 ± 4.22 ng/g dw. Surface soils from the Kumasi metropolis were dominated by 4 ring PAHs (40.9%), followed by the 5 rings (28.0%), the 6 ring PAHs (16.2%), the 3 ring (13.5%) then, the 2 ring PAH (1.34%). During vehicular emissions the high molecular weight PAH compounds (≥ 4 rings) are dominant (Laflamme and Hites, 1978). This suggests that PAHs in surface soils from the Kumasi metropolis were mainly from vehicular emissions. The findings from this study is confirmed by the PAHs profile developed by Harrison *et al*, 1996 on the types of emission sources which suggests that fluoranthene and pyrene (the 1st and 2nd most abundant PAHs in soil

samples from the Kumasi metropolis) are typical diesel vehicles markers and BghiP (the 3rd most abundant) is a typical gasoline vehicle markers

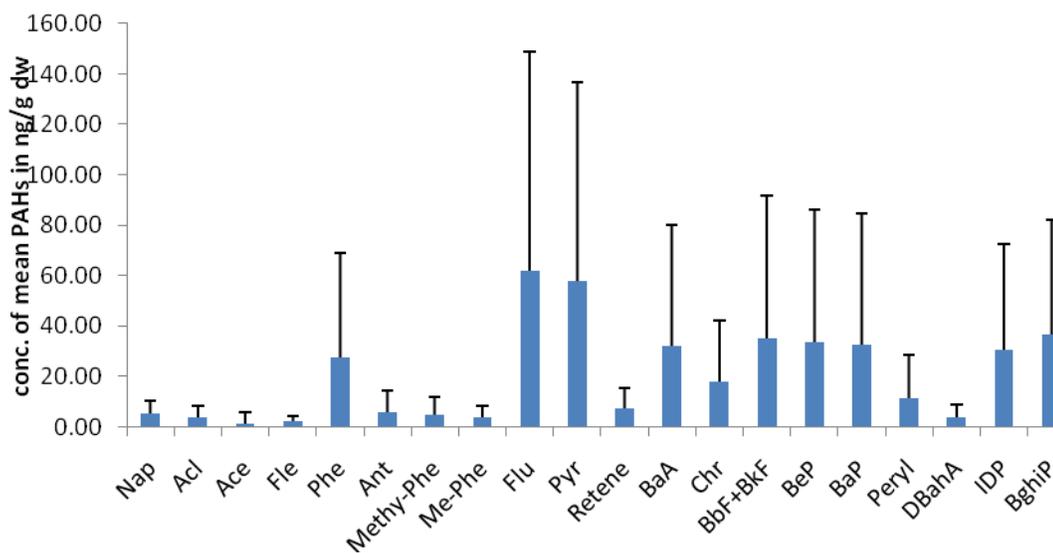


Figure 4.12: Mean concentrations of individual PAHs in surface soil from the Kumasi metropolis

The high molecular weight PAHs (with four or more rings) accounted for a large fraction of the total PAHs in these soils this may be due to their resistance to degradation and migration (Pichler *et al*, 1996). Fluoranthene, pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene and benzo(b)fluoranthene, were the most abundant PAHs in surface soils from the Kumasi metropolis (Fig. 4.12). This is in agreement with results from Omar *et al*, 2002 which states that fluoranthene and pyrene are normally the most abundant PAHs in roadside soil. The dominance of benzo(ghi)perylene, pyrene and

fluoranthene in the surface soils from the Kumasi metropolis was therefore derived mainly from vehicular emissions.

Fluoranthene was the most abundant PAH in the surface soil from the Kumasi metropolis (Fig. 4.12) with relative abundance of 15.59%. From Fig. 4.13, the community most polluted with fluoranthene was Suame. The mean concentration of fluoranthene in Suame was 381.34 ± 574.57 ng/g dw, which indicates a significant variation in the concentrations of fluoranthene in Suame. The lowest concentration of fluoranthene through the communities was Ahinsan (Fig. 4.13) with a mean concentration of 1.13 ± 0.49 ng/g dw. The mean concentration of fluoranthene within all the 36 communities was 61.70 ± 86.86 ng/g dw. The higher standard deviation shows a significant variation in the concentrations of fluoranthene in the surface soil samples (Table 17, Appendix 3).

Suame was the fourth most polluted community with PAHs in the Kumasi metropolis (Fig. 4.11). The least and highest concentrations of individual PAHs from Suame were 5.61 and 381.34 ng/g dw for fluorene and fluoranthene respectively. Suame recorded mean concentration of individual PAHs of 75.76 ± 111.20 ng/g dw.

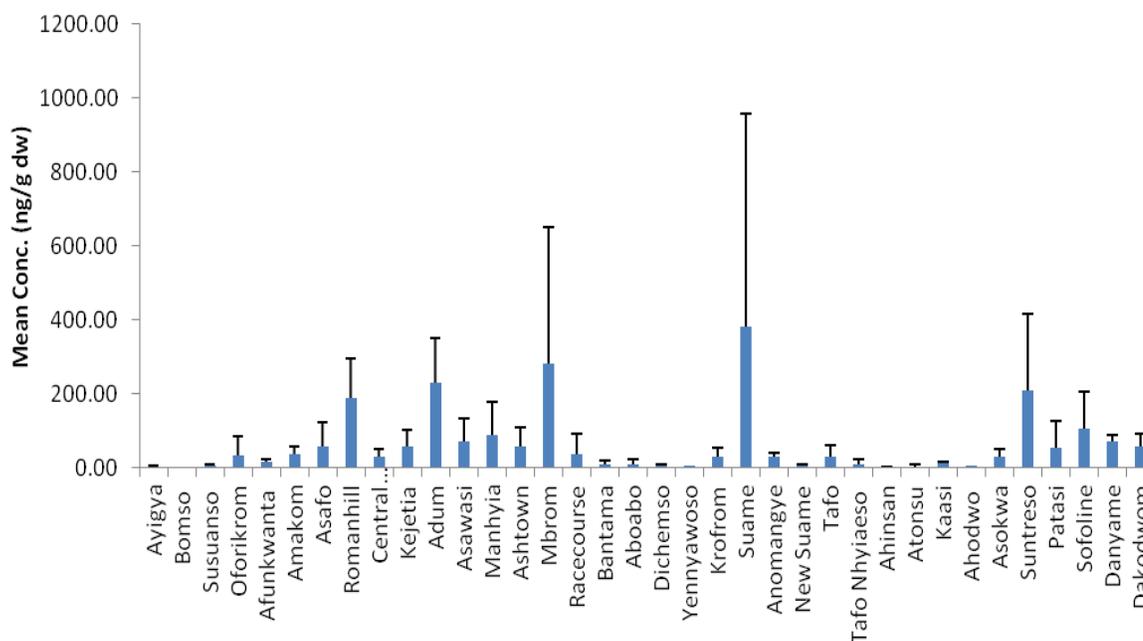


Figure 4.13: Distribution of fluoranthene in surface soils from Kumasi metropolis

Pyrene (a 4 ring PAH) was the second most abundant PAH in surface soils from Kumasi (Fig. 4.12). Its percentage abundance in the surface soil from Kumasi was 14.66%. The mean concentration of pyrene through all the soil sample communities was 57.94 ± 78.68 ng/g dw. The most polluted community with pyrene was Suame (Fig. 4.14). The mean concentration of pyrene from Suame was 355.12 ± 449.42 ng/g dw which shows that there was a significant variation in the concentrations of pyrene in Suame. Ahinsan on the other hand recorded the lowest mean concentration of pyrene with value 1.04 ± 0.49 ng/g dw and this also shows that the variation in the concentrations of pyrene from Ahinsan was insignificant.

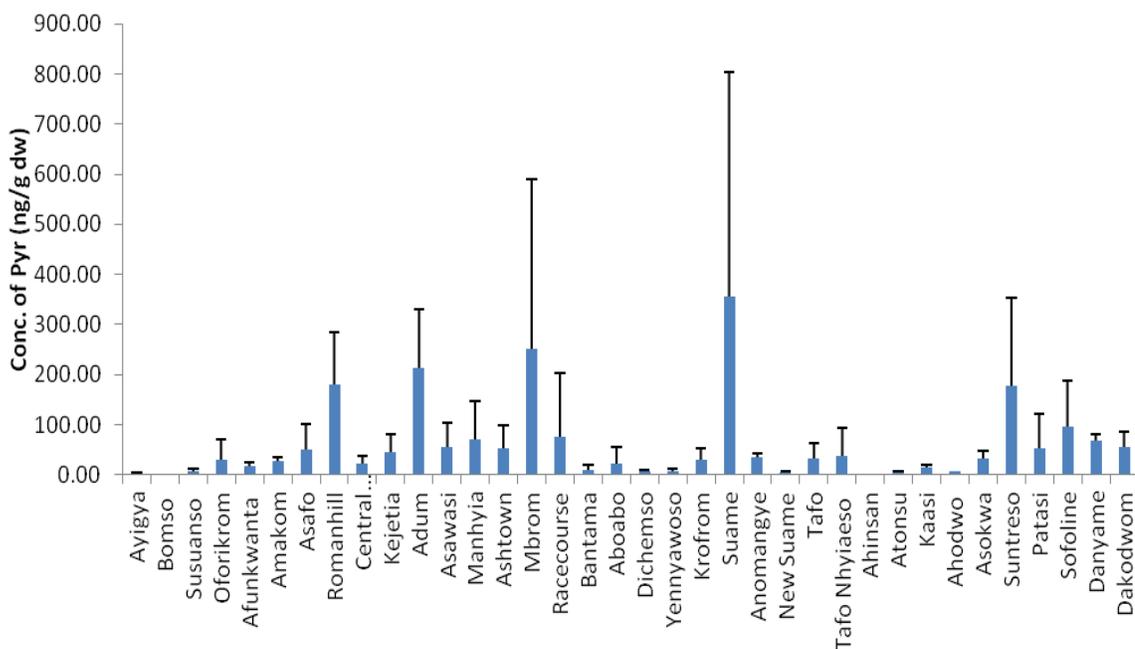


Figure 4.14: Distribution of Pyrene in surface soils from the Kumasi metropolis

BghiP was the third most abundant PAH in the surface soil from Kumasi (Fig. 4.12). The percent abundance of BghiP was 8.62%. The mean concentration of BghiP in the surface soils from the communities was 36.67 ± 45.41 ng/g and this shows that there was a significant variation in the concentrations of BghiP in the soil samples (Table 17, Appendix 3). As shown in Fig. 4.15, the community most polluted with BghiP was Adum. The lowest and highest concentrations of BghiP in Adum were 42.85 and 595.34 ng/g dw respectively. The mean concentration of BghiP from Adum was 214.38 ± 256.13 ng/g dw. The least polluted communities with BghiP was New Suame with mean concentration of 0.2 ± 0.07 ng/g dw as represented in Fig. 4.15.

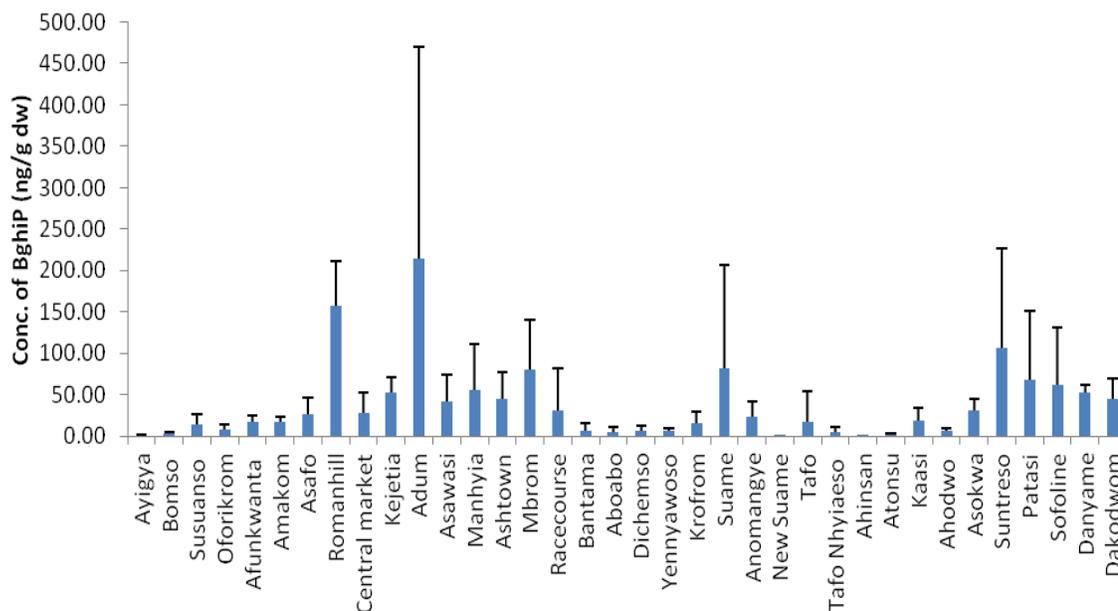


Figure 4.15: Distribution of BghiP in surface soils from the Kumasi metropolis

BbF+BkF was the fourth most abundant PAH in the surface soil from the Kumasi metropolis as presented in Fig. 4.12. The percentage abundance of BbF+BkF was 8.17 %. The mean concentrations of BbF+BkF, a 5 ring PAH, through the communities ranged from 0.92 ± 0.55 (Ahinsan) to 298.05 ± 465.23 ng/g dw (Adum) (Table 17, Appendix 3). Fig. 4.16 shows that Adum and Ahinsan recorded the highest and lowest mean concentrations of BbF+BkF in the surface soils from the Kumasi metropolis respectively.

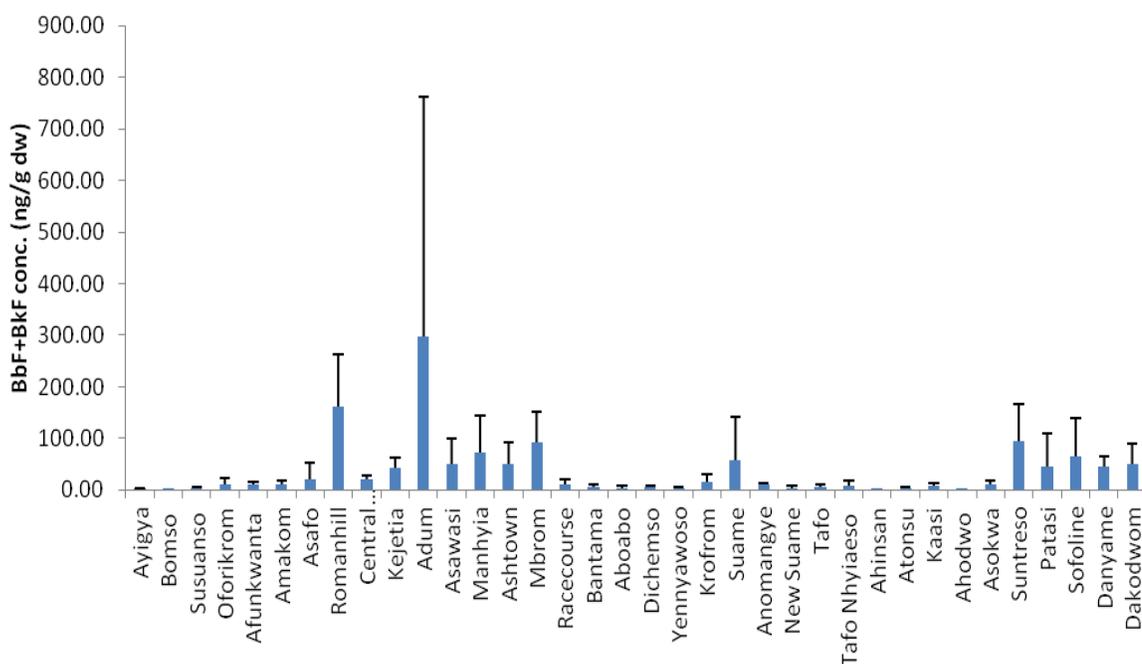


Figure 4.16: Distribution of BbF+BkF in surface soils from the Kumasi metropolis

4.3.2. Concentrations of Benzo(a)Pyrene (BaP) in Surface Soil

The component typically of greatest interest in terms of potential cancer hazard is BaP. This compound had been known to exhibit a high carcinogenic activity in animals and has been listed as a proven human carcinogenicity (WHO, 2000). BaP concentration in the soils recorded a percentage abundance of 7.55% and it was the 6th most abundant PAH determined in surface soils from the study area (Fig. 4.12). The mean concentrations of BaP in the soil samples from the communities ranged from 0.59 ± 0.33 at Ahinsan to 259.46 ± 388.37 ng/g dw at Adum. However, the mean value of BaP through all the communities was 32.59 ± 51.90 ng/g dw, which indicates that there was a

significant variation in the concentrations of BaP through the communities. Fig. 4.17 shows the mean concentrations of BaP in surface soils from the Kumasi metropolis.

