UNIVERSITY OF CAPE COAST

IMPACTS OF VEHICULAR EMISSIONS AND DUST ON THE RESPIRATORY HEALTH OF ROADSIDE VENDORS

JACOB OFORI

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BY

JACOB OFORI

Thesis submitted to the Department of Chemistry of the School of Physical Science, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Doctor of Philosophy Degree in Chemistry

FEBRUARY 2023

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Signature:.. Date:..........................

Name: Jacob Ofori

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:.................................. Date:........................

Name: Prof. David Kofi Essumang

Co-Supervisor's Signature: .... Date:........................

Name: Dr. Francis Tanam Djankpa

ABSTRACT

The business of roadside vendors is most lucrative at the areas of heavy vehicular traffic, which expose them to toxic vehicular emissions and roadside dust. These pollutants are known to cause and/or exacerbate respiratory illness with very little or no effort going towards protecting the vendors against the air pollutants. A cross-sectional study was done to evaluate the impacts of the air pollutants on the respiratory health and perception of roadside vendors. The level of particulate matter measuring 2.5µm or less ($P.M_{2.5}$), carbon monoxide (CO) and ozone (O_3) were measured with a monitor equipped with sensors. A spirometer and a questionnaire were used to assess vendors' respiratory health. Levels of Dust-bound polycyclic aromatic hydrocarbons (PAHs) were also determined with gas chromatography coupled with mass spectrometer (GC-MS). The 24-hour mean concentrations of $PM_{2.5}$, CO and O_3 were 69.21 µg/m^3, 8.52 ppm and 93.95 ppb respectively. The mean concentration of $PM_{2.5}$-bound PAHs ranged between 0.86 µg/kg for Anthracene to 567.68 µg/kg for Benzo[g,h,i]perylene. The concentration of $PM_{2.5}$ and O_3 exceeded WHO limits. The result of PAHs source identification ratios indicates that liquid fossil fuel combustion and biomass burning are the major sources of PAHs along the road. Vendors reported a high (82%) prevalence of respiratory symptoms. There was a significant difference between the pre-shift and post-shift spirometry for vendors compared to controls. Vendors are exposed to higher levels of air pollutants at the roadside explaining the high prevalence (82%) of respiratory symptoms.

KEY WORDS

Air Pollution

Roadside air quality

Roadside vendors

Vehicular emission

Spirometry

Particulate matter

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DEDICATION

To the loving memory of my late father Mr. John Kwamena Ofori.

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LIST OF ABBREVIATIONS

ABS	Dermal Adsorption Fraction
AD	Alzheimer's disease
AF	Absorption Factor
AQ	Air Quality
AQI	Air Quality Index
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AT	Averaging Time
BaP-eq	Benzo(a)pyrene toxicity equivalent
BW	Body Weight
CF	Conversion Factor
CANS	College Agriculture and Natural Sciences
COPD	Chronic Obstructive Pulmonary Disease
CSF	Carcinogenic Slope Factor
ED	Exposure Duration
EF	Exposure Frequency
EPA	Environmental Protection Agency
FEV_1	Force Expiratory Volume
FVC	Force Vital Capacity
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GS/MS	Gas Chromatography/Mass Spectrometry
HMW	High Molecular Weight
IARC	International Agency for Research on Cancer
ILCR	Incremental Lifetime Cancer Risk

IR	Ingestion Rate or Inhalation Rate
ISTD	Internal Standard
LDV	Light-Duty Vehicles
LFT	Lung Function Tests
LMW	Low molecular weight
MMDAs	Metropolitan, Municipal and District Assemblies
MRM	Multiple Reaction Monitoring
NIOSH	National Institute for Occupational Safety & Health
NOx	Nitrogen oxides
OECD	Organisation for Economic Co-Operation and Development
OSHA	Occupational Safety and Health Administration
PaEF	Particle Emission Factor
PAHs	Polycyclic Aromatic Hydrocarbons
PD	Parkinson's Disease
PEF	Peak Expiratory Flow
$PM_{2.5}$	Particulate Matter with diameter less or equal to 2.5µm
PM_{10}	Particulate Matter with diameter less or equal to 10µm
PSA	Primary Secondary Amine
PMF	Positive Matrix Factorization
TEF	Toxic Equivalency Factor
TED	Toxicity Equivalence Quotient
SF	Inhalation Slope Factor
USEPA	United States Environmental Protection Agency
UNICEF	United Nations Children's Fund
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

The work of roadside vendors closely situates them together with slow-moving vehicles whose emissions pollute the roadside air. Vendors likely inhale high doses of harmful air pollutants during their working periods by the roadside. Additionally, the vehicular population in the Cape Coast Metropolitan area like the other major cities is rapidly increasing causing heavy traffic and heavier exhaust emissions. However, the level of roadside air pollutants and the associated impact(s) on vendors as well as vendors' perception of the effect of vehicular emissions in the Metropolis is still unknown.

Air pollutants are often not seen or smelt and hence are least suspected to be harmful and their effects are not familiar. The asphyxiation of twenty (20) people in Donora, Pennsylvania, in 1948 and the death of four thousand (4,000) people (recent estimates put the figure at nearly 12,000) in London in 1952 which were the result of smog and soot from factories and home fireplaces signaled the harmful effects of air pollutants (Bell et al., 2004; Polivka, 2018; Snyder, 1994). These triggered the investigation of components of polluted air, its adverse consequences on human health and the environment, as well as determining the relationship between high concentrations of ambient air pollutants and mortality (Fowler et al., 2020).

Further research has established that one of the key causes of air pollution in the metropolitan areas is vehicular emission, especially pollution from passenger vehicles and heavy-duty trucks (Du et al., 2023;

Gu et al., 2022; Huang et al., 2022; Lang et al., 2021; Ucheje et al., 2022). An average passenger vehicle is projected to discharge roughly 4.6 metric tons of carbon dioxide (a greenhouse gas) annually. In developing countries where most vehicles are over-aged, poorly maintained and combust low-quality fuels, up to 85% of all anthropogenic air pollutants in big urban cities are released by motor vehicles (Faiz, 1993; Nayak & Basak, 2021; Palve & Tilak, 2019). This statistic is even projected to increase with rapid population growth, rising pace of urbanization and the quick motorization of residents of developing countries (Deshmukh et al., 2020; R. Wang et al., 2020).

According to an analysis by United Nations Children's Fund (formerly United Nations Children's Emergency fund) (UNICEF), the number of people dying in Africa due to outdoor air pollution has risen by 57% in less than three decades, from 164,000 in 1990 to 258,000 in 2017 (Rees et al., 2019). As a result of this over $215billion of Africa's Gross Domestic Product (GDP) lost every year. Again, an estimated 6.5 to 9 million premature deaths are recorded each due high air pollution levels (≥ 6.7 % of all deaths) in the world (Fuller et al., 2022). The majority of these preventable deaths (about 88%) occurred in countries with low or middle income (Fuller et al., 2022; WHO, 2016; World Bank, 2022). In 2017, air pollution ranked the fifth highest risk factor for mortality worldwide and accounted for 2.5% of all deaths in developed countries (Health Effect Institute, 2019; Tong, 2019). Statistics show that annual mortality figures are steadily increasing (Cohen et al., 2005; Iriti et al., 2020).

Again, WHO's International Agency for Research on Cancer (IARC) assessment in 2013, concluded that some of the pollutants in outdoor air are carcinogenic, citing the particulate matter component of air pollution as being highly linked with increased incidence of lung cancer (IARC, 2013). Outdoor air pollution contributes to about 6% of lung cancer; 11% of chronic obstructive pulmonary disease (COPD); 3% of acute lower respiratory infections in children, 40% of ischemic heart disease and 40% of stroke (He et al., 2022). Hospital admissions for angina, myocardial infarction, and heart failure have all been associated with acute exposure to air pollution (He et al., 2022; IARC, 2013). The risk of developing coronary heart disease over time increases with prolonged exposure. Recent findings from epidemiological, observational, clinical, and experimental studies suggests that ambient air pollution may have a strong correlation to some neurological disorders, including Parkinson's disease (PD), Alzheimer's disease (AD), stroke, and urinary tract cancer (Costa et al., 2020; Genc et al., 2012).

Although air pollutants are ubiquitous, a person's closeness to the source of pollution increases the dose as well as the risk of exposure (Kibble & Harrison, 2005). Vendors are generally considered to be extra vulnerable to air pollutants because apart from the fact that they are closely situated to vehicular emissions, the aggressive part of their work to compel customers to buy from them makes them breathe more quickly and often through their mouths, skipping their noses' filtering function (Madureira, 2014). This result in greater exposure of vendors to airborne pollutants.

In developed countries, policies against over-aged vehicles which are associated with high emissions are strictly implemented to reduce vehicular emissions. Developing countries, however, import used vehicles whose emissions may be higher and use them for several years (Kojo Agyemang-Bonsu et al., 2010; Sulemana, 2012a).

In Ghana for example, the government's policy of 1998 to ban over-aged cars in an attempt to eliminate the associated environmental hazards, was amended in 2002 to allow for the imposition of progressive fines on cars older than ten years (Ghana, 2010; Kombat & Wätzold, 2019; Sulemana, 2012b). Consequently, a 5% penalty fee is added to the cost of the car delivery insurance freight. Vehicles older than 12 years but under 15 years are subject to a 20% fine, while vehicles older than 15 years are subject to a 50% surcharge (Essel & Spadaro, 2020; Sulemana, 2012b). Unfortunately, this restriction amendment was ineffective in preventing buyers from purchasing older automobiles, and instead led to a greater-than-anticipated flood of older vehicles into the nation. Unfortunately, this ban revision could not adequately deter buyers from purchasing older cars, but rather resulted in a higher-than-expected influx of older vehicles into the country.

Another government policy; the bus fleet renewal policy of 2010, aimed at replacing aging and highly polluting mini-buses had a successful implementation at the initial stage but failed to have a long-term effect on urban air quality (Essel & Spadaro, 2020; WHO, 2022). This was because the vehicles were poorly maintained and relied on high-sulphur content fuels (as high as 3000 ppm). Consequently, the 2016 low-sulphur fuel reduction strategy was introduced which directed that fuel sulphur content should be reduced to 50 ppm by 2020 (Anafo, 2016; WHO, 2022).

Finally, a new regulation that bans the importation of light-duty vehicles (LDV) older than 10 years as well as salvage vehicles was introduced and its implementation was set to commence in October 2020 (Ayetor et al., 2021; MOTI, 2019). This new agenda which is a revision to the Customs Act of 2015 is aimed at encouraging local manufacturing and assembly of vehicles by discouraging importation but was met with a lot of public criticism and outcry that led to its suspension.

It can therefore be concluded from the above that the impact of several government policies, efforts and initiatives have not been adequate to control toxic vehicular emissions and the associated hazards. Vehicles continue to emit high levels of toxic substances and as a result, the level of roadside air pollutants far exceeds the WHO recommended levels (Dionisio et al., 2010; Kojo Agyemang-Bonsu et al., 2010; Sulemana, 2012a). However, the mode of operation of vendors necessitates their presence at the same place as the toxic substances. There is therefore the need to measure the current levels of air pollutants along the roadside and investigate their effects on the respiratory health of the vendors. Previous studies have focused on measuring the level of exhaust pollutants along the roadside of only two (2) major cities i.e., Accra and Kumasi. Against this background, this research seeks to determine the level of air pollutants along the arterial roads in the Cape Coast Metropolis and the associated impacts on vendors' respiratory health. It will also examine the perception of roadside vendors on the effect of air pollution along the roadside.

