UNIVERSITY OF GHANA, LEGON

COLLEGE OF BASIC AND APPLIED SCIENCE

INDOOR AIR QUALITY ASSESSMENT. A PILOT STUDY AT THE UNIVERSITY OF GHANA

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL CHEMISTRY DEGREE

DEPARTMENT OF CHEMISTRY

OCTOBER, 2020

DECLARATION

I, ADDO RICHARD YEBOAH hereby declare that this submission is my work, under the supervision of the under listed lecturers towards the award of MPhil Chemistry degree in the Chemistry Department of the University of Ghana, and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ACKNOWLEDGEMENT

I am happy and sincerely thankful to the Almighty God, creator of Heaven and Earth for the strength, wisdom and fortitude he bestowed in me during the conduct of this research.

My profound gratitude goes to my Supervisors, Dr. E. Y. Osei-Twum and Prof Augustine K Donkor whose advice, directions, and constructive criticism made this work a success.

I am also indebted to all those who supported me in diverse ways especially in acquisition of the right data for this project work.

Finally, my appreciation goes to all my family and friends for their prayers and encouragement.

ABSTRACT

Polycyclic Aromatic Hydrocarbons (PAHs) are a class of unique carcinogenic and mutagenic pollutants and are the byproducts of incomplete combustion of organic materials such as fossil fuels, wood and tobacco. PAHs are distributed in the environment (i.e. air, soil and water). The health effects of PAHs are driven by exposure. Assessment of human exposure to PAHs in ambient air can be accomplished by monitoring the concentration of PAHs in the environment. The concentrations and compositional patterns of the 16 PAHs prioritized by US Environmental Protection Agency (EPA) were determined in organic film on glass window surfaces in different buildings on University of Ghana (UG) campus with the view of providing the information on the extent of contamination, sources of pollution and human health risk of PAHs in the organic film. The analyses were performed by means of GC-MS after soxhlex extraction with hexane and acetone (1:1). The concentration levels of the 16 USEPA PAHs in the organic film ranged from 126.8µg/kg to 628.8µg/kg with a mean value of 336 ± 190 µg/kg. A concentration gradient of the total PAHs was observed as follows; African Studies Department Library> Jones Quartey> Sarbah Dining Hall> Balme Library> Central Cafeteria> University of Ghana Basic School> Chemistry Lower Lecture Theater. The distribution was characterized by 2-4 rings PAHs contributing about 82% of the total PAHs in the studied area. Assessment of their sources using diagnostic ratio showed that emission of PAHs was mostly from fossil fuel combustion. The $\sum_8$PAH (carcinogenic) concentration ranged from 38.9µg/kg to 75µg/kg. The estimated BaP$_{eq}$ (Cancer Risk Level) varied from 13.0µg/kg to 17.7µg/kg. The results show low BaP$_{eq}$ as compared to 600µg/kg which according to Canadian ministry of Ecology corresponds to a carcinogenic risk for persons (based on an incremental lifetime cancer risk (ILCR) of 10^{-6}).

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LIST OF ABBREVIATIONS

ACE: Acenaphthene

ACY: Acenaphthylene

ANT: Anthracene

ATSDR: Agency for Toxic Substances and Disease Registry

BaA: Benzo(a)anthracene

BaP: Benzo(a)pyrene

CHR: Chrysene

DBA: Dibenzo(a,h)anthracene

DNPH: Dinitrophenyl hydrazine

FLT: Fluoranthene

FLU: Fluorene

GC-MS: Gas Chromatography- Mass Spectrometry

HMW: Higher Molecular Weight

HPLC: High Performance Liquid Chromatography

IAQ: Indoor Air Quality

IND: Indeno(1,2,3-c,d)pyrene

IARC: International Agency for Research Cancer

LMW: Lower Molecular Weight

NAP: Naphthalene

PAH: Polycyclic Aromatic Hydrocarbon

PHE: Phenanthrene

POP: Persistent Organic Pollutant

PYR: Pyrene

PM: Particulate Matter

SVOC: Semi volatile organic compound

TEF: Toxic Equivalency Factor

TEQ: Toxic Equivalent Quotient

TVOC: Total Volatile Organic Compound

UG: University of Ghana

UN: United Nations

USEPA: United States Environmental Protection Agency

VOC: Volatile Organic Compound

VVOC: Very Volatile Organic Compound

WHO: World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background

Air pollution has turned out to be one of the most worrying environmental concerns in urban areas throughout the world, particularly in developing countries (Mayer, 1999; Faiz and Sturm, 2000). According to the United Nations (UN), majority of the world's seven billion inhabitants lives in urban areas and occupies just about 3% of the earth's land mass. Sub-Saharan Africa (SSA) is said to have the fastest urbanization rate in the world. Numerous cities across SSA including Ghana have experienced rapid urbanization, industrialization and motorization over the last decade and due to lack of economic resources and low levels of income to deal with the associated challenges, cities in SSA have being included among the greatest polluted places in the world (UNEP, 2012).

Air pollution is the introduction into the atmosphere of a substance (i.e. chemicals or compounds and biological materials) which has a poisonous effect, and can cause uneasiness, ailment, or death to humans and other living organisms, or cause damage to the climate while indoor air quality (IAQ) is the standard of air inside buildings and structures particularly as it is represented by levels of pollutants that have numerous effect on the health and wellbeing of its occupants. Indoor air can be categorized as of acceptable quality when it contains no known pollutants at unsafe concentration and a significant majority of the populace exposed thereto do not express dissatisfaction or develop ailment over a period of time. In Ghana air pollution is driven by rapid population growth and urbanization in cities such as Kumasi and Accra. Several activities such as construction, biomass combustion and vehicular emissions are major contributors. The health effects of pollution range from headache, nausea, vomiting, cancer etc.

According to WHO (2016), as of September 2018, more than 28,000 deaths were attributed to air pollution in Ghana. Pollution of the air with different chemicals is determined by the source of emission. Anthropogenic sources (i.e. cooking, traffic and industrial emissions) and natural sources (including bushfires and volcanic eruptions) are major sources of ambient air pollutants. Others including greenhouse gases, trace elements and volatile organic compounds, are contaminants that originates from human activities. According to Vallero (2014), processes such as chemical reactions and transformations, local meteorological conditions and long range transport can affect both the indoor and outdoor air quality.

Indoor air in buildings represent a combination of outdoor contaminants related to industrial activities and vehicular traffic which can enter the buildings by infiltrations via mechanical and natural aeration systems as well as indoor pollutants, which are generated inside the building from emissions from building materials and furnishings, combustion sources (e.g. burning fuels), behavior of building occupants (e.g. smoking, painting, etc.) and others. According to Sharpe, (2004) and Triantafyllou *et al,* (2007), most people spend about 60-90% of their time indoors (e.g. office, workplace, school and house) and as such more attention is needed in the study of indoor air quality even though the outside air is also hazardous.

Poor air standard has been revealed to negatively influence the wellbeing of people in many ways. Generally, respiratory systems are affected, leading to shortness of breath, coughing and sneezing. Other symptoms of terrible air include fatigue, headache and dizziness. Chronic effects leads to heart related ailment, respiratory disease, cancer and other (Dockery et al., 1993; Li et al., 2003; Viegi et al., 2004; and Mitchell et al., (2007). Particularly hazardous for human wellbeing with well-established carcinogenic and mutagenic potency are polycyclic aromatic hydrocarbons

(PAHs) and their derivatives. The sizable occurrence of PAHs and their derivatives in the surroundings including soil, water and air are linked to their formation.

Polycyclic aromatic hydrocarbons has been classified as part a group called persistent organic pollutants (POPs). According to Wang et al, (2013), these contaminants have the ability to cause adverse environmental effects, are resistant to degradation and can stay longer in the environment. They are the by- product of the incomplete combustion and pyrolysis of organic matter. PAHs are ubiquitous pollutants in the atmosphere and the amount in the environment has been substantial due to emissions from industrial processes, motor vehicular traffic and incineration of refuse. PAHs in the surroundings present a major risk to humans, owing to their intake into the human system by ingestion of food, through the respiratory system or the skin. Exposure to PAHs and their derivatives may possibly lead to short term ailment such as headache, irritation of eyes and nose etc. and long-term health effects including cardiovascular and respiratory diseases (WHO 2014). The recent data indicates that benzo (a) pyrene (BaP) and PAHs mixtures including tobacco smoke, household combustion of coal, and fumes from petrol and diesel engine are classified to group 1 as carcinogenic to humans (IARC 2016).

Urban impervious surfaces including roofs, pavement, and glass are characteristic products of high urbanization. Organic films have been found to develop on impervious surface like glass window. According to Diamond et al. (2000), the organic film is formed from atmospheric sources, especially emissions of organic compounds and their derivatives that occur at higher concentrations in ambient air. Once the film is formed, particles accumulate at a faster rate due to the film's "greasy" nature, and this has been proposed to be an effective passive sampler for air pollutants such as PAHs as concluded Law and Diamond (1998).

Thus, the film acts as a dynamic sink for wide range of chemicals including PAHs as suggested by Diamond et al. (2000). The particulate and gaseous phase air pollutants, are absorbed into the organic film and then released into the air (Diamond et al. 2001).

Ghana is arguably one of the fast-developing countries on the African continent. However, this fast-economic growth seem to have influence a gradual surge in air pollution in the country. According to AirVisual's 2019 World Air Quality Report, Ghana in terms of air pollution levels is the second-worst on the African continent. The annual mean concentrations of particulate matter ($PM_{2.5}$) in Ghana is 31.1µg/m^3, this surpasses the WHO annual recommended guideline for $PM_{2.5}$ of 10µg/m^3 by as much as three times. According to a report by WHO in 2018, more than 28,000 deaths were attributed to air pollution in Ghana as of September 2018. The Environmental Protection Agency (EPA) is the government body responsible for improving and protecting the environment in Ghana. The agency states on its website: "*It's our job to make sure that air, land and water are looked after by everyone in today's society, in order that tomorrow's generations inherit a cleaner, healthier world.*" Ghana's Environmental Protection Agency solely monitors particulate matter (PM). They do not monitor carbon dioxide, nitrogen dioxide gas or any gaseous pollutant like PAHs. To make matters worse, Ghana's Environmental Protection Agency does not release any sort of air quality warnings even when poor air standard is anticipated to negatively influence human health. Inadequacy of reliable data, exposure information, real-time air quality monitoring networks, and cognizance ought to be contributing to mortality and disease burden due to air pollution in Ghana.

The University of Ghana which was established in 1948 is the oldest public university with a population of over thirty-seven thousand as at December 2019, comprising both students and workers. It is located in Accra, Ghana's capital city, which according to all publicly available data has the worst air pollution in Ghana. Due to a significant upsurge in construction activities, electronic waste, biomass burning and vehicular activities, there is a possibility of airborne pollutants such as polycyclic aromatic hydrocarbons. However, because these contaminants can travel long distances, the populace can be at risk of suffering from bad air. However, information on indoor air quality i.e. PAHs levels in the organic film on window glass on university campus is lacking.

In the present study, fourteen samples were taken from glass window surfaces in buildings to determine the levels of PAHs and their sources in organic film on glass surfaces on the university of Ghana campus.

1.2 Problem Statement

Indoor air quality has attracted an awful lot of attention, as there has been considerable wide variety of research displaying their damaging consequences on human health and harm to the environment. Indoor air consists of a broad range of contaminants including outdoor pollutants which can enter buildings by way of infiltrations via ventilation systems as well as indoor contaminants, which originate from inside the building from deodorizers, combustion sources, off-gassing from building materials and furnishings, behavior of the occupants of building and others.

Numerous substances including gases (CO, CO_2), particulate matter, organic and inorganic contaminants etc. can affect the standard of air indoors. These air pollutants can get pass the body's defense systems, penetrating into the respiratory and circulatory system, damaging our lungs, heart and brain. The result is varied diseases encountered by occupants of buildings.

Thus, Accra is not an exception in this case. Accordingly measures to understand the IAQ situation in buildings in some areas in Accra is imperative. Closer examination of polycyclic aromatic hydrocarbons (PAHs) as organic film on glass surfaces of selected buildings at the University of Ghana was studied.

1.3 Aim of the Study

To determine the indoor air quality in terms of levels of PAHs in organic film on glass windows surfaces on University of Ghana campus.

1.4 Objectives of the Study

- To evaluate the contamination levels of PAHs on glass surfaces.
- To identify the possible source of PAHs using diagnostic ratio model.
- To evaluate the cancer risk levels of PAHs identified.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Numerous chemicals are released into ambient air by human and natural actions. Volcanic eruptions, fires etc., consist of natural sources of air pollution while anthropogenic sources include domestic activities, industrial processes, vehicular emissions and fossil fuel combustion. These organic pollutants remain intact in the environment for longer periods due to their resistance to degradation by chemical or biological means. These organic pollutants include pesticides, polycyclic aromatic hydrocarbons etc. Lohmann *et al.* 2007 states that, the bulk of these compounds are semi volatile in nature and can be conveyed over long distances in the environment, making them extensively circulated all over the globe.

2.2 Indoor Air Quality

The USEPA defines indoor air quality as “the air quality within and around buildings and structures, especially because it relates to the health and luxury of building occupants” (EPA, 2016a). According to WHO (2016), air pollution is related to a multiplicity of health concerns, ranging from short-term to long term serious diseases and even death. Poor air quality according to studies has been shown to worsen chronic respiratory diseases (diseases of the airway and lungs) (WHO, 2016). IAQ is mostly affected by gaseous substances including carbon monoxide, particulate matter, microbial contaminants (bacteria, mold etc.), and volatile organic compounds (formaldehyde). In the midst of these several air contaminants that are released by a variety of indoor sources, the ones that have attracted greater consideration due to its carcinogenic and mutagenic potencies according to Han and Naeher (2006) are particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), heavy metals example lead, volatile organic compounds (VOCs), and carbonyls. The characteristic properties of those pollutants that are of significant interest are discussed in the following sections.