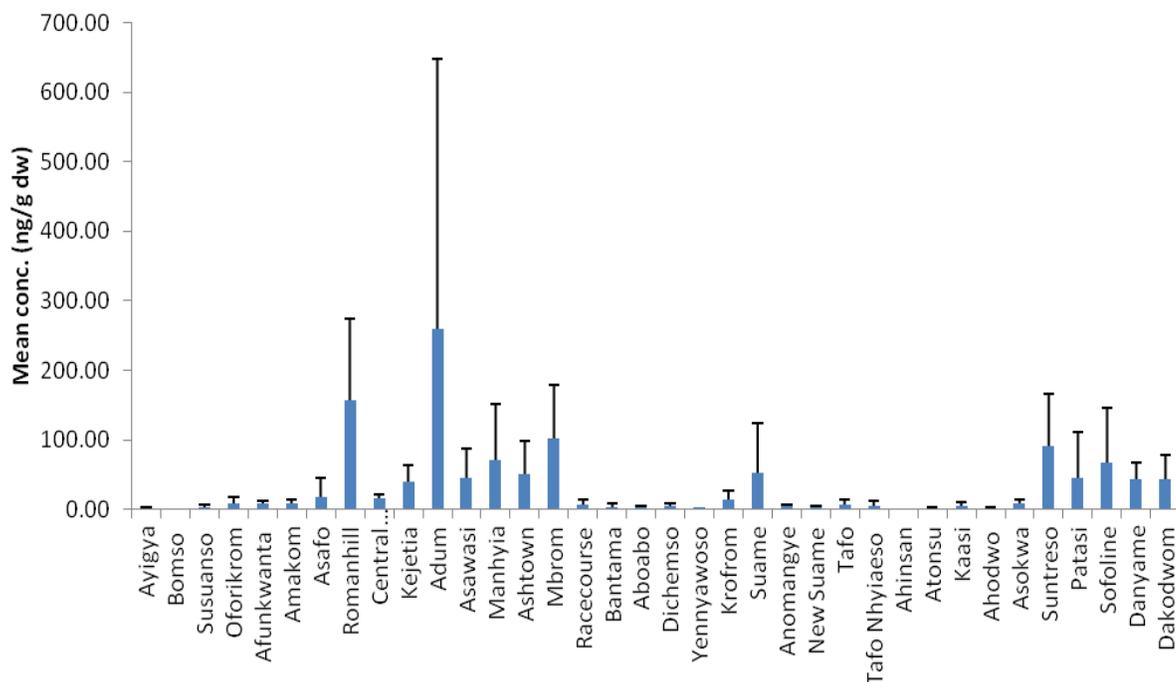


Figure 4.17: Mean concentrations of BaP in surface soils from the Kumasi metropolis

The results of this study show that the concentrations of BaP in soil samples from the Kumasi metropolis was lower than those in the industrial areas (170–6030 ng/g) and commercial areas (90–4190 ng/g) in Tokyo (Matsushita *et al*, 1980).

As presented in Fig. 4.12, the 9th most abundant PAH in the surface soil from the Kumasi metropolis was phenanthrene. The mean concentration was 27.35 ± 41.84 ng/g dw and the higher standard deviations shows a significant variation in the concentrations

of phenanthrene (Table 17, Appendix 3). Lighter molecular weight PAHs such as phenanthrene are easily degraded, but all of the soil samples from the communities contained phenanthrene. This may be related to the frequent and incomplete combustion of wood or diesel from vehicles (Berset *et al*, 2001). Phenanthrene has a higher aqueous solubility, and this might contribute to groundwater contamination in areas with high levels of phenanthrene such as Suame which recorded the highest phenanthrene concentration (208.4 ± 316.65 ng/g dw). The water solubility of phenanthrene is 1.0 mg/L at 25 °C, thus phenanthrene can move more readily further down the soil with the soil solution increasing the potential hazard of groundwater contamination in the absence of any effective countermeasures (Berset *et al*, 2001).

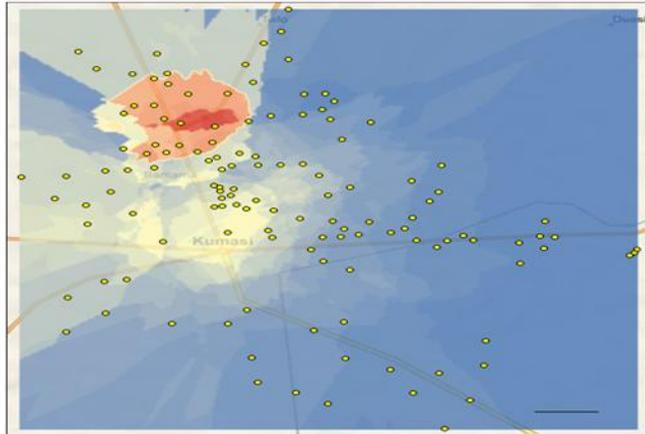
4.4. Distribution Maps for PAH Concentrations in Surface Soil of the Kumasi Metropolis

PAHs concentrations spread throughout the communities with the highest concentrations occurring at deeply coloured portions of the distribution map. The distributions maps of the most abundant PAHs (fluoranthene, pyrene, benzo(ghi)perylene benzo(k)fluoranthene and benzo(b)fluoranthene) in surface soils are shown in the Fig. 4.18 whilst (benzo(e)pyrene, benzo(a)pyrene, benzo(a)anthracene and indeno(1,2,3-cd)pyrene) are shown in Fig. 4.19. The distribution maps of the remaining PAHs are shown in Appendix 4. Geographic Information System coordinates and concentrations of PAHs in surface soils obtained from Kumasi were used to create a distribution map. In the surface soils from Kumasi, fluoranthene recorded the highest PAH concentration

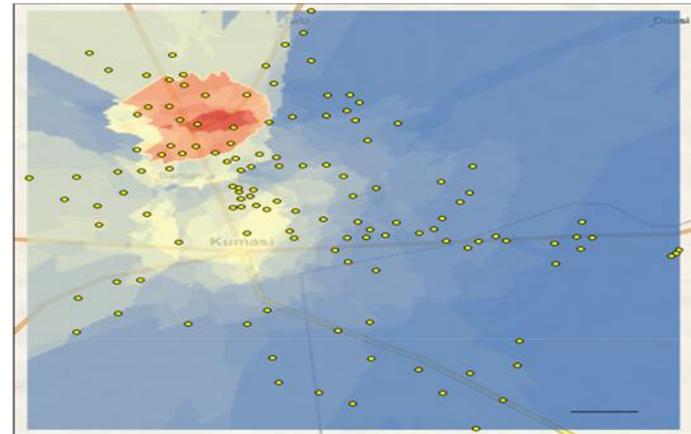
followed by its isomeric pyrene, interestingly these two showed the same distribution pattern with extremely high concentrations at Suame, Mbrom, Adum, Suntreso, Romanhill and Sofoline. Suame recorded the highest for both fluoranthene and pyrene at concentrations of 381.34 and 355.12 ng/g dw respectively. The high fluoranthene and pyrene concentrations were depicted in the distribution map by the red (deep) colour. The distribution map for benzo(a)anthracene is not too different from the 2 mentioned above, since very high concentrations were also recorded at the same sampling communities as fluoranthene and pyrene (Table 17). The distributions of the benzofluoranthenes, benzo(e)pyrene and benzo(a)pyrene with same molecular weight are nearly identical and higher concentrations were recorded in Romanhill and Adum. This trend is observed for all PAH of similar molecular weight, and critical observation has shown that PAHs of the same molecular weight have similar distributions (Venkataraman and Friedlander, 1994).

Figure 4.18: Distribution Maps for the Various PAHs in Surface Soil from the Kumasi Metropolis.

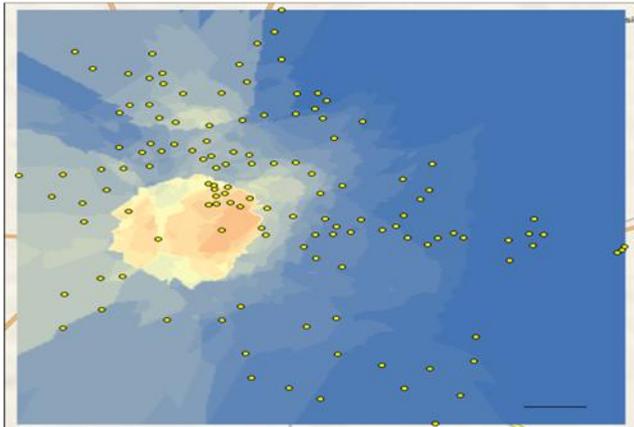
Flu



Pyr



BghiP



BbFBkF

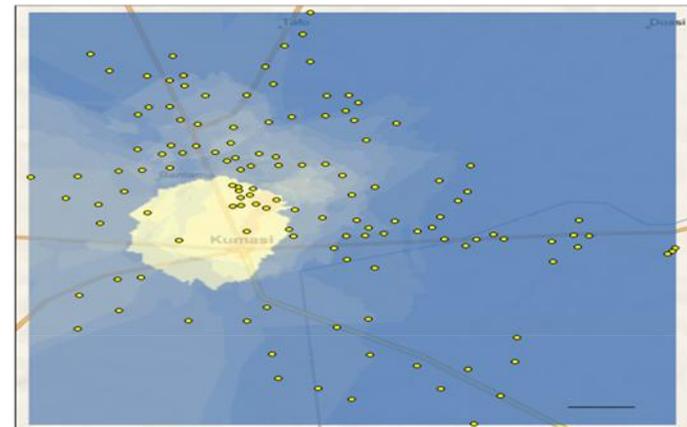
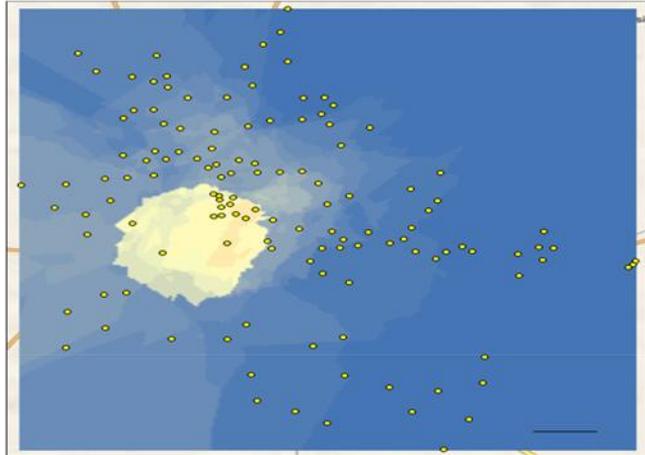
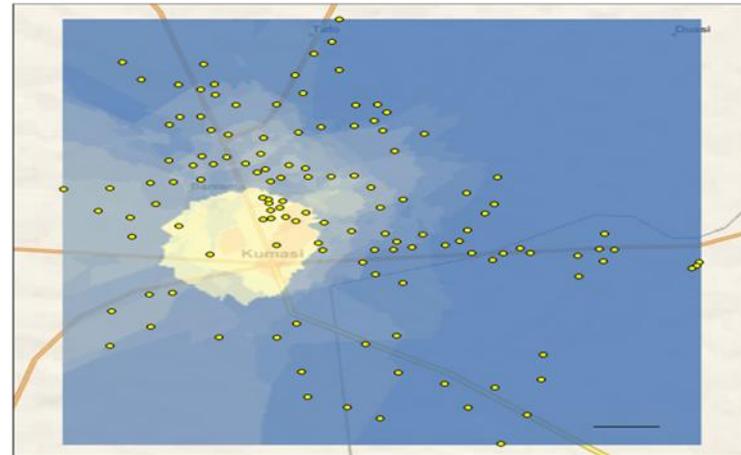


Figure 4.19: Distribution Maps for the Various PAHs in Surface Soil from the Kumasi Metropolis.

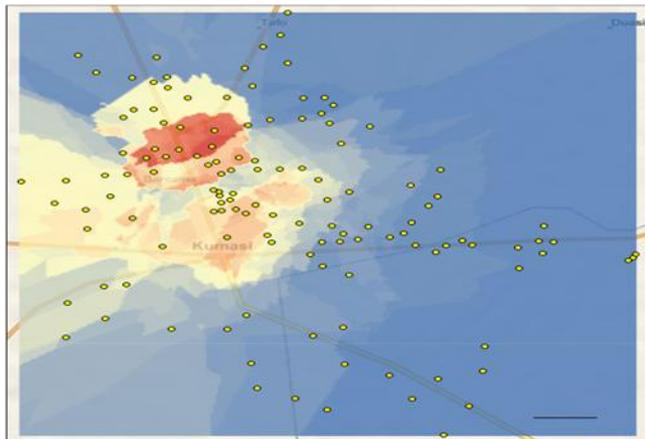
BeP



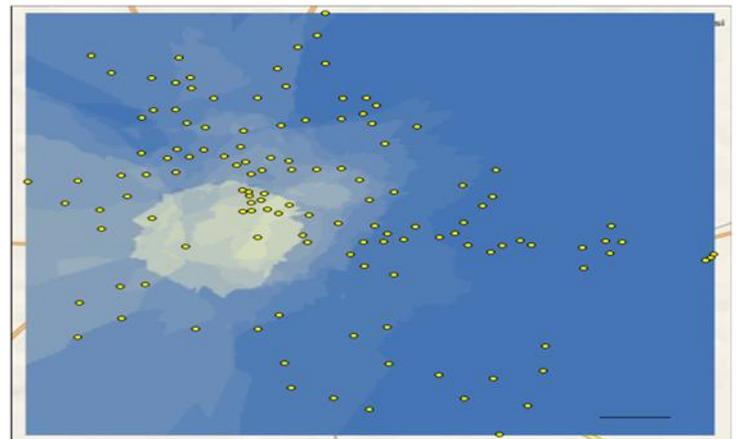
BaP



BaA



IDP



4.5. Determination of sources of PAHs in the surface soils by Diagnostic Ratio Method

There have been several methods applying to apportion the origin of PAHs presented in different environmental media. Diagnostic ratio is one of the widely used techniques (Yunker *et al*, 2002, Bucheli *et al*, 2004). The ratios of different PAHs are expected to vary with sources most likely due to various routes of PAH formation under different combustion conditions. This method is probably more pronounced at extreme locations such as urban areas close to the point sources

4.5.1. Diagnostic Ratio Charts for Flu/(Flu+Pyr) and IDP/(IDP+BghiP), BaP/BghiP and IDP/(IDP+BghiP) in Air Samples

Two pairs of PAH ratios, Flu/(Flu+Pyr) and IDP/(IDP+BghiP) are commonly used to distinguish between the sources. Flu/(Flu+Pyr) ratios between 0.40 and 0.50 are defined as fuel combustion sources whilst IDP/(IDP+BghiP) ratios greater than 0.5 are indicative of wood, grass or coal combustion source (Bucheli *et al*, 2004). The other molecular diagnostic ratios include BaP/BghiP (indicative of traffic and non-traffic sources) (Yunker *et al*, 2002, Bucheli *et al*, 2004). Samples were characterized by IDP/(IDP+BghiP) ratios and a higher percentage were between 0.2 and 0.5 indicating pyrogenic origin of PAHs deriving from fuel combustion. This is confirmed by the Flu/(Flu+Pyr) ratio between 0.4 and 0.5 implying the same fuel combustion source. Some samples exhibited ratios greater than 0.5 for IDP/(IDP+BghiP) , which are more typical of wood or grass combustion. BaP/BghiP ratios significantly over 0.6 suggest

traffic origin for those contaminants which originate from fuel combustion. Figs. 4.20 and 4.21 indicates that 62% of the PAHs identified in the air samples from KNUST campus and the Kejetia lorry stations by the $IDP/(IDP+BghiP)$ ratios were between 0.20 and 0.50 and therefore were coming from fuel combustion. Again, $IDP/(IDP+BghiP)$ ratios greater than 0.5 represent 29% and were coming from wood or grass combustion and 9% (that is $IDP/(IDP+BghiP)$ ratios less than 0.2) were from petroleum sources.

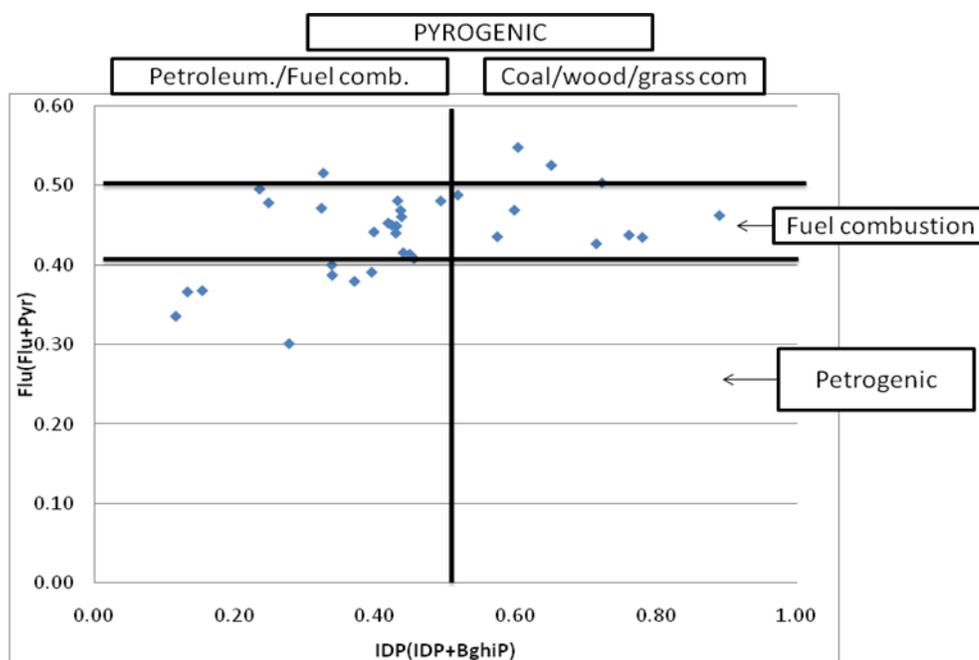


Figure 4.20: Diagnostic Ratio Chart for Flu/(Flu+Pyr) and IDP/(IDP+BghiP) in Air Samples from KNUST campus and Kejetia lorry station

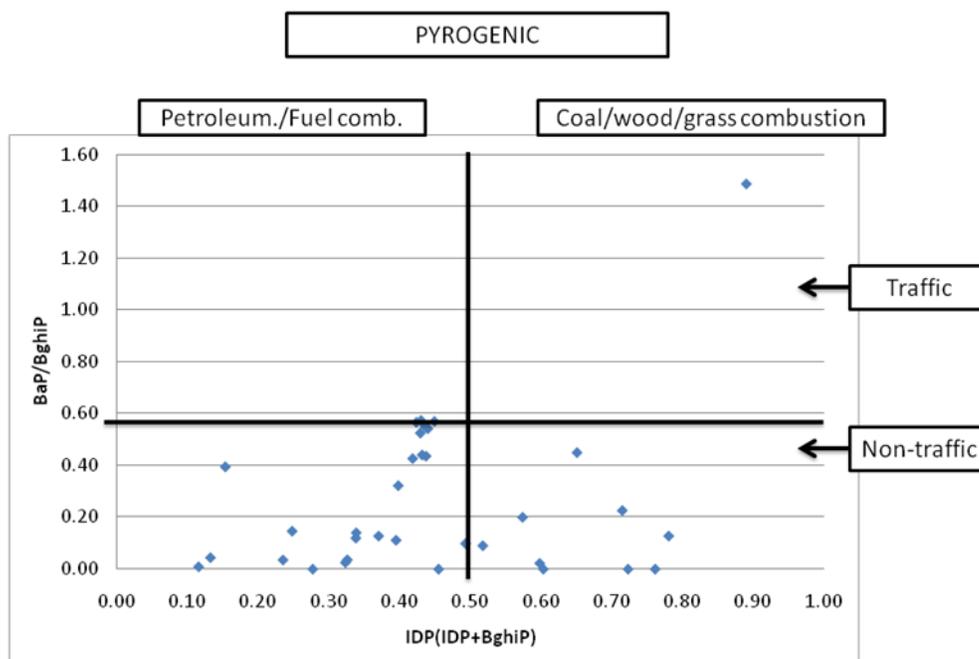


Figure 4.21: Diagnostic Ratio Charts for BaP/BghiP and IDP/(IDP+BghiP) in Air Samples from KNUST campus and Kejetia lorry station

4.5.2. Diagnostic Ratio Charts for Flu/(Flu+Pyr) and IDP/(IDP+BghiP), BaP/BghiP and IDP/(IDP+BghiP) in Soil Samples

IDP/(IDP+BghiP) ratios ranged from 0.01 to 1.00 in surface soil samples from the Kumasi metropolis. Accordingly to literature (Mark *et al*, 2002), IDP/(IDP+BghiP) ratios between 0.20 and 0.50 imply fuel combustion (vehicle and crude oil). The results from this study suggest that most of the PAHs identified in the surface soil in the study area originate from fuel combustion processes and in particular from vehicular traffic and non-traffic. IDP/(IDP+BghiP) ratios greater than 0.50 imply grass or wood combustion.