1.2 Statement of the problem

Vehicular transport is the most patronized means of transportation in Ghana besides car exhausts are known to release a wide range of gaseous and solid air pollutants that have immediate and long-term effects on humans and the environment. The level of emissions and their effects upsurges when cars become old and poorly maintained. In the city centers where cars move slowly in long traffic jams, higher levels of pollutants are introduced into the air (Baumbach et al., 1995). According to the Ghana EPA, in 2014, particulate matter 10 micrometers or less in diameter (PM_{10}) data from the roadside air monitoring sites showed concentrations that were much higher than the PM_{10} standards previously established by both the EPA Ghana (70 g/m^3) and the World Health Organization (50 g/m^3, 24-hour mean) (Ghana EPA, 2018). Numerous measurements revealed values over 200 $\mu g/m^3$ for the 24-hour with some even readings exceeding 800 $\mu g/m^3$. Very few readings met the guidelines. However, concentrations at monitoring stations far from arterial roadways more frequently complied with EPA limits (Ghana EPA, 2018). In the year 2020, air pollution in Ghana ranked the deadliest of threats compared to other environmental health risks and prominent communicable diseases such as HIV/ AIDS, malaria, unsafe water and sanitation (Lee & Greenstone, 2021).

Cape Coast like the other major cities in Ghana has trading as the major economic activity. The wholesale and retail trade industry engages about a quarter (25.1%) of the employed population in the Metropolis (Ghana Statistical Service, 2014b). The metropolis has just a few markets for trading activities, as such, there are trading activities along the roadsides of most arterial roads in the Metropolis. These roadside vendors, stay close to higher levels of pollutants for longer periods. Aside this, roadside vendors are presumed to have higher breathing rates and increased doses of inhaled pollutants to the lungs due to their involvement in more physical activities such as shouting and brisk movements (Madureira, 2014). It is therefore possible that air pollutants along the roadside may be clogging the lungs of vendors and consequently, causing respiratory diseases as well as premature deaths.(Goudarzi et al., 2013).

In a study by Addo-Yobo *et al*, (2007), the researchers suggested that greater exposure from automobiles, over-crowding and allergens are risk factors for asthma (Addo-Yobo et al., 2007). Also, World Health Organization (WHO) estimations indicates that, the incidence rate for asthma in Ghana is 1.5/1000 per year, while rates for Greece, is as low as 0.3/1000 (Amoah et al., 2012). The Ghana Health Service Report, 2016, reveals that upper respiratory tract infections ranked second, leading rheumatism, diarrhoea, eye infections in the top ten diseases reported for the year (Ghana Health Service, 2017). Research on Asthma reveals that Asthma and allergic diseases are increasing in prevalence and severity (Addo-Yobo et al., 2007; Liao et al., 2009; Ndlovu et al., 2020). According to Liao et al., (2009), it is more likely that changes in environmental exposure are responsible for the rise in the prevalence of asthma and allergy illnesses in Taiwanese children over the past several decades rather than only genetic variations (Liao et al., 2009). Meanwhile, there is insufficient information on vehicular emissions and their effects in the Cape Coast Metropolis. The few research works on outdoor air pollution along the roadside are carried out by the Environmental Protection Agency (EPA-

Ghana) in Accra and Kumasi. Despite these few interests in the linkage between respiratory health and low air quality, many questions still remain unanswered. Further explanation with regards to the contribution of exposure to vehicular emission and the entire health of vendors along major busy roads is needed.

This thesis aims to gather current data on air quality and associated health consequences from vendors in the Cape Coast Metropolis. It will also investigate the perception of vendors on roadside air pollution and its impacts on human health.

1.3 Purpose of the study

The purpose of this cross-sectional, correlational research is to determine the contribution of vehicular emissions to the overall health of vendors/retailers along the arterial roads in the Cape Coast metropolitan area and also investigate the perception of the vendors on vehicular emission and the associated health conditions. According to the literature, those who are exposed to a lot of automobile emissions run the risk of having worse lung and cardiovascular health (Jones et al., 2008). Since vendors are often situated along major roads in a busy urban environment to maximize customers and are directly exposed to these pollutants, they may have poor lung function compared with individuals who are protected from these emissions. This study aims to determine the difference in the concentration of some air pollutants especially Carbon monoxide (CO), topographic ozone (O_3) and respirable particles of diameter 2.5 μm or less ($PM_{2.5}$) of vendors and others who are far away from vehicular emissions and to compare the lung function parameters.

1.4 Objectives of the research

The primary objective of this research was to study the effects of Roadside Air Quality on vendors along selected arterial roads in the Cape Coast Metropolitan area. The specific objectives are to:

1. measure the air quality parameters such as temperature, humidity, particulate matter ($PM_{2.5}$), carbon monoxide (CO), ozone (O_3) and polycyclic aromatic hydrocarbons (PAHs) in dust along the main Abura – Kotokoraba road.
2. examine the respiratory health conditions of vendors by conducting lung function tests.
3. establish a correlation between pollution levels and respiratory conditions.
4. investigate the perception of vendors on air pollution along the roadside and its associated effects.

1.5 Research Questions

The following are the research questions addressed in this thesis:

1. What are the current levels of some widespread air pollutants namely, particulate matter ($PM_{2.5}$), carbon monoxide (CO), and ozone (O_3) at the lengthways of the arterial roads in the Cape Coast Metropolis?
2. Are the pollution levels at the roadside higher than that of other places farther from the roadside as well as the WHO guidelines?
3. What are the health effects of roadside air quality on vendors who do their business along busy roads?
4. What is the perception of the vendors on vehicular emissions and the associated effects?

1.6 Significance of the study

This research represents a unique approach to the broad topic of air quality by not only determining the levels of pollutants but will move further to investigate how the situation affects the respiratory health of roadside vendors as well as their perception of air pollution. Unlike most researches, further studies would be done on the particulate matter to determine the levels of carcinogenic polycyclic aromatic hydrocarbons (PAHs) from vehicular emissions that adsorb onto particulate matter as well as their associated risks to vendors within the Cape Coast Metropolis. It will also collaborate with the school of medical science to examine the respiratory health characteristics using lung function tests.

The outcomes of this research among other things will:

- be an input to the authority in improving the quality of ambient air in the cities.
- disclose the need for city authorities and governments to provide a good and sufficient market structure for vendors or retailers.
- provide data that can potentially be used by stakeholders and institutions to validate and enforce policies on vehicular emissions and air pollution.
- sensitize vendors on protective measures that can be taken against ambient air pollution in order to improve their respiratory health.
- Will provide insight into further research.

1.7 Delimitation

The oral, dermal, and respiratory pathways are possible exposure routes for airborne contaminants from both indoors and outside. This research exclusively studied exposure through the respiratory route at the roadside since breathing is the most common pathway for air pollutants. Airborne pollutants studied are those of two categories, namely, chemical (Carbon monoxide, ozone and polycyclic aromatic hydrocarbons) and physical (Particulate matter). Biological pollutants such as molds, fungi etc were not considered. The participants were specifically roadside vendor closely situated at the very busy points along the arterial roads.

1.8 Limitation

This study did not access a random sample necessary for boosting the generalizability of findings because most vendors saw the research as a nuisance to their business. A convenience sampling technique was rather employed. Other outdoor environments such as residential areas of vendors were not considered to be part of this study because the study was focused on the effects of air pollution during work shift of vendors at the roadside. Although ingestion, inhalation, and skin absorption are the three main ways that people are exposed to pollution, ingestion and skin absorptions were not considered because their effects are minimal. Other airborne pollutants such as oxides of nitrogen (NOx) were also not studied in this research.

This study was not concerned with air pollutants of biological origin such as molds, mildew fungi, dust mites etc. since they are not usually associated with vehicular emissions.

1.9 Definition of Terms

Assessment (of air pollution): describes the quantitative and qualitative evaluation of the danger posed to human health by the actual or probable presence of and exposure to particular pollutants.

Vehicular emission: Substances introduced into the atmosphere from a vehicle as a result of internal combustion.

Roadside air quality: is a measurement of the amount of solid, liquid, or gaseous air pollutants in the air along a route which indicates the purity and appropriateness of the air for humans or the environment.

Vendor: Any person who offers or exposes goods or wares for sale in the street, either from a stall, a van or with their goods laid out on the pavement to maximize customers.

1.10 Organization of the study

This important research which collaborates with the Department of Physiology, University of Cape Coast Medical School to evaluate the current air quality of the main Abura - Kotokoraba road has the following structure: Chapter One presents a concise overview of the issue of Air Quality along the roadside, and associated health effects. It also gives the research questions, purpose, significance and scope of the study.

Chapter Two presents the review of relevant literature on air pollution in Ghana and related effects, methodologies for determining the level of air pollutants in roadside air and dust as well as strategies for the reduction of pollution.

Chapter Three describes the extent of vehicular emissions and air pollution in the study area and the research design. It also gives details of the materials and methods, participants, sample size and selection procedures, environmental and health data collection procedures, variables measured as well as statistical tools for the analysis of results.

Chapter Four focuses on the presentation and discussion of the result. It gives the result of the measurements of pollutants at the roadside, temperature and humidity along the roadside as well as polycyclic aromatic hydrocarbons, and heavy metals in dust and urine samples. It also presents the result of the lung function test followed by the discussions.

Chapter Five of this thesis provides an overview of the result, the conclusions made from the analysis of the result and the recommendations made. It also gives suggestions for further research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The focus of this chapter was to extensively review literature on the state of air pollution around the globe so as to compare pollutant levels in Africa as well as Ghana to the rest of the world. The trends and projections of some prevalent air pollutants were also reviewed in addition to their behaviour and fate in the human body and their health effect.

The review was concluded with a delve into the policies countries especially Ghana have made to control air pollution and the outcome as well as their commitment to the implementation of the policies.

2.1 Global Air pollution status

Air pollution is a global problem and is described in literature as "the largest environmental risk factor", "an invisible killer", "a public health emergency", "a global health concern", "a major public health and environmental challenge and "the leading risk factor for premature death" (Holgate, 2022; WHO, 2016; World Bank, 2022). These phrases suggest severity of the issue and the urgent comprehensive attention needed to control air pollution. The seriousness of the matter is that about 92% of the global population inhale unsafe concentrations of air pollutants which exceeds WHO exposure targets for air pollutant (Kovach et al., 2020; WHO, 2016).

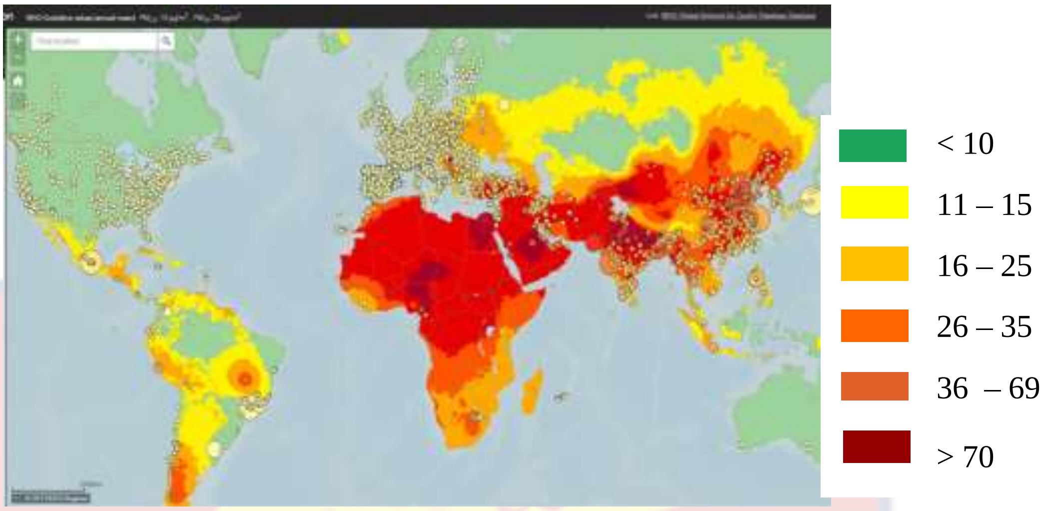

Figure 1: Map showing global ambient air pollution

Over the last few years, air pollution has been listed among the world's top ten major risk factors for death. It was graded as the fourth (4th) key risk factor for mortality globally in 2015 and the fifth (5th) in 2017 (Health Effect Institute, 2019). Air pollution causes more deaths than malnutrition, alcoholism, physical inactivity, traffic carnage road traffic injuries and malaria (Health Effect Institute, 2019).