2.3 Volatile organic compounds (VOCs)

"Volatile organic compounds (VOCs) are defined according to the EU Directive 1999/13/ EC as organic compounds having a vapour pressure of 0.01kP at room temperature and low water solubility". The World Health Organization (WHO, 2000) defines VOCs as "group of organic compounds with boiling points ranging from 50 – 100 °C (lower limit) and 240 – 260 °C, (upper limit)". Some VOCs are harmful by themselves, including those that can cause cancer. VOCs can be found in the air indoors and outdoors. Some of the more familiar VOCs include toluene, benzene and formaldehyde. Combustion processes such as the use of kerosene heaters, tobacco smoking etc. constitute indoor sources of VOCs. Other sources include a host of home products and materials such as air fresheners, cosmetics and deodorants, pesticides, adhesives, paints, furnishing and clothing (Barroet et al., 2009, Demirel et al., 2014). Combustion activities involving high temperature grilling and frying are also sources of VOCs releases (Huang et al., 2011). Diesel emissions, industrial emissions and wood burning etc. also constitute outdoor sources of VOCs. The World Health Organization's definition of VOCs are put into the following classes.

Table 2.1: Classification of volatile organic compounds (WHO 2000)

Description	Abbreviation	Boiling Point (°C)	Example of chemicals
Very Volatile organic Compounds	VVOC	<0 to 50°-100	methyl chloride, butane,
Volatile organic Compounds	VOC	50-100 to 240-260	Formaldehyde, ethanol, Acetone.
Semi volatile organic Compounds	SVOC	240- 260 to 380 400	Pesticides Fire retardants

2.3.1 Sources of VOCs

Huge amounts of volatile organic compounds are emitted into the environs from anthropogenic and natural sources. Emission from vegetation, soil microbiota, marine environments, and geological hydrocarbon reservoirs are amongst the natural sources of atmospheric VOCs (Stavrakou *et al.* 2009, Sahu 2012). Fuel burning, vehicular emissions, solvents and evaporative loss are anthropogenic sources of ambient VOCs, with the emissions from traffic usually the principal source in urban areas (Ohura *et al.* 2006; Guo *et al.* 2004; Ho *et al.* 2002).

2.3.2 Indoor Sources of VOCs

A number of volatile organic compounds are found in indoor surrounding. Building materials, solvents, cleaning products, fungicides, adhesives, cosmetics, appliances, air fresheners etc. are the major sources of VOCs. Human actions, such as tobacco smoking, domestic heating, cooking, renovation and reconstruction are also a contributing factor to indoor VOCs as stated by Talapatra and Srivastava (2011) and Annesi-Maesano *et al. (*2013). Outdoor air containing VOCs that enter buildings from various outdoor sources also accounts for the total indoor levels of these compounds apart from the indoor sources that originate from inside the buildings. In the office environment, computers and printers are the major sources of VOCs while in residential buildings, smoking and cooking are the major contributors of VOCs. In the school environments, primary emission includes cleaning products, adhesives, resins of wood products, paints, polishes, sealants and coatings.

2.3.3 Health Effects of volatile organic compounds

The extent of VOCs to cause health problems differs from compounds that are highly toxic, to those with unknown health effect. The extent and nature of health effects, depends on several factors including duration and level of exposure. People are exposed to VOCs by ingestion, inhalation and dermal contact. Key signs and symptoms linked with exposure to VOCs through inhalation, ingestion or dermal contact include;

- Nose and throat discomfort
- Dyspnea
- Nausea
- dizziness
- Headaches

The health effects include the following; (Rumchev et al. 2007, WHO 2000).

- Irritation of the eye, nose, and throat.
- Damage to liver, kidneys and brain
- Loss of coordination
- Various types of cancer (blood, lung cancer)

Exposure to VOCs can be minimize by the following steps;

- Do not store opened containers of unused paints within the house.
- Increase ventilation when using products that emit VOCs.
- Use household products according to manufacturer's directions.

2.4 Particulate matter (PM)

"Particulate matter" also called particulate pollution is a "complex mixture of solid and liquid droplets found in air many of which are harmful". This complex mixture is made up of numerous components such as organic and inorganic particles, like smoke, soot, liquid droplets, pollen, and dust. These particles range noticeably in size, composition and origin. Particulate matter originates from many sources. These sources can be both natural and anthropogenic. Particulate matter can be released directly into the environment (primary particulate matter) or be formed in the environment from gaseous precursors such as oxides of nitrogen, sulphur dioxide etc. (secondary particulate matter). Natural sources of particulate matter include natural vegetation (plant fragments, microorganism, pollen, etc.), wildfires, windblown dust, and harmattan whiles anthropogenic sources of particulate matter include industrial emissions, vehicular emissions, heating, cooking, dust from disturbed land, wood burning, heavy duty diesel engine, agriculture, power plants, construction and demolition. The behavior of particulate matter in the atmosphere and its ability to cause harm to humans and other living organism depends on the following properties; (Morawska and Zhang, 2002).

- Size of the particles
- Composition and concentration
- Geographic location and season

According to Jantunen et al., (1999), the major sources of particulate matter occurring naturally are from dust storms, bush fires, volcanoes etc. Human activities such as industrial processes, burning of fossil fuel and road dust also generate a significant amount of particulate materials.

2.4.1 Effects of PM

2.4.1.1 Environmental Effects

High levels of particle pollution can be devastating to the environment since particles move over long distance by wind and settle on surfaces of water and other surfaces. Depending on the chemical configuration, the consequences on the surroundings may include;

- Depletion of soil nutrients
- Contributing to acid rain effects
- Affecting the diversity of ecosystems
- Damaging sensitive forests and farm crops

2.4.1.2 Health Effects

The particles size has a direct linkage to their potential for causing health harms to persons exposed to particulate matter. Several scientific studies have shown that exposure to particulate matter may cause the following health problems; (Oberdorster et al, 1992).

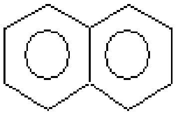
- Aggravated asthma
- Increased respiratory symptoms
- Decreased lung function
- Irregular heart beat
- Nonfatal hearts problems

2.5 Polycyclic Aromatic Hydrocarbons (PAHs)

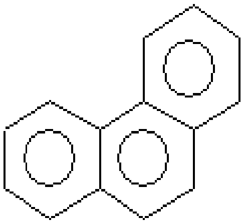
Polycyclic aromatic hydrocarbons (PAHs) are defined “as a group of complex organic chemicals, which contain carbon and hydrogen with fused benzene rings structure containing at least two benzene rings”. They belong to a class of persistent organic pollutants (POPs). They are the by-product of incomplete combustion of organic matter. PAHs are compounds that can resist degradation, can continue to be in the environs for longer periods, and have the possibility to cause adverse effect on the environs. As organic pollutants, they are of great concern due to their mutagenic and carcinogenic and mutagenic potency. The occurrence of PAHs is ubiquitous in the surroundings and they have been discovered in air, water, soils and other several number of consumer goods. (WHO 1998). Out of hundreds of PAHs identified, sixteen PAHs have been classified as having carcinogenic and mutagenic properties by the US EPA and are frequently studied.

PAHs can be grouped into two main groups based on of the number of rings found in each compound. Two or three ringed PAHs, such as Anthracene(Ant), Phenanthrene(Phe), Fluorene(Flu), Acenapthene(Ace), Acenapthylene (Acy) and Naphthalene (Nap), are called low molecular weight PAHs, while four to six ringed PAHs, such as Indeno (1,2,3-cd) pyrene (IcdP), Benzo(a)anthracene(BaA), Benzo(b)Fluoranthene(BbF), Dibenzo(a,h)anthracene(DahA), Benzo(g,h,i)perylene(BghiP), Fluoranthene(Flt), Pyrene(Pyr), Benzo(a)pyrene(BaP), Chrysene(Chr), are also called high molecular weight PAHs (US EPA, 2002).

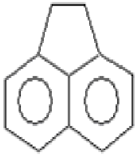
The molecular structures and physical characteristics of some USEPA defined priority PAHs are shown in Figure 2.1 and Table 2.2, respectively;



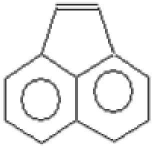
Naphthalene (Nap)



Phenanthrene (Phe)



Acenaphthene(Ace)



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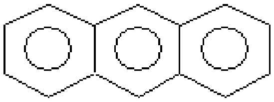
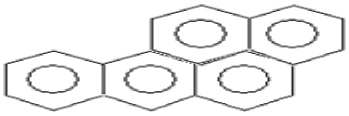
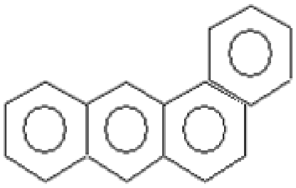


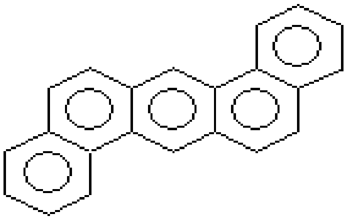
Anthracene (Ant)



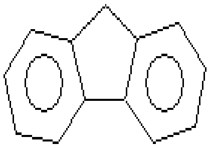
Benzo (a) pyrene (BaP)



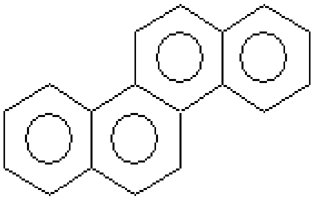
Benzo(a)anthracene(BaA)



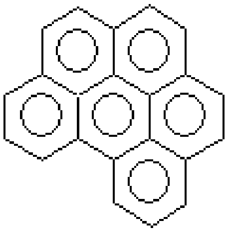
Dibenzo (a, h) anthracene (DahA)

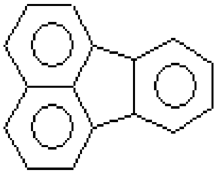


Fluorene (Flu)



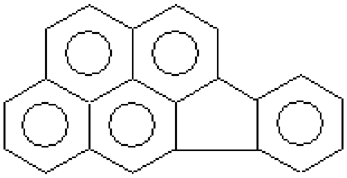
Chrysene (Chr)



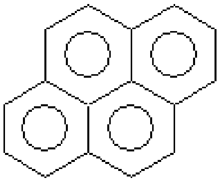


Fluoranthene(Flt)

Benzo (g, h, i) perylene(BghiP)



Indeno (1, 2, 3-cd) pyrene (IcdP)



Pyrene (Pyr)

Figure 2.1: molecular structures of some US EPA listed priority PAHs.

Table 2.2: Physical characteristics of the 16 listed priority PAHs (US EPA)

Compound	Formulae	Molecular Weight	Melting point (°C)	Boiling point (°C)
Naphthalene (Nap)	$C_{10}H_8$	128	80	218
Acenapthelene (Acy)	$C_{12}H_8$	152.20	92-93	265-275
Acenapthene (Ace)	$C_{12}H_{10}$	154	196	279
Fluorene (Flu)	$C_{14}H_{10}$	178	100	340
Anthracene (Ant)	$C_{14}H_{10}$	178	218	340
Fluoranthene (Flt)	$C_{16}H_{10}$	202	110	384
Pyrene (pyr)	$C_{16}H_{10}$	202	156	392
Chrysene (Chr)	$C_{18}H_{12}$	228	256	448
BaA	$C_{18}H_{12}$	228	162-167	435
BaP	$C_{20}H_{12}$	252	179	495
DahA	$C_{22}H_{14}$	278	267	524
BghiP	$C_{22}H_{12}$	276	273	-
BbF	$C_{20}H_{12}$	168	168	-
IcdP	$C_{22}H_{12}$	276.34	161.5-163	530

2.5.1 Sources and Emission of PAHs

"Polycyclic aromatic hydrocarbons" are largely released into the environment by the incomplete combustion of organic materials including coal, tobacco, wood, and industrial and vehicular emissions. Pyrogenic PAHs are typically formed during pyrolysis and incomplete combustion of organic materials at temperatures greater than 500°C. Polycyclic aromatic hydrocarbons mostly generated from this source have four to six (4-6) benzene rings such as pyrene, flouranthene, benzo (b) flouranthene, dibenz (ah) anthracene, benzo (k) flouranthene and benzo (a) pyrene. Petrogenic source of PAHs are formed over a long duration between the temperatures of 100-300°C and at high pressure environments where petroleum and coal is formed from organic matter. Petrogenic PAHs have two or three (2-3) fused rings, among them are flourene, naphthalene, acenaphthene, anthracene and its by-products.

The main sources of PAH emissions can be grouped into two, i.e. natural sources and anthropogenic sources.

2.5.1.1 Natural sources

Natural sources of PAHs formation such as forests and bush fires due to lightning strikes, decaying organic matter and volcanic eruptions (Baek et al. 1991). Natural sources of PAHs can be formed in the following methods ;(Prabhukumar 2011).

- High-temperature burning of organic matter.
- Direct biosynthesis by plants and microbes.

However, according to Lima et al. (2005), PAHs formed through combustion process have comparatively higher levels as compared to biosynthesis. The extent of natural PAH emissions may primarily depend on climatic conditions, such as temperature and humidity.