Vehicles as the sources of PAHs found confirmation with BaP/BghiP ratios which was significantly over 0.6 suggesting traffic origins for those contaminants, which originate from fuel combustion. Figs. 4.22 and 4.23 indicate that 74.5% of the PAHs identified in surface soils from the Kumasi metropolis by the IDP/(IDP+BghiP) ratios were between 0.20 and 0.50 and were therefore coming from fuel combustion. IDP/(IDP+BghiP) ratios greater than 0.5 represent 22.5% were coming from wood or grass combustion and 3%, that is IDP/(IDP+BghiP) ratios less than 0.2 were from petroleum sources.

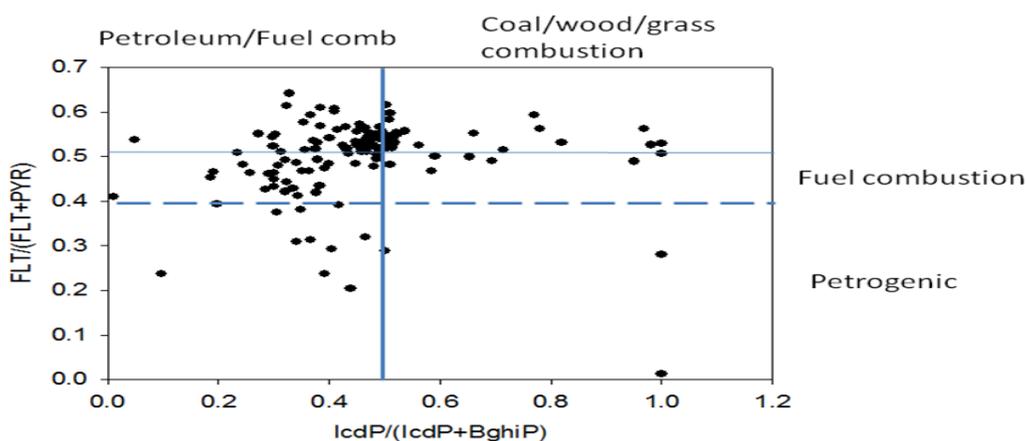


Figure 4.22: Diagnostic Ratio Chart for Flu/(Flu+Pyr) and IDP/(IDP+BghiP) in Soil Samples

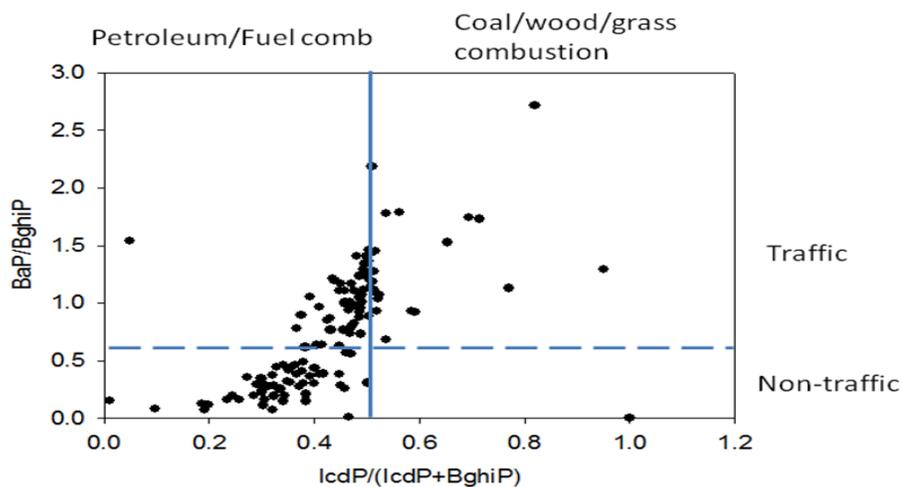


Figure 4.23: Diagnostic Ratio Charts for $BaP/BghiP$ and $IDP/(IDP+BghiP)$ in Soil Samples

IcdP is the same as IDP.

The diagnostic ratios for both air and surface soil samples show that fuel combustion is the prevailing source of PAHs in the Kumasi metropolis and wood is still used in some communities for cooking.

CHAPTER FIVE

CONCLUSION

Concentrations of 22 PAHs including 16 US EPA priority PAHs were measured in air samples and surface soils from different communities in the Kumasi metropolis. The concentrations of total PAHs in the air samples from KNUST campus ranged from 0.66 to 16.58 ng/m³ and that of the Kejetia lorry station ranged from 19.95 to 38.72 ng/m³.

BaP concentrations in the air samples from KNUST campus varied from below detection to 0.08 ng/m³ and 1.69 to 5.66 ng/m³ from the Kejetia lorry station. The mean concentrations of BaP in air samples from KNUST campus and Kejetia lorry station were 0.02±0.03 and 3.74±1.12 ng/m³ respectively. By the United Kingdom Air Quality Standards (EPAQS) and the Swedish guideline value for BaP in the air, the Kejetia lorry station is polluted with BaP.

Phenanthrene was the most abundant PAH in the air samples from KNUST with mean concentration of 0.7±0.49 ng/m³. On the other hand BghiP recorded the highest mean concentration from Kejetia with a value of 8.62±2.26 ng/m³ whilst 1-methyl phenanthrene was least at the Kejetia lorry station with mean concentration 0.01±0.04 ng/m³.

The diagnostic ratio shows that air samples from KNUST campus and the Kejetia lorry station were from two main sources. These sources were fuel and grass or wood

combustion. 62 % of PAHs originated from fuel combustion. Individual and total concentrations of PAHs in the air samples from the Kejetia lorry station were by far greater than the individual and total concentrations of PAHs from KNUST campus. This can be attributed to the greater number of vehicular movement and high human population density at the city centre. The mean concentration of total PAHs from the Kejetia lorry station was $30.23 \pm 4.96 \text{ ng/m}^3$ and $3.71 \pm 3.52 \text{ ng/m}^3$ was recorded from KNUST campus.

The concentrations of total PAHs in surface soils from 36 communities ranged from 10.85 to 2084.87 ng/g dw. The concentrations of PAHs in the city centre were higher than those in the other sampling points. The concentration of total PAHs in the various communities decreased in the order Adum, Romanhill, Mbrom, Suame, Suntreso, Sofoline, Atonsu, Bomso, Ayigya, and Ahinsan.

The most abundant PAH in surface soils was fluoranthene; followed by its isomeric pyrene with mean concentrations of 61.70 ± 86.86 and $57.94 \pm 78.68 \text{ ng/g dw}$ respectively. The least abundant PAH was acenaphthene with mean concentration of $1.39 \pm 4.22 \text{ ng/g dw}$.

Benzo(a)pyrene is the only PAH classified as a Group 1 carcinogen (carcinogenic to human beings) by the IARC (Straif, 2005) and has traditionally been used as an indicator for the carcinogenic potential of PAHs (Boström *et al*, 2002). The highest concentration

of BaP in the surface soils from the Kumasi metropolis was recorded in Adum. Its mean concentration was 259.46 ± 388.37 ng/g dw.

Diagnostic ratio method was used to identify the sources of PAHs in soil samples from the study area. The results demonstrated that most PAHs identified in this study originate from fuel and grass or wood combustion. 74.5% of the PAHs identified in surface soils in the Kumasi metropolis were from fuel combustion processes. The distribution maps indicate that PAHs spread throughout the Kumasi metropolis and Suame, Mbrom, Romanhill, Suntreso, Sofoline, Adum were the most polluted communities with PAHs.

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APPENDIX 1

Table 1: Concentrations of PAHs (ng/m³) in Air Samples from the KNUST Campus

sample site/date	Nap	Ace	Acen	Fle	Phe	Ant	methyphe	1-mphe	flu	pyr	ret	BaA	chr+triphe	B[k]F+B[b]F	BeP	BaP	pery	DahA	IDP	BghiP	ΣPAHs
S ₁	0.00	0.02	0.03	0.17	1.56	0.00	0.02	0.18	0.39	0.52	0.83	0.03	0.01	0.05	0.09	0.03	0.07	0.39	0.39	0.15	4.96
S ₂	0.00	0.04	0.05	0.09	0.80	0.00	0.04	0.08	0.26	0.23	0.57	0.04	0.00	0.02	0.16	0.083	0.04	0.36	0.35	0.19	3.39
S ₃	0.00	0.08	0.01	0.12	1.88	0.00	0.18	0.38	0.37	0.58	2.01	0.00	0.00	0.03	0.04	0.077	0.06	0.42	0.28	0.55	7.08
S ₄	0.00	0.00	0.03	0.05	0.78	0.00	0.01	0.04	0.27	0.29	0.61	0.01	0.00	0.01	0.00	0.06	0.10	0.35	0.13	0.38	3.12
S ₅	0.00	0.00	0.02	0.07	0.59	0.00	0.00	0.11	0.22	0.26	0.43	0.01	0.00	0.07	0.10	0.073	0.02	0.30	0.39	0.05	2.72
S ₆	0.00	0.01	0.03	0.17	0.80	0.00	0.02	0.09	0.26	0.42	0.57	0.08	0.00	0.04	0.05	0.05	0.07	0.41	0.23	0.40	3.70
S ₇	0.00	0.03	0.00	0.16	0.22	0.10	0.00	0.00	0.09	0.12	0.00	0.06	0.00	0.00	0.02	0.00	0.01	0.12	0.16	0.05	1.17
S ₈	0.00	0.06	0.04	0.28	0.76	0.13	0.02	0.00	0.29	0.31	0.14	0.05	0.00	0.03	0.04	0.03	0.02	0.14	0.31	0.31	2.96
S ₉	0.00	0.10	0.01	0.26	0.73	0.09	0.05	0.00	0.37	0.54	0.46	0.05	0.00	0.02	0.05	0.00	0.01	0.12	0.12	0.14	3.11
S ₁₀	0.00	0.08	0.01	0.26	0.70	0.15	0.04	0.00	0.32	0.49	0.45	0.04	0.00	0.02	0.05	0.01	0.02	0.16	0.07	0.11	2.99
S ₁₁	0.00	0.04	0.00	0.12	0.08	0.00	0.00	0.00	0.05	0.05	0.00	0.04	0.00	0.00	0.00	0.01	0.01	0.13	0.09	0.19	0.81
S ₁₂	0.00	0.08	0.09	0.39	1.14	0.00	0.06	0.00	0.38	0.43	0.23	0.06	0.00	0.03	0.04	0.01	0.02	0.18	0.19	0.39	3.71
S ₁₃	0.00	0.03	0.00	0.12	0.09	0.07	0.00	0.00	0.05	0.04	0.00	0.04	0.00	0.00	0.00	0.01	0.10	0.06	0.04	0.66	
S ₁₄	0.00	0.06	0.06	0.34	0.98	0.00	0.06	0.00	0.37	0.41	0.31	0.04	0.00	0.01	0.02	0.00	0.02	0.15	0.13	0.09	3.05
S ₁₅	0.00	0.02	0.00	0.43	1.27	1.31	1.79	0.00	0.32	0.73	3.49	0.07	0.01	0.09	0.20	0.00	0.04	0.52	1.74	4.54	16.58
S ₁₆	0.00	0.04	0.01	0.16	0.18	0.09	0.00	0.00	0.09	0.12	0.00	0.06	0.00	0.02	0.04	0.02	0.02	0.20	0.16	0.12	1.30
S ₁₇	0.00	0.03	0.00	0.15	0.15	0.08	0.00	0.00	0.10	0.10	0.00	0.06	0.00	0.01	0.02	0.01	0.07	0.21	0.08	0.27	1.34
S ₁₈	0.00	0.03	0.00	0.13	0.11	0.08	0.00	0.00	0.07	0.07	0.00	0.06	0.00	0.00	0.00	0.00	0.01	0.16	0.08	0.03	0.83
S ₁₉	0.95	0.06	0.02	0.20	0.68	0.28	0.02	0.00	0.42	0.82	0.06	0.05	0.03	0.05	0.06	0.03	0.05	0.15	0.37	2.83	7.11
S ₂₀	0.00	0.03	0.00	0.12	0.12	0.08	0.00	0.00	0.07	0.07	0.00	0.03	0.00	0.01	0.00	0.01	0.01	0.12	0.14	0.13	0.95
S ₂₁	1.77	0.06	0.06	0.26	1.02	0.18	0.04	0.01	0.93	1.61	0.17	0.09	0.04	0.04	0.04	0.03	0.03	0.27	0.10	0.65	7.40
S ₂₂	0.07	0.11	0.01	0.25	0.68	0.00	0.04	0.00	0.29	0.37	0.21	0.04	0.00	0.02	0.04	0.01	0.22	0.14	0.17	0.05	2.72

Table 2: Mean, Standard Deviation, Minimum and Maximum Concentrations of PAHs in air samples from KNUST Campus

PAHs	MEAN	SD	MIN	MAX
Nap	0.13	0.42	0.00	1.77
Acl	0.05	0.03	0.00	0.11
Ace	0.02	0.02	0.00	0.09
Fle	0.2	0.10	0.05	0.43
Phe	0.7	0.49	0.08	1.88
Ant	0.12	0.27	0.00	1.31
Methy phe	0.11	0.38	0.00	1.79
Me phe	0.04	0.09	0.00	0.38
Flu	0.27	0.19	0.05	0.93
Pyr	0.39	0.35	0.04	1.61
Ret	0.48	0.81	0.00	3.49
BaA	0.05	0.02	0.00	0.09
Chr+Trip	0	0.01	0.00	0.04
B(k)F+B(b)F	0.03	0.02	0.00	0.09
BeP	0.05	0.05	0.00	0.20
BaP	0.02	0.03	0.00	0.08
Pery	0.04	0.05	0.01	0.22
DahA	0.23	0.12	0.10	0.52
IDP	0.26	0.35	0.06	1.74
BghiP	0.53	1.07	0.03	4.54

Table 3: Diagnostic Ratios for Source Identification in Air Samples from KNUST Campus

sample site/date	IDP/(IDP+BghiP)	BaP/BghiP	Flu/(Flu+Pyr)
S ₁	0.71	0.23	0.43
S ₂	0.65	0.45	0.53
S ₃	0.34	0.14	0.39
S ₄	0.25	0.15	0.48
S ₅	0.89	1.49	0.46
S ₆	0.37	0.13	0.38
S ₇	0.76	0.00	0.44
S ₈	0.49	0.10	0.48
S ₉	0.46	0.00	0.41
S ₁₀	0.39	0.11	0.39
S ₁₁	0.33	0.04	0.52
S ₁₂	0.32	0.03	0.47
S ₁₃	0.60	0.00	0.55
S ₁₄	0.60	0.02	0.47
S ₁₅	0.28	0.00	0.30
S ₁₆	0.57	0.20	0.44
S ₁₇	0.24	0.04	0.50
S ₁₈	0.72	0.00	0.50
S ₁₉	0.12	0.01	0.34
S ₂₀	0.52	0.09	0.49
S ₂₁	0.13	0.04	0.37
S ₂₂	0.78	0.13	0.44

Table 4: Mean, Standard Deviation, Minimum, Maximum and Percent Abundances of PAHs Concentrations in the Air Samples from KNUST Campus

PAHs	RING No.	MIN	MAX	MEAN	SD	% ABUNDANCE
Nap	2	0.00	1.77	0.13	0.42	3.42
Acl	3	0.00	0.11	0.05	0.03	1.23
Ace	3	0.00	0.09	0.02	0.02	0.59
Fle	3	0.05	0.43	0.20	0.10	5.27
Phe	3	0.08	1.88	0.70	0.49	18.77
Ant	3	0.00	1.31	0.12	0.27	3.24
Methy-Phe	3	0.00	1.79	0.11	0.38	2.96
Me-Phe	3	0.00	0.38	0.04	0.09	1.10
Flu	4	0.05	0.93	0.27	0.19	7.31
Pyr	4	0.04	1.61	0.39	0.35	10.54
Retene	3	0.00	3.49	0.48	0.81	12.91
BaA	4	0.00	0.09	0.05	0.02	1.23
Chr	4	0.00	0.04	0.00	0.01	0.12
BbF+BkF	5+5	0.00	0.09	0.03	0.02	0.68
BeP	5	0.00	0.20	0.05	0.05	1.31
BaP	5	0.00	0.08	0.02	0.03	0.65
Peryl	5	0.01	0.22	0.04	0.05	1.15
DBahA	5	0.10	0.52	0.23	0.12	6.26
IDP	6	0.06	1.74	0.26	0.35	7.04
BghiP	6	0.03	4.54	0.53	1.07	14.29