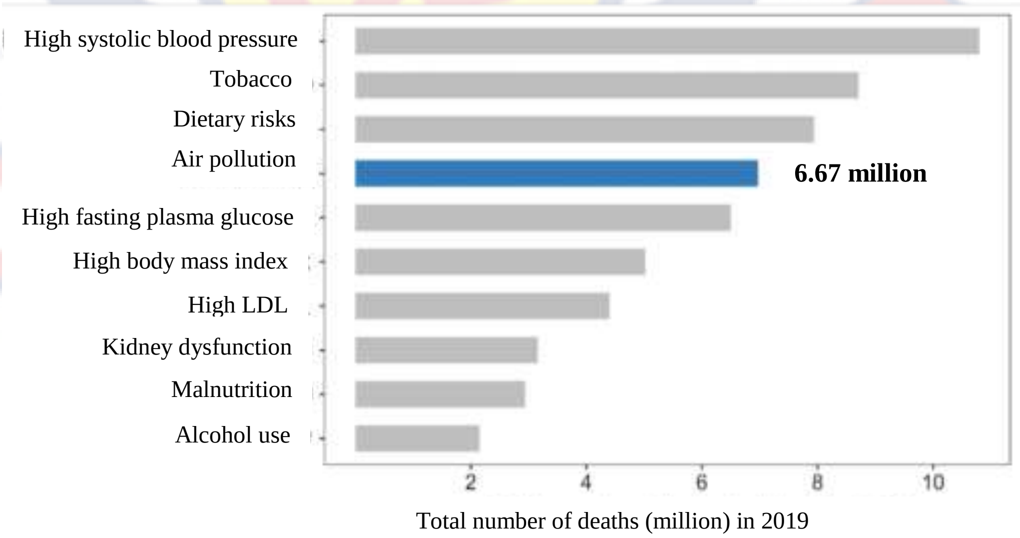

Figure 2: Global risk factor rankings based on the total number of death rate worldwide in 2017 from all causes for all ages and both sexes

Globally, Air pollution is thought to be responsible for an approximately 7 million premature deaths each year and outdoor alone is responsible for about 6% of global mortality. Air pollution also carries responsibility for about 147 million years of healthy life lost. In some countries, it can cause as much as one-in-ten deaths (Health Effect Institute, 2019).

In less developed countries, about 98% of children under five are projected to breathe toxic air (Air pollution and Child Health, 2018). Air pollution is therefore fingered as the leading cause of mortality for kids under 15. It kills 600,000 children every year (WHO, 2018).

In fiscal terms, A $5 trillion loss in global wellbeing is attributed to early mortality brought on by air pollution (The World Bank, 2015).Africa's economic production decreased by $3.02 billion in Ethiopia (11.6% of Gross Domestic Product), $1.63 billion in Ghana (95% of Gross Domestic Product), and $349 million in Rwanda (19% of Gross Domestic Product) due to air pollution-related sickness and death, in 2019 (Fisher et al., 2021). It was also calculated that PM_{2-5} pollution cost African children 196 billion IQ points in 2019 (Fisher et al., 2021).

From the facts above, it is reliably evident that the air pollution's health burden is rising at a terrifying rate disturbing economy and quality of life of people (Addo-Yobo et al., 2007; Good et al., 2021). It is on record that citizens of Africa, Asia or the Middle East are the worst affected (Lenine, 2016; WHO, 2014, 2016). They breathe in much higher volumes of polluted air than people living in other regions of the world. Level of air pollutant in some of the places in these regions are several times greater than what safe according the World Health Organization guidelines. For example, majority of the 3.6 billion people (47% of people worldwide) who were exposed to air pollutants from household use of solid fuels for cooking were from South and East Asia (Bennitt et al., 2021; Rao et al., 2012). It can therefore be extrapolated that, air pollutant levels in the Ghanaian environment are possibly above recommended levels.

It is suspected that the closeness of these regions to the Sahara Desert, as well as the use of low-quality fuels, increased motor vehicle use, industrial growth, use of wood-fired cooking stoves and dust storms from untarred roads and other construction sites are responsible for the choking levels of air pollution (Health Effect Institute, 2019).

2.2 Trends in Level of Major Air Pollutants

A lot of disparities are seen in the type, levels and trend of air pollutants between countries, and sub-regions. The factors that influence these disparities includes rapid urbanization, economic activities, fuel type and many others. However, some air pollutants for instance Particulate Matter (PM) and ozone are common and are monitored in almost all countries.

2.2.1 Trends in Particulate Matter (PM) pollution

Particulate matter exposure vary significantly across countries and regions. While emissions are increasing tremendously in Asia, and African countries (Bangladesh, China, India Thailand, Niger, Nigeria and Mauritania), there is a steady trend or a decline in other areas such as Japan, Brazil Russia and Mongolia from 1990 to 2017 (Somboonsin & Canudas-Romo, 2021).

The Highest global annual levels of $PM_{2.5}$ were recorded in Asia followed by Africa, in the year 2017 (The World Bank, 2019). In Asia, the highest annual level of 100 µg/m^3 was recorded in Nepal and the lowest level of 38 µg/m^3 which was still above WHO's air quality guideline recorded at Bhutan. Similar levels were recorded in Africa where the highest level of 94 µg/m^3 occurred at Niger with all other countries in the region having $PM_{2.5}$ exposures above 30 µg/m^3 (Health Effect Institute, 2019; Johnston et al., 2022).

The top ten (10) nations having the lowest levels of national $PM_{2.5}$ exposure, according to Health effect Institute, were Brunei, Canada, Estonia, Finland. Iceland, the Maldives, New Zealand, Norway, Sweden, and the United States, Average Population-weighted $PM_{2.5}$ concentrations of 8 µg/m^3 or less were recorded in these countries (Health Effect Institute, 2019).

In some countries, restriction on activities or emissions are reducing the type and magnitude of the various air pollution sources while others keep using or grow their dependency on coal and other significant air pollution producers. The percentage of the global population living in places that surpass the strictest WHO Air Quality Guideline of 10 µg/m^3 $PM_{2.5}$ decreased slightly, from 96% in 1990 to 92% in 2017. In spite of this, the percentage living in areas that fall of the least-stringent WHO target, of 35 µg/m^3 $PM_{2.5}$ concentration, remained steady at around 54%. As a result, many nations have suffered inconsistent variations in PM concentrations during the past few decades (from 1990 to 2017). Only half of the world's most populous nations saw the minor global decline in the percentage of people living in regions that exceed WHO guidelines. The United States had the most significant decline, with the percentage of residents living in places that exceeded the WHO recommendation falling from 50% in 1990 to around 40% in 2010 and to just 3% in 2017 (Health Effect Institute, 2019).

There is a clear inverse correlation between a nation's degree of social and economic development and the $PM_{2.5}$ exposure that its citizens are exposed to; in other words, less developed nations experience $PM_{2.5}$ exposures that are four to five times higher than those in more developed nations. (Health Effect Institute, 2019).

2.2.2 Future Projections of some Major Pollutants

Predicting future levels of air pollutants will increase our understand in the management of air quality, design national and international policies for air quality control, and evaluating mitigation policies and make the necessary amendments.

2.2.3 Particulate Matter Projection

If no new regulations are put in place to control pollution by Particulate Matter ($PM_{2.5}$ and PM_{10}), the OECD Environmental Outlook Baseline scenario projections indicate that particulate matter and ground-level ozone will be the leading cause of environmentally-related mortality worldwide. By 2050 (OECD, 2012). Fang Yana *et al.*, 2014, modeled particulate matter emissions from on-road cars under four widely-used global fuel consumption scenarios from 2010 to 2050 (Heywood et al., 2015; Yan et al., 2014) . They observed that global PM emissions, throughout the first 30 years, consistently fell under all circumstances. This was explained by the implementation of more modern and refined emission regulations and the elimination of older and inferior standard engines. Base on this, they were able to make projections that global PM concentrations shall range between 1100

Gg to 1360 Gg in 2030, depending on the particular scenario. However, in Africa only, PM emissions are expected to increase significantly (1.2–3.1% per year). The fundamental reason for the expected rise was that the continent of Africa's income levels would make it possible for those advanced and cleaner standards to be implemented 30–40 years later than in other countries, thus, significantly boosting world emissions by 2050. All of South Asia, East Asia, and Southeast Asia’s contribution to world totals will decrease over time i.e. from 32% in 2030 to about 22% in 2050.

Figure 3: Exhaust fumes from old poorly maintained cars (Sri Krishna, 2021)

2.2.4 Tropospheric Ozone Projection

Another air pollutant of global concern is the ground-level ozone. It is not produced directly from vehicle exhausts but are generated through photochemical reaction of primary pollutants such as oxides of nitrogen (NOx) and volatile organic compounds (VOCs)in the presence of sunlight and moisture. It is thus a secondary air pollutant whose formation is favoured by increased atmospheric temperatures.

2.3 Air Pollution in Ghana

Data on exposure to air pollutants in Ghana is mostly restricted to the capital city, Accra, with about fifteen monitoring stations. The other major cities such Cape Coast, Takoradi etc., have no official data on air pollution. Even so, this air pollution data of the capital city is not real-time. However, like most West African countries, air pollution remains one of the biggest causes for early death in Ghana (Mudu, 2021). Annual levels of urban outdoor air pollutants such as $PM_{2.5}$ of 31.1 $\mu g/m^3$ far exceeds WHO guidelines of 10 $\mu g/m^3$ (Dionisio et al., 2010; Odonkor & Mahami, 2020). This results in roughly 28,000 premature deaths in Ghana each year (Odonkor & Mahami, 2020). Disease burden linked to air pollution-related mortality rose significantly from 80 for every 100,000 people in 2012 to 203 for every 100,000 people 2016 (Chasant, 2020). Additionally, Ghana's non-continuous air quality monitoring focuses only on particulate matter, ignoring all other significant air pollutants such as carbon monoxide (CO), nitrogen oxides (NOx) and ground-level ozone (O_3)

The education of citizens on air pollution is very scanty (Odonkor & Mahami, 2020). Despite the existence of by-laws to reduce air pollution, there is no or little legal enforcement in Ghana (Mensah et al., 2022; Sabaheta & Hansen, 2012). The municipal and metropolitan assemblies, who are responsible for maintaining the environment, prioritize solid and liquid waste while ignoring air pollution. Thus, people indiscriminately pollute the air as it is not regarded as an illegal act. There are still a lot of Ghanaians who are addicted to the traditional methods of burning trash and toilet papers.

As thousands continue to die from inhaling toxic fumes from rickety and overaged vehicles, soot from biomass-fueled cookstoves and rubbish fires, dusty roads also contribute significantly to air pollution (Ghana Web, 2019). Only 23% of Ghana's 72,381km of roads are tarred with bitumen, according to official statistics (Ministry of roads and Highways, 2020). The 77 percent of roads in Ghanaian roads that are unpaved are dusty. (Ghana Web, 2019). Hazardously high levels of toxic air, is thus killing thousands of people in Ghana.