2.5.1.2 Anthropogenic Sources

PAHs are mostly generated from anthropogenic activities associated with incomplete combustion and pyrolysis of organic matter. Anthropogenic sources of PAHs are often divided into stationary (i.e. industrial and domestic sources), agriculture activities and mobile emissions.

2.5.1.3 Stationary Sources

2.5.1.3.1 Domestic Sources

The dominant sources of domestic PAHs are cooking and heating. The combustion of wood, garbage, oil, gas and other organic matter are the major contributor of domestic PAHs. Domestic emission are very significant suppliers to the entire emissions of PAHs in the surroundings. PAHs that are released from these sources may additionally be a key health problem due to their occurrence in the environment (Ravindra et al., 2006). As stated by the World Health Organization (WHO), about 75% of persons in India, South East Asia and China and 50-75% of the populace in Africa and parts of South American continent use wood, charcoal etc. for their daily cooking. Cooking, heating and infiltration from outdoors are the main indoor PAHs emissions. Research from Zhu et al., (2009) concluded that, “PAHs emissions associate with cooking account for 32.8% of total PAHs in residential homes”.

2.5.1.3.2 Industrial Sources

PAHs from the industries are emitted into ambient air during combustion processes such as cooking, coal and petroleum refining. As stated by IARC, 1989, emissions from petroleum refining mostly contain 2-3 fused ring PAHs depending on the process used. Consequently, the PAHs composition from petroleum refining (petrogenic) versus the PAHs composition from combustion (pyrogenic) can be broadly diverse. Other industrial emissions of PAHs are power generation, bitumen and asphalt industries, primary aluminum, wood preservation, coke production, rubber tire manufacturing, and waste incineration and cement manufacturing.

2.5.1.3.3 Mobile Sources

The main emissions of PAH in urban areas are from mobile sources. PAHs are largely released from exhaust fumes of vehicles, ships, aircrafts and other combustion processes. Releases of PAHs from exhaust of motor vehicles into the environment are formed by processes such as storage in engine deposits and in fuel, Synthesis from smaller molecules and aromatic compounds in fuel and pyrolysis of lubricant (Baek et al., 1991).

Vehicle exhaust fumes are the major contributor of PAHs levels in road dust and the urban areas. A report from Abrantes et al. (2009) states that the "total emissions of PAHs released from light-duty vehicles using ethanol as fuel are less than those using gasohol. For example, in ethanol vehicles, total Enrichment factors (EFs) of PAHs ranged from 11.7 to 27.4 µg/km whiles in gasohol vehicles, total EFs ranged from 41.9 to 612 µg/km."

2.5.1.3.4 Agricultural Sources

Open wood and straw burning are the main contributor of PAHs in agricultural the sector. All these activities consist of burning of organic matter under optimum combustion conditions. As a result, it is estimated that a considerable number of PAHs released into the atmosphere are the product from the open burning of biomass. PAHs levels generated from wood burning depend on the type of wood, combustion and kiln temperature. 80-90% of PAHs released from biomass combustion are low molecular weight PAHs; these include pyrene, flouranthene, phenanthrene, acenaphthylene and naphthalene.

2.5.2 Routes of Exposure

In indoors (homes or workplace) or outdoors air, people are sometimes exposed to dust and other particulate matter contaminated with PAHs. Sources of these human PAHs exposures include vehicle exhaust, cigarette smoke, agriculture burning, residential heating, industrial emission, processes and waste incineration. The United State Agency for Toxic Substance and Disease Registry states that, breathing in of air that contains PAHs from traffic emissions, wood smoke, tobacco smoke and consumption of PAHs contaminated food are the major exposures of the U.S. population to PAHs. Introduction of PAHs into the environment are through water, air, food and soil. The exposure of persons to ambient PAHs at traffic zones are mainly from breathing in of exhaust fumes from vehicles and road dust containing PAHs. Polycyclic aromatic hydrocarbons can enter our system through eating of food and drinking of water or skin contact. PAHs can be found in considerable amounts in foods, depending on the mode of cooking. PAHs are transported and accumulated in all tissues of the human body containing fat, and can be stored in liver and kidneys.

2.5.3 Sources of PAHs by Diagnostic Ratios

To evaluate and minimize the effects of PAHs, some specific compounds (diagnostic ratio) have been widely used to detect pollution emission sources. These ratios differentiate between pollution source emanating from biomass or coal burning, petroleum combustion and petroleum products. The PAHs diagnostic ratios used for this purpose include: “fluoranthene/(fluoranthene + pyrene), anthracene/(anthracene + phenanthrene), indeno[1,2,3-c,d]pyrene/(indeno[1,2,3-c,d]pyrene + benzo[g,h,i]perylene), and benzo[a]anthracene/(benzo[a]anthracene + chryzene)”. These compounds have the same molecular mass, so they are assumed to have similar physical and chemical properties – water solubility, vapour pressure, lipophilicity, and sorption coefficients

(Mark B. et al 2005). According to Tobizewski (2014), the PAH diagnostic ratios literature values based on parent PAHs are presented in Table 2.3.

Table 2.3 Characteristics values and their corresponding pollution sources.

Diagnostic Ratio	**Petrogenic**	**Fuel Combustion**	**Coal, Grass, Wood Burning**
FLT/(FLT+PYR)	<0.4	0.4-0.5	>0.5
ANT/(ANT+PHE)	<0.1	>0.10	-
IcdP/(IcdP+BghiP)	<0.2	0.2-0.5	>0.5
BaA/(BaA+CHR)	<0.2	>0.35	0.2-0.35

FLT (Flouranthene), PYR (Pyrene), ANT (Anthracene), PHE (Phenethrane), IcdP (Indeno (cd) Perylene), BghiP (Benzo (ghi) Pyrene), BaA (Benzo (a) Anthracene), CHR (Chrysene).

Table 2.4: PAHs ratios and their reported values corresponding to the originating source (Tobiszewskit et. al. 2012)

Diagnostic ratio	Values	Source	Reference
∑LMW/∑HMW	>1 <1	Petrogenic Pyrogenic	(Zhang *et al.* 2008)
Flu/(Flu + Pyr)	>0.5 <0.5	Diesel emissions Petrol emissions	(Ravindra *et al.* 2008b)
Ant/(Ant+ Phe)	>0.1 <0.1	Pyrogenic Petrogenic	(Pies *et al.* 2008)
Flt/(Flt+Pyr)	<0.4 0.4-0.5 >0.5	Petrogenic Fossil fuel combustion Grass, wood, coal combustion	(DeLaTorre-Roche *et al.* 2009)
BaA/(BaA+Chr)	<0.35 >0.2 <0.35	Coal combustion Vehicular emissions Petrogenic combustion	(Yunker *et al.* 2002, Akyüz and Çabuk 2008)
BaP/(BaP+BeP)	0.5 <0.5	Petrogenic Pyrogenic	(Oliveira *et al.* 2011)
IcdP/(IcdP+BghiP)	<0.2 0.2-0.5 >0.5	Petrogenic Petroleum combustion Grass, wood andcoal combustion	(Yunker *et al.* 2002)
BaP/BghiP	>0.6 <0.6	Traffic emissions Non-traffic emissions	(Katsoyiannis *et al.* 2011)

“PAHs - sum of total PAHs, ∑LWW – sum of low molecular weight PAHs, ∑HMW – sum of high molecular weight PAHs”

2.5.4 Toxicity Assessment of PAHs

PAHs are considered carcinogenic and mutagenic and are considered highly toxic for human beings. The health risk associated with inhalatory exposure to PAHs was assessed on the basis of Benzo(a)pyrene levels in ambient air and toxic equivalency factor (TEF) for individual PAH as developed by the U.S. Environmental Protection Agency (EPA) (Ramirez et al. 2011). "TEF represents the toxicity of an individual PAH compound relative to the reference chemical benzo(a)pyrene". TEF assessment is the most common method used to identify the toxicity of PAHs. TFTs are used to calculate the toxic equivalent concentrations (TEQ). To calculate the TEQ of a specific PAH, "its concentration is multiplied by the determined TEF value. The total potential carcinogenic potency of PAH mixtures in air samples is determined by summing up concentrations of individual PAHs, which are multiplied by the determined TEFs of individual PAHs" (Nisbet at el.1992).

$TEQ = (C_n \times TEF_n)$

Where:

TEQ= Toxic equivalent concentration

C_n = levels of individual PAH

TEF_n = Toxic equivalency factor of the individual PAH

Many organizations including US EPA, The International Agency for Research on Cancer (IARC), and the Department of Health and Human Services (DHHS) have classify certain PAHs as carcinogenic and mutagenic compounds. Table 2.5 highlights the carcinogenic classification of the 16 priority listed PAHs. IARC has classified Benzo[a]pyrene (BaP) as Group 1 (IARC 2010).

This has led to the extensive studies of BaP, as a marker for carcinogenic risk levels in environmental studies (Ramirez et al. 2011). According to Halek et at. (2008), the estimated lung cancer cases per year attributable to carcinogenic PAH compounds in 2005 was 58 persons per million.

Table 2.5**:** the 16 priority listed PAHs classified by IARC, DHHS and US EPA

PAHs	No. of ring	US EPA	IARC	DHHS
Naphthalene	2	-	2B	-
Acenaphthylene	3	No classification	-	-
Acenaphthene	3	-	3	-
Flourene	3	No classification	3	-
Phenanthrene	3	No classification	3	-
Anthracene	3	No classification	3	-
Fluoranthene	4	No classification	3	-
Pyrene	4	No classification	3	-
Chrysene	4	Probable carcinogen	2B	-
Benz[*a*]anthracene	4	Probable carcinogen	2B	Animal carcinogen
Benzo[*b*]flouranthene	5	Probable carcinogen	2B	Animal carcinogen
Benzo[*k*]fluoranthene	5	Probable carcinogen	2B	-
Benzo[*a*]pyrene	5	Probable carcinogen	1	Animal carcinogen
Dibenz[*a,h*]anthracene	5	Probable carcinogen	2A	Animal carcinogen
Benzo[*ghi*]perylene	6	No classification	3	-
Indeno[*1,2,3-cd*]pyrene	6	Probable carcinogen	2B	Animal carcinogen

“IARC classification: Group 1 (carcinogenic); 2A (probably carcinogenic); 2B (possibly carcinogenic); 3 (not classifiable)”.

2.5.5 Effects of PAHs

2.5.5.1 Environmental Effects

PAHs can enter the atmosphere mostly through emissions from domestic wood burning, volcanoes, forest fires and vehicular exhaust fumes and industrial releases. They can also enter surface water via discharges from waste water treatment plants and industrial plants. They can enter the soil from hazardous waste sites if they escape from storage containers. Polycyclic aromatic hydrocarbons move through the environment depending on how easily they dissolve in water, and how easily they evaporate into the air. PAHs in general have very low solubility in water. They are present in air as vapors or stuck to the surfaces of small solid particles. In soils, PAHs are most likely to stick tightly to soil particles. The relatively more volatile PAHs evaporate from surface soils into air. Certain PAHs in soils also contaminate underground water.

2.5.5.2 Health Effects

The effects of PAHs on human wellbeing depends largely on the length and extend of exposure and the inherent toxicity of the PAHs, and whether exposure occurs via ingestion (into the body through foodstuffs containing PAHs, such as charcoal-grilled meat), inhalation (of vehicle exhaust fumes, domestic PAH emissions or cigarette smoke); and skin adsorption. An array of other factors can also affect health impacts, including pre-existing health conditions and age. According to Collins et al; (1998) exposure to high level PAH mixtures has resulted in symptoms such as skin rash, eye irritation with redness, nausea, vomiting and diarrhea.

Chronic effects of PAHs exposure may include dermatitis, chronic bronchitis, liver and kidney damage, cataract and breathing problems, skin inflammation and chronic cough irritation as a result of long term exposure. Naphthalene to be specific, can cause breakdown of red blood cell if inhaled or ingested in large amounts (Collins et al; 1998).

Table 2.6: Summary of the effects of some Polycyclic Aromatics Hydrocarbons (Health%20eff%20of%20PAH%20Giri_Baddi_conference.pdf, accessed on May, 2019).

PAH	EFFECTS	REFERENCES
Anthrancene	Toxic, skin sensitizer, eye irritation, nausea, vomiting, diarrhea and confusion.	(ATSDR, 2009)
Acenaphthylene	Toxic, eye irritation.	(ATSDR, 2010)
Benzo(a)anthrance	Toxic, carcinogenic, heart malformations, childhood asthma, skin irritations.	(Luch, 2005)
Pyrene	Toxic, eye irritation	(ATSDR, 2009)
Benzo(a)pyrene	Carcinogenic, mutagenic, birth defects, decrease in body weight, toxic, skin irritants, heart malformations, childhood asthma eye irritation, nausea, vomiting, diarrhea and confusion.	(ATSDR,2009)
Chrysene	Toxic, Carcinogenic, kidney and liver damage and jaundice cataracts.	(ATSDR,2009; Luch, 2005)
Benzo(k)fluoranthene	Toxic, Carcinogenic, Tumors of the gastrointestinal tract and lungs	(Cross et al 2010)
Benzo(j)fluoranthene	Toxic, Tumors of the breast, lungs.	(ATSDR, 2010)
Benzo(b)fluoranthene	Toxic, Carcinogenic.	(Luch, 2005)

Naphthalene	Toxic,Skinirritants, Breakdown of red blood cell, heart malformations, childhood asthma, eye irritation, nausea, vomiting, diarrhea and confusion	(ATSDR, 2009)
Dibenz(a,h)anthracene	Carcinogenic, toxic, cataracts, kidney and liver damage and jaundice cataracts	(ATSDR, 2009)
Indeno(1,2,3-cd)pyrene	Carcinogenic, toxic, increase in mammary tumors in rat kidney and liver damage and jaundice cataracts.	(ATSDR, 2009)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area and sample collection

Indoor samples were obtained from organic films which were collected from glass surface (glass window) of buildings at the University of Ghana main campus i.e. Sarbah Dining Hall (SDH), Balme Library (BL), Jones Quartey (JQ), Central Cafeteria (CC), University of Ghana Basic School (UGBS), African Studies Department Library (ASDL) and Chemistry Lower Lecture Theatre (CLLT). These buildings were selected because of the availability of glass windows and their frequent use by many students and other university community. All the buildings selected are ventilated by natural ventilation through open windows or mechanical ventilation using fan except ASDL and BL where there were air conditioners.