APPENDIX 2

Table 5: Concentrations of PAHs (ng/m³) in Air Samples from the Kejetia Lorry Station

sample site/date	Nap	Ace	Acen	Fle	Phe	Ant	methyphe	1-mphe	flu	pyr	ret	BaA	chr+triphe	B[k]F+B[b]F	BeP	BaP	pery	DahA	IDP	BghiP	ΣPAHs
C ₁	0.00	0.07	0.05	0.31	0.80	0.21	0.05	0.00	0.33	0.40	0.40	0.37	0.17	4.60	5.76	5.62	1.44	0.91	7.29	9.93	38.72
C ₂	0.00	0.09	0.03	0.26	0.83	0.16	0.06	0.00	0.36	0.50	0.22	0.28	0.14	3.36	4.18	3.74	0.98	0.29	5.41	6.90	27.80
C ₃	0.00	0.05	0.01	0.17	0.30	0.14	0.01	0.00	0.23	0.29	0.00	0.24	0.08	2.48	3.40	3.24	0.93	0.64	6.64	10.05	28.90
C ₄	0.00	0.07	0.05	0.30	0.79	0.20	0.05	0.00	0.35	0.43	0.40	0.37	0.17	4.51	5.62	5.66	1.40	0.49	7.44	9.86	38.17
C ₅	2.00	0.07	0.04	0.25	0.74	0.32	0.02	0.00	0.38	0.58	0.10	0.17	0.08	1.10	1.85	1.69	0.39	0.39	7.20	14.09	31.45
C ₆	0.00	0.08	0.05	0.35	1.48	0.18	0.08	0.00	0.71	0.80	0.89	0.33	0.19	3.33	4.28	4.00	1.03	0.48	5.61	7.26	31.14
C ₇	0.00	0.06	0.01	0.17	0.40	0.16	0.03	0.00	0.37	0.43	0.04	0.36	0.17	3.54	4.51	3.77	1.05	0.44	6.71	8.64	30.87
C ₈	0.00	0.06	0.01	0.17	0.33	0.14	0.02	0.00	0.35	0.42	0.00	0.37	0.18	3.42	4.40	3.83	1.03	0.57	6.46	8.98	30.72
C ₉	0.00	0.04	0.01	0.27	0.85	1.26	0.18	0.13	0.31	0.53	0.76	0.22	0.25	3.23	4.39	3.30	0.44	0.42	1.52	8.37	26.47
C ₁₀	0.00	0.08	0.02	0.24	0.82	0.14	0.07	0.00	0.40	0.56	0.23	0.28	0.13	3.36	4.18	3.83	1.01	0.36	5.47	6.71	27.91
C ₁₁	0.00	0.09	0.05	0.36	1.47	0.22	0.11	0.00	0.62	0.79	0.91	0.33	0.18	3.23	4.14	3.84	1.01	0.47	5.49	7.30	30.62
C ₁₂	0.00	0.05	0.04	0.28	0.71	0.15	0.05	0.00	0.29	0.31	0.39	0.17	0.05	1.87	2.56	2.38	0.63	0.51	4.10	5.40	19.95

Table 6: Mean, Standard Deviation, Minimum and Maximum Concentrations of PAHs in air samples from Kejetia lorry station

PAHs	MEAN	SD	MIN	MAX
Nap	0.17	0.58	0.00	2.00
Acl	0.07	0.02	0.04	0.09
Ace	0.03	0.02	0.01	0.05
Fle	0.26	0.06	0.17	0.36
Phe	0.79	0.38	0.30	1.48
Ant	0.27	0.31	0.14	1.26
Methy phe	0.06	0.05	0.01	0.18
Me phe	0.01	0.04	0.00	0.13
Flu	0.39	0.14	0.23	0.71
Pyr	0.5	0.16	0.29	0.80
Ret	0.36	0.33	0.00	0.91
BaA	0.29	0.08	0.17	0.37
Chr+Trip	0.15	0.06	0.05	0.25
B(k)F+B(b)F	3.17	0.98	1.10	4.60
BeP	4.11	1.10	1.85	5.76
BaP	3.74	1.12	1.69	5.66
Pery	0.94	0.32	0.39	1.44
DahA	0.5	0.16	0.29	0.91
IDP	5.78	1.66	1.52	7.44
BghiP	8.62	2.26	5.40	14.09

Table 7: Diagnostic Ratios for Source Identification in Air Samples from Kejetia Lorry Station

sample site/date	IDP/(IDP+BghiP)	BaP/BghiP	Flu/(Flu+Pyr)
C ₁	0.42	0.57	0.45
C ₂	0.44	0.54	0.42
C ₃	0.40	0.32	0.44
C ₄	0.43	0.57	0.45
C ₅	0.34	0.12	0.40
C ₆	0.44	0.55	0.47
C ₇	0.44	0.44	0.46
C ₈	0.42	0.43	0.45
C ₉	0.15	0.39	0.37
C ₁₀	0.45	0.57	0.41
C ₁₁	0.43	0.53	0.44
C ₁₂	0.43	0.44	0.48

Table 8: Mean, Standard Deviation, Minimum, Maximum and Percent Abundances of PAHs Concentrations in the Air Samples from KNUST Campus

PAHs	RING No.	MIN	MAX	MEAN	SD	% ABUNDANCE
Nap	2	0.00	2.00	0.17	0.58	0.55
Acl	3	0.04	0.09	0.07	0.02	0.22
Ace	3	0.01	0.05	0.03	0.02	0.10
Fle	3	0.17	0.36	0.26	0.06	0.86
Phe	3	0.30	1.48	0.79	0.38	2.63
Ant	3	0.14	1.26	0.27	0.31	0.91
Methy-Phe	3	0.01	0.18	0.06	0.05	0.20
Me-Phe	3	0.00	0.13	0.01	0.04	0.03
Flu	4	0.23	0.71	0.39	0.14	1.30
Pyr	4	0.29	0.80	0.50	0.16	1.67
Retene	3	0.00	0.91	0.36	0.33	1.20
BaA	4	0.17	0.37	0.29	0.08	0.96
Chr	4	0.05	0.25	0.15	0.06	0.49
BbF+BkF	5+5	1.10	4.60	3.17	0.98	10.49
BeP	5	1.85	5.76	4.11	1.10	13.58
BaP	5	1.69	5.66	3.74	1.12	12.37
Peryl	5	0.39	1.44	0.94	0.32	3.13
DBahA	5	0.29	0.91	0.50	0.16	1.64
IDP	6	1.52	7.44	5.78	1.66	19.12
BghiP	6	5.40	14.09	8.62	2.26	28.53

APPENDIX 3

Table 9: GPS Readings, Latitudes and Longitudes for Soil Samples from Kumasi Metropolis

SAMPLE SITE	GPS READING	ELEVATION(m)	LATITUDE	LONGITUDE
Ayigya 1	N06 ⁰ 41'16.8",W001 ⁰ 34'37.1"	288	6.69	-1.58
Ayigya 2	N06 ⁰ 41'16.2",W001 ⁰ 34'29.5"	287	6.69	-1.57
Ayigya 3	N06 ⁰ 41'28.4",W001 ⁰ 34'34.5"	273	6.69	-1.58
Bomso 1	N06 ⁰ 41'07.5",W001 ⁰ 34'35.1"	283	6.69	-1.58
Bomso 2	N06 ⁰ 40'56.0",W001 ⁰ 34'47.2"	277	6.68	-1.58
Bomso 3	N06 ⁰ 41'11.8",W001 ⁰ 34'47.8"	274	6.69	-1.58
Susuanso 1	N06 ⁰ 41'13.8",W001 ⁰ 35'11.2"	262	6.69	-1.59
Susuanso 2	N06 ⁰ 41'17.3",W001 ⁰ 35'16.3"	255	6.69	-1.59
Susuanso 3	N06 ⁰ 41'13.4",W001 ⁰ 35'24.6"	262	6.69	-1.59
Oforikrom 1	N06 ⁰ 41'08.4",W001 ⁰ 35'29.9"	270	6.69	-1.59
Oforikrom 2	N06 ⁰ 41'13.7",W001 ⁰ 35'40.3"	262	6.69	-1.59
Oforikrom 3	N06 ⁰ 41'22.8",W001 ⁰ 35'46.3"	265	6.69	-1.60
Afunkwanta 1	N06 ⁰ 41'19.8",W001 ⁰ 35'53.4"	258	6.69	-1.60
Afunkwanta 2	N06 ⁰ 41'27.8",W001 ⁰ 36'04.5"	266	6.69	-1.60
Afunkwanta 3	N06 ⁰ 41'18.1",W001 ⁰ 36'09.8"	281	6.69	-1.60
Amakom 1	N06 ⁰ 41'16.4",W001 ⁰ 36'19.0"	282	6.69	-1.61
Amakom 2	N06 ⁰ 41'22.4",W001 ⁰ 36'17.3"	278	6.69	-1.60
Amakom 3	N06 ⁰ 41'28.5",W001 ⁰ 36'23.1"	292	6.69	-1.61
Asafo 1	N06 ⁰ 41'30.4",W001 ⁰ 36'39.8"	287	6.69	-1.61
Asafo 2	N06 ⁰ 41'06.6",W001 ⁰ 36'34.2"	269	6.69	-1.61
Asafo 3	N06 ⁰ 41'16.1",W001 ⁰ 36'28.3"	273	6.69	-1.61
Asafo 4	N06 ⁰ 41'21.3",W001 ⁰ 36'56.2"	262	6.69	-1.62
Asafo 5	N06 ⁰ 41'15.9",W001 ⁰ 36'54.0"	260	6.69	-1.62
Roman hill 1	N06 ⁰ 41'36.8",W001 ⁰ 36'53.3"	290	6.69	-1.61
Roman hill 2	N06 ⁰ 41'44.4",W001 ⁰ 37'02.3"	284	6.70	-1.62
Roman hill 3	N06 ⁰ 41'38.0",W001 ⁰ 37'07.3"	275	6.69	-1.62
Central market 1	N06 ⁰ 41'41.1",W001 ⁰ 37'12.3"	261	6.69	-1.62
Central market 2	N06 ⁰ 41'48.2",W001 ⁰ 37'15.3"	266	6.70	-1.62
Central market 3	N06 ⁰ 41'53.2",W001 ⁰ 37'13.8"	264	6.70	-1.62

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Kejetia 1	N06°41'51.6", W001°37'20.6"	260	6.70	-1.62
Kejetia 2	N06°41'54.5", W001°37'20.9"	255	6.70	-1.62
Kejetia 3	N06°41'55.8", W001°37'23.8"	258	6.70	-1.62
Adum 1	N06°41'46.2", W001°37'19.8"	271	6.70	-1.62
Adum 2	N06°41'40.1", W001°37'19.6"	263	6.69	-1.62
Adum 3	N06°41'39.4", W001°37'23.6"	277	6.69	-1.62
Adum 4	N06°41'19.7", W001°37'16.8"	281	6.69	-1.62
Asawase 1	N06°41'48.3", W001°36'25.5"	279	6.70	-1.61
Asawase 2	N06°41'54.4", W001°36'14.2"	272	6.70	-1.60
Asawase 3	N06°42'03.6", W001°36'30.1"	291	6.70	-1.61
Asawase 4	N06°42'12.5", W001°36'38.4"	295	6.70	-1.61
Manhyia 1	N06°42'11.8", W001°36'49.8"	302	6.70	-1.61
Manhyia 2	N06°42'11.5", W001°37'01.2"	299	6.70	-1.62
Manhyia 3	N06°42'18.2", W001°37'02.6"	298	6.71	-1.62
Ashtown 1	N06°42'20.6", W001°37'10.8"	301	6.71	-1.62
Ashtown 2	N06°42'11.0", W001°37'14.8"	294	6.70	-1.62
Ashtown 3	N06°42'17.4", W001°37'22.4"	300	6.70	-1.62
Ashtown 4	N06°42'29.1", W001°37'24.7"	299	6.71	-1.62
Mbrom 1	N06°42'21.8", W001°37'32.2"	300	6.71	-1.63
Mbrom 2	N06°42'15.0", W001°37'26.5"	298	6.70	-1.62
Mbrom 3	N06°42'08.2", W001°37'19.8"	296	6.70	-1.62
Race course 1	N06°42'26.7", W001°37'41.6"	296	6.71	-1.63
Race course 2	N06°42'27.2", W001°37'53.8"	287	6.71	-1.63
Race course 3	N06°42'21.3", W001°37'48.2"	270	6.71	-1.63
Race course 4	N06°42'20.3", W001°37'58.2"	284	6.71	-1.63
Bantama 1	N06°42'09.5", W001°37'54.4"	301	6.70	-1.63
Bantama 2	N06°42'07.7", W001°38'08.0"	292	6.70	-1.64
Bantama 3	N06°42'24.1", W001°38'10.2"	298	6.71	-1.64
Aboabo 1	N06°41'31.1", W001°35'42.3"	278	6.69	-1.60
Aboabo 2	N06°41'43.8", W001°35'33.6"	272	6.70	-1.59
Aboabo 3	N06°41'50.9", W001°35'29.0"	280	6.70	-1.59
Aboabo 4	N06°41'59.4", W001°35'42.8"	276	6.70	-1.60
Aboabo 5	N06°42'11.3", W001°35'27.5"	275	6.70	-1.59
Dichemso 1	N06°42'44.4", W001°36'03.7"	255	6.71	-1.60

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Dichemso 2	N06 ⁰ 42'31.3",W001 ⁰ 36'18.4"	262	6.71	-1.61
Dichemso 3	N06 ⁰ 42'46.8",W001 ⁰ 36'24.3"	260	6.71	-1.61
Yennyawoso 1	N06 ⁰ 42'54.3",W001 ⁰ 36'28.5"	294	6.72	-1.61
Yennyawoso 2	N06 ⁰ 43'06.5",W001 ⁰ 36'26.9"	278	6.72	-1.61
Yennyawoso 3	N06 ⁰ 43'00.7",W001 ⁰ 36'22.3"	278	6.72	-1.61
Krofrom 1	N06 ⁰ 42'50.4",W001 ⁰ 36'38.4"	301	6.71	-1.61
Krofrom 2	N06 ⁰ 42'49.5",W001 ⁰ 36'54.8"	301	6.71	-1.62
Krofrom 3	N06 ⁰ 42'45.4",W001 ⁰ 37'06.1"	298	6.71	-1.62
Krofrom 4	N06 ⁰ 42'41.3",W001 ⁰ 37'23.3"	297	6.71	-1.62
Suame 1	N06 ⁰ 42'43.8",W001 ⁰ 37'40.8"	309	6.71	-1.63
Suame 2	N06 ⁰ 43'06.2",W001 ⁰ 37'37.0"	292	6.72	-1.63
Suame 3	N06 ⁰ 43'14.0",W001 ⁰ 37'47.2"	278	6.72	-1.63
Suame 4	N06 ⁰ 43'18.1",W001 ⁰ 37'54.4"	285	6.72	-1.63
Suame 5	N06 ⁰ 43'37.2",W001 ⁰ 37'53.0"	286	6.73	-1.63
Suame 6	N06 ⁰ 42'57.5",W001 ⁰ 37'54.5"	317	6.72	-1.63
Anomangye 1	N06 ⁰ 43'21.7",W001 ⁰ 38'05.5"	293	6.72	-1.63
Anomangye 2	N06 ⁰ 43'25.6",W001 ⁰ 38'23.9"	286	6.72	-1.64
Anomangye 3	N06 ⁰ 43'38.8",W001 ⁰ 38'33.2"	291	6.73	-1.64
New Suame 1	N06 ⁰ 42'57.2",W001 ⁰ 38'04.7"	301	6.72	-1.63
New Suame 2	N06 ⁰ 42'51.3",W001 ⁰ 38'10.0"	301	6.71	-1.64
New Suame 3	N06 ⁰ 42'47.2",W001 ⁰ 37'49.3"	304	6.71	-1.63
Tafo 1	N06 ⁰ 43'06.6",W001 ⁰ 37'16.9"	288	6.72	-1.62
Tafo 2	N06 ⁰ 43'29.0",W001 ⁰ 37'07.7"	299	6.72	-1.62
Tafo 3	N06 ⁰ 43'45.3",W001 ⁰ 36'58.4"	209	6.73	-1.62
Tafo 4	N06 ⁰ 44'11.4",W001 ⁰ 36'45.8"	308	6.74	-1.61
Tafo 5	N06 ⁰ 43'54.3",W001 ⁰ 36'49.5"	318	6.73	-1.61
Tafo 6	N06 ⁰ 43'32.9",W001 ⁰ 36'45.8"	293	6.73	-1.61
Tafo Nhyiaeso 1	N06 ⁰ 43'22.0",W001 ⁰ 37'47.7"	305	6.72	-1.63
Tafo Nhyiaeso 2	N06 ⁰ 43'15.3",W001 ⁰ 37'03.8"	292	6.72	-1.62
Tafo Nhyiaeso 3	N06 ⁰ 43'06.1",W001 ⁰ 36'37.7"	284	6.72	-1.61
Ahinsan 1	N06 ⁰ 39'56.4",W001 ⁰ 35'04.8"	243	6.67	-1.58
Ahinsan 2	N06 ⁰ 39'37.5",W001 ⁰ 35'05.8"	269	6.66	-1.58