Among the numerous harmful health impacts of air pollution are heart disease, stroke, lung cancer, miscarriage, a decline in IQ, and even mental disorder (Chasant, 2020).

Around seven million premature deaths globally are attributed to the stale air that clogs our lungs each year, with developing nations like Ghana, Nigeria, and India being the most severely affected.

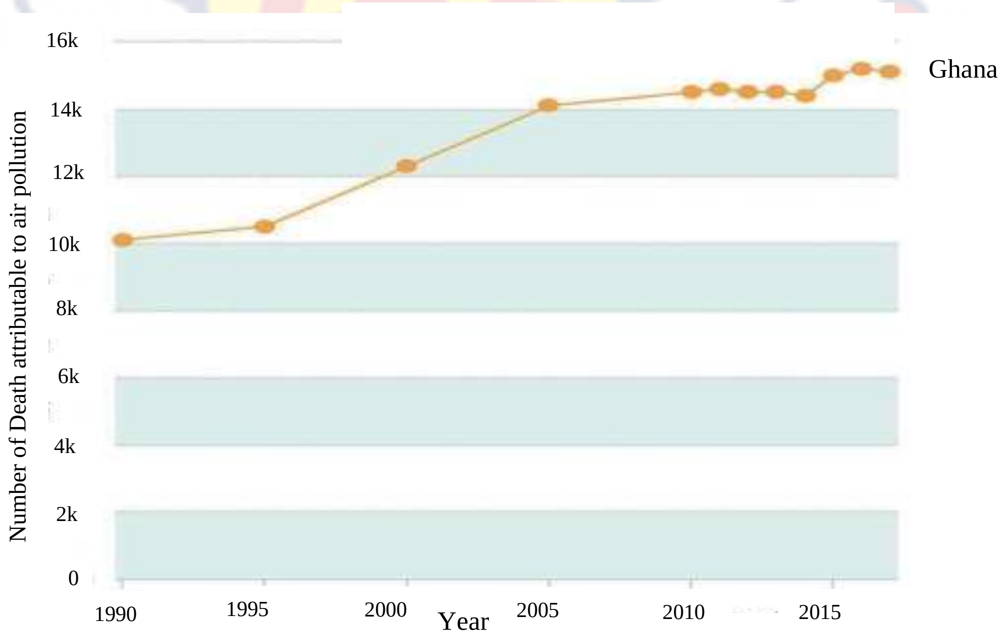

Figure 4: Number of mortality attributable to air pollution in Ghana (1990-2017) (Health Effect Institute, 2019)

2.4 Pollutants

The air around us is not entirely free from particles (pollutants). In a supposedly clean air, there are fewer than 500 dust particles per cubic centimeter whereas dirty air may contain more than 50,000 particle per cubic centimeter (Ostro et al., 2021). Inside a house where there is a major activity, the concentration of organic dust alone may reach 100,000 particle per cubic centimeter. These particles which are not naturally part of the air but are added through anthropogenic activities and capable of causing harm to humans and the environment are referred to as air pollutants.

Air pollutants are placed into three categories base on their nature and origin namely, physical, chemical, and biological.

2.4.1 Physical pollutants

Physical pollutants such as dust, soot, fly ash, smoke, metals, liquid droplets and rubber are commonly called particulate matter (PM) and are divided into two ie $PM_{2.5}$and PM_{10}.

PM_{10} are particles that are ten micrometers or less whiles $PM_{2.5}$ describes particulate matter in the atmospheric which have diameter equal to or less than 2.5 µm (or roughly 3% the diameter of a human hair). These particles, also known as fine particles, are so tiny that they can only be seen using an electron microscope. Due to its size and weight, PM_{10} can suspend in the air for minutes to hours and cover small distances (hundreds of yards to several miles) (Alias et al., 2007; K.-H. Kim et al., 2015).

2.4.2 Chemical pollutants

Chemical pollutants in the air comprises of carbon (II) oxide (CO), oxides of nitrogen (NOx) i.e. NO and NO_2, Sulphur (IV) oxides (SO_2), Volatile Organic Compounds (VOCs), tropospheric or ground level ozone (O_3) and Polycyclic Aromatic Hydrocarbons (PAHs).

Volatile organic compounds comprise of organic chemicals with a high vapor pressure at normal room temperature. Common examples include: methylene chloride, formaldehyde, benzene, toluene, ethylene glycol, tetrachloroethylene, xylene and 1,3-butadiene.

Polycyclic aromatic hydrocarbons are the products of incomplete incineration of organic matter. They can also be created naturally from the chemical conversion of organic sediments into fossil fuels like oil and coal.

Most of these chemical pollutants are emitted into the atmosphere directly through human activities while others are end products of photochemical reactions between other pollutants. Ozone is one of such chemicals that results from the photochemical reactions other pollutants. It is a greenhouse gas containing three oxygen atoms. It is naturally present in the stratospheres where it is considered good because it plays a protective role of safeguarding the earth from harmful rays and UV-radiations from the sun. Though stratospheric ozone can drop to the troposphere and cause harm to humans, ozone from the photochemical reactions of other pollutants is the predominant source of tropospheric or ground level ozone (O_3). The precursors of this reaction which are volatile organic compounds (VOCs) and oxides of nitrogen (NOx), primarily comprising of NO_2 and nitric oxide (NO) are of close association with traffic emissions. The oxidation of CO by the hydroxyl radical (•OH) marks the commencement of the reaction. This forms the radical adduct (•HOCO) which is unstable and quickly combines with oxygen to give a peroxy radical, HO_2• through the equations below:

$$\bullet OH + CO \rightarrow \bullet HOCO$$

$$\bullet HOCO + O_2 \rightarrow HO_2\bullet + CO_2$$

The peroxy-radicals proceed to react with NO to produce NO_2, which is subsequently photolyzed by UV-A light to produce a ground-state atomic oxygen that combines with molecular oxygen to create ozone (P. Wang et al., 2000)

$$HO_2\bullet + NO \rightarrow \bullet OH + NO_2$$

$$NO_2 + h\nu \rightarrow NO + O(3P),\ \lambda<400\ nm$$

$$O(3P) + O_2 \rightarrow O_3$$

The net reaction in this case is then: $CO + 2O_2 \rightarrow CO_2 + O_3$ (Carpenter et al., 2000; P. Wang et al., 2000)

2.4.3 Biological pollutants

Some air pollutants of biological nature are fungi, dust mites, bacteria, viruses, mildew, animal dander, house dust, mites, and pollen. Biological pollutants were not considered in this study because they are not from traffic (or vehicular) sources (Xie et al., 2021).

2.5 Roadside Exposure

An intricate mixture of chemicals pollutants is left along roadsides from vehicles in gaseous forms in addition to liquid and solid aerosols. These chemicals are categorized as either primary pollutants or secondary pollutants. The primary pollutants include those that emanate straight from combustion engines. They include carbon (II) oxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM) which comprise of soot and metals, PAHs such as Benzene, Benzo a pyrene, xylene and Volatile Organic Contaminants (Formaldehyde). Upon their release, the primary pollutants, i.e., VOCs undergo complex atmospheric photochemical reactions to form the secondary pollutants such as ozone (O_3). The components of the exhaust mixture depend on the fuel type, the operating conditions of the engine, and the effectiveness of any emission control devices. There is therefore, a great potential for chemical diversity of the mixture. Furthermore, the chemical composition is dynamic making the air we breathe now different from the air existing 10 years ago. Thus, any assessment of the consequences of chronic health conditions must also take into account a changing composition.

2.6 Biological Interactions of Air Pollutants

Inhaled air pollutants settle on the respiratory tract’s inner walls. Mucociliary motion moves the insoluble substances deposited (either intra-or extracellularly) into the throat where it is ultimately ingested. As an alternative, particles might spend a lot of time trapped in nearby lymph nodes or pulmonary tissue. Chemicals that are inhaled and dissolved in bodily fluids may go from the respiratory tract into the circulation and circulate throughout the body. Metabolic enzymes in the body have the ability to chemically change the pollutants. Although other organs, such as the lung, are also capable of metabolizing foreign substances, the liver is particularly active in this regard. Generally, metabolism aids in the body's ability to eliminate contaminants though excretion. This lowers the concentrations of pollutants in bodily tissues. Additionally, metabolic conversion may lessen the toxicity potential of some parent chemicals. On the contrarily, there is also the possibility of metabolism unexpectedly resulting in the production of more hazardous byproducts. The sensitivity of a person to a harmful substance is significantly influenced by the balance between metabolic activities that enhance toxicity, decrease toxicity, or promote elimination (Jaishankar et al., 2014; Pascual, 2021),

2.7 Human bodies responses to the toxic pollutants

The body's mechanisms of toxic reaction are triggered when pollutants interact with biological molecules, also known as receptors. Some of these responses are a direct and immediate outcome of the pollutant’s impact on the receptor. For instance, an inhaled pollution may directly stimulate airway irritant receptors, causing some kinds of asthma.

In contrast, certain other toxicity symptoms are extremely indirect and, as a result, are not well understood. This is typically the case with chronic or delayed consequences of toxicity. In such cases, the hazardous chemical's initial contact with a target site receptor may initiate a chain reaction of molecular and cellular activities that eventually harm tissue different from the initial target site. Emphysema and pulmonary fibrosis are examples of these indirect effects of poisoning.

Pulmonary fibrosis and emphysema illustrate such indirect manifestations of toxicity. For example, inhaled hazardous pollutants do not directly cause harm to the pulmonary connective tissue, instead, an intricate, multistep process is involved. Exposure to pollutants sets off an inflammatory reaction, which then encourages excessive connective tissue development or results in the enzymatic breakdown of elastic tissue. Damaged tissue and inflammatory cells produce chemical mediators in a self-improving process that encourages the recruitment and growth of additional inflammatory cells. These cells also produce growth hormones, digesting enzymes, and extremely reactive and deadly oxygen-derived radicals. Along with the intricacy of cellular and molecular processes, it is uncertain what controls the ratio of healthy defense or repair processes to unusual ones. Macrophages, neutrophils, and complement are among the inflammatory system's key defensive mechanisms against pathogenic pathogens and inhaled dusts. When these elements are in harmony with biological regulatory mechanisms, they eliminate invasive germs and aid in preventing or repairing tissue damage. However, they can cause lung illnesses under specific pathological conditions. This implies that a variety of elements, such as heredity, diet, and other environmental toxins, affect each of the several phases in the emergence of detrimental consequences, as well as the interplay of promoting or inhibiting elements at each level. These factors determine the sensitivity of any person to the toxic effects of a pollutant.

2.8 Health Effects of Air Pollution

The term "air pollution" refers to the intentional or unintentional release of materials or energy into the atmosphere by humans that are detrimental to the health of humans, animals and the entire ecosystems. Additionally, it may have an impact on amenities or obstruct other legal usage of the environment (Manisalidis et al., 2020).

The potential of any chemical that is inhaled to pose a negative health risk depends on the concentration of the pollutant, how long it is present, and how frequently it is inhaled. The ubiquitous nature of air pollutants coupled with our reliance on the constant supply of air for existence makes it difficult to escape air pollutants. These pollutants are able to slip past the defense structures of the body, penetrate our respiratory as well as the circulatory systems deeply, harming organs like the lungs, eyes, heart, brain, spleen, and other organs. Consequently, various damages are caused to these organs by air pollution exposures. Among them are respiratory disorders and cardiovascular damage (arrhythmias, stroke, the risk of heart attack and heart failure in susceptible people), fatigue, head pain, and worry, irritation of the nose, throat, and eyes, reproductive organ injury, injury to the nervous system, the spleen, the liver, and the blood.