The samples were collected by cleaning the surface of windows with dichloromethane (DCM)-rinsed laboratory tissues (tissue papers). The laboratory tissues were pre-extracted with DCM. A 10-cm border was left around the outside of the window area to minimize contamination from window sealant materials or paints. The samples were collected from approximately 0.08- 0.1 m^2. Field blank was prepared by waving the laboratory tissues that had been wetted with DCM in the air until dry (Butt et al. 2004). The samples were covered with aluminium foil and brought back to the laboratory for extraction.

3.2 Chemicals

All solvents and chemicals used were of analytical and high-performance liquid chromatography (HPLC) grades. A composite standard solution of 18PAHs including acenaphthene(ANA), acenaphthylene (ANY), benzo(b)fluoranthene (BbF), benzo(k)fluoranthene (BkF), benzo(g,h,i)perylene (BPE), chrysene (CHR),fluoranthene (FLT), fluorene (FLU),naphthalene (NAP), phenanthrene (PHE), anthracene (ANT), benzo(a)- anthracene (BEA), benzo(j)fluoranthene (BjF), benzo(a) pyrene (BaP), benzo(e)pyrene(BeP), bibenzo(a,h)anthracene (BaA), indeno(1,2,3-cd)pyrene (IPY)and pyrene (PYR) was used as the internal standard mix and was obtained from Cambridge Isotope Laboratories (CIL, Andover, MA,USA). Silica (100–200 mesh), and alumina, manufactured by Baker (New Jersey, USA) were purchased from VWR Scientific (New York, USA). Acetone, hexane, DCM was also purchased from Macron chemicals USA. For a quantitative analysis the calibration curve of 6 different concentrations (from 5 to 200 µg/L) was constructed.

3.3 Sample preparation and analysis

The samples were extracted for PAHs using a procedure from Wang et al. (2012) which was slightly modified. Briefly, samples were extracted with 200 mL of mixed solvent [acetone and n-hexane (1:1, v/v)] for 20 hours using a Soxhlet apparatus. Extracts were concentrated using the rotary evaporator, and the samples were then purified by passing them through a silica– alumina column (activated silica: 8 g, 100–200 mesh; activated alumina: 4 g, 50–200 mesh). The target PAHs, were eluted with 100 mL of mixed solvent (DCM and n-hexane (3:7, v/v). Method blank was prepared following the same procedure. The PAHs eluent and Blank were reduced to 1 mL for gas chromatography/mass spectrometry (GC/MS) analysis.

3.4 GC-MS Instrumentation and Conditions

The PAHs compounds were separated and quantified using a Gas Chromatography (Agilent Technologies, USA) equipped with an Agilent Injector (Agilent Technologies, USA), a 30 m, 0.25 mm i.d. HP-5MS capillary column (Hewlett-Packard) coated with 5% phenyl-methylsiloxane (film thickness 0.25 µm) and an Agilent mass selective detector (MSD). The samples were injected in the splitless mode at an injection temperature of 300 °C. The column temperature was initially held at 40 °C for 1 min, raised to 120 °C at the rate of 25 °C/min, then to 160 °C at the rate of 10 °C/min, and finally to 300 °C at the rate of 5 °C/min, held at final temperature for 15 min. Detector temperature was kept at 280 °C. Helium was used as a carrier gas at a constant flow rate of 1 mL/min. Mass spectrometry was acquired using the electron ionization (EI) and selective ion monitoring (SIM) modes.

3.5 Identification and Quantification

Identity of each PAH in the samples was confirmed by the retention time and abundance of confirmation ions in the PAHs standards. Sixteen priority PAHs by the United States Environmental Protection Agency (USEPA) i.e. naphthalene (NaP), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Fluo), phenanthrene (Phe), anthracene (An), fluoranthene (Fl), pyrene (Py), benzo[a]anthracene (BaA), chrysene (Chry), benzo[b]fluoranthene (B[b]F), benzo[k]fluoranthene (B[k]F), benzo[a]pyrene (BaP), indeno[1,2,3-cd]pyrene (InP), dibenz[a,h]anthracene (DahA), benzo[ghi]perylene (BghiP) were quantified using the response factors related to the respective internal standards based on six-point calibration curve for individual compounds.

3.6 Quality Assurance and Quality Control

All data were subjected to strict quality control procedures. Field blanks and control method blanks were analysed to determine any background contamination.

3.7 PAHs Diagnostic Ratios for Identification of Pollution Emission Source

Polycyclic aromatic hydrocarbon contamination sources were identified by calculating diagnostic ratios (Table 2.3). These ratios distinguish PAHs pollution originating from petroleum products, petroleum combustion and biomass or coal burning. The compounds involved in each ratio have the same molar mass therefore it is assumed to they have similar physicochemical properties.

3.8 Toxicity equivalency factors (TEFs)

TEF evaluation is the most popular method used to identify the toxicity of PAHs. The toxic equivalency factor (TEF) was used to estimate the relative toxicity of individual chemical components. Toxicity associated with inhalation of PAHs is usually estimated on the basis of the Benzo(a) pyrene (BaP) concentration in the atmosphere. Usually, BaP is used as an indicator compound in health risk studies, as it is responsible for 50% of the carcinogenic potential of PAHs and scientific studies have shown it to be sufficient for establishing a limit value (Petry et al. 1996). In this study, the Nisbet and LaGoy (1992) approach was used to evaluate the toxicity of PAHs. Toxicity equivalency concentrations (TEQs) are calculated as the product of summing up the values obtained by TEF values and concentrations of PAHs, as follows:

$$\text{TEQ}= C_i \times TEF_i$$

$$TotalBaPeq = \sum \text{TEQ}$$

Where:

TEQ= toxic equivalent concentration

C_i= concentration of PAH for the individual PAH.

$BaPeq$= Benzo(a)pyrene equivalent concentration

3.9 Statistical Analysis

The statistical measurements, average, standard deviation and relative standard deviation were calculated using the MS excel software. The concentrations of the individual PAHs and total PAHs (TPAH) in the atmosphere resulting from GC-MS analysis were also treated using MS excel software.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Mass of Organic Film on Glass

The total mass of film (Table 4.1) varied according to how ‘‘dirty’’ the glass was. The mass of organic film ranged from 1.16g to 2.27g for the same area of glass window sampled. The mass of film for JQB was the highest with 2.27g followed by SDH with 2.16g and UGBS being the lowest with a mass of 1.24g. Research results have shown that a 10–1,000-nm thickness of organic film may be formed on an urban impervious surface (Law and Diamond 1998). The film mass and bulk film thickness are contributed by both organic and inorganic compounds.

4.2 PAHs in Organic Film

Overall sixteen PAHs were detected in the organic film samples. The concentrations of individual PAH are summarized in Table 4.1 and Figure 4.1-4.8 for each building. The total concentrations of the 16 PAHs ranged from 140.1µg/kg to 623.8 µg/kg for the different functional areas of UG campus. With the exclusion of naphthalene, the total concentration of the 15 PAHs in the film ranged from 113 µg/kg to 367.6 µg/kg (Table 4.1). This result indicates that PAHs tend to accumulate in organic film, which could be used as an indicator of environmental pollution.

The results showed predominance of naphthalene (Nap) among the 16 PAHs. Naphthalene recorded the highest concentrations ranging from 15.3µg/kg – 388.7nµ/kg (Table 4.1). The total concentration of naphthalene (Nap) was 890.5µg/kg with mean value of 127.2 µg/kg. Compared with two other indoor PAH studies in the US (Chaung et al., 1991; Van Wingle and Scheff, 2001), indoor naphthalene concentrations found in this study was lower. Van Wingle and Scheff (2001) found that indoor naphthalene emissions were largely associated with naphthalene ball (popularly called camphor in Ghana) usage, although in this study, no naphthalene ball usage was reported in any of the sampling locations. Naphthalene ball is usually used in many homes as insect repellent in Ghana. Studies by Wakefield (2007), Jia and Batterman (2010) reviewed the health effects of naphthalene as hemolytic anemia, damage to the liver and neurological damage, long term exposure by ingestion has been reported to cause cataracts. It is a hazardous pollutant according to U.S. EPA. The Department of Health and Humans Services (DHHS) also concluded that naphthalene is reasonably anticipated to be a human carcinogen. And the International Agency for Research on Cancer (IARC) (2016) also concluded that naphthalene is possibly carcinogenic to humans.

Following naphthalene, phenanthrene and anthracene were found to be the second highest in the film (Table 4.1). Although their presence was lower as compared to naphthalene, chronic exposure to these non-carcinogenic polycyclic aromatic hydrocarbons according to Environmental Health and Medicine education (2009) affects the pulmonary, gastrointestinal, renal and dermatological systems.

A concentration gradient of PAHs was observed as follows: African Studies Department Library> Jones Quartey> Sarbah Dining Hall> Balme Library> Central Cafeteria> University of Ghana Basic School> Chemistry Lower Lecture Theater (Fig. 4.9). This pattern may have been mainly due to the proximity of the sampling sites to the heavy traffic zone featured by heavy traffic flow at the entrance of the school, thus ASDL and SDH were closer to the traffic zone and therefore vehicle emissions are a major source of PAHs. This agrees with the findings made by (Liu et al, 2007) that concentrations of PAHs were higher at DHU (Donghua University) and SHU (Shanghai University) than in other educational areas because these two university campus are in close proximity to traffic lane.

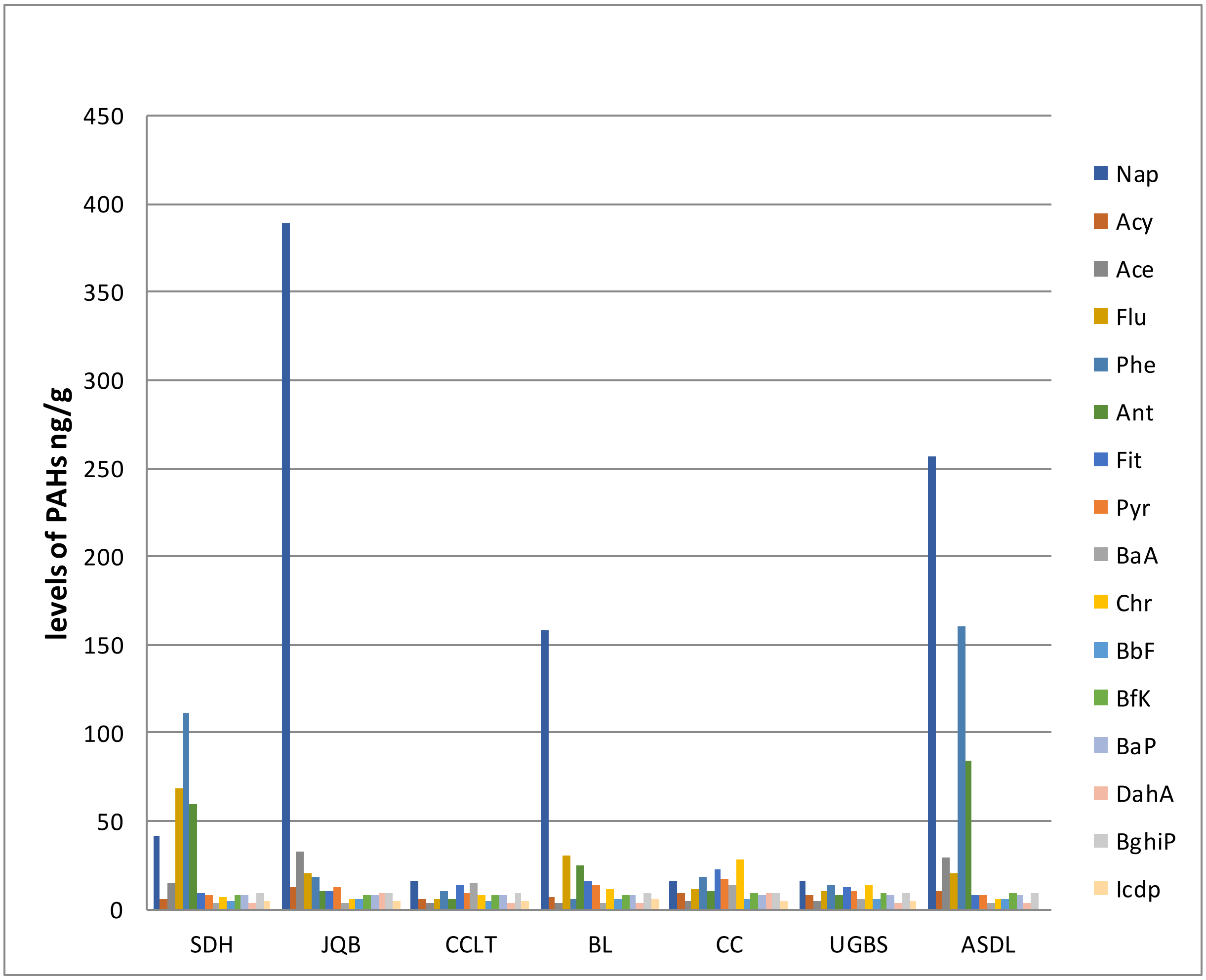


Fig. 4.1 Concentration of 16 PAHs in organic film from different functional areas. SDH, JQB, CLLT, CC, BL, UGBS and ASDL