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Ahinsan 3	N06 ⁰ 39'34.3", W001 ⁰ 35'53.7"	246	6.66	-1.60
Atonsu 1	N06 ⁰ 39'31.5", W001 ⁰ 35'28.7"	260	6.66	-1.59
Atonsu 2	N06 ⁰ 39'10.7", W001 ⁰ 35'12.8"	283	6.65	-1.59
Atonsu 3	N06 ⁰ 38'48.7", W001 ⁰ 35'25.8"	276	6.65	-1.59
Atonsu 4	N06 ⁰ 39'16.2", W001 ⁰ 35'42.0"	246	6.65	-1.60
Kaasi 1	N06 ⁰ 39'42.8", W001 ⁰ 36'16.6"	269	6.66	-1.60
Kaasi 2	N06 ⁰ 39'08.0", W001 ⁰ 36'25.6"	261	6.65	-1.61
Kaasi 3	N06 ⁰ 39'16.5", W001 ⁰ 36'41.9"	245	6.65	-1.61
Ahodwo 1	N06 ⁰ 39'24.4", W001 ⁰ 37'01.4"	264	6.66	-1.62
Ahodwo 2	N06 ⁰ 39'43.4", W001 ⁰ 37'04.5"	251	6.66	-1.62
Ahodwo 3	N06 ⁰ 40'20.1", W001 ⁰ 37'07.0"	275	6.67	-1.62
Asokwa 1	N06 ⁰ 40'04.4", W001 ⁰ 36'32.8"	255	6.67	-1.61
Asokwa 2	N06 ⁰ 40'10.9", W001 ⁰ 36'17.4"	273	6.67	-1.60
Asokwa 3	N06 ⁰ 40'51.0", W001 ⁰ 36'14.3"	277	6.68	-1.60
Asokwa 4	N06 ⁰ 40'57.6", W001 ⁰ 36'27.9"	278	6.68	-1.61
Suntreso 1	N06 ⁰ 42'07.0", W001 ⁰ 38'19.4"	283	6.70	-1.64
Suntreso 2	N06 ⁰ 41'51.0", W001 ⁰ 38'16.7"	274	6.70	-1.64
Suntreso 3	N06 ⁰ 41'40.7", W001 ⁰ 38'29.3"	277	6.69	-1.64
Suntreso 4	N06 ⁰ 41'26.1", W001 ⁰ 38'28.5"	279	6.69	-1.64
Patasi 1	N06 ⁰ 40'42.1", W001 ⁰ 38'19.9"	262	6.68	-1.64
Patasi 2	N06 ⁰ 40'29.5", W001 ⁰ 38'38.6"	261	6.67	-1.64
Patasi 3	N06 ⁰ 40'03.2", W001 ⁰ 38'39.4"	284	6.67	-1.64
Sofoline 1	N06 ⁰ 41'45.8", W001 ⁰ 38'45.2"	284	6.70	-1.65
Sofoline 2	N06 ⁰ 42'02.3", W001 ⁰ 39'02.4"	274	6.70	-1.65
Sofoline 3	N06 ⁰ 42'03.0", W001 ⁰ 38'39.4"	283	6.70	-1.64
Danyame 1	N06 ⁰ 41'34.3", W001 ⁰ 38'05.3"	283	6.69	-1.63
Danyame 2	N06 ⁰ 41'12.6", W001 ⁰ 37'49.9"	282	6.69	-1.63
Danyame 3	N06 ⁰ 40'43.5", W001 ⁰ 38'08.4"	249	6.68	-1.64
Dakodwom 1	N06 ⁰ 40'17.7", W001 ⁰ 38'19.2"	258	6.67	-1.64
Dakodwom 2	N06 ⁰ 40'09.6", W001 ⁰ 37'45.3"	264	6.67	-1.63
Dakodwom 3	N06 ⁰ 40'09.4", W001 ⁰ 37'16.7"	267	6.67	-1.62

Table 10: Results for Soil Characterisation

Sample site	% water contnt	IL%	soil pH	Sample site	% water contnt	IL%	soil pH
Ayigya 1	5.40	3.59	6.24	Yennyawoso 1	0.99	6.79	8.91
Ayigya 2	9.52	5.04	6.41	Yennyawoso 2	0.80	2.81	8.88
Ayigya 3	8.33	3.90	6.19	Yennyawoso 3	1.00	3.43	8.54
Bomso 1	2.96	2.65	8.40	Krofrom 1	0.60	6.40	8.17
Bomso 2	7.30	3.83	8.72	Krofrom 2	0.20	6.31	8.83
Bomso 3	6.37	2.34	9.05	Krofrom 3	0.20	4.13	8.84
Susuanso 1	3.20	1.86	8.68	Krofrom 4	8.37	4.13	8.28
Susuanso 2	6.96	5.13	8.33	Suame 1	0.00	2.79	8.67
Susuanso 3	3.54	1.63	8.91	Suame 2	4.53	9.48	8.69
Oforikrom 1	16.67	7.49	8.10	Suame 3	0.59	5.31	8.67
Oforikrom 2	7.58	5.40	8.32	Suame 4	0.00	3.56	8.83
Oforikrom 3	12.79	9.41	7.14	Suame 5	2.18	3.44	8.87
Afunkwan 1	3.79	3.32	8.78	Suame 6	11.29	3.57	8.71
Afunkwan 2	5.74	3.78	8.43	Anomangye 1	0.20	1.80	8.95
Afunkwant3	1.97	2.62	8.77	Anomangye 2	0.79	1.79	8.97
Amakom 1	4.25	2.56	8.66	Anomangye 3	9.06	4.55	8.37
Amakom 2	7.01	5.14	7.06	New Suame 1	3.78	2.90	8.85
Amakom 3	5.40	2.55	8.83	New Suame 2	9.11	3.05	8.83
Asafo 1	1.58	4.02	8.72	New Suame 3	12.55	7.62	8.13
Asafo 2	12.77	5.03	8.95	Tafo 1	1.19	4.62	8.07
Asafo 3	0.98	2.58	7.76	Tafo 2	2.17	4.44	8.49
Asafo 4	6.72	2.75	8.68	Tafo 3	11.37	4.65	8.65
Asafo 5	3.37	2.46	9.32	Tafo 4	10.50	4.87	8.66
Roman hill 1	2.17	2.62	8.68	Tafo 5	1.78	5.03	8.56
Roman hill 2	4.36	11.80	9.66	Tafo 6	9.16	2.85	8.38
Roman hill 3	2.77	2.24	8.98	Tafo Nhyiaes 1	1.76	7.17	8.79
Central market 1	11.68	7.62	7.75	Tafo Nhyiaes2	8.78	3.50	8.61
Central market 2	1.00	6.64	8.12	Tafo	9.20	6.03	8.43

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				Nhyiaeso 3			
Central market 3	2.96	3.67	8.45	Ahinsan 1	8.58	5.48	8.47
Kejetia 1	16.87	13.84	7.33	Ahinsan 2	9.01	5.29	8.23
Kejetia 2	9.74	5.07	8.26	Ahinsan 3	5.47	3.63	8.71
Kejetia 3	7.16	4.50	8.05	Atonsu 1	7.74	5.51	6.87
Adum 1	14.99	15.55	8.05	Atonsu 2	7.67	3.53	8.26
Adum 2	6.71	6.98	7.45	Atonsu 3	8.43	3.78	8.72
Adum 3	1.57	3.59	8.82	Atonsu 4	12.37	3.02	8.68
Adum 4	2.11	4.12	8.58	Kaasi 1	5.57	4.35	8.67
Asawase 1	3.93	3.68	8.41	Kaasi 2	7.00	6.02	8.87
Asawase 2	5.95	2.74	8.67	Kaasi 3	10.87	2.99	9.39
Asawase 3	6.29	5.45	7.94	Ahodwo 1	4.39	1.92	8.90
Asawase 4	1.79	3.85	8.74	Ahodwo 2	8.06	2.23	8.85
Manhyia 1	0.99	3.01	8.52	Ahodwo 3	10.79	5.97	8.47
Manhyia 2	1.99	3.25	8.63	Asokwa 1	3.25	22.59	8.89
Manhyia 3	7.75	6.25	7.17	Asokwa 2	9.24	3.18	8.94
Ashtown 1	2.75	2.82	8.82	Asokwa 3	4.50	3.06	8.40
Ashtown 2	11.26	6.90	8.81	Asokwa 4	5.13	3.96	8.25
Ashtown 3	4.52	3.29	9.08	Suntreso 1	6.13	3.06	9.17
Ashtown 4	1.98	9.11	7.81	Suntreso 2	8.90	4.03	8.71
Mbrom 1	8.37	6.96	7.17	Suntreso 3	5.94	2.95	8.57
Mbrom 2	11.95	3.62	9.06	Suntreso 4	10.35	5.84	9.92
Mbrom 3	2.35	2.61	8.98	Patasi 1	4.75	2.29	8.72
Race course1	4.39	7.93	7.83	Patasi 2	1.40	7.10	8.06
Race course2	2.39	6.33	8.68	Patasi 3	8.40	4.80	8.86
Race course3	13.35	4.98	9.00	Sofoline 1	7.78	3.46	9.36
Race course4	13.86	4.83	9.10	Sofoline 2	8.58	3.93	8.29
Bantama 1	1.59	4.23	8.58	Sofoline 3	12.20	8.20	5.29
Bantama 2	6.35	3.18	8.64	Danyame 1	14.34	7.21	8.08
Bantama 3	3.17	2.46	8.76	Danyame 2	12.75	7.19	6.74
Aboabo 1	7.69	4.27	7.66	Danyame 3	1.99	2.43	8.59
Aboabo 2	0.59	5.58	8.45	Dakodwom 1	7.66	8.94	8.48
Aboabo 3	0.80	9.22	7.34	Dakodwom 2	8.93	7.46	8.02
Aboabo 4	0.39	3.17	8.55	Dakodwom 3	8.12	3.23	8.79
Aboabo 5	0.39	4.34	7.91	Dichemso 2	8.30	6.68	8.90
Dichemso 1	0.00	1.58	8.99	Dichemso 3	0.59	3.95	8.76

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Table 11: Concentrations (ng/g dw) of PAHs in Surface Soil from the Kumasi Metropolis

(ng/g dry wt)	Nap	Acl	Ace	Fle	Phe	Ant	Methy-Phe	Me-Phe	Flu	Pyr	Retene	BaA	Chr	BbF+BkF	BeP	BaP	Peryl	DBahA	IDP	BghiP	ΣPAHs
Ayigya 1	0.00	0.14	0.00	0.31	1.40	0.12	0.12	0.05	1.68	1.37	0.76	0.45	0.52	0.82	0.71	0.45	0.15	0.15	0.46	0.42	10.08
Ayigya 2	0.00	0.32	0.00	0.41	2.25	0.33	0.33	0.10	2.52	1.99	0.87	0.72	0.75	1.32	1.33	0.80	0.22	0.67	0.89	1.25	17.09
Ayigya 3	0.00	0.12	0.00	0.30	2.37	0.36	0.36	0.06	6.02	4.77	0.73	2.85	1.52	3.13	2.47	2.61	0.84	0.30	1.69	1.46	31.95
Bomso 1	0.77	0.65	0.03	0.50	3.03	0.60	0.30	0.69	1.74	2.01	0.71	0.70	1.49	1.44	3.41	0.90	0.64	0.85	1.89	5.48	27.84
Bomso 2	0.00	0.15	0.02	0.16	1.15	0.22	0.31	1.33	0.84	0.90	0.61	0.32	0.44	0.66	1.12	0.52	0.20	0.66	0.85	2.61	13.09
Bomso 3	3.54	0.44	0.10	0.38	2.32	0.52	0.14	0.14	2.40	2.01	0.95	0.81	0.75	1.52	1.87	1.08	0.29	0.31	1.50	3.53	24.59
Susuanso 1	1.73	0.20	0.03	0.37	1.28	0.37	0.13	0.06	0.96	1.29	0.35	0.29	0.34	0.30	0.49	0.24	0.52	0.17	0.47	0.93	10.52
Susuanso 2	6.21	2.71	0.24	1.39	13.74	3.81	1.04	1.88	10.12	10.97	3.59	5.62	5.42	5.75	11.87	7.80	1.87	2.95	12.14	27.30	136.40
Susuanso 3	8.03	1.73	0.12	1.10	8.54	1.79	0.77	0.90	5.03	6.17	2.21	2.22	3.02	3.72	9.89	3.07	1.33	1.72	5.88	13.69	80.93
Oforikrom 1	0.00	0.94	0.22	0.93	4.60	0.78	0.51	0.22	6.17	6.57	1.17	1.87	1.75	2.35	2.48	1.74	0.48	0.24	3.79	5.68	42.49
Oforikrom 2	7.16	1.02	0.11	1.20	8.49	1.20	1.06	1.51	6.05	6.03	3.76	1.91	2.49	3.77	5.27	2.11	1.41	0.18	3.31	2.29	60.34
Oforikrom 3	16.69	6.42	0.72	2.53	59.45	14.44	8.24	4.60	94.87	77.82	3.49	34.89	20.49	24.38	20.66	19.87	3.69	1.56	15.52	15.59	445.95
Afunkwanta 1	11.06	1.48	0.04	1.09	8.82	1.08	1.08	1.41	12.05	17.27	3.04	4.14	5.77	7.70	14.02	4.94	1.87	0.91	12.93	24.72	135.44
Afunkwanta 2	3.06	1.79	0.03	0.44	3.61	0.77	0.77	0.21	8.96	8.68	0.69	5.80	3.26	9.18	8.09	8.92	3.17	1.36	8.90	9.36	87.06
Afunkwanta 3	5.22	2.54	0.13	1.06	9.06	1.71	1.71	1.50	26.02	22.80	4.81	13.26	8.57	14.85	14.92	12.91	4.69	1.92	14.48	16.25	178.43
Amakom 1	15.20	2.46	0.13	0.96	8.58	1.08	0.86	0.79	31.98	27.85	1.46	3.25	2.83	2.05	3.71	2.54	0.86	0.21	5.38	9.12	121.30
Amakom 2	0.01	5.01	0.19	1.70	18.43	2.84	0.79	0.67	59.73	33.43	1.24	6.21	6.80	11.62	13.34	8.35	2.18	0.47	9.23	18.86	201.09
Amakom 3	3.90	5.13	0.10	1.13	9.67	2.60	1.12	1.17	16.52	21.55	5.13	13.64	11.09	16.19	19.13	13.90	4.60	1.96	13.96	22.51	184.99
Asafo 1	15.49	2.65	0.15	1.94	16.05	2.78	2.45	1.58	19.57	14.63	5.57	9.05	6.16	12.00	10.13	9.40	2.86	0.17	10.22	12.25	155.10
Asafo 2	3.01	4.56	0.35	0.95	18.30	7.96	4.83	2.07	99.37	89.51	4.73	50.97	10.73	77.23	56.82	66.31	16.80	0.71	13.28	0.25	528.74
Asafo 3	9.32	0.42	0.88	0.19	0.00	3.49	17.25	10.77	2.35	5.03	2.69	0.88	0.45	0.57	1.15	0.45	1.04	5.44	25.36	29.19	116.95
Asafo 4	6.86	2.34	0.25	0.79	7.87	2.15	1.24	1.03	154.88	117.67	0.85	11.76	7.33	9.21	11.99	10.69	3.87	2.72	31.49	50.58	435.57
Asafo 5	16.66	1.67	0.32	2.43	19.40	6.10	2.71	3.84	17.11	17.63	2.60	2.16	2.19	3.47	5.09	2.72	0.95	0.38	18.21	38.71	164.36