2.9 Dust-bound Polycyclic Aromatic Hydrocarbons (PAHs)

Atmospheric dust is well recognized as a significant carrier of air pollutants for example PAHs, heavy metals and adsorbed gases. Against this background, street dust is regarded as a reliable measure of the overall condition (extent of pollution) of the city's atmosphere. Additionally, it is perceived as a composite source of several complicated pollutants, for instance, polycyclic aromatic hydrocarbons (PAHs).

The street, therefore, becomes a site of combination for dust and PAHs as most PAHs compounds present at the roadside are the outcome of imperfect fossil fuel combustion. With the continuous accumulation of PAHs in the dust, PAH levels may exceed environmental regulations, posing harm to urban ecosystems and human health, found that the levels of the dust were relatively high at lots of bus stops. Emissions from gasoline and diesel cars account for a significant level of particulate PAHs in metropolitan areas. Residential cooking and heating with coal and burning biomass both produce particulate PAHs in rural settings.

2.10 Fate of Polycyclic Aromatic Hydrocarbons in the Air

PAHs enter the surrounding air as vapourized forms or cling onto airborne particulate particles such as dust. Typically, low-volatile PAHs with more than five aromatic rings that have relatively high condensation temperatures get adsorbed onto airborne particles. They fall within the group of persistent organic pollutants (POPs) with poor mobility that are susceptible to rapid deposition and subsequent accumulation in close proximity to the source. The lower-molecular weight molecules with two or three aromatic rings and low temperatures of condensation are more prevalent in the gas phase. Semi-volatile four-ring PAHs (such as phenanthrene and pyrene) exist across both phases and the characteristics of the surrounding environment influence their gas-to-particle partition coefficients. The high or moderately high mobility PAHs undergo global atmospheric dispersion, and preferentially collect in polar latitudes. The range of PAH adsorption on air sorbents is also influenced by the amount and type of suspended particles (such as pollen, soot, dust, and fly ash).

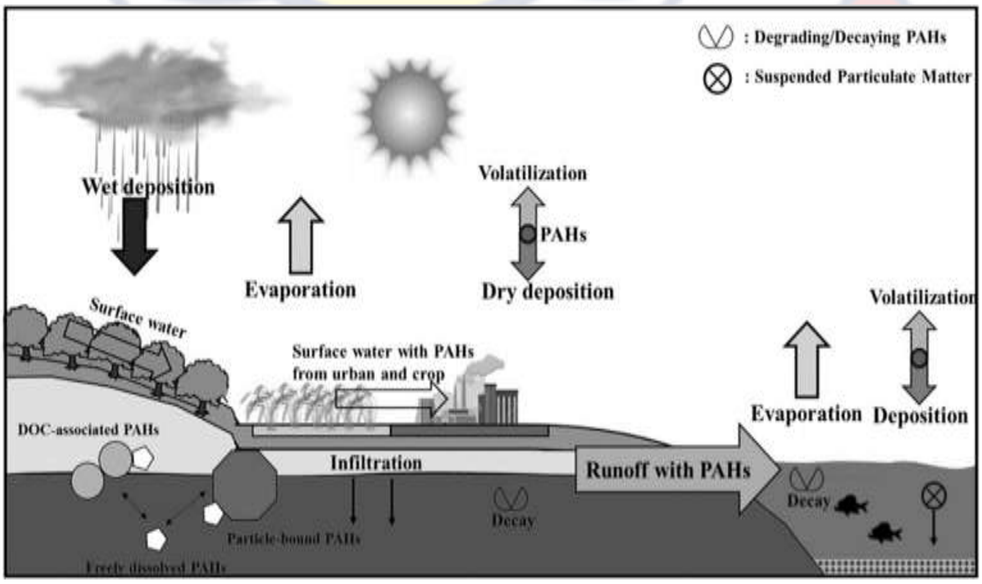

Figure 5: Environmental fate of PAHs

While in the atmosphere, PAHs undergo a variety of intricate physico-chemical interactions and changes that causes the reduction in the concentration of PAHs. The physical mechanisms loss of PAHs from the atmosphere are dry and wet deposition, photochemical transformations and long-range transport.

The chemical reactions include reactions with molecular oxygen in the absence of light, however, these reactions appear to be very slow and represent an insignificant degradation pathway. It has been shown that PAHs may interact with both ambient ozone and NO_X to form nitro-PAHs, which may be more mutagenic and carcinogenic than PAH precursors.

2.11 Application of Diagnostic Ratios

The concept of "source characterization of PAHs" entails tracing the origins of these pollutants. PAHs enter the environment as a mixture and different PAH sources contain certain congeners that distinguish them from the others. For instance, the predominant PAHs in the emissions from unburned fuel are light, two- or three-ring PAHs, while the predominant PAHs in the emissions from combustion processes are four-and five-ring. Low-temperature operations, like burning wood, often result in low molecular weight PAHs, while high-temperature processes, such as burning gasoline in an engine, result in high molecular weight PAH molecules (Herngren et al., 2010; Jamhari et al., 2014). Also, petroleum-related PAHs (those from spills of petroleum products) are characterized by higher content of alkyl -substituted compared to PAHs derived from combustion sources. The ratio of the relative concentration of specific PAHs in the environment, has been identified to possess the potential to distinguish between sources. However, PAHs have different fates in the environment which can affect their relative concentration. Source characteristic PAHs emission profiles can be altered during PAHs environmental fate. To minimize the effect of changes in the PAH profile after emission to the environment, the ratio of two PAHs compounds with the same molar mass and similar physicochemical parameters is calculated. This is because compounds which have identical molar mass and comparable physicochemical parameters will have similar environmental fates, As a result, from the time of emission until the time of sample collection, the relative ratio of the two isomers should ideally stay constant. Thus, the following PAHs ratios presented in the table below have been established and used in the determination of source of PAHs.

Table 1: Some commonly used PAH ratios

PAHs	Diagnostic Ratio	Sources
Phe/Ant	< 10	Pyrogenic
	> 15	Petrogenic
Fla/Pyr	< 1	Pyrogenic
	> 1	Petrogenic
Ant/(Ant+Phe)	< 0.1	Petroleum
	> 0.1	Combustion
Flu/(Flu + Pyr)	< 0.4	Petroleum
	0.4 – 0.5	Liquid fossil fuel Combustion
	> 0.5	Coal, wood or grass combustion
BaA/(BaA + CHR)	< 0.2	Petroleum
	0.2 – 0.35	Petroleum or combustion
	> 0.35	Combustion
IcdP/(IcdP + BghiP)	< 0.2	Petrogenic
	0.2 – 0.5	Fuel combustion
	> 0.5	Grass/coal/wood combustion
LMW/HMW PAHs	< 1	Pyrogenic
	>1	Petrogenic
BaP/(BaP + Chr)	< 0.2	Petroleum
	0.2 – 0.35	Coal wood or grass combustion
	> 0.35	Combustion

(Moyo et al., 2013)

The FLA/(FLA/PYR) ratio is resistant to alterations brought on by phase transitions and environmental deterioration. Because of this, it appears that the FLA/(FLA + PYR) ratio is more credible in predicting the sources of pollutant emission.

2.12 Human Health Effects of PAHs

PAHs and alkyl-substituted PAHs are well recognized to be key toxic environmental contaminants. The health effects of PAHs are categorized as short-term and long-term depending on the exposure concentration, duration, and how the body responds to them. The short-term health impacts of PAHs are uncertain. Some believe that short-term PAH exposure symptoms such as eye nausea, vomiting, irritation, diarrhea, and confusion are triggered by other substances or compounds that are frequently identified alongside PAHs.

Long-term health impacts of PAH exposure may include exacerbation of asthma, reduced lung function, increased rates of obstructive lung diseases, cataracts, jaundice, liver and kidney damage. Some PAHs have been associated the development of cancers of the lungs, breasts, esophagus, gastric, pancreas, colorectal, prostate, bladder, cervical and skin tissues in both animal models and people. Increased cases of these cancers have been linked to a variety of occupational environments, such as the manufacturing of aluminum, coal gasification, tar distillation, coke, shale oil extraction, iron, and steel foundries, wood impregnation, roofing, road paving, carbon black, chimney sweeping, carbon electrode, calcium carbide, fire-fighting and diesel engine maintenance. In addition to being carcinogenic, PAHs have been linked to cardio-, hemato-, neuro-, renal-, reproductive-, immuno-, and developmental toxicity in humans and laboratory animals. Limited epidemiological research also points to adverse consequences on children's cognitive or behavioral function.

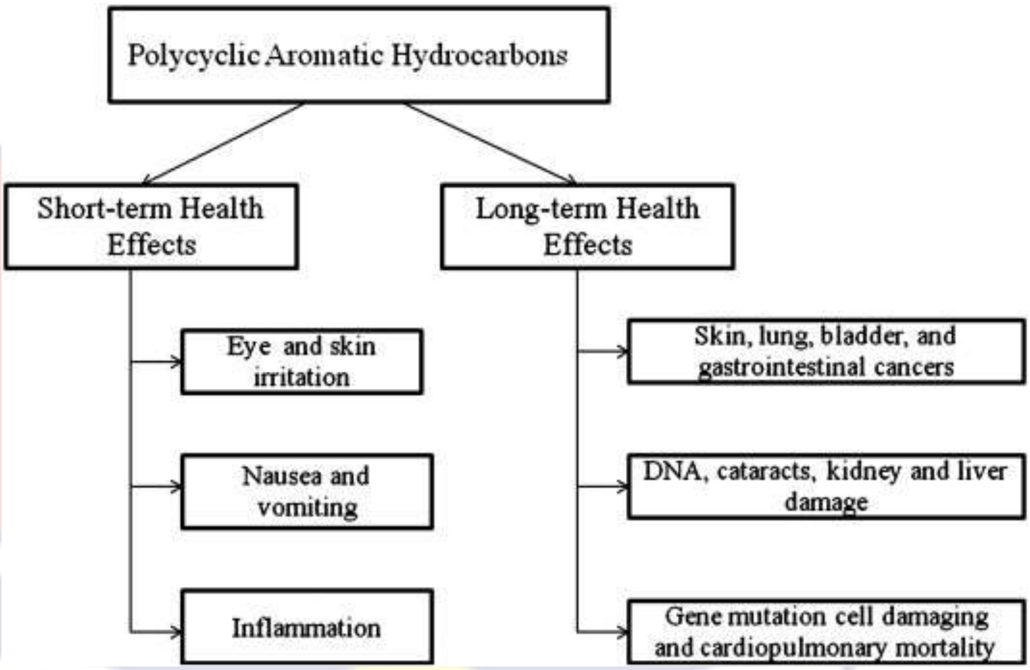

Figure 6: Short and long-term human health effects of PAHs

Evidence points out that both PAH mixtures and individual PAH can be harmful. For example, prolonged dermal contact with the PAH naphthalene can result in skin swelling and redness. Also, when consumed or breathed in high concentrations, naphthalene can induce the destruction of red blood cells. High doses of anthracene can cause acute dermatitis in humans, with symptoms such as swelling, burning, and itching. Those exposed to anthracene experienced stomach and intestinal irritation, headaches, nausea, and a lack of appetite. They also felt weak and their response time slowed. High dosages of the PAH benzo(a)pyrene caused reproductive issues in pregnant mice. Additionally, the offspring of pregnant mice had a loss in body weight and birth abnormalities. The release of PAHs into our environment is of concern because they can induce teratogenicity, mutagenicity, and carcinogenicity in humans.