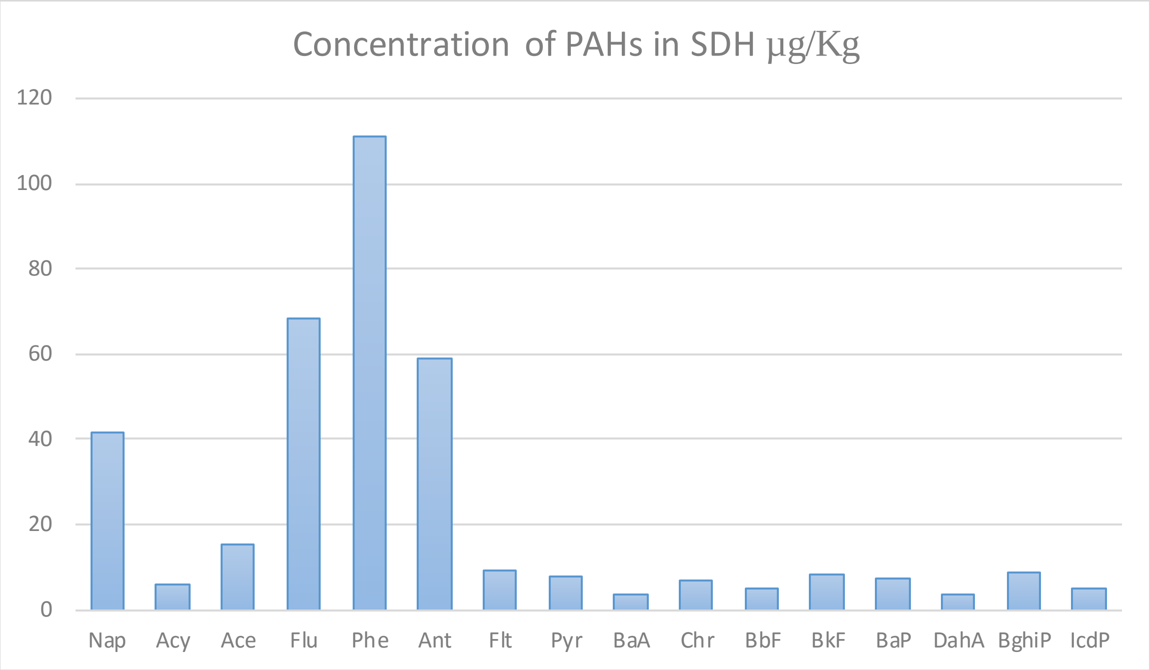


Fig. 4.2 Concentration of PAHs in Sarbah Dining Hall

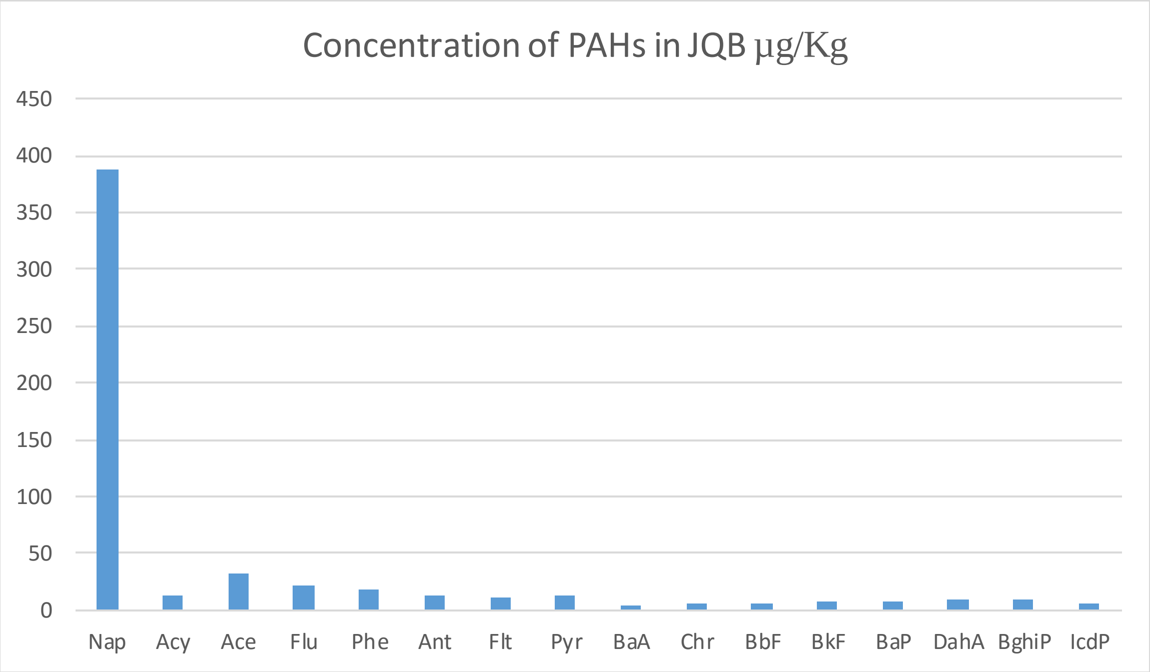


Fig. 4.3 Concentration of PAHs in Jones Quartey Building

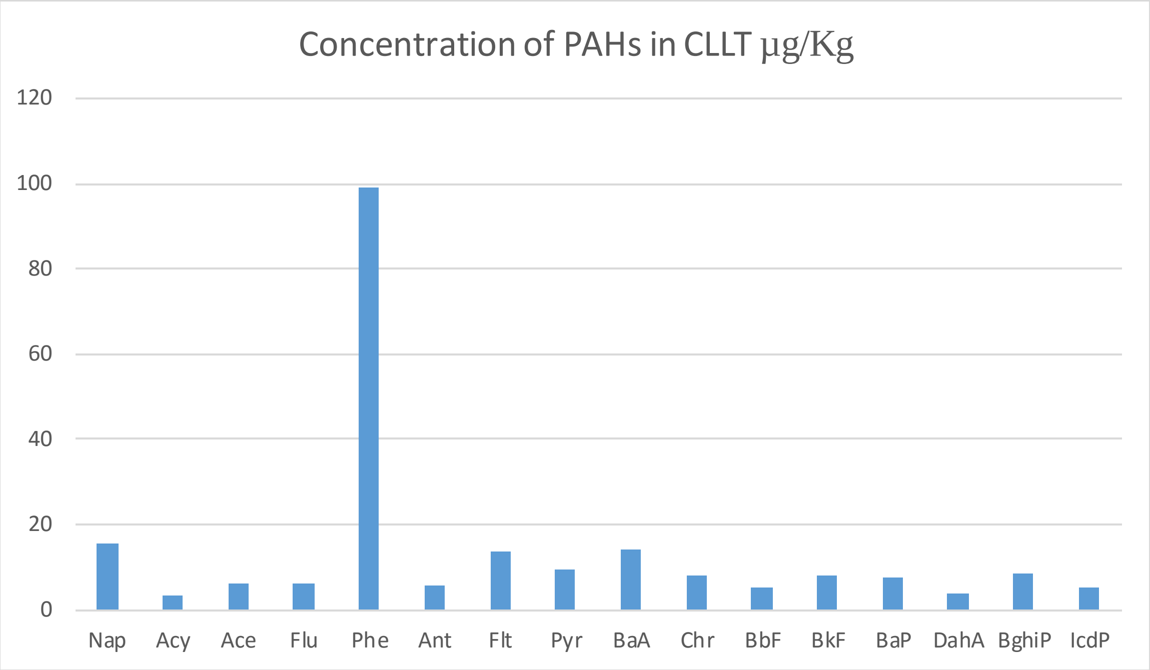


Fig. 4.4 Concentration of PAHs in Chemistry Lower Lecture Theater

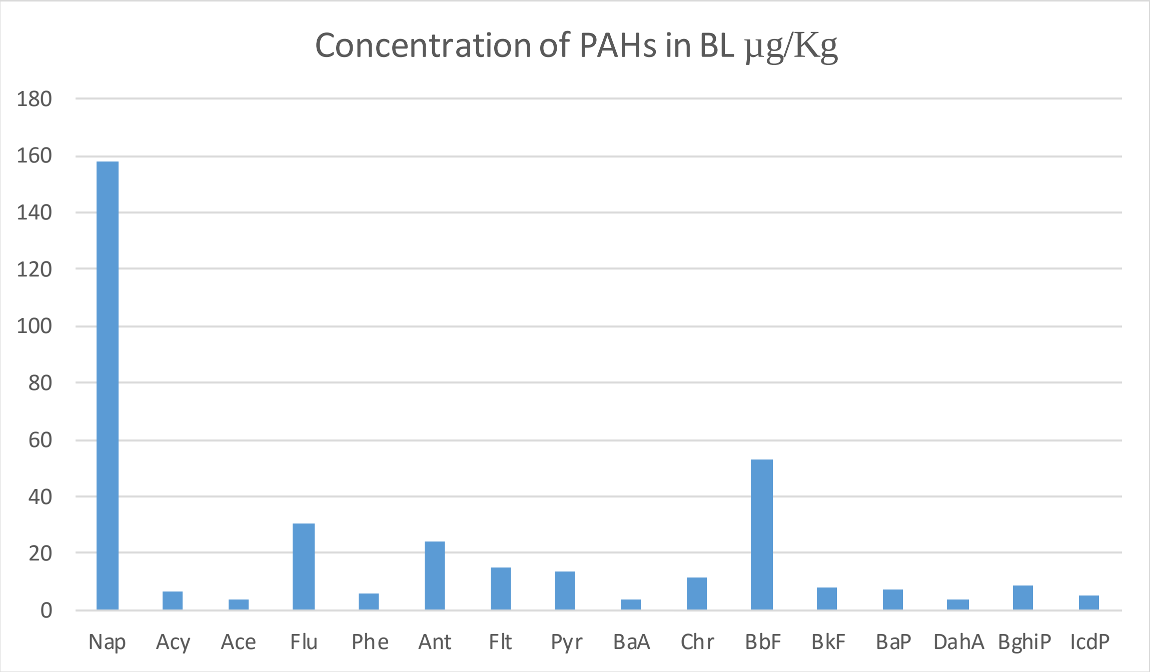


Fig. 4.5 Concentration of PAHs in Balme Library

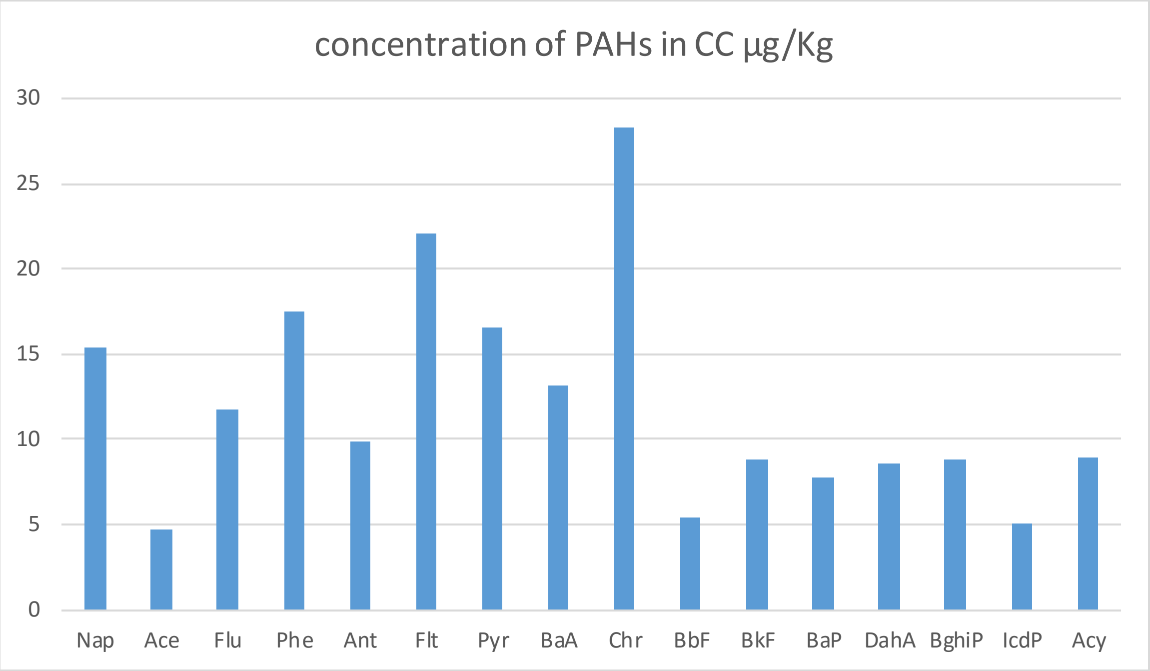


Fig. 4.6 Concentration of PAHs in Central Cafeteria

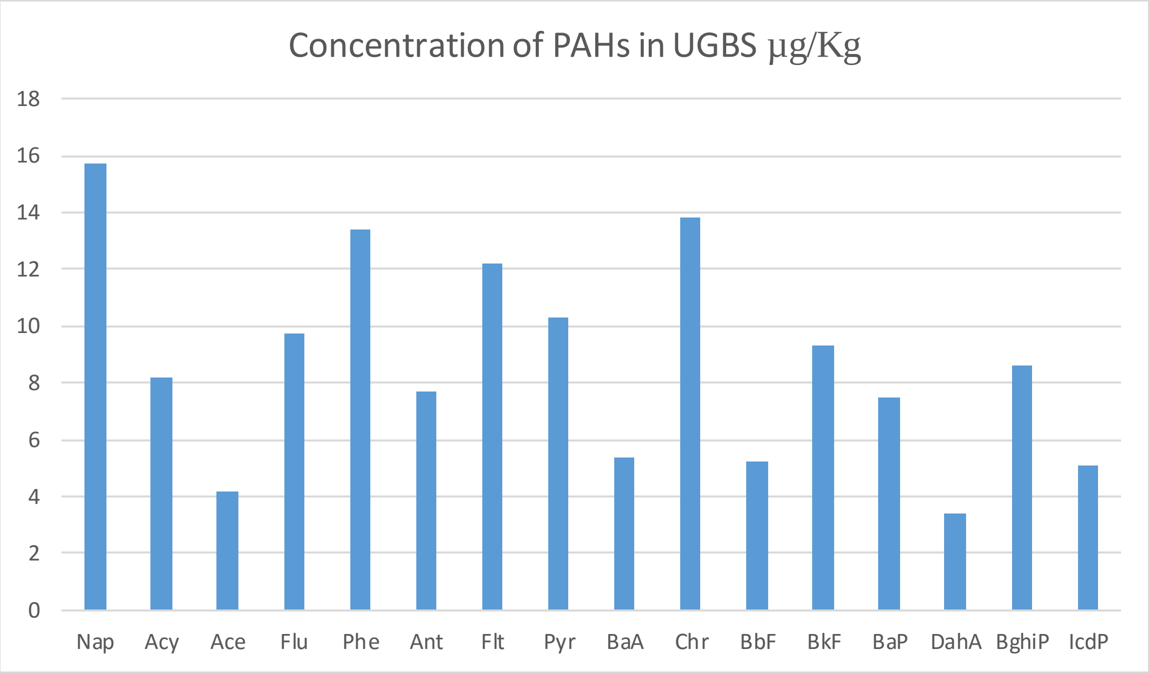


Fig. 4.7 Concentration of PAHs in University of Ghana Basic School

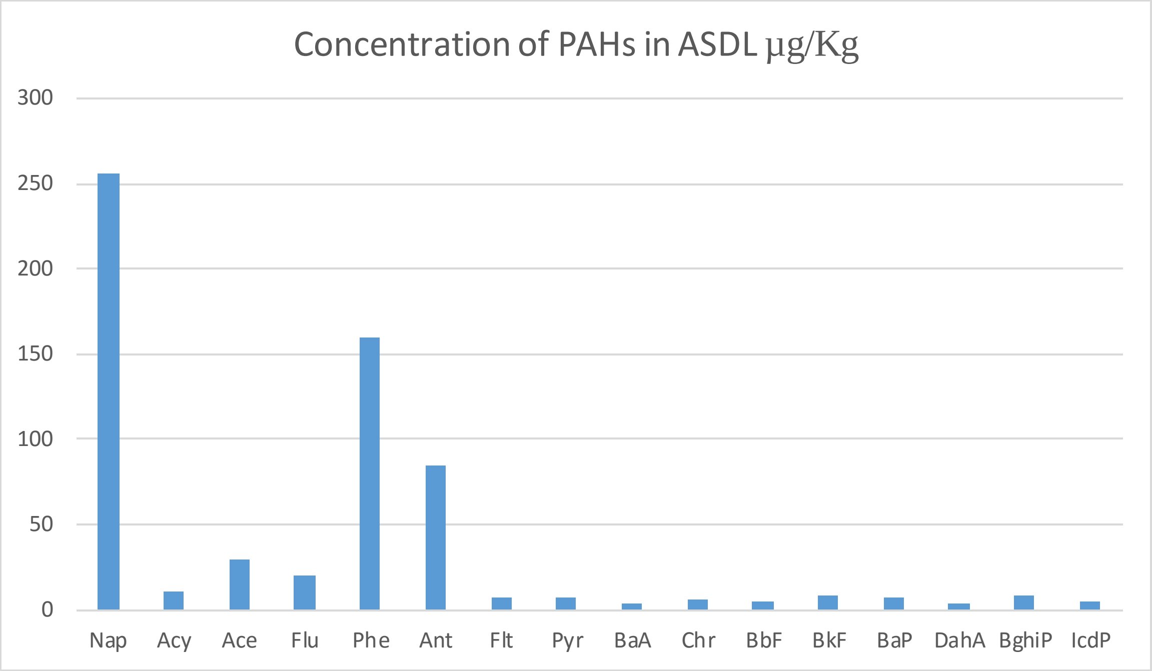


Fig. 4.8 Concentration of PAHs in African Studies Department Library

Table 4.1.mass of organic film and PAH distribution in organic film
Sampling sites mean + SD

	SDH	JQB	CCLT	CC	BL	UGBS	ASDL
film (mass (g)	2.16	2.27	1.44	1.79	1.92	1.31	2.03
Nap (μg/kg)	41.5 ± 0.3	388.7 ± 14.9	15.3 ± 0.8	15.4 ± 0.9	15.7 ± 4.8	15.7 ± 0.7	256.2 ± 9.3
Acy	5.8 ± 1.8	12.5 ± 1.3	5.3 ± 1.9	8.9 ± 0.8	6.8 ± 0.1	8.2 ± 0.6	10.4 ± 0.4
Ace	15.1 ± 0.8	32.6 ± 0.2	3.5 ± 1.5	4.7 ± 1.2	3.6 ± 0.7	4.2 ± 1.5	29.7 ± 0.9
Flu	68.4 ± 2.2	20.5 ± 0.5	6.1 ± 1.3	11.7 ± 1.0	30.2 ± 0.3	9.7 ± 7.1	20.3 ± 0.5
Phe	110.9 ± 2.7	17.8 ± 0.5	9.9 ± 0.6	17.5 ± 0.4	5.9 ± 0.5	13.4 ± 0.5	159.9 ± 3.9
Ant	59.1 ± 1.9	10.1 ± 1.3	5.9 ± 1.6	9.9 ± 1.3	24.4 ± 0.8	7.7 ± 1.4	84.4 ± 3.6
Flt	8.1 ± 0.6	10.7 ± 0.5	11.2 ± 0.4	20.1 ± 0.2	15.3 ± 0.4	10.3 ± 0.4	7.7 ± 0.6
Pyr	7.9 ± 0.7	12.2 ± 0.6	10.8 ± 0.6	19.5 ± 0.4	14.8 ± 0.5	12.6 ± 0.6	7.7 ± 0.7
BaA	4.5 ± 1.2	3.6 ± 1.5	14.3 ± 0.3	13.2 ± 0.9	7.7 ± 0.9	7.4 ± 0.3	3.6 ± 1.2
Chr	7.0 ± 0.3	5.8 ± 0.3	8.1 ± 0.2	26.3 ± 0.1	11.3 ± 0.2	11.8 ± 0.2	5.8 ± 0.3
BbF	5.1 ± 0.2	5.7 ± 0.1	5.1 ± 0.2	5.4 ± 0.2	5.3 ± 0.1	5.2 ± 0.2	5.2 ± 0.1