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Roman hill 1	8.44	9.38	3.64	2.94	118.0 ₇	17.99	17.99	9.58	250.0 ₅	232.0 ₄	4.95	197.4 ₁	110.0 ₄	190.18	183.6 ₃	179.2 ₈	61.77	21.82	162.6 ₇	158.7 ₆	1940.62
Roman hill 2	31.2 ₈	5.71	6.15	11.0 ₈	109.8 ₇	10.87	10.87	16.25	63.62	57.75	61.20	14.91	16.69	51.04	63.21	28.95	14.13	2.63	82.32	100.6 ₄	759.1 ₇
Roman hill 3	0.13	14.2 ₃	1.97	2.54	59.64	16.47	16.47	6.69	251.5 ₃	247.4 ₃	9.48	232.2 ₈	114.5 ₁	244.70	230.8 ₀	260.8 ₄	96.97	26.39	199.4 ₅	211.0 ₄	2243.54
Central market 1	18.0 ₅	2.57	0.59	3.22	12.37	2.24	2.33	2.42	17.27	13.32	30.27	9.66	6.86	10.47	10.97	8.45	2.93	1.32	7.84	9.03	172.1 ₈
Central market 2	4.90	2.27	0.34	1.37	6.87	2.06	2.30	1.81	24.03	15.18	20.14	12.86	4.11	25.22	32.17	15.98	8.90	3.51	26.92	56.43	267.3 ₇
Central market 3	24.0 ₆	2.66	0.38	3.03	23.52	5.09	8.87	2.92	52.45	40.15	46.77	32.68	17.18	23.98	21.13	21.16	5.60	3.59	19.09	19.76	374.0 ₇
Kejetia 1	0.00	1.86	0.14	1.00	6.07	2.45	2.45	0.82	23.38	21.19	6.89	41.46	22.00	66.03	63.38	66.27	23.65	6.10	47.63	37.10	439.8 ₅
Kejetia 2	0.00	3.04	1.89	3.25	30.66	7.75	7.75	4.35	108.5 ₆	86.74	36.99	44.05	23.32	35.94	38.89	33.07	11.17	6.22	55.90	48.31	587.8 ₅
Kejetia 3	0.04	2.74	0.38	2.16	14.54	3.77	3.77	1.68	38.10	29.58	13.21	17.20	13.02	25.36	36.82	18.92	7.46	6.06	61.90	73.29	369.9 ₉
Adum 1	15.4 ₄	17.8 ₇	2.55	3.39	92.32	29.17	12.93	5.25	334.8 ₆	268.3 ₈	3.09	111.5 ₂	64.62	146.02	109.5 ₁	112.8 ₃	34.27	12.20	79.18	96.78	1552.19
Adum 2	34.7 ₇	7.67	1.36	3.38	34.60	8.92	6.98	4.00	60.87	57.12	6.23	35.24	21.77	36.79	35.39	38.24	15.13	2.31	25.75	42.85	479.3 ₅
Adum 3	8.91	31.7 ₂	2.27	2.96	85.14	58.23	13.65	7.25	303.9 ₂	332.1 ₅	7.61	162.9 ₇	96.56	990.78	918.3 ₉	839.8 ₆	267.7 ₂	57.35	551.3 ₀	595.3 ₄	5334.07
Adum 4	7.64	27.6 ₇	0.05	2.74	11.92	4.93	2.58	0.20	220.4 ₀	193.2 ₄	2.91	98.73	57.11	18.62	44.28	46.90	8.51	3.75	99.16	122.5 ₅	973.8 ₉
Asawase 1	0.00	3.55	1.39	1.76	34.01	6.62	6.62	1.76	122.5 ₂	88.07	4.38	84.01	41.51	88.59	75.63	94.51	31.61	9.65	67.92	65.81	829.9 ₃
Asawase 2	6.90	1.61	0.12	1.32	10.14	1.76	1.76	1.27	22.03	16.94	3.11	10.23	5.52	11.35	11.91	11.10	4.18	1.10	9.68	12.80	144.8 ₂
Asawase 3	8.23	2.74	0.13	1.15	8.58	1.21	1.21	0.88	19.60	12.67	2.85	6.63	6.04	8.91	10.25	6.73	2.27	1.27	12.33	17.71	131.4 ₀
Asawase 4	0.71	6.99	1.07	3.82	38.81	7.21	7.21	5.06	130.1 ₅	107.0 ₁	10.25	74.02	45.25	96.27	84.49	67.70	24.09	7.77	68.85	73.24	859.9 ₉
Manhyia 1	3.23	8.89	2.90	2.30	47.36	13.70	13.70	4.03	187.5 ₀	154.8 ₁	5.23	146.2 ₈	71.42	149.69	128.1 ₈	160.4 ₈	57.15	19.27	118.9 ₂	117.4 ₈	1412.53
Manhyia 2	0.01	4.73	0.58	1.30	22.10	5.58	5.58	1.72	67.46	45.64	4.87	46.61	25.27	54.89	46.86	46.93	14.74	5.90	41.23	39.65	481.6 ₅
Manhyia 3	8.67	1.72	0.13	0.90	8.05	1.24	1.24	0.75	16.17	10.07	3.04	6.32	6.01	9.59	9.33	7.20	2.50	1.76	8.19	8.09	110.9 ₇
Ashtown 1	11.4 ₆	5.76	0.63	1.79	32.24	8.11	4.36	3.53	96.68	78.43	6.65	62.96	29.81	61.13	52.30	54.05	18.15	7.69	47.43	48.56	631.7 ₁
Ashtown 2	2.70	4.23	0.70	0.87	13.77	5.30	4.84	2.22	106.3 ₅	101.4 ₅	2.15	98.97	46.53	103.13	93.28	115.7 ₂	42.68	12.91	86.91	89.50	934.2 ₂
Ashtown 3	5.91	3.38	0.25	1.21	10.38	3.30	2.23	1.27	26.35	26.87	1.86	19.22	10.71	27.14	29.43	29.38	11.57	4.32	26.37	28.00	269.1 ₄
Ashtown 4	0.20	0.61	0.00	0.14	0.43	0.53	0.02	0.00	0.57	0.88	1.69	3.65	2.86	9.32	10.94	6.15	2.57	1.46	11.38	15.90	69.30
Mbrom 1	14.5 ₄	33.6 ₀	73.3 ₀	31.5 ₆	394.3 ₈	109.5 ₂	97.89	36.70	706.3 ₉	643.0 ₆	17.73	524.5 ₈	256.5 ₆	159.62	154.3 ₀	190.1 ₂	71.66	18.99	157.5 ₃	149.4 ₆	3841.50

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Mbrom 2	1.69	3.58	0.84	0.79	16.09	4.86	3.46	1.71	72.97	58.63	2.03	50.58	23.85	61.02	54.48	60.22	21.81	5.72	45.88	51.49	541.6 ₉
Mbrom 3	0.00	1.53	1.14	0.97	18.95	4.41	4.17	1.60	62.56	50.76	1.86	44.92	21.54	54.76	47.31	56.13	19.73	5.49	39.53	39.84	477.2 ₂
Race course 1	0.74	7.68	5.94	24.6 ₈	207.5 ₅	32.71	91.76	89.00	119.3 ₇	266.4 ₇	94.15	27.18	29.91	25.09	31.89	16.00	6.31	5.37	55.52	107.2 ₉	1244.6 ₃
Race course 2	0.03	2.60	0.84	9.06	39.31	6.22	8.00	11.12	21.69	23.21	10.99	6.07	5.96	5.99	7.13	3.59	1.19	0.46	4.58	5.67	173.7 ₃
Race course 3	3.01	0.59	0.04	0.68	5.07	0.91	0.90	0.49	10.68	9.44	1.36	5.79	3.85	7.14	6.94	6.42	2.75	1.21	7.45	6.91	81.63
Race course 4	3.99	0.52	0.01	0.94	3.94	0.58	0.74	0.90	4.01	4.56	1.40	1.87	1.26	2.49	2.62	2.06	1.04	0.50	3.11	2.22	38.77
Bantama 1	0.00	1.47	0.16	2.07	8.30	1.36	1.29	0.92	6.25	5.85	2.93	2.14	1.65	2.54	2.46	1.73	0.54	0.31	1.51	1.72	45.20
Bantama 2	0.00	0.22	0.00	0.35	1.82	0.34	0.20	0.11	2.07	1.42	0.61	0.75	0.92	1.41	1.97	0.83	0.36	0.28	1.26	2.17	17.09
Bantama 3	0.00	0.92	0.09	0.94	7.71	1.42	1.19	1.26	22.47	19.67	2.52	9.14	6.98	12.45	14.92	9.42	3.20	1.62	14.09	16.52	146.5 ₅
Aboabo 1	10.9 ₃	1.82	0.21	1.22	12.13	2.22	1.49	1.92	7.34	9.25	5.23	2.47	2.68	7.02	8.08	2.54	1.10	0.09	6.27	13.09	97.11
Aboabo 2	4.98	2.69	0.33	3.56	35.40	20.07	3.62	12.08	33.88	82.09	78.05	10.00	18.00	8.82	16.01	5.52	1.72	0.26	5.90	8.69	351.6 ₄
Aboabo 3	1.09	0.18	0.04	0.38	1.91	0.26	0.43	0.40	2.27	2.15	4.46	0.45	0.56	0.67	0.51	0.37	0.28	0.13	0.53	0.21	17.29
Aboabo 4	2.76	1.12	0.18	0.52	5.28	1.22	0.71	0.92	8.45	8.79	4.98	3.69	3.75	1.80	1.88	1.08	0.60	0.02	1.40	0.62	49.80
Aboabo 5	0.29	1.28	0.09	0.50	2.23	0.16	0.48	0.00	2.34	6.00	9.89	2.20	0.32	2.83	13.72	4.84	1.81	0.21	6.31	0.00	55.48
Dichemso 1	2.43	0.49	0.02	0.54	3.34	0.57	0.57	0.51	4.89	5.43	1.06	2.53	2.03	3.61	5.03	2.84	1.07	0.51	5.03	7.79	50.30
Dichemso 2	3.43	0.78	0.02	0.80	4.42	0.60	0.60	0.49	4.68	3.76	3.00	1.74	1.52	2.41	2.19	1.51	0.46	0.21	1.58	1.45	35.65
Dichemso 3	18.2 ₈	0.71	0.17	1.26	7.17	0.71	0.71	1.13	10.52	9.80	2.69	5.27	3.36	9.84	10.63	9.48	3.82	1.31	9.37	12.37	118.6 ₂
Yennyawoso 1	0.00	0.28	0.12	1.11	4.53	1.35	2.20	1.90	3.55	3.34	3.07	0.62	0.41	2.00	3.43	1.88	0.57	0.21	2.33	4.22	37.12
Yennyawoso 2	0.00	0.50	0.07	1.08	7.63	1.14	0.97	1.43	6.74	11.25	2.60	2.11	2.26	2.84	5.42	1.63	0.94	0.32	4.46	10.16	63.57
Yennyawoso 3	0.00	0.38	0.01	0.56	3.09	0.51	0.59	0.36	6.72	5.86	0.95	3.52	2.28	4.78	3.90	3.71	1.09	0.38	3.10	3.05	44.83
Krofrom 1	1.74	2.59	0.15	0.59	4.85	5.04	1.24	1.10	37.32	24.72	3.64	14.03	7.42	18.07	18.01	18.67	6.42	1.21	13.43	19.29	199.5 ₅
Krofrom 2	27.7 ₅	1.83	2.83	7.38	46.56	12.31	11.03	16.45	16.12	35.47	22.64	6.08	7.16	9.33	10.79	5.11	2.25	0.89	3.80	6.58	252.3 ₈
Krofrom 3	6.41	0.92	0.14	0.79	5.08	1.55	0.61	0.62	6.11	5.41	3.60	2.41	2.38	4.75	4.57	2.70	0.96	0.35	3.39	5.55	58.29
Krofrom 4	12.9 ₈	3.72	0.74	1.55	24.77	4.59	2.50	1.85	62.19	57.12	4.89	29.26	18.63	34.76	30.63	30.35	8.39	2.27	32.61	34.50	398.2 ₈
Suame 1	5.95	19.2 ₇	10.3 ₅	5.18	410.6 ₈	99.37	30.42	25.95	1318.00	1137.49	27.08	556.0 ₀	286.6 ₃	205.91	156.5 ₀	179.9 ₂	50.44	18.36	5.89	116.6 ₇	4666.07
Suame 2	0.10	9.08	29.0 ₆	22.2 ₂	768.3 ₃	30.90	16.44	9.10	884.7 ₁	652.0 ₃	3.26	61.43	64.55	105.70	117.2 ₆	95.58	21.71	23.42	168.6 ₇	309.4 ₇	3393.02

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Suame 3	0.78	5.12	0.70	3.41	52.85	11.88	13.70	18.13	50.87	163.5 ₄	23.09	5.35	8.31	2.05	6.55	3.26	0.94	2.57	4.26	39.57	416.9 ₆
Suame 4	5.91	0.58	0.26	0.94	8.54	2.05	1.12	1.34	5.65	7.77	2.16	2.78	4.20	3.72	6.46	2.49	0.62	0.13	3.13	6.63	66.46
Suame 5	34.8 ₁	6.94	1.90	0.75	0.46	3.37	0.51	0.34	1.73	140.9 ₈	2.27	1.84	0.35	0.35	0.00	7.30	0.33	12.01	88.99	0.00	305.2 ₄
Suame 6	8.45	1.59	0.21	1.16	9.56	4.15	2.06	1.37	27.09	28.88	5.46	18.76	11.31	26.82	22.28	24.71	7.57	1.51	18.10	22.35	243.4 ₂
Anomangye 1	10.3 ₉	2.07	0.27	4.22	29.92	1.52	1.52	10.01	37.21	44.81	15.92	5.59	11.85	10.55	21.39	5.35	5.98	1.65	9.85	43.07	273.1 ₄
Anomangye 2	9.45	1.28	0.08	1.52	10.18	1.12	1.12	3.72	19.00	29.22	11.76	4.05	8.80	6.18	12.46	2.58	3.10	1.31	5.36	21.79	154.0 ₈
Anomangye 3	0.00	1.42	0.30	2.66	17.08	2.12	2.12	3.20	33.88	29.06	7.46	7.38	7.56	12.62	12.00	5.52	2.00	0.41	6.06	6.67	159.5 ₂
New Suame 1	6.13	0.72	0.10	1.57	9.13	1.87	1.38	0.93	10.00	7.80	9.62	5.30	4.25	7.65	6.56	4.33	1.15	0.82	4.62	0.15	84.09
New Suame 2	0.00	0.18	0.03	0.30	1.48	0.00	0.17	0.15	2.12	1.65	1.23	0.90	0.79	1.65	1.50	1.36	0.55	0.03	0.58	0.16	14.83
New Suame 3	0.17	0.51	0.04	0.49	3.06	0.00	0.38	0.50	5.60	4.54	0.85	1.41	1.47	2.45	2.96	1.84	1.07	0.20	0.55	0.28	28.37
Tafo 1	13.3 ₄	1.62	0.39	1.27	16.74	4.49	1.08	1.31	72.50	70.06	0.40	9.12	7.30	16.01	21.70	15.18	5.21	1.81	27.96	91.79	379.2 ₈
Tafo 2	2.12	0.36	0.06	0.66	8.48	1.34	3.04	1.97	5.30	7.61	6.33	2.44	0.81	2.74	0.25	0.44	1.46	0.16	0.03	2.81	48.39
Tafo 3	4.67	0.25	0.03	0.36	2.78	0.41	0.26	0.34	8.11	5.21	0.09	0.74	0.86	0.69	1.17	0.58	0.23	0.17	2.42	3.88	33.27
Tafo 4	42.0 ₆	1.95	0.26	1.93	23.44	2.75	0.70	2.74	31.40	32.83	43.03	4.66	9.79	1.00	1.28	0.43	0.59	0.45	6.29	0.33	207.9 ₂
Tafo 5	4.68	1.75	0.98	6.25	44.80	8.94	7.49	11.47	65.31	70.34	58.67	27.46	21.43	4.07	8.42	18.17	6.77	1.80	8.66	8.32	385.7 ₉
Tafo 6	2.63	0.38	0.06	0.64	2.17	0.68	0.95	0.78	3.38	2.32	5.39	1.40	1.05	3.17	1.91	0.46	0.42	0.62	1.38	0.41	30.22
Tafo Nhyiaeso 1	17.9 ₁	4.52	0.60	4.01	30.53	9.98	19.67	26.01	26.64	103.3 ₉	32.34	17.22	15.78	19.19	21.64	13.30	0.35	0.71	8.69	11.11	383.5 ₇
Tafo Nhyiaeso 2	1.94	0.40	0.11	0.62	6.23	0.99	0.50	0.72	3.99	4.67	0.61	1.63	1.84	2.54	4.25	1.75	0.94	0.17	2.41	5.86	42.15
Tafo Nhyiaeso 3	1.34	0.24	0.01	0.36	1.99	0.34	0.27	0.20	4.08	3.63	0.35	1.73	1.26	2.42	1.96	1.86	0.68	0.04	0.17	0.00	22.92
Ahinsan 1	1.54	0.22	0.10	0.28	1.27	0.34	0.12	0.09	1.57	1.43	0.07	0.64	0.45	0.99	1.08	0.78	0.33	0.37	0.95	2.24	14.89
Ahinsan 2	0.56	0.17	0.08	0.23	0.59	0.16	0.04	0.03	0.60	0.49	0.00	0.20	0.18	0.33	0.37	0.21	0.10	0.29	0.23	0.61	5.49
Ahinsan 3	0.12	0.26	0.01	0.24	0.82	0.36	0.18	0.11	1.22	1.19	0.67	0.96	0.84	1.43	1.39	0.79	0.28	0.14	0.50	0.65	12.17
Atonsus 1	0.00	0.14	0.00	0.14	0.33	0.14	0.14	0.00	0.51	0.51	0.00	0.12	0.05	0.22	0.18	0.14	0.05	0.04	0.17	0.09	2.99
Atonsus 2	0.00	0.21	0.00	0.41	2.20	0.44	0.44	0.57	3.17	4.40	3.81	0.98	1.12	1.51	1.97	0.72	0.27	0.13	1.06	1.76	25.17
Atonsus 3	0.00	0.05	0.00	0.16	0.40	0.00	0.00	0.02	0.44	0.38	0.01	0.14	0.17	0.28	0.35	0.12	0.06	0.04	0.18	0.27	3.06
Atonsus 4	0.00	2.90	0.18	1.57	11.97	1.50	1.50	0.92	11.58	9.44	5.13	3.84	3.49	6.15	5.20	4.26	1.05	0.49	3.50	3.85	78.52