2.13 Endocrine Disruption

Endocrine disruption occurs when an exogenous chemical or mixture modifies or mimics an endocrine system function and, as a result, has a negative impact on an intact organism, or its offspring. The Polycyclic Aromatic Hydrocarbons (PAHs) have been identified to possess the ability to disrupt endocrine functions of humans and animals. The type of endocrine functions disrupted and the associated potencies depends on the kind and extent of alkylation of the PAH. Due to PAHs' benzene ring structure, which is similar to that of steroid hormones, they are able to quickly disrupt reproductive hormones.

These endocrine disruptors can interfere with the body's normal hormone production, secretion, movement, binding, action, and elimination of hormones essential to growth, behavior, reproduction, and homeostasis.

2.14 Chapter Summary

The state and trends of air pollution around the globe, Africa and Ghana showed that countries in Asia and Africa like Ghana have high levels of air pollutants. Road transport is a chief sources of air pollution, thus making the roadside environment worse.

Air pollutants affect organs like lungs, liver, brains, eyes etc. and has been linked to respiratory diseases, stroke, cataract, kidney and liver diseases.

Finally, air pollution has been estimated as a leading cause of mortality worldwide and a public health emergency.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter describes the research methods that were used to conduct this study. It outlines the research design and describes how the data essential to addressing the research objectives and questions were collected, presented and analyzed. It describes the participants, sampling technique, sample size and gives the criteria for the inclusion and exclusion of participants in the study. Additionally, the instruments utilized for data collection and the methods employed to carry out this investigation are described.

The chapter concludes with a brief explanation of the ethical considerations, limitations posed by the research methodology, as well as problems that came up during the research.

3.1 Research Design

In qualitative research, a phenomenon is explained by relying on the perception of a person's experience in a given situation (Supadi et al., 2021; Willy Lima & Prof. Enid F. Newell-McLymont, 2021). A quantitative approach is however, employed when a researcher seeks to understand relationships between variables (Creswell, 2009). In this study, the quantitative approach is used to examine the relationship between vehicular emissions and the respiratory health of vendors. The qualitative method is also used to investigate the perception of vendors on the effects of vehicular emissions.

To quantitatively determine the association between air pollution levels along some arterial roads in the Cape Coast Metropolis and respiratory health outcomes of roadside vendors, a cross-sectional study design was employed and the study was planned as follows:

- The assessment of air quality along the main Abura – Kotokoraba road through a set of physical and chemical measurements and
- Determination of respiratory health characteristics of vendors through the use of Lung Function Tests (LFT).

During this cross-sectional study, the researcher records information on the exposure and outcome of the participants but does not manipulate the study environment. This study design is employed for this research because the main focus of this research is to measure the exposure and outcome of roadside air pollutants on vendors without manipulating the roadside environment. It also measured the exposure and outcome of a control group whose workplaces are far away from the busy roads in the city. This group consists of National Service Personnel at the College of Agriculture and the Natural Sciences (CANS) of University of Cape Coast. This group was selected as control because their offices were far (over 5 km) from the roadside. Their offices are also provided with air conditioners which maintained good temperature and humidity and have filters to sieve particulate matter. A total fifty – three (53) control participants were recruited for the study.

3.2 Assessment of Roadside Air Quality

The level of roadside air pollutants that may cause chronic health effects were measured at selected points along the main Abura – Kotokoraba road for a period of three months (from January to March, 2021). A 24-hour real-time air samples were measured with a low-cost air monitor (ASE air box).

These monitors are equipped with sensors to measure the levels of carbon monoxide (CO), particulate matter ($PM_{2.5}$) and ozone (O_3). Additionally, dust was collected by allowing the particles to settle on Teflon sheets placed on Teflon sheet placed on shelves within breathing zones in the immediate environment of the vendors. The levels of polycyclic aromatic hydrocarbons (PAHs) from exhaust fumes adsorbed onto the dust carbon monoxide (CO), particulate matter ($PM_{2.5}$), and ozone (O_3) were determined to evaluate their health risk on vendors along the busy roads.

3.3 Respiratory Health Characteristics of Vendors

The respiratory health effect of air pollutants at the lengthways of arterial roads were examined by carrying out lung function tests and administering a questionnaire to vendors. The questionnaire was used to evaluate the perception of vendors on air pollution along the road as well as the short-term effects of air pollution (such as coughing, sneezing, irritation of the eye, etc.) that vendors usually experience. See Appendix A

3.4 Study Variables

Three (3) categories of variables were studied. These were;

- Physical parameters: Temperature, Relative humidity and Particulate matter ($PM_{2.5}$),
- C1hemical pollutants: Carbon (II) oxide (CO), ground-level ozone (O_3) and $PM_{2.5}$ – bound polycyclic aromatic hydrocarbons (PAHs).
- Lung function parameters: Force Vital Capacity (FVC), Force Expiratory Volume (FEV_1), FEV_1/FVC in percentage, PEF.

3.5 The Study Area

The study was conducted at the lengthways of the main Abura – Kotokoraba road in the Cape Coast metropolitan area in the Central Region of Ghana. Specifically, the road linking Abura Market, Pedu traffic light, Adisadel, Siwdo and Kotokoraba market. The selection of these areas for investigation is based on:

- Observed of heavy and regular vehicular traffic,
- Presence of roadside vendors.

The Cape Coast Metropolis is the smallest metropolis among the 260 Metropolitan, Municipal and District Assemblies (MMDAs) in the country with its administrative capital as Cape Coast**.** It covers about 122 square kilometers area of land and is located at longitude 1° 15'W and latitude 5°06'N. The Gulf of Guinea borders the Metropolitan on its south, the Komenda Edina Eguafo/Abrem Municipal on its west, the Abura Asebu Kwamankese District on its east, and the Twifo Hemang Lower Denkyira District on its north (Livingbird & Sowah, 2014; Metropolitan Planning Coordinating Unit, 2014). It has a population of about 169,894 according to the 2010 census and a population density of 1520/km² (Livingbird & Sowah, 2014). It is one of Ghana's smaller urban centers with a total road network of 220.83km, out of which 17.60km is asphalted, 106.93 km is bituminous and 96.30 km is graveled (Amoako-Sakyi, 2013). The Metropolis is an economic hub with lots of trading activities along the lengthways of most of its roads, traffic lights and the few markets.

All of the major commercial establishments are located in or close to the Kotokoraba Market, which is the biggest in the Cape Coast city. As a result, the market's roadways become severely congested with cars. Cars regularly run their engines, releasing harmful gases into the environment.

The next bustling city within the metropolis is Abura. This is because Abura houses the second largest market in the metropolis making Abura another busy, congested area. The market’s vicinity is characterized by constant traffic jams. Numerous vendors who take advantage of the traffic slowdown on major highways and major intersections to try to trade with passengers often prolong and worsen traffic delays. Again, the middle class of the city (consisting primarily of university and government employees) who own personal cars, also adds to the traffic jams in the morning and afternoon as the start of the workday and the closing of the government offices and schools draw near (Porter, 2013).

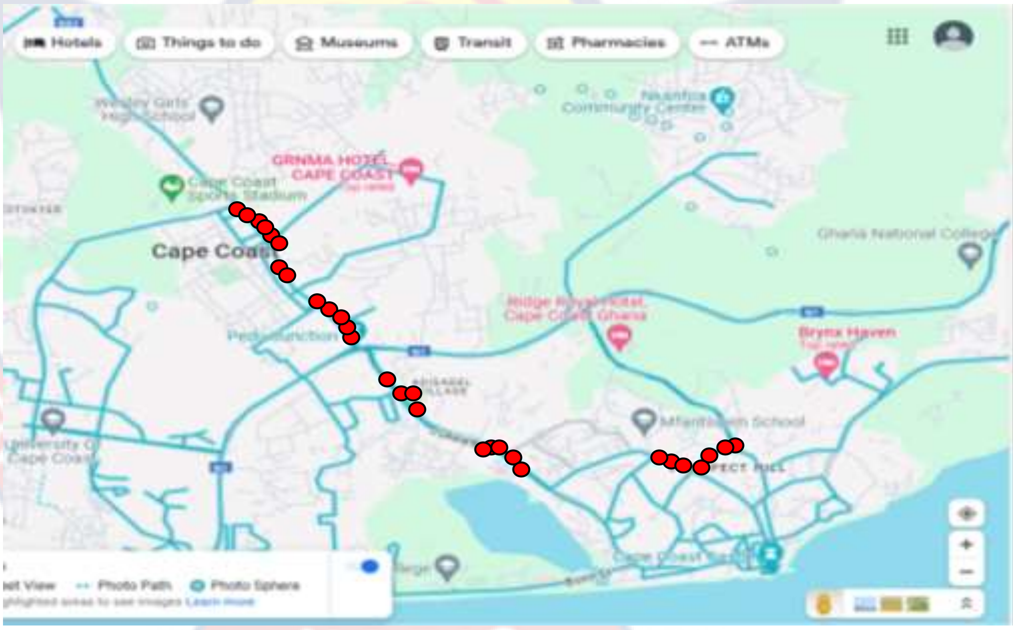

Figure 7: Map of the study area. (Retrieved from Google map, June 20, 2018)

The climate in Cape Coast is tropical and humid having a typical mean monthly relative humidity range of 85% to 99%. Air pollution's generation and dispersion are influenced by humidity. Pollutants are kept close to the ground in humid air, which stops them from spreading into the sky. As a result, humid air traps more contaminants in the air, particularly in cities (Emekwuru & Ejohwomu, 2023). The sea breeze has a moderating effect on the local climate. All year long, the Cape Coast Metropolis has high temperatures. The warmest months are February and March, which come right before the main rainy season, while the coldest months are June, July, and August. Rainfall has a greater effect on climatic fluctuation in the Metropolis than temperature does. The Metropolis has twice the average annual rainfall, accumulating between 750 and 1,000 mm (Ghana Statistical Service, 2014a).

Cape Coast, like many peri-urban and rural areas in underdeveloped nations, struggles with all known types of pollution issues. Although, the metropolitan authorities is tasked with enforcing the bye-laws on pollution, it focuses more on solid waste management than the other types of pollution. Furthermore, dust from the dusty surroundings is carried into the air by the wind, which has an impact on the quality of the air that people breathe. Additionally, open-air production of palm kernel oil at Abura pollutes the environment constantly with copious amounts of smoke and particulate particles.

3.6 Sample Size and Population

The source population was roadside vendors in the Cape Coast Metropolis. Both male and female roadside vendors were randomly selected. No age limitation or level of education was used in selecting vendors. Sixty – Six (66) roadside vendors and fifty-three (53) control participants were sampled in this study. Vendors who sell their wares in stalls by the roadside were sampled at areas along the roadside where there is observed heavy and regular vehicular traffic. This is because aside the fact that air pollutants can travel long distances, nearness to the source increases the level of exposure and the effects of air pollutants on people in those areas. Again, vendors who sell their wares in stalls by the roadside mostly stay in the immediate environment of the stall unlike the vendors on the street. The control participants were selected from National Service Personnel working at the College of Agriculture and the Natural Sciences (CANS) of University of Cape Coast (UCC).

3.7 Inclusion Criteria

- Participants selected have been in the street for more than three months before the beginning of the study as indicated on the questionnaire by participants.
- Participants have not been diagnosed of any respiratory health condition such as asthma and common cold, sinusitis, pharyngitis, epiglottitis, Laryngotracheitis etc. before the start of the study.
- All participants should be willing to participate in the study.

3.8 Exclusion Criteria

- Vendors who indicated on the questionnaire that they have not been in the street for more than three months were excluded from the study.
- Participants who have been diagnosed or have symptoms of any respiratory health issue such as asthma and upper respiratory tract infections before the start of the study were also excluded.
- Vendors who were not willing to be part of the study were not selected.