BkF	8.1 ± 0.2	8.3 ± 0.3	8.1 ± 0.2	8.8 ± 0.2	8.2 ± 0.2	9.3 ± 0.2	8.5 ± 0.2
BaP	7.5 ± 0.3	8.1 ± 0.3	7.7 ± 0.7	7.7 ± 0.3	7.5 ± 0.3	7.5 ± 0.3	7.5 ± 0.3
DahA	3.4 ± 0.8	8.9 ± 0.6	3.6 ± 0.8	8.6 ± 0.6	3.8 ± 0.8	3.4 ± 0.8	3.3 ± 0.7
BghiP	8.6 ± 0.8	8.6 ±0.8	8.7 ± 0.8	8.8 ± 0.8	8.6 ± 0.8	8.6 ± 0.8	8.6 ± 0.8
IcdP	5.0 ± 0.7	5.0 ± 0.7	5.1 ± 0.7	5.2 ± 0.7	5.2 ± 0.7	5.1 ± 0.6	5.0 ± 0.6
$\sum_{16} \boldsymbol{PAH}$	354.9 ± 15.5	599 ± 24	126.8 ± 13.3	193.9 ± 11.5	315.3 ± 12.1	140.1 ± 9.1	623.8 ± 24.5
$\sum_{16} \boldsymbol{PAH - Nap}$	313.4 ± 15.2	210.3 ± 9.4	113 ±12.4	178.5 ± 10.6	153.6 ± 7.3	124.4 ± 8.4	367.6 ± 15.2
$\sum_{6} \boldsymbol{PAH}_{\mathbf{LMW}}$	300.8 ± 9.7	482.2 ± 18.9	46 ± 8.9	68.1 ± 4.5	228.6 ± 7.2	57.9 ± 5.8	569.9 ± 19.6
$\sum_{10} \boldsymbol{PAH}_{\mathbf{HMW}}$	54.1 ± 5.8	116.8 ± 5.6	80.8 ± 4.6	125.8 ± 7.0	87.7 ± 4.9	82.1 ± 3.3	62.9 ± 4.9
$\mathbf{PAH}_{\mathbf{(carcinogenic)}}$	38.9 ± 3.7	45.4 ± 4.9	52.0 ± 3.1	75 ± 3.0	45 ± 3.2	49.7 ± 2.6	38.9 ± 3.4
$\mathbf{PAH}_{\mathbf{(non\text{-}carcinogenic)}}$	315.3 ± 11.8	553.6 ± 19.4	76.8 ± 10.2	11.7 ± 8.5	266.3 ± 8.9	90.4 ± 6.5	584.9 ± 21.1

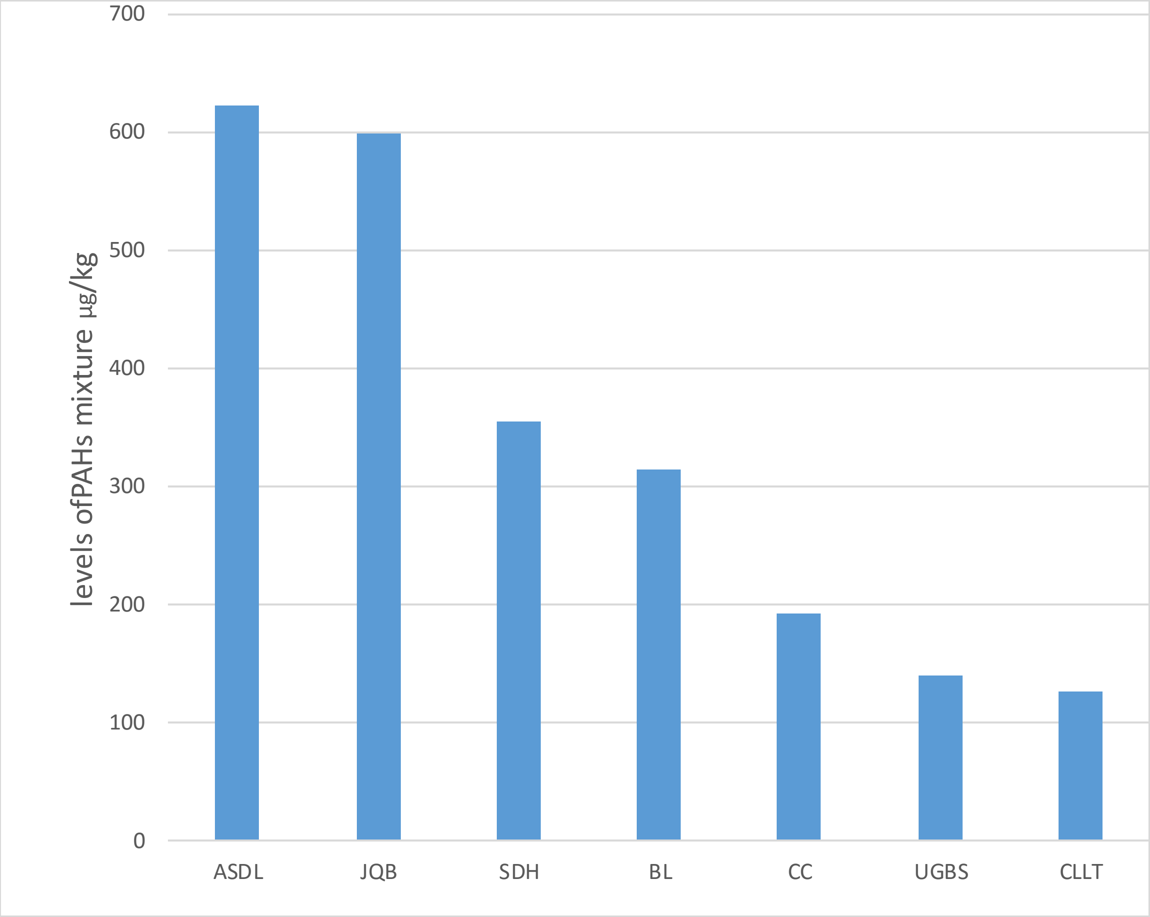


Figure 4.9 Total concentration of PAHs mixture in all sampling sites

4.3 Distribution Patterns of PAHs

The average distribution patterns of PAHs are shown in Figure 4.11 and the percentages of PAH component in organic film in each sampling site is shown in Figure 4.10. The highest contributors were Nap (28%), Phe (13 %), Ant (8%), and Flt (8 %). Generally, the patterns of PAHs in this study were similar to those in previous studies like Shanghai and Donghua university (Ying peng et al.2013), Baltimore (Liu et al. 2003) and Guangzhou and Hong Kong (Pan et al. 2012).