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Kaasi 1	9.04	2.89	0.20	1.17	11.94	4.35	1.36	1.20	8.16	13.22	2.36	2.48	3.47	4.98	7.85	2.34	1.17	0.13	3.90	7.30	89.52
Kaasi 2	16.93	3.31	0.16	0.97	9.16	1.41	0.43	0.59	16.27	18.70	0.09	1.64	2.61	2.43	6.98	2.77	0.63	0.38	8.62	36.50	130.58
Kaasi 3	3.01	0.52	0.91	0.63	7.69	1.88	0.79	0.31	15.92	14.38	0.74	9.50	6.02	14.68	13.27	10.65	3.77	0.89	9.25	12.54	127.38
Ahodwo 1	0.00	0.95	0.07	0.62	3.25	0.46	0.49	0.33	7.32	7.03	0.94	2.07	1.57	3.15	4.86	2.22	0.82	0.30	3.62	7.96	48.02
Ahodwo 2	1.14	0.73	0.12	0.66	3.66	0.45	0.36	0.35	2.99	7.38	2.83	2.22	5.25	4.44	7.92	2.48	1.51	4.25	8.11	8.06	64.92
Ahodwo 3	0.00	0.67	0.00	0.64	3.04	0.40	0.61	0.45	5.46	6.21	1.81	1.63	2.04	2.65	3.59	1.62	0.68	0.25	2.07	3.82	37.65
Asokwa 1	2.86	2.15	0.21	0.90	9.09	2.53	1.81	1.60	17.29	18.30	3.95	10.11	8.99	14.43	17.49	12.34	4.95	0.83	13.92	26.86	170.66
Asokwa 2	13.98	2.57	0.10	0.82	7.90	0.88	0.79	1.05	55.19	45.16	0.91	1.76	2.84	1.76	3.34	1.36	0.50	0.22	5.19	11.94	158.26
Asokwa 3	10.04	11.72	0.15	1.50	17.86	3.86	1.49	1.33	14.04	18.91	3.64	5.80	5.58	8.50	14.09	9.10	2.33	1.39	18.37	45.90	195.62
Asokwa 4	22.10	34.81	0.58	6.64	48.28	10.08	6.69	3.73	38.04	44.02	13.03	11.88	13.55	16.36	20.41	12.63	3.69	2.02	15.81	36.87	361.22
Suntreso 1	0.00	17.00	6.15	4.94	115.39	28.70	19.73	11.49	276.28	233.95	6.07	181.62	83.86	170.38	133.77	151.26	49.43	17.62	110.86	103.94	1722.44
Suntreso 2	0.00	5.10	0.76	2.27	19.30	3.70	4.72	3.56	77.73	62.20	5.35	48.57	26.24	63.87	50.98	52.96	16.07	5.90	38.80	39.46	527.52
Suntreso 3	6.67	23.54	1.68	2.02	95.65	35.31	9.49	9.62	470.51	399.65	2.76	202.60	91.09	135.80	113.41	154.45	46.84	27.99	244.85	277.09	2351.03
Suntreso 4	0.00	1.47	0.15	1.14	6.65	0.82	1.21	1.23	12.65	10.42	6.64	4.74	5.03	7.38	6.99	3.74	1.37	0.38	4.86	5.11	82.00
Patasi 1	0.78	0.66	0.03	0.29	2.83	0.79	0.79	0.32	9.76	9.36	0.50	6.29	3.27	7.78	7.02	7.19	2.28	0.88	6.06	7.14	74.03
Patasi 2	8.07	1.26	0.12	1.00	7.16	0.85	0.85	0.96	11.88	15.55	3.64	4.74	6.24	9.54	16.57	7.66	3.37	0.90	13.83	32.08	146.30
Patasi 3	18.82	7.21	1.28	2.41	36.19	9.54	9.54	4.02	138.75	132.62	6.97	100.49	53.03	119.52	115.80	120.87	44.36	14.80	143.98	163.75	1243.95
Sofoline 1	0.00	0.89	0.08	0.87	5.04	1.06	1.06	0.51	11.93	10.77	1.25	6.32	3.62	9.19	8.61	8.29	3.04	0.83	7.86	8.53	89.76
Sofoline 2	0.00	0.91	0.01	0.26	29.78	7.00	7.00	2.24	96.34	82.40	1.32	49.90	23.02	39.12	35.91	38.99	14.01	4.81	37.28	38.69	509.00
Sofoline 3	0.00	6.86	2.32	1.92	65.65	19.76	19.76	6.75	210.23	194.52	2.87	182.54	90.78	148.31	152.20	156.06	58.90	22.46	148.53	140.20	1630.61
Danyame 1	2.19	2.23	1.01	1.00	23.72	4.35	4.35	1.83	82.28	74.75	2.33	53.63	28.64	60.19	53.30	63.87	21.31	6.31	44.40	43.63	575.30
Danyame 2	4.76	2.93	0.70	1.05	22.23	5.22	5.22	1.54	83.96	74.82	2.17	43.96	23.96	53.50	50.82	49.86	18.13	6.16	45.22	51.43	547.65
Danyame 3	4.65	1.52	0.36	1.15	11.26	1.75	1.75	3.20	53.01	54.51	8.07	15.04	15.13	20.27	26.31	18.97	7.02	3.26	38.13	62.20	347.54
Dakodwom 1	3.42	3.13	0.33	0.74	11.20	3.65	1.89	1.18	55.35	51.81	3.10	34.80	18.91	50.11	44.23	45.70	16.83	4.91	38.85	45.88	436.04
Dakodwom 2	3.00	1.15	0.30	0.96	7.71	1.40	1.74	1.62	21.83	24.95	5.89	9.66	7.73	10.06	13.04	8.93	4.03	1.92	11.15	19.43	156.51
Dakodwom 3	0.00	3.25	0.45	1.25	16.96	5.12	3.32	2.05	94.16	86.91	5.68	62.33	33.00	89.71	74.68	77.36	28.40	6.54	59.15	69.81	720.13

Table 12: Composition of PAHs in Surface Soil Samples from the Kumasi metropolis

sample site	\sum PAH ng/g dw	sample site	\sum PAH ng/g dw
Ayigya	19.71	Dichemso	68.19
Bomso	21.84	Yennyawoso	48.5
Susuanso	75.95	Krofrom	227.13
Oforikrom	182.93	Suame	1515.2
Afunkwanta	133.64	Anomangye	195.58
Amakom	169.13	New Suame	42.43
Asafo	280.14	Tafo	180.81
Roman hill	1647.78	Tafo Nhyiaeso	149.55
Central market	271.21	Ahinsan	10.85
Kejetia	465.9	Atonsu	27.44
Adum	2084.87	Kaasi	115.83
Asawase	491.53	Ahodwo	50.2
Manhyia	668.38	Asokwa	221.44
Ashtown	476.09	Suntreso	1170.75
Mbrom	1620.14	Patasi	488.09
Race course	384.69	Sofoline	743.12
Bantama	69.62	Danyame	490.16
Aboabo	114.26	Dakodwom	437.56

Table 13: Mean, Standard Deviation, Median, Minimum and Maximum concentrations of PAHs (ng/g dw) in surface soils from the Kumasi Metropolis.

PAH	No. of rings	mean	Stand Dev	Min	Max
Nap	2	5.56	4.80	0.00	16.69
Acl	3	3.64	4.53	0.12	21.23
Ace	3	1.39	4.22	0.00	25.09
Fle	3	2.05	2.29	0.23	11.11
Phe	3	27.35	41.84	0.90	208.40
Ant	3	6.02	8.41	0.18	39.60
Methy-Phe	3	4.94	7.15	0.11	35.17
Me-Phe	3	3.55	4.86	0.07	25.38
Flu	4	61.70	86.86	1.05	381.34
Pyr	4	57.94	78.68	1.04	355.12
Retene	3	7.23	8.16	0.25	32.39
BaA	4	32.32	47.56	0.33	206.69
Chr	4	18.16	24.08	0.42	100.65
BbF+BkF	5+5	35.11	56.52	0.92	298.05
BeP	5	33.83	52.26	0.95	276.89
BaP	5	32.59	51.90	0.59	259.46
Peryl	5	11.18	17.26	0.24	81.41
DBahA	5	3.82	4.86	0.10	18.90
IDP	6	30.57	42.10	0.56	188.85
BghiP	6	36.67	45.41	0.20	214.38

Table 14: Diagnostic Ratios for PAHs in the Surface Soil from the Kumasi Metropolis

sample site	IDP/(IDP+BghiP)	Flu/(flu+Py)	BaP/BghiP	sample site	IDP/(IDP+BghiP)	Flu/(flu+Py)	BaP/BghiP
Ayigya 1	0.52	0.55	1.07	Yennyawoso1	0.36	0.52	0.45
Ayigya 2	0.41	0.56	0.64	Yennyawoso2	0.31	0.37	0.16
Ayigya 3	0.54	0.56	1.78	Yennyawoso3	0.5	0.53	1.22
Bomso 1	0.26	0.46	0.16	Krofrom 1	0.41	0.6	0.97
Bomso 2	0.25	0.48	0.2	Krofrom 2	0.37	0.31	0.78
Bomso 3	0.3	0.54	0.31	Krofrom 3	0.38	0.53	0.49
Susuanso 1	0.33	0.43	0.26	Krofrom 4	0.49	0.52	0.88
Susuanso 2	0.31	0.48	0.29	Suame 1	0.05	0.54	1.54
Susuanso 3	0.3	0.45	0.22	Suame 2	0.35	0.58	0.31
Oforikrom 1	0.4	0.48	0.31	Suame 3	0.1	0.24	0.08
Oforikrom 2	0.59	0.5	0.92	Suame 4	0.32	0.42	0.38
Oforikrom 3	0.5	0.55	1.27	Suame 5	1	0.01	0
Afunkwanta 1	0.34	0.41	0.2	Suame 6	0.45	0.48	1.11
Afunkwanta 2	0.49	0.51	0.95	Anomangye 1	0.19	0.45	0.12
Afunkwanta 3	0.47	0.53	0.79	Anomangye 2	0.2	0.39	0.12
Amakom 1	0.37	0.53	0.28	Anomangye 3	0.48	0.54	0.83
Amakom 2	0.33	0.64	0.44	NewSuame1	0.97	0.56	28.52
Amakom 3	0.38	0.43	0.62	NewSuame2	0.78	0.56	8.28
Asafo 1	0.45	0.57	0.77	NewSuame3	0.66	0.55	6.51
Asafo 2	0.98	0.53	265.62	Tafo 1	0.23	0.51	0.17
Asafo 3	0.46	0.32	0.02	Tafo 2	0.01	0.41	0.16
Asafo 4	0.38	0.57	0.21	Tafo 3	0.38	0.61	0.15
Asafo 5	0.32	0.49	0.07	Tafo 4	0.95	0.49	1.29
Roman hill 1	0.51	0.52	1.13	Tafo 5	0.51	0.48	2.18
Roman hill 2	0.45	0.52	0.29	Tafo 6	0.77	0.59	1.13
Roman hill 3	0.49	0.5	1.24	Tafo Nhyiaeso 1	0.44	0.2	1.2
Central market 1	0.46	0.56	0.94	Tafo Nhyiaeso 2	0.29	0.46	0.3
Central market 2	0.32	0.61	0.28	Tafo Nhyiaeso 3	1	0.53	0
Central market 3	0.49	0.57	1.07	Ahinsan 1	0.3	0.52	0.35
Kejetia 1	0.56	0.52	1.79	Ahinsan 2	0.27	0.55	0.35
Kejetia 2	0.54	0.56	0.68	Ahinsan 3	0.43	0.51	1.21
Kejetia 3	0.46	0.56	0.26	Atonsu 1	0.65	0.5	1.53
Adum 1	0.45	0.56	1.17	Atonsu 2	0.38	0.42	0.41
Adum 2	0.38	0.52	0.89	Atonsu 3	0.4	0.54	0.43

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Adum 3	0.48	0.48	1.41	Atonsu 4	0.48	0.55	1.11
Adum 4	0.45	0.53	0.38	Kaasi 1	0.35	0.38	0.32
asuasi 1	0.51	0.58	1.44	Kaasi 2	0.19	0.47	0.08
asuasi 2	0.43	0.57	0.87	Kaasi 3	0.42	0.53	0.85
asuasi 3	0.41	0.61	0.38	Ahodwo 1	0.31	0.51	0.28
asuasi 4	0.48	0.55	0.92	Ahodwo 2	0.5	0.29	0.31
Manhyia 1	0.5	0.55	1.37	Ahodwo 3	0.35	0.47	0.42
Manhyia 2	0.51	0.6	1.18	Asokwa 1	0.34	0.49	0.46
Manhyia 3	0.5	0.62	0.89	Asokwa 2	0.3	0.55	0.11
Ashtown 1	0.49	0.55	1.11	Asokwa 3	0.29	0.43	0.2
Ashtown 2	0.49	0.51	1.29	Asokwa 4	0.3	0.46	0.34
Ashtown 3	0.48	0.5	1.05	Suntreso 1	0.52	0.54	1.46
Ashtown 4	0.42	0.39	0.39	Suntreso 2	0.5	0.56	1.34
Mbrom 1	0.51	0.52	1.27	Suntreso 3	0.47	0.54	0.56
Mbrom 2	0.47	0.55	1.17	Suntreso 4	0.49	0.55	0.73
Mbrom 3	0.5	0.55	1.41	Patasi 1	0.46	0.51	1.01
Racecourse1	0.34	0.31	0.15	Patasi 2	0.3	0.43	0.24
Racecourse2	0.45	0.48	0.63	Patasi 3	0.47	0.51	0.74
Racecourse3	0.52	0.53	0.93	Sofoline 1	0.48	0.53	0.97
Racecourse4	0.58	0.47	0.93	Sofoline 2	0.49	0.54	1.01
Bantama 1	0.47	0.52	1.01	Sofoline 3	0.51	0.52	1.11
Bantama 2	0.37	0.59	0.38	Danyame 1	0.5	0.52	1.46
Bantama 3	0.46	0.53	0.57	Danyame 2	0.47	0.53	0.97
Aboabo 1	0.32	0.44	0.19	Danyame 3	0.38	0.49	0.3
Aboabo 2	0.4	0.29	0.63	Dakodwom 1	0.46	0.52	1
Aboabo 3	0.72	0.51	1.73	Dakodwom 2	0.36	0.47	0.46
Aboabo 4	0.69	0.49	1.75	Dakodwom 3	0.46	0.52	1.11
Aboabo 5	1	0.28	0				
Dichemso 1	0.39	0.47	0.37				
Dichemso 2	0.52	0.55	1.04				
Dichemso 3	0.43	0.52	0.77				

Table 15: Concentration of BaP in surface soil from the Kumasi Metropolis

sample site	BaP conc.	sample site	BaP conc.	sample site	BaP conc.
Ayigya 1	0.45	Ashtown 1	54.05	Tafo 3	0.58
Ayigya 2	0.8	Ashtown 2	115.72	Tafo 4	0.43
Ayigya 3	2.61	Ashtown 3	29.38	Tafo 5	18.17
Bomso 1	0.9	Ashtown 4	6.15	Tafo 6	0.46
Bomso 2	0.52	Mbrom 1	190.12	Tafo Nhyiaeso 1	13.3
Bomso 3	1.08	Mbrom 2	60.22	Tafo Nhyiaeso 2	1.75
Susuanso 1	0.24	Mbrom 3	56.13	Tafo Nhyiaeso 3	1.86
Susuanso 2	7.8	Race course1	16	Ahinsan 1	0.78
Susuanso 3	3.07	Race course2	3.59	Ahinsan 2	0.21
Oforikrom 1	1.74	Race course3	6.42	Ahinsan 3	0.79
Oforikrom 2	2.11	Race course4	2.06	Atonsu 1	0.14
Oforikrom 3	19.87	Bantama 1	1.73	Atonsu 2	0.72
Afunkwanta 1	4.94	Bantama 2	0.83	Atonsu 3	0.12
Afunkwanta 2	8.92	Bantama 3	9.42	Atonsu 4	4.26
Afunkwanta 3	12.91	Aboabo 1	2.54	Kaasi 1	2.34
Amakom 1	2.54	Aboabo 2	5.52	Kaasi 2	2.77
Amakom 2	8.35	Aboabo 3	0.37	Kaasi 3	10.65
Amakom 3	13.9	Aboabo 4	1.08	Ahodwo 1	2.22
Asafo 1	9.4	Aboabo 5	4.84	Ahodwo 2	2.48
Asafo 2	66.31	Dichemso 1	2.84	Ahodwo 3	1.62
Asafo 3	0.45	Dichemso 2	1.51	Asokwa 1	12.34
Asafo 4	10.69	Dichemso 3	9.48	Asokwa 2	1.36
Asafo 5	2.72	Yennyawoso 1	1.88	Asokwa 3	9.1
Roman hill 1	179.28	Yennyawoso 2	1.63	Asokwa 4	12.63
Roman hill 2	28.95	Yennyawoso 3	3.71	Suntreso 1	151.26
Roman hill 3	260.84	Krofrom 1	18.67	Suntreso 2	52.96
Central market 1	8.45	Krofrom 2	5.11	Suntreso 3	154.45
Central market 2	15.98	Krofrom 3	2.7	Suntreso 4	3.74
Centralmarket 3	21.16	Krofrom 4	30.35	Patasi 1	7.19
Kejetia 1	66.27	Suame 1	179.92	Patasi 2	7.66
Kejetia 2	33.07	Suame 2	95.58	Patasi 3	120.87

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Kejetia 3	18.92	Suame 3	3.26	Sofoline 1	8.29
Adum 1	112.83	Suame 4	2.49	Sofoline 2	38.99
Adum 2	38.24	Suame 5	7.3	Sofoline 3	156.06
Adum 3	839.86	Suame 6	24.71	Danyame 1	63.87
Adum 4	46.9	Anomangye 1	5.35	Danyame 2	49.86
Asuasi 1	94.51	Anomangye 2	2.58	Danyame 3	18.97
Asuasi 2	11.1	Anomangye 3	5.52	Dakodwom 1	45.7
Asuasi 3	6.73	New Suame 1	4.33	Dakodwom 2	8.93
Asuasi 4	67.7	New Suame 2	1.36	Dakodwom 3	77.36
Manhyia 1	160.48	New Suame 3	1.84		
Manhyia 2	46.93	Tafo 1	15.18		
Manhyia 3	7.2	Tafo 2	0.44		

Table 16: Mean Concentrations of BaP in the surface soils from the Kumasi Metropolis

sample site	average BaP	SD
Ayigya	1.29	1.16
Bomso	0.83	0.29
Susuanso	3.70	3.82
Oforikrom	7.91	10.36
Afunkwanta	8.92	3.98
Amakom	8.26	5.68
Asafo	17.91	27.40
Romanhill	156.36	117.63
Central market	15.20	6.39
Kejetia	39.42	24.30
Adum	259.46	388.37
Asuasi	45.01	43.13
Manhyia	71.54	79.55
Ashtown	51.32	47.18
Mbrom	102.16	76.20
Racecourse	7.02	6.26
Bantama	3.99	4.72
Aboabo	2.87	2.26
Dichemso	4.61	4.27
Yennyawoso	2.41	1.14
Krofrom	14.21	12.85
Suame	52.21	71.88
Anomangye	4.48	1.65
New Suame	2.51	1.59
Tafo	5.88	8.42
Tafo Nhyiaeso	5.63	6.64
Ahinsan	0.59	0.33
Atonsu	1.31	1.99
Kaasi	5.26	4.68
Ahodwo	2.10	0.44
Asokwa	8.86	5.25
Suntreso	90.60	74.65
Patasi	45.24	65.50
Sofoline	67.78	77.98
Danyame	44.23	22.97
Dakodwom	44.00	34.25

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Table 17: Mean Concentration of PAHs in the surface Soils from the Sampling Communities in Kumasi.