3.9 Sample Selection Procedure

The snowball sampling methods was used in the selection of participants. The snowball sampling method was used because some vendors saw the research as a bother to their trading activities while others felt they were too busy to be part of the research. Additionally, some vendors trusted their colleague vendor's recommendation more than the researcher who is not known to them thus necessitating the use of the snowball sampling method.

3.9.1 Environmental Data (Real-time)

The ASE sampling box (model: 1 – 0003) which is an already calibrated passive air sampler was used to measure real-time levels of particulate matter ($PM_{2.5}$), ground-level ozone (O_3) and carbon (II) oxide (CO). The monitor was hung within the breathing zone (within the height of one and two metres above the ground) in the immediate environment of the vendor. The same instrument was also used to measure meteorological parameters such as temperature, and humidity during each monitoring period. Real-time measurement of pollutants was to enable the researcher to assess the temporal variations in pollutant concentrations due to changes in vehicular traffic volumes and weather conditions. Twenty-four-hour measurement of pollutants provided information on the extent to which vehicular traffic affected the concentration of pollutants and also made it possible to compare pollutants levels with EPA and WHO 24–hour air quality guidelines/standards (Ministry of roads and Highways, 2020; Williams et al., 2023).

Three (3) monitors with the following identifications were used:

1. Sensors ID: MICS_2614_O3_1-0033, MICS_5524_CO_1-0043, Shinyie_1-0053, Temp/RH_DHT22_1-0073, SD Card_1-0083).
2. Sensors ID: MICS_2614_O3_1-0036, MICS_5524_CO_1-0046, Shinyie_1-0056, Temp/RH_DHT22_1-0076, SD Card_1-0086),
3. Sensors ID: MICS_2614_O3_1-0038, MICS_5524_CO_1-0048, Shinyie_1-0058, Temp/RH_DHT22_1-0078, SD Card_1-0088).

These are passive air samplers which have sensors to measure particulate matter ($PM_{2.5}$), carbon monoxide (CO) and ozone (O_3). The monitors were hung in the immediate environment of the vendors at the roadside where vendors have displayed items for sale and as result spend most time of the day. Each monitor was checked occasionally to ensure it is working properly.

3.9.2 Questionnaire administration

Data collection also included the use of questionnaire with well-structured and close-ended questions, administered to vendors by the researcher. This questionnaire was used to examine vendors' perceptions of air pollution along the roadside, the types of air pollutants they usually get exposed to, as well as the short-term effect of air pollution (such as coughing, sneezing, irritation of the eye etc.) that vendors have observed. The questionnaire also sought to obtain demographic, medical, and self-reported respiratory conditions such as asthma, and wheezing of vendors among others. A total of one hundred and nineteen (119) questionnaires were administered to vendors and controls.

3.9.3 Spirometry test

Lung function test was conducted on forty – five out of the sixty – six vendors at the roadside. The test was done very early in the morning (when the vendors have just reported to the street) and in the afternoon (when the vendors have been exposed to the pollutant for about six to eight hours). The Minispir PC-based Spirometer with the WinspiroPRO software obtained from Medical International Research was the instrument used.

This test requires the participant to deeply breathe in and breathe out (one cycle of breath) with maximal effort through a spirometer so that lung parameters such as forced vital capacity (FVC) and forced expiratory volume in the first second of the forceful exhalation (FEV_1), FEV_1/FVC ratio and peak expiratory flow (PEF) could be measured. During each section (morning or evening), the process was repeated three times to obtain averages of lung function parameters. Disposable mouthpieces were used to prevent the transmission of oral infections. Participants' hands were also sanitized with alcohol to eliminate any risk(s) to the participants.

3.10 Materials and Reagent

3.10.1 Materials

- Centrifuge: desktop centrifuge with maximum speed of 5000rpm, obtained from Laboao,
- Centrifuge tubes (10 mL)
- Beakers (250 mL)
- Analytical balance (Sartorius CP124S): with maximum capacity of 120g obtained from Marshall scientific.

- Sample vials: Clear 1.5ml Screw-thread vial with write on spot from Shimadzu.

3.10.2 Reagents

The reagents and standards used were of high purity. The Semi volatile (SV) internal standards (6 components; 31206), B/N Surrogates mix (4/89 SOW, #31062) and GCMS tuning mixture (benzidine; Decafluorotriphenylphosphine (DFTPP); 4, 4′-DDT and pentachlorophenol, #31615) used were all purchased from Restek. The Acetonitrile 99% gradient grade was obtained from LiChrosolv Reag. Ph. Eur. Millipore Corporation, Germany. QUECHERS salt containing 1.5g NaCl, 6g MgSO4, 1g trisodium citrate dihydrate, and 0.5g disodium hydrogen citrate for extraction was also obtained from Phenomenex Inc, California, USA. QUECHERS pouch containing PSA (primary secondary amine) and magnesium sulphate for clean-up and drying respectively (4mL packed in 10ml centrifuge tube) was obtained from Phenomenex Inc, California, USA.

QuEChERS column containing Primary Secondary amine (PSA) and $MgSO_4$), Blank solutions were also prepared from deionized water.

3.11 Preparation of Standards and GC-MS analysis

Standard solutions of analyses 10, 20, 50, and 100 500ppm were prepared from 1000ppm standard. The Agilent 7890 B GC was used to analyze PAHs in the dusdevst samples. The following PAHs were analyzed: 2-fluorophenol(S), 2-chloro-1, 4-Dichlorobenzene-d4, benzene, 1,2-dichloro-phenol, benzene, 1,3-dichloro-, benzene, naphthalene, acenaphthene, Pyrene, Chrysene, anthracene, phenanthrene, fluoranthene. In addition these PAHs were analysed: Pyrelene, benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, Benzo[e]pyrene, Indeno[1,2,3-cd]pyrene, Dibenz[a,h]anthracene, and benzo[ghi]perylene.

3.12 Dust Sample collection

Pre-weighed Teflon sheets were placed on shelves in the stalls along the roadside where vendors spend most of their time, for particulate matter to settle on. The Teflon sheets were placed within the breathing zone of the participants (i.e. Between the range of one and two meters above the ground). The edges of the Teflon sheets were folded vertically to prevent settled dust from being blown away. The Teflon sheets were held with pins onto the shelve for three weeks to obtain sufficient dust for the extraction procedure. Teflon sheets were collected after three weeks, carefully folded and wrapped with Aluminum foil and sent to the laboratory of the department of chemistry, University of Cape Coast, for analysis.

At the laboratory, each Teflon sheet was re-weighed to obtain the mass of settled dust after which the settled dust was carefully transferred into a centrifuge tube.

3.13 Sample Preparation and Analysis

The method used was EN 15662 QuECHERS Method (Schmidt & Snow, 2016; Zheng et al., 2019). An amount of the QuECHERS salt which is equal to the quantity of dust from each sampling site were added together in a centrifuge tube. 5 mL of acetonitrile and internal standard were added to the mixture and shaken by hand for 1 minute. The resultant mixture was centrifuged at 3500 revolutions per minute for 15 minutes. For cleaning and drying purposes, the supernatant was decanted into a different tube containing primary secondary amine (PSA) and $MgSO_4$. This was then centrifuged at

3500 revolutions per minute for 15 minutes and then transferred into 1.5 mL glass sample vials for GC-MS analysis at the Ghana Standards Authority.

3.14 Analysis of Samples using GC-MS

For the GC/MS analysis, the EPA method 8270 (SIM) was used. An Agilent 7890B GCMS equipped with Agilent Technologies GC sampler 80 was used for the analysis. The dimension of the capillary column used was 30m +10m EZ Guard x 0.25mm internal diameter fused silica capillary coated with VF-5ms (0.25μm film) from Agilent. Helium gas (purity: 99.9995%) was used as the carrier gas.

3.15 Operational conditions for Gas Chromatography

Initial temperature settings for the column oven were 70.0 °C and 280.0 °C for the split-less mode injection port. The GC was operated using temperature programming. A temperature of 70 °C was first established and maintained for two minutes. The temperature was then ramped up to 150 °C at a rate of 25 °C/min, and then again to 200 °C at a rate of 3 °C/min. The temperature was then increased by 8 °C per minute to 280 °C and maintained there for 3.0 min. 32 minutes were used for the entire program. The injection volume was 1.0 µL. The linear velocity flow control mode was employed; the linear velocity resulted in 42.3 cm/sec for a column flow of 1.33 mL/min and a total flow of 8.7 mL/min (Adjei et al., 2019; Kusi, 2020),

3.16 Mass Spectrometer Operational Conditions

The electron impact ionization source was used and quantitative data were gathered utilizing Multiple Reaction Monitoring (MRM) mode with ≥ 2 ions monitored for each molecule. Ion source and interface temperatures (Adjei et al., 2019; Kusi, 2020) were set at 230 °C and 280 °C, respectively.

3.17 Quality Control

This study used an internal standard quantitative methodology. For quantification, a five-point calibration curve for 8270 standards ranging from 0.01 to 0.5 mg/L, for which 50.0 µL of 5.0 mg/L internal standard (ISTD) has been added to each, was employed. To test for method recovery, surrogate standards (S) of 0.30–3.0 mg/L were additionally added to each standard and sample (EPA method 8270).

For each run of ten continuous sample runs, initial calibration standards (ICVs) at 0.2 mg/L and comparative calibration values (CCVs) at 0.5 mg/L were conducted to verify the GCMS technique. Prior to analyzing each batch of samples, method reagent black that had been spiked with ISTD and surrogates was examined. Manual tuning was done every 12 hours using the GCMS tuning mixture in accordance with the method 8270 E/D criterion (Environmental Protection Agency, 2008).

3.18 Quality Assurance

Blanks solutions containing distilled water were also taken through the sample preparation method and analyzed to assess the possibility of contamination of dust samples. Research assistants/consultants employed for this research were briefed to ensure that they understand the research topic, the objectives, the sensitivity of the topic and the need for confidentiality. The training was also to ensure that they were adequately equipped to assist in data collection. Supervision was carried out by the researcher during the entire period of the fieldwork.

3.19 Data Analysis

Data were analyzed with the Statistical Package for Social Sciences version 22 (SPSS, Chicago, IL, USA). Descriptive statistics were used to describe the background variables. Pre-shift FVC and FEV_1 and cross-shift differences in FVC and FEV_1 were analyzed with an independent t-test. Pre-shift FVC and FEV_1 and expected values were analyzed with one sample t-test. Linear regression and correlation were used to estimate the relationship between lung function and the level of air pollutants. P-values less 0.05 (i.e., $p < 0.05$) were regarded as statistically significant.

3.20 Human Health Risk Assessment of PAHs

Human health effects of PAHs are usually long-term. Literature on short-term health effects is scanty, rather, other compounds found with PAHs are suggested to cause short-term effects. Aside stroke, kidney problems, etc., carcinogenic potential of PAHs, mainly High Molecular Weight (HMW) PAHs and their metabolites or derivatives, is extensively documented in the literature (Aslam et al., 2022; Ofori et al., 2020; Yu, 2002). PAHs effects are hinge on dose, duration of exposure and the body's responds. To estimate the cancer risk of the PAHs at a particular site, the potential of individual PAHs to cause cancer is estimated relative to Benzo[a]pyrene which is vastly carcinogenic.