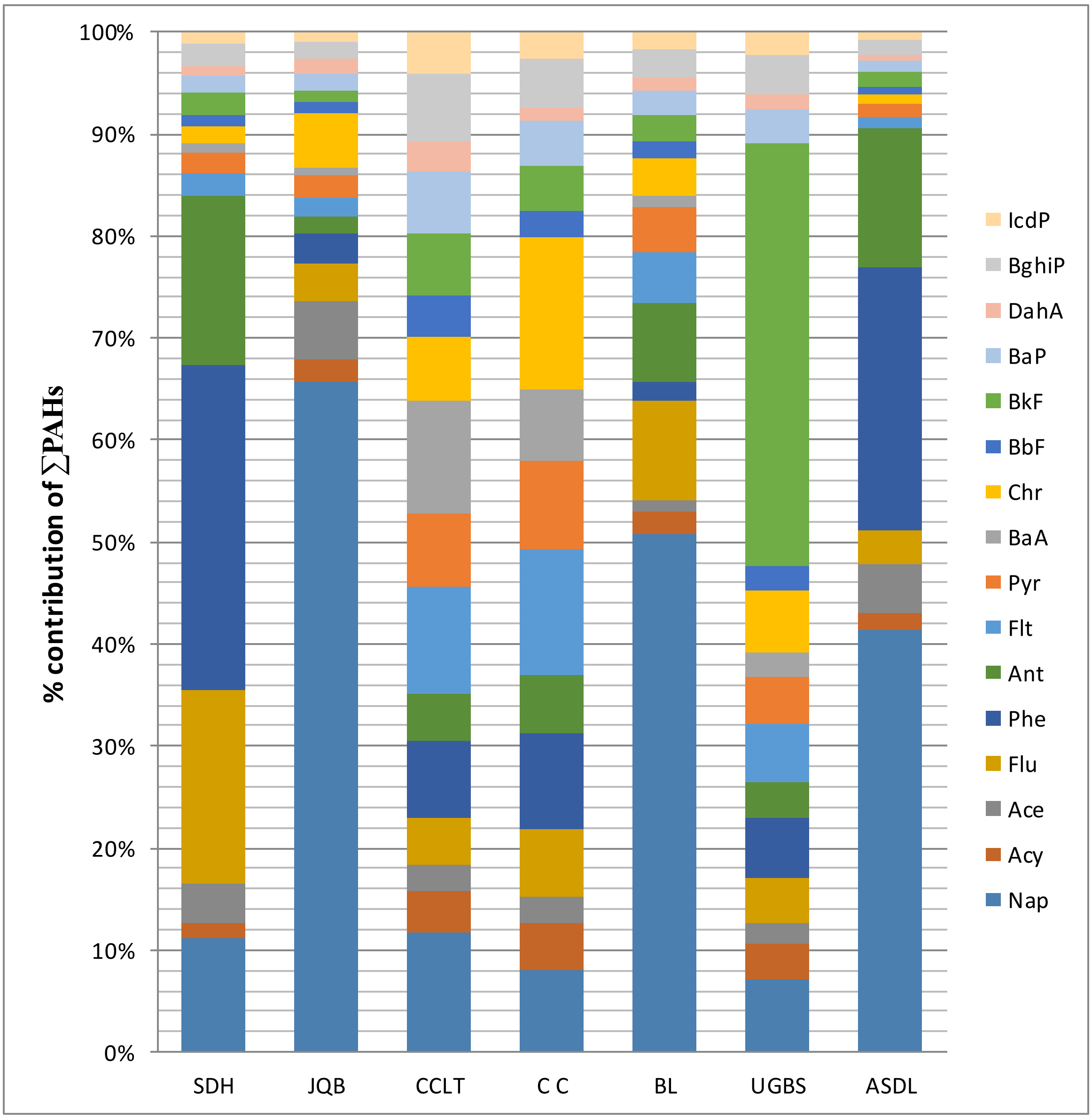


Fig 4.10 Percentages of PAH components in organic film in Sarbah Dining Hall (SDH), Balme Library (BL), Jones Quartey (JQ), Central Cafeteria (CC), University of Ghana Basic School (UGBS), African Studies Department Library (ASDL) and Chemistry Lower Lecture Theatre (CLLT).

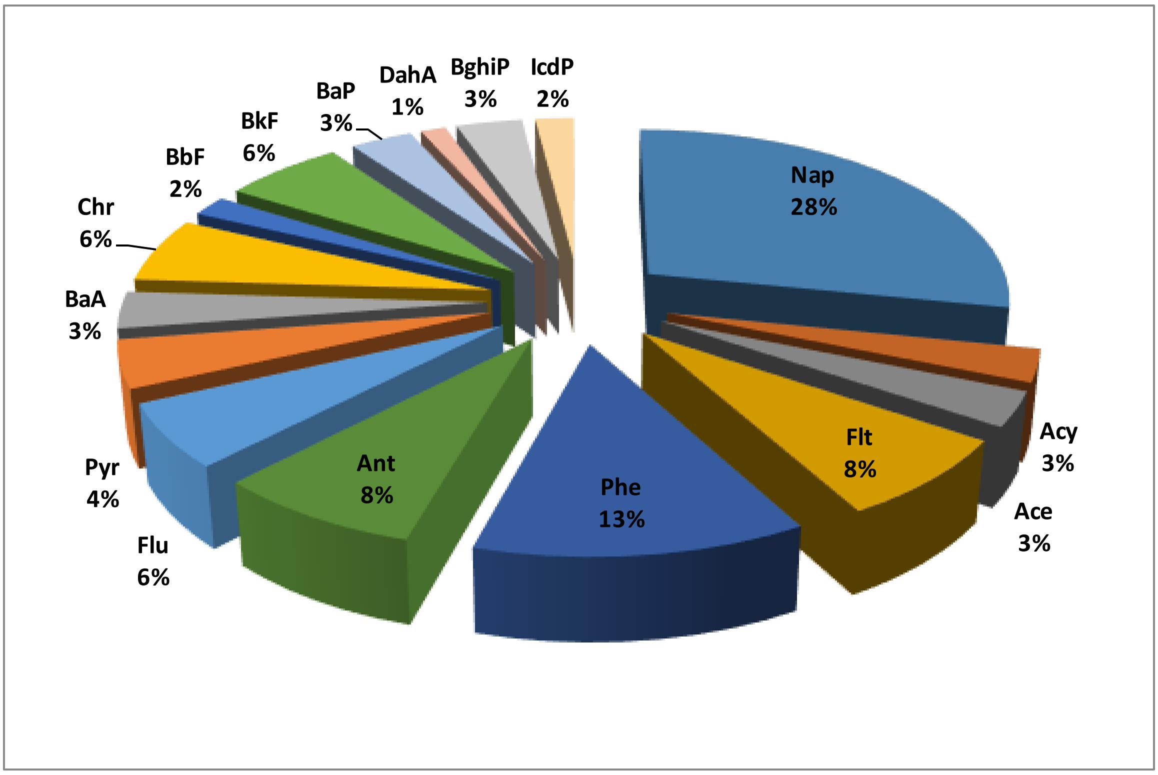


Figure 4.11 The average distribution of 16 EPA PAHs in organic films.

4.4 Polycyclic Aromatic Hydrocarbons Composition Patterns

The sixteen USEPA priority polycyclic aromatic hydrocarbons were grouped into two, according to their number of aromatic rings into low molecular weight (LMW) PAHs composed of less than four aromatic rings (2-3 aromatic rings) thus (Napththalene, Acenaphthene, Acenaphthylene, Fluorene, Phenanthrene and Anthracene) and high molecular weight (HMW) PAHs composed of four or more aromatic rings (4-6 rings) (e.g. flouranthene, pyrene, benzo (b) flouranthene, benzo (k) flouranthene, benzo (a) pyrene and dibenz (a h) anthracene).

The concentration of low molecular weight PAHs ranges from 46µg/kg to 569.9µg/kg and this on the average was the most abundant of the total PAHs, contributing about 76% of the total PAHs. High molecular weight PAHs concentrations ranged from 4.1µg/kg to 125.8µg/kg contributing on the average 24% of the total PAHs (Figure 4.12). In terms of compositional pattern, the HMW PAHs were the predominant PAHs in organic film from CC, CCLT and UGBS while in organic film from SDH, JQB, BL and ASDL, LMW contributed more to the total PAHs (Figure 4.13). No particular information collected with these samples could explain these differences. On the average PAHs of 2-4 rings were the most abundant of the total PAHs on UG campus contributing 82% of the total PAHs. These findings were similar to the patterns in dust fall and suspended particulate matter from Shanghai (Yan et al. (2012), suggesting that high molecular weight PAHs (4–6 rings) were mostly associated with the particulate phase (Pan et al. 2012). The average compositional pattern of polycyclic aromatic hydrocarbons in the analyzed samples is as follows: 2 – 3 rings > 4 - 6 rings (Figure 4.11).

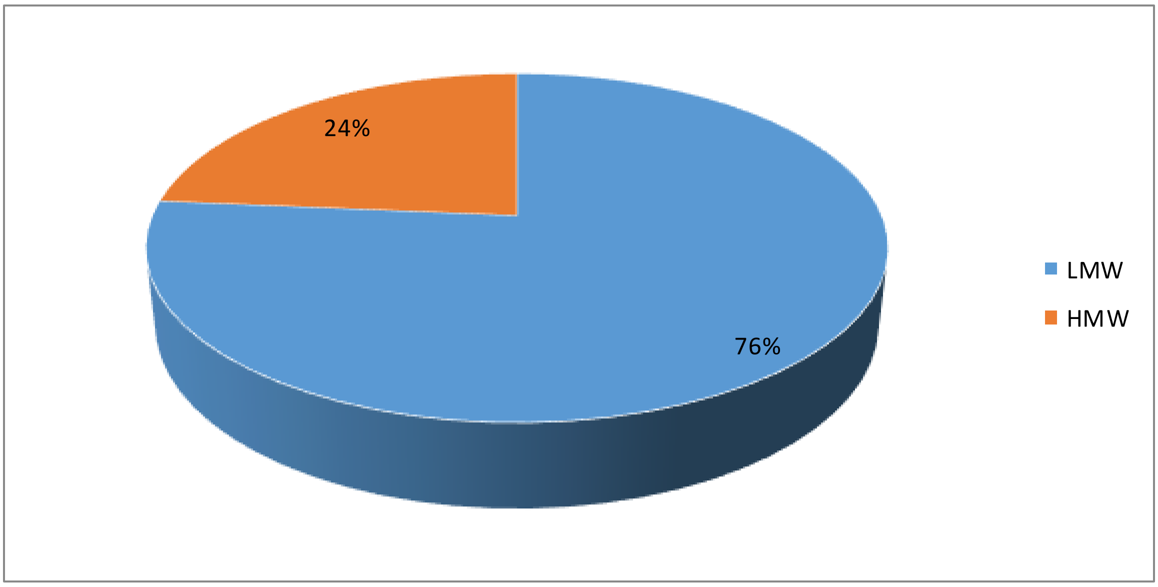


Figure 4.12 Average percentage abundance of LMW and HMW PAH

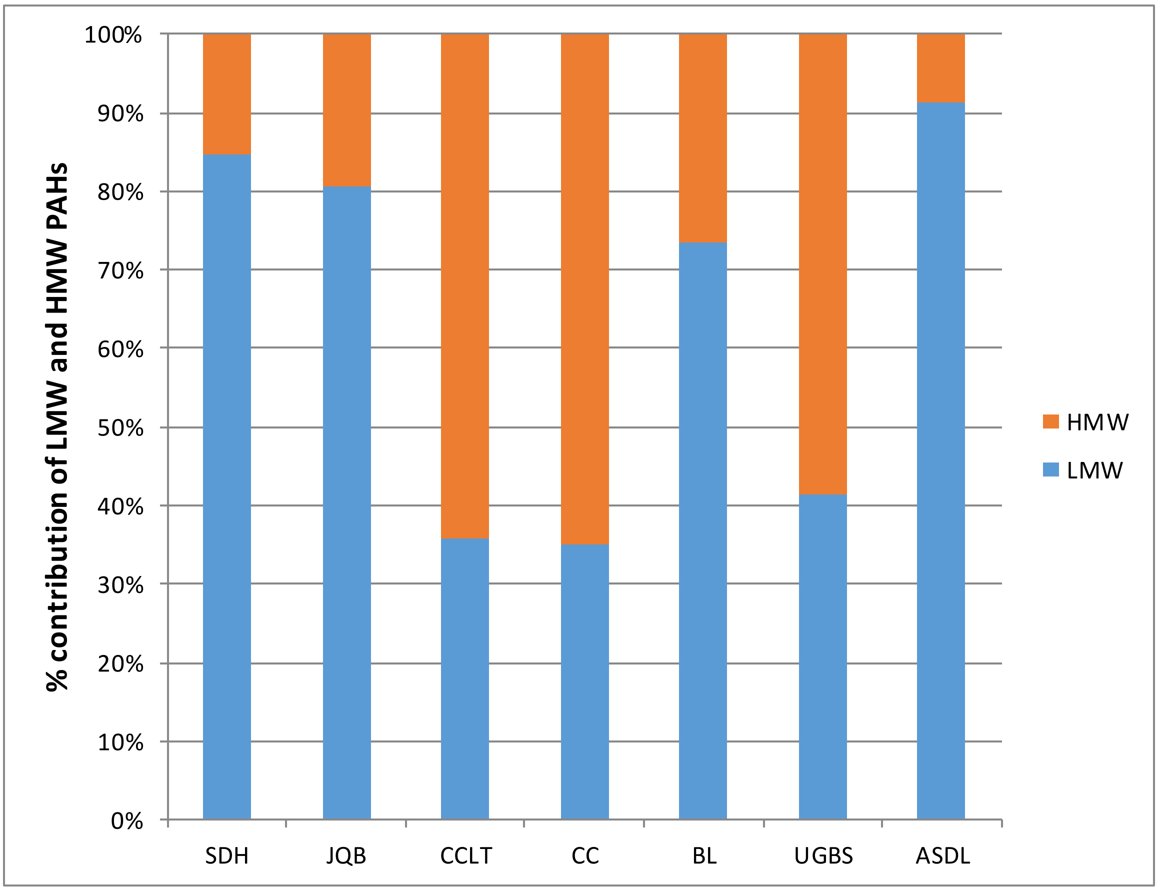


Figure 4.13. Percentage abundance of Low and High molecular weights PAHs for each sampling sites.