MEAN																				
sample site	Nap	Acl	Ace	Fle	Phe	Ant	Methy-Phe	Me-Phe	Flu	Pyr	Retene	BaA	Chr	BbF+BkF	BeP	BaP	Peryl	DBahA	IDP	BghiP
Ayigya	0.00	0.19	0.00	0.34	2.01	0.27	0.27	0.07	3.41	2.71	0.78	1.34	0.93	1.76	1.50	1.29	0.40	0.38	1.01	1.05
Bomso	1.44	0.41	0.05	0.35	2.17	0.45	0.25	0.72	1.66	1.64	0.76	0.61	0.89	1.21	2.14	0.83	0.38	0.61	1.41	3.88
Susuanso	5.32	1.55	0.13	0.95	7.85	1.99	0.65	0.95	5.37	6.14	2.05	2.71	2.93	3.26	7.41	3.70	1.24	1.62	6.16	13.97
Oforikrom	7.95	2.79	0.35	1.56	24.18	5.48	3.27	2.11	35.70	30.14	2.80	12.89	8.24	10.17	9.47	7.91	1.86	0.66	7.54	7.85
Afunkwanta	6.45	1.94	0.07	0.86	7.17	1.19	1.19	1.04	15.68	16.25	2.85	7.74	5.87	10.58	12.34	8.92	3.25	1.40	12.11	16.78
Amakom	6.37	4.20	0.14	1.26	12.23	2.17	0.92	0.88	36.07	27.61	2.61	7.70	6.90	9.95	12.06	8.26	2.54	0.88	9.52	16.83
Asafo	10.27	2.33	0.39	1.26	15.40	4.50	5.70	3.86	58.66	48.89	3.29	14.97	5.37	20.50	17.04	17.91	5.10	1.88	19.71	26.20
Romanhill	13.28	9.77	3.92	5.52	95.86	15.11	15.11	10.84	188.40	179.07	25.21	148.20	80.41	161.97	159.21	156.36	57.62	16.95	148.15	156.81
Central market	15.67	2.50	0.44	2.54	14.26	3.13	4.50	2.38	31.25	22.88	32.39	18.40	9.38	19.89	21.42	15.20	5.81	2.81	17.95	28.40
Kejetia	0.01	2.54	0.80	2.14	17.09	4.66	4.66	2.28	56.68	45.84	19.03	34.24	19.45	42.44	46.36	39.42	14.09	6.13	55.15	52.90
Adum	16.69	21.23	1.56	3.12	55.99	25.31	9.03	4.17	230.01	212.72	4.96	102.11	60.02	298.05	276.89	259.46	81.41	18.90	188.85	214.38
Asawasi	3.96	3.72	0.68	2.01	22.89	4.20	4.20	2.24	73.57	56.17	5.15	43.72	24.58	51.28	45.57	45.01	15.54	4.95	39.69	42.39
Manhyia	3.97	5.11	1.20	1.50	25.84	6.84	6.84	2.17	90.38	70.17	4.38	66.40	34.24	71.39	61.46	71.54	24.79	8.98	56.11	55.07
Ashtown	5.07	3.49	0.39	1.00	14.21	4.31	2.86	1.76	57.49	51.91	3.09	46.20	22.48	50.18	46.49	51.32	18.74	6.60	43.02	45.49
Mbrom	5.41	12.90	25.09	11.11	143.14	39.60	35.17	13.34	280.64	250.81	7.21	206.69	100.65	91.80	85.36	102.16	37.74	10.07	80.98	80.27
Racecourse	1.94	2.85	1.71	8.84	63.97	10.10	25.35	25.38	38.94	75.92	26.98	10.23	10.24	10.18	12.15	7.02	2.83	1.88	17.66	30.52
Bantama	0.00	0.87	0.08	1.12	5.94	1.04	0.89	0.76	10.26	8.98	2.02	4.01	3.19	5.47	6.45	3.99	1.37	0.74	5.62	6.81
Aboabo	4.01	1.42	0.17	1.24	11.39	4.79	1.35	3.06	10.86	21.65	20.52	3.76	5.06	4.23	8.04	2.87	1.10	0.14	4.08	4.52
Dichemso	8.05	0.66	0.07	0.87	4.97	0.63	0.63	0.71	6.70	6.33	2.25	3.18	2.30	5.29	5.95	4.61	1.79	0.68	5.32	7.21
Yennyawoso	0.00	0.39	0.07	0.92	5.09	1.00	1.25	1.23	5.67	6.82	2.21	2.08	1.65	3.21	4.25	2.41	0.86	0.30	3.30	5.81
Krofrom	12.22	2.27	0.96	2.58	20.31	5.87	3.84	5.00	30.44	30.68	8.70	12.95	8.90	16.73	16.00	14.21	4.50	1.18	13.31	16.48
Suame	9.33	7.10	7.08	5.61	208.40	25.29	10.71	9.37	381.34	355.12	10.55	107.69	62.56	57.42	51.51	52.21	13.60	9.67	48.17	82.4

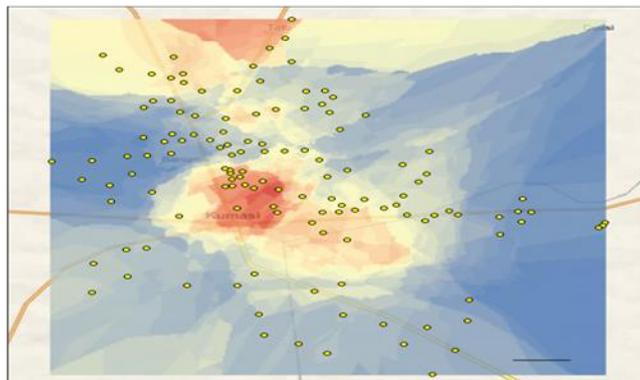
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Anomangye	6.61	1.59	0.21	2.80	19.06	1.59	1.59	5.64	30.03	34.36	11.71	5.68	9.40	9.78	15.28	4.48	3.69	1.12	7.09	23.84
New Suame	2.10	0.47	0.06	0.78	4.56	0.62	0.64	0.53	5.91	4.66	3.90	2.54	2.17	3.92	3.67	2.51	0.93	0.35	1.92	0.20
Tafo	11.5 ₈	1.05	0.30	1.85	16.40	3.10	2.25	3.10	31.00	31.40	18.99	7.64	6.87	4.61	5.79	5.88	2.45	0.84	7.79	17.92
Tafo Nhyiaeso	7.06	1.72	0.24	1.66	12.91	3.77	6.82	8.98	11.57	37.23	11.10	6.86	6.29	8.05	9.28	5.63	0.66	0.31	3.75	5.66
Ahinsan	0.74	0.22	0.06	0.25	0.90	0.29	0.11	0.08	1.13	1.04	0.25	0.60	0.49	0.92	0.95	0.59	0.24	0.27	0.56	1.16
Atonsu	0.00	0.83	0.04	0.57	3.73	0.52	0.52	0.37	3.93	3.68	2.24	1.27	1.21	2.04	1.93	1.31	0.36	0.18	1.23	1.50
Kaasi	9.66	2.24	0.43	0.92	9.60	2.55	0.86	0.70	13.45	15.43	1.06	4.54	4.03	7.37	9.37	5.26	1.86	0.46	7.26	18.78
Ahodwo	0.38	0.79	0.07	0.64	3.31	0.43	0.49	0.37	5.26	6.88	1.86	1.97	2.95	3.41	5.46	2.10	1.00	1.60	4.60	6.61
Asokwa	12.2 ₅	12.8 ₁	0.26	2.47	20.78	4.34	2.70	1.93	31.14	31.60	5.38	7.39	7.74	10.26	13.83	8.86	2.87	1.11	13.32	30.39
Suntreso	1.67	11.7 ₈	2.18	2.59	59.25	17.1 ₃	8.79	6.48	209.2 ₉	176.5 ₅	5.20	109.3 ₈	51.56	94.36	76.29	90.60	28.43	12.97	99.84	106.4 ₀
Patasi	9.22	3.04	0.48	1.23	15.39	3.73	3.73	1.77	53.46	52.51	3.71	37.17	20.85	45.62	46.47	45.24	16.67	5.53	54.63	67.66
Sofoline	0.00	2.89	0.81	1.02	33.49	9.27	9.27	3.17	106.1 ₇	95.89	1.81	79.59	39.14	65.54	65.57	67.78	25.32	9.37	64.55	62.47
Danyame	3.87	2.23	0.69	1.07	19.07	3.77	3.77	2.19	73.08	68.03	4.19	37.55	22.58	44.66	43.47	44.23	15.49	5.25	42.58	52.42
Dakodwom	2.14	2.51	0.36	0.98	11.96	3.39	2.32	1.62	57.11	54.56	4.89	35.60	19.88	49.96	43.98	44.00	16.42	4.46	36.39	45.04

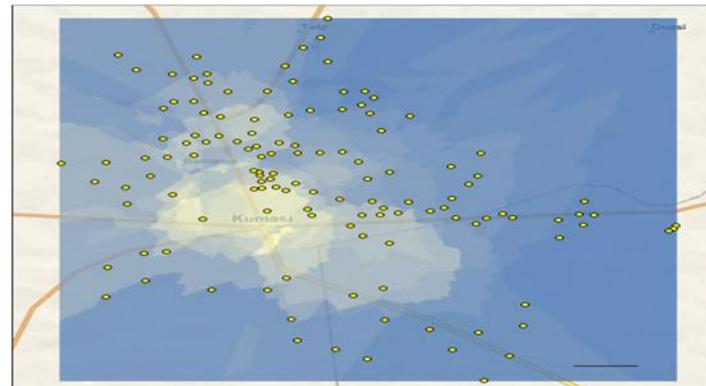
APPENDIX 4

Figure 4.24: Distribution Maps for the Various PAHs in Surface Soil from the Kumasi Metropolis.

Nap



AcI



Ace



Fle

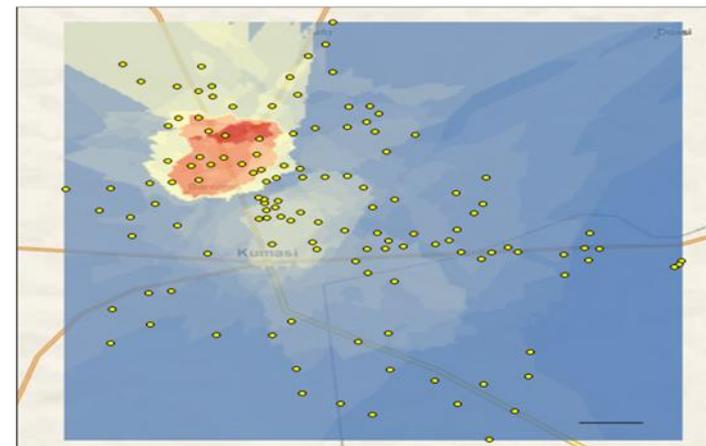
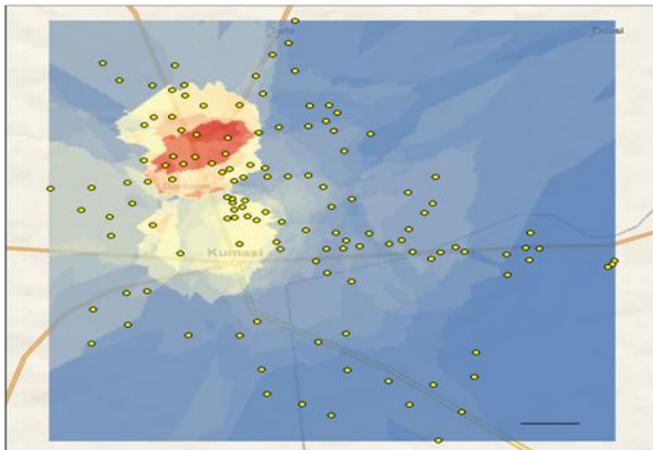
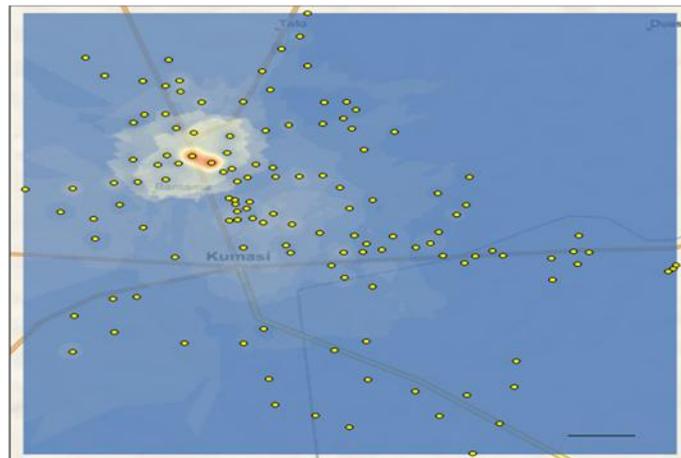


Figure 4.25: Distribution Maps for the Various PAHs in Surface Soil from the Kumasi Metropolis

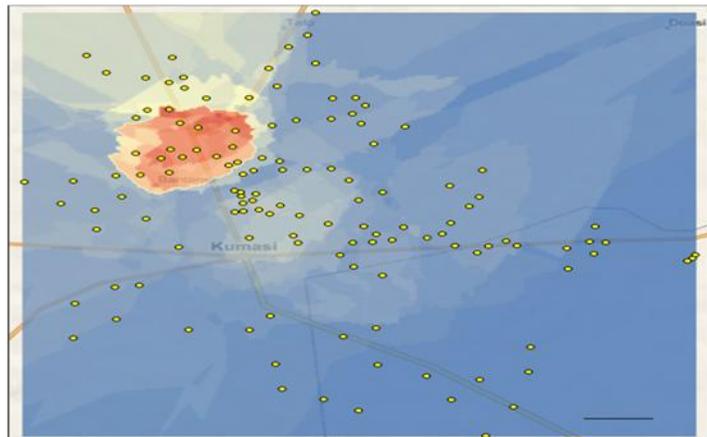
Ant



Methy-Phe



Me-Phe



Phe

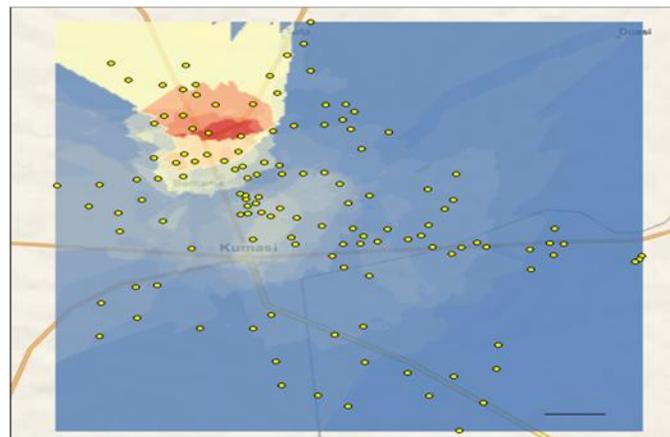
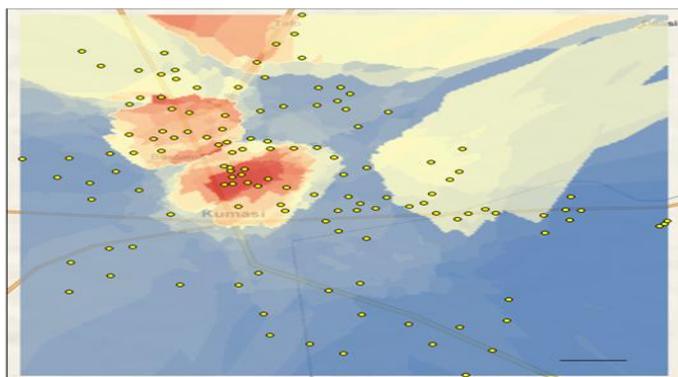
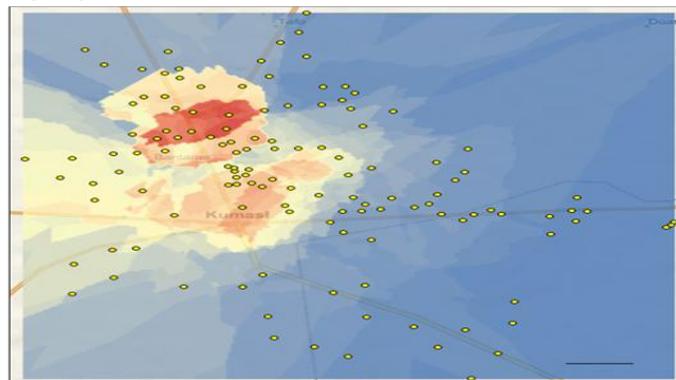


Figure 4.26: Distribution Maps for the Various PAHs in Surface Soil from the Kumasi Metropolis.

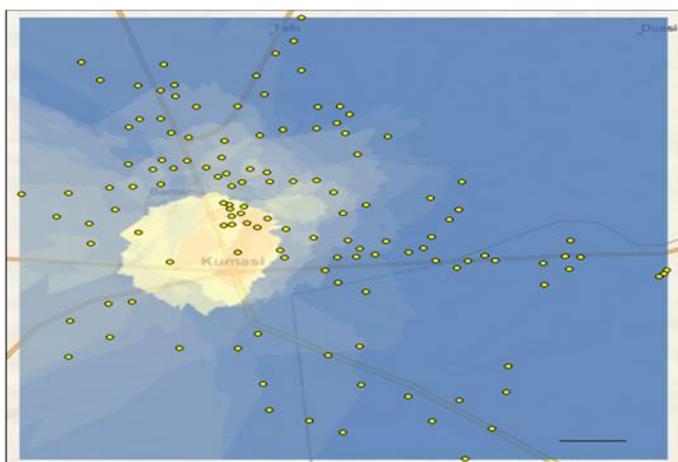
Ret



ChryTrip



Pery



DBahA