4.5 Sources of PAHs

To evaluate and reduce the impact of PAHs on health and the environment, some specific compounds have been extensively used to detect the potential sources of PAHs (Yunker et al. 1999). Several PAHs diagnostic ratios have been used to identify different sources that contribute PAHs to the environment. These ratios distinguish PAH pollution originating from petroleum products, petroleum combustion and biomass or coal burning. The compounds involved in each ratio have the same molar mass; so it is assumed they have similar physico-chemical properties (Tobiszewskit et. al. 2012). The ratios used in this study are fluoranthene/(fluoranthene + pyrene), anthracene/(anthracene + phenanthrene), and benzo[a]anthracene/(benzo[a]anthracene + chrysene.

Previous studies have showed that the content of BaA was significantly reduced after long-range transport because of the rapid photodegradation rate (Fraser et al. 1998). The ratio of BaA/(BaA+Chry) can be used as a tracer for the diagnostic transmission process. A smaller ratio indicates that the PAHs go through a long-distance atmospheric transmission, while a larger ratio indicates local sources (Y Yu et. al. 2013). As shown in Table 4.4, the ratios of BaA/(BaA+Chry) were all less than 1, suggesting that PAHs were derived from long-distance pollution sources. However, BaA/(BaA+Chry) values for road dust in Shanghai were mostly larger than 1, indicating that PAHs mainly come from local emission sources (Liu et al. 2007).

Table 4.2. The concentrations of Anthracene, Phenanthrene and ANT/(ANT+PHE) values

	Ant(µg/kg)	Phe(µg/kg)	Ant/ (Ant + phe)
SDH	59.1±1.9	110.9±2.7	0.35
JQB	10.1±1.3	17.8±0.5	0.36
CCLT	5.9±1.6	9.9±06	0.37
CC	9.9±1.3	17.5±0.4	0.36
BL	24.4±0.8	5.9±05	0.8
UGBS	7.7±1.4	13.4±0.5	0.36
ASDL	84.4±3.6	159.9±3.9	0.35

Table 4.3. The concentations of fluoranthene, pyrene and FLU/ (FLU+PYR) values

	Flu(µg/kg)	Pyr(µg/kg)	Flu/(Flu + Pyr)
SDH	8.1±06	7.9±0.7	0.50
JQB	10.7±0.5	12.2±0.6	0.45
CCLT	11.2±04	10.8±0.6	0.51
CC	20.1±0.2	19.5±0.4	0.51
BL	15.3±0.4	14.8±0.5	0.50
UGDS	10.3±04	12.6±0.6	0.45
ASDL	7.7±0.6	7.7±0.7	0.5

Table 4.4 The concentrations of Benzo(a) anthracene, Chrysene and BaA/(BaA+Chr values

	BaA(µg/kg)	Chr(µg/kg)	BaA/(BaA + Chr)
SDH	3.5±1.2	7.0±0.3	0.39
JQB	3.6±1.3	5.8±0.3	0.38
CCLT	14.3±0.3	8.1±0.2	0.64
CC	13.2±0.9	26.3±0.1	0.33
BL	7.7±0.9	11.3±0.2	0.41
UGDS	7.4±0.3	11.8±0.2	0.39
ASDL	3.6±1.2	5.8±0.3	0.38

In this study, the ratios of FLU/ (FLU +PYR) were between 0.4-0.5 (Table 4.3) which implies that the source of PAHs were from combustion of fuel while the ratio of ANT/ (ANT +PHE) were higher than 0.1 (Table 4.2), for all sampling sites supporting the fact that the source of PAHs were more likely to be due to combustion of fuel. Also, the use of BaA/(BaA+Chry) ratio gave values of >0.35, which further confirms a fossil fuel combustion source. The result of this study agrees with the conclusion that vehicular traffic and coal combustion are major contributors of atmospheric PAHs (Hu et al. 2012; Zhang et at. 2012), and was consistent with the sources of PAHs in urban surface dust in central Shanghai (Wang et al.2013) and Guangzhou areas (Tan et al. 2011). The results of these study also confirm the results from a previous study that vehicles were the dominant source of particulate PAHs in the cities of the Istanbul, Turkey (Hanedar et al. 2014). In summary, PAHs in the organic film originated mainly from fossil fuel combustion.

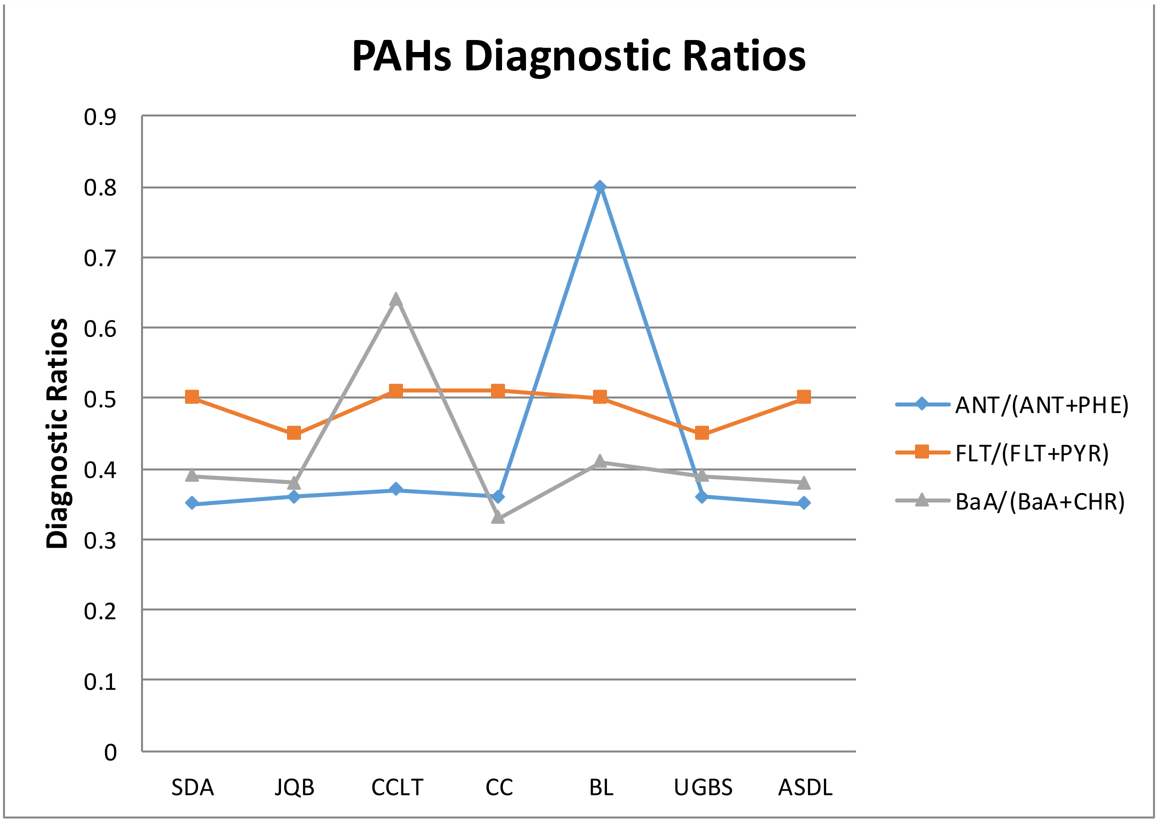


Fig. 4.14. Diagnostics for distinguishing pollution sources for PAHs in organic film

4.6 Toxicity Assessment of PAHs in Organic Film

PAHs generally have a low degree of acute toxicity to humans. The most significant endpoint of PAHs toxicity is cancer (www.atsdr.cdc.gov/csem/csem.aps). Meanwhile some PAH mixtures have been classified by USEPA as carcinogenic to humans. The EPA has classified the following seven PAH compounds benzo(b)flouranthene, benzo(k)flouranthene, benzo(a)pyrene, chrysene, dibenz(a h)anthracene and indeno(1,2,3 cd)pyrene as possible carcinogens (Qui et al. 2010). The concentrations of these seven carcinogenic PAHs in glass film ranged from 38.9µg/kg to 75µg/kg with CC recording the highest and ASDL the lowest (Table 4.1).

To assess the carcinogenic potential of PAHs in the film, toxic equivalency factors (TEFs) were used to quantify the benzo[a]pyrene equivalent (BaPeq) concentration. The carcinogenic potency for an organic film sample is calculated by multiplying the concentration of the individual PAHs with their TEFs (Wang et al. 2013). In this study, the concentrations of BaPeq varied from 13.1 µg/kg to19.7µg/kg (Table 4.5). On the other hand, the values of BaPeq in organic film were lower than those of the dust in air conditioner filters sampled from different types of room: office (1,010µg/kg), bedroom (901µg/kg), and restaurants (782µg/kg), (Zhouetal.2010). The average value of BaPeq in organic film from UG campus was lower, with a safe BaPeq value of 600µg/kg, than the Canadian soil guideline [based on an incremental lifetime cancer risk (ILCR) of 10^{-6}] (Wang et al. 2013).

Table 4.5 Benzo (a) pyrene toxicity equivalence concentration (Bapeq)

		PAH concentration µg/kg							TEQ						
PAH	TEF values	SDA	JQB	CCLT	CC	BL	UGBS	ASDL	SDH	JQB	CCLT	CC	BL	UGBS	ASDL
BaA	0.10	4.5±1.2	3.6±1.5	14.3±0.3	12.5±0.9	7.7±0.9	7.4±0.3	3.6±1.2	0.45	0.36	1.43	1.25	0.77	0.74	0.36
Chr	0.01	7.0±0.3	5.8±03	8.1±0.2	26.3±0.1	11.3±0.2	11.8±0.2	5.8±0.3	0.07	0.06	0.08	0.26	0.11	0.118	0.06
Bbf	0.10	5.1±0.2	5.7±0.2	5.1±0.2	5.4±0.2	5.3±0.1	5.2±0.2	5.2±0.2	0.51	0.57	0.51	0.54	0.53	0.52	0.52
Bkf	0.10	8.1±0.2	8.3±0.3	8.2±0.2	8.8±0.2	8.2±0.2	9.3±0.3	8.5±0.3	0.81	0.83	0.82	0.88	0.82	0.93	0.85
BaP	1.00	7.5±0.3	8.1±0.3	7.7±0.7	7.7±0.3	7.5±0.3	7.5±0.2	7.5±0.3	7.50	8.10	7.70	7.70	7.50	7.50	7.50
DahA	1.00	3.4±0.8	8.90.6	3.6±0.8	8.6±0.8	3.8±0.8	3.4±0.8	3.3±0.7	3.40	8.90	3.60	8.60	3.80	3.40	3.30
1cdP	0.10	5.0±0.8	5.0±0.8	5.1±0.8	5.0±0.8	5.2±0.8	5.1±0.8	5.1±0.8	0.50	0.50	0.54	0.50	0.52	0.51	0.50
(Bapeq) ng/g									13.24	19.32	14.68	19.73	14.05	13.71	13.09

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main goal for this study was to determine and analyze the indoor air quality on university of Ghana (UG) campus in terms of PAH levels in organic film on impervious surfaces such as glass window. A total of fourteen organic film samples collected from UG were analyzed for 16 USEPA priority PAHs. The total PAHs concentration ranged from 126 µg/kg to 632 µg/kg with a mean value of 336µg/kg. The concentration gradient was observed as follows; African Studies Department Library> Jones Quartey> Sarbah Dining Hall> Balme Library> Central Cafeteria> University of Ghana Basic School> Chemistry Lower Lecture Theater. This indicates that as one moves towards main highway, the concentrations PAHs in organic film increases. In terms of compositional pattern, the HMW PAHs were the predominant PAHs in organic film from CC, CCLT and UGBS while in organic film from SDH, JQB, BL and ASDL, LMW contributed more to the total PAHs. On the average PAHs of 2-4 rings were the most abundant, contributing 82% of the total PAHs. The PAHs were dominated by Nap (28.2%), Phe (13 %), Ant (8%), Flt (8 %), Py (6 %) and Chry (6 %). The results of the diagnostic ratio suggest that the source of PAHs in organic film in UG were mainly from combustion of fossil fuel. The average value of BaP_{eq} in film from UG was lower than that for other environmental media and ILCR (Incremental Lifetime Cancer Risk)

The results presented in this study indicates that there is reduced risk of adverse health effects from indoor air pollution inside buildings on campus. However, it is important to keep indoor air conditions within permissible and healthy limits as established and determined by special air quality standards.

5.2 Recommendation

- In future research more representative sites and more PAHs measurement should be done to better represent health risk status.
- Seasonal variation should be investigated as these could provide information in the assessment of indoor air pollutants.

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