A risk assessment calculates the likelihood that a particular environmental pollutant will have negative consequences after being exposed to humans. PAHs are known to be carcinogenic therefore the data on PAHs were put in two different models to evaluate their human cancer risk. The models were Incremental Lifetime Cancer Risk (ILCR) and the Toxicity equivalence Factor by Nisbet and Lagoy of the PAHs (Li et al., 2018; Liu et al., 2015). The incremental lifetime cancer risk determines whether the PAH concentrations are safe or detrimental whiles the toxicity equivalence factor by Nisbet and Lagoy estimates the number of persons who are likely to suffer from cancer in their lifetime of seventy years (Aquilina & Harrison, 2023; Hussain et al., 1998; Jakovljević et al., 2023).

Incremental lifetime cancer risk was determined by calculating the lifetime cancer risk through the three main routes of exposure, namely: dermal, ingestion and inhalation. The results of these were then summed up to obtain the Incremental Lifetime Cancer risk.

The equations employed for the calculation of Lifetime Cancer Risk are as follows (Pongpiachan, 2016):

$$LCR_{ingestion} = \frac{CS\ x\ \left(CSF_{ingestion}\ x\ \sqrt[3]{\left(\frac{BW}{70}\right)}\right)\ x\ IR_{ingestion}\ x\ EF\ x\ ED}{BW\ x\ AT\ x\ 10^{6}}$$

$$LCR_{Dermal} = \frac{CS\ x\ \left(CSF_{Dermal}\ x\ \sqrt[3]{\left(\frac{BW}{70}\right)}\right)\ x\ SA\ x\ AF\ x\ ABS\ x\ EF\ x\ ED}{BW\ x\ AT\ x\ 10^{6}}$$

$$LCR_{inhalation} = \frac{CS\ x\ \left(CSF_{inhalation}\ x\ \sqrt[3]{\left(\frac{BW}{70}\right)}\right)\ x\ IR_{inhalation}\ x\ EF\ x\ ED}{BW\ x\ AT\ x\ PaEF}$$

Where:

CS (µg kg^{-1}) = sum of converted PAHs concentrations based on toxic equivalency factor (TEF)

$CSF_{ingestion}$ = Cancer Slope Factor for ingestion (7.3 mg kg^{-1} day^{-1})

$CSF_{inhalation}$ = Cancer Slope Factor for inhalation (3.85 mg kg^{-1} day^{-1})

CSF_{dermal} = Cancer Slope Factor for dermal (25 mg $kg^{-1}$$day^{-1}$)

BW = Body weight of 71.05± 13.60 kg

AF = Absorption Factor of 0.07 mg cm^{-2}

ED = Exposure duration of 24 year

IR = Ingestion rate of 100 mg day^{-1}

= inhalation rate 20 m^3 day^{-1}

AT = Averaging time of 25,550 days

EF = Exposure frequency of 180 days $year^{-1}$

SA = Surface exposure (5700 cm^2 day^{-1})

PaEF = Particle Emission factor of 1.36 x 10^9 m^3 kg^{-1}

ABS = Dermal adsorption fraction of 0.13

The Cancer risk factor using the toxicity Equivalence Factor by Nisbet and Lagoy was also calculated as follows:

$$BaP_{(eq)}dose = \frac{TEQ\ x\ IR\ x\ EF\ x\ ED\ x\ CF}{BW\ x\ AT}$$

$$RISK = SF_{BaP}\ x\ BaP_{dose}$$

Where:

TEQ = Toxicity Equivalence Quotient

IR = Inhalation rate of 20 x 10^{12}

EF = Exposure frequency 1day/year

ED = Exposure duration of 30 years

CF = Conversion factor of 1 x 10^{-12}

BW = Body weight of 75 kg

AT = Average lifetime of 70 years for adults

$SF_{(BaP)}$ = inhalation slope factor of 3.1mg/kg/day

3.21 Ethical consideration

The issues of anonymity, confidentiality, and informed consent were taken into consideration in this study to avoid improper handling of data supplied by vendors.

As a result, the University of Cape Coast Institutional Review Board's ethical clearance, with the ethical clearance ID; UCCIRB/CANS/2019/08, was acquired. The guidelines of the ethical clearance were strictly followed by ensuring that questionnaires and spirometry results of vendors and controls were identified with an ID number, kept confidential and used solely for this research.

3.22 Statistical Analysis

Data gathered were interpreted through the use of analytical and logical reasoning to determine levels, patterns, relationships or trends.

Data on levels of outdoor air pollutants were analyzed using means and standard deviation on excel and were compared with World Health Organization (WHO) and the Ghana environmental protection agency (EPA-Ghana) recommended limits. The results were also compared with the results of other similar research to examine the agreements and trends.

Data on lung function were correlated with the level of pollutants including $PM_{2.5}$, O_3 and CO in air to determine patterns and relationships.

3.23 Chapter Summary

This chapter clarifies the basis for the research methodology and described study areas, sampling procedures as well as the method of analysis. It also discussed the data collection, data processing and risk assessment procedure of the research design. Finally, it points out the methodological weakness of the design.

CHAPTER FOUR

RESULT AND DISCUSSIONS

4.0 Introduction

This chapter presents and discusses the data on roadside air quality, spirometry, questionnaires completed by vendors and the control participants. These data were analyzed to identify and describe the relationship between roadside air quality and respiratory health characteristics of vendors at the arterial roads in the Cape Coast Metropolitan area. The data were obtained from vendors who sell their wares on tables or in stalls closely situated along the arterial roads. Vendors who consented to participate in the research were first given the questionnaires. This was followed by the measurement of levels of air pollutants (i.e. $PM_{2.5}$, CO, O_3) with an air quality monitor as well as $P.M_{2.5}$-bound PAHs through deposition on a Teflon sheet. The spirometry test was done during the period of measurement of air pollutants for each vendor. A total of One hundred and nineteen (119) participants which comprised of 66 vendors and 53 control participants agreed to be part of the study. Sixteen (16) out of the Sixty-six (66) vendors did not take part in the spirometry but completed the questionnaires. Of the fifty (50) vendors who took part in spirometry and questionnaire, five could not undergo spirometry after-shift. The number of vendors who went through all sections of the research (i.e., questionnaires, spirometry and air quality monitoring) were forty-five (45).

On the part of the controls recruited, three (3) completed questionnaires only, five completed questionnaires and pre-shift spirometry.

The total number of controls who went through all sections of the study were forty-five (45).

The data were analyzed in line with the research question (Chapter one).

4.1 Demographic Data

Demographic features of the research population, n = 45 for both control and vendors are displayed in the Table 2.

Table 2: Demographic Characteristics of Controls and Vendors

Variable	Control *N (%)*	Vendors *N (%)*
Gender		
Male	26 (57.8%)	32 (71.1%)
Female	19 (42.2%)	13 (28.9)
Average age, *years*	23.5 ±1.5	26.0 ±9.45
Average height, *cm*	170.8 ±7.3	169.2 ±7.5
Average weight, *kg*	64.2 ±11.4	64.4 ±12.4
Level of Education		
Tertiary	45 (100.0)	4 (8.89)
Senior High School	0 (0.0)	18 (40.0)
Junior High School	0 (0.0)	19 (42.2)
Primary	0 (0.0)	4 (8.89)
Alcohol use		
Yes	0 (0.00)	7 (15.56)
No	45 (100.0)	38 (84.44)
Smoking status		
Yes	1 (2.27)	0 (0.0)
NO	44 (97.78)	45 (100.0)

Source: Field survey, Ofori (2023).

From the demographic data, Table 2, both vendors and control group had higher percentages of males than females. i.e., 57.8 and 71.1 respectively. The mean age of the vendors and the control participants were 26.0 ± 9.45 and 23.5 ± 1.5 respectively. This is reflective of the age and sex structure observed in the Cape Coast metropolis in the 2010 census which states that there are more males between ages 20 – 29 than females (Livingbird & Sowah, 2014).

It also indicates that more male youth engage in roadside vending than females in Cape Coast metropolis, which may be due to the brisk and aggressive tactics employed by roadside vendors to maximize profit. Also, the kind of wares mostly sold by the roadside (dresses, shoes, hardware etc.) engages more men than women. The women mostly sell foodstuffs inside the market. The mean ages show that the vendors were older than the control participants.

All the control participants (100%) had attained tertiary education as compared to only 4 (8.89%) of the vendors. The educational level of the vendors was mostly JHS (42.22%) and SHS (40.00%). This agrees with the assertion that a lot of the road side vendors are youth who sell to support the family or are those engaged in the business as they wait to further their education (Beccles, 2014). There was no vendor among the participants who had never had a taste of formal education. None of the control participants drinks alcohol or smokes cigarette. On the part of the vendors, though none smokes, a few of them (15.56 %) drink alcohol.

4.2 Air Quality Monitoring

Levels of three widespread air pollutants in addition to ambient temperature and humidity were measured for vendors and control participants and the means are presented in the Table 3.

Table 3: Air Quality Assessment of the Environment of Controls and Vendors

Variable	Controls				Vendors				p-value	Air Quality Index
	Mean	SEM	Min	Max	Mean	SEM	Min	Max		
Temperature (°C)	25.53	0.35	21.98	30.53	33.61	0.59	23.73	40.15	0.0001	
Humidity (%)	54.28	0.93	46.35	68.34	84.22	0.82	70.88	99.60	0.0001	
$PM_{2.5}$ (µg/m^3)	49.51	1.59	39.27	78.57	70.78	2.68	41.11	111.74	0.000	180
CO (ppm)	8.12	0.46	4.87	12.14	20.89	1.53	2.61	44.00	0.000	174
O_3 (ppb)	3.17	0.19	1.12	4.68	93.26	4.210	12.25	124.28	0.000	169

Source: Field survey, Ofori (2023).

Table shows that there is a statistically significant difference in temperature and humidity of the vendors and the controls ($p<0.0001$). Also, the ambient air of the controls is significantly cleaner than that of the vendors ($p<0.000$).

SEM = Standard Error of mean, Min = Minimum value, Max = Maximum value

From the Table 3, the environment of the control participants recorded a significantly lower level of all the pollutants compared to that of the vendors ($p<0.05$). The temperature at the roadside ranged between 23.73 ºC to 40.15 ºC with a mean of 33.61ºC. This was significantly higher than that of the environment of the control participants which ranged between 21.98 ºC to 30.53 ºC having a mean of 25.53ºC. The mean temperatures of the control group compare well with the average daily temperature range of 24 °C to 30 °C which is characteristic of the southern part of Ghana (Owusu-Sekyere, Andoh, et al., 2011). However, the upper boundary temperature of the vendors slightly exceeds the average daily range. Warmer temperatures are associated reduced lung function with an impact magnitude comparable to that of traffic pollution. reduced peak expiratory flow and increased frequency of respiratory tract infection (Collaco et al., 2018; Kang, 2019). Mann *et al* 1993, posits that high ambient temperatures reduced peak expiratory flow and increased frequency of respiratory tract infection (Collaco et al., 2018; Mann et al., 1993).

The mean relative humidity for the vendors (84.22%) was within the relative humidity range (70% - 90%) characteristic of the Cape Coast Metropolis and the Southern sector of Ghana (Ghana Statistical Service, 2014b; Owusu-Sekyere, Alhassan, et al., 2011). That of the control group (54.28%) which was far lower than the relative humidity of the vendors was within the standard set by American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) (30% to 60%) for indoors of tropical regions (Koranteng et al., 2011; McDowall, 2007). A control group with different environmental conditions was selected so that the effects of different environment could be determined. Most areas along the arterial roads need the appropriate level of humidity to achieve conditions that are conducive for human health and comfort.

4.3 Particulate Matter (P.$M_{2.5}$)

The level of P.$M_{2.5}$ varied between 41.11 µg/m^3 and 111.74 µg/m^3 for vendors as against 39.27 µg/m^3 and 78.57 µg/m^3 for the controls. The mean total $PM_{2.5}$ for the control environment was 49.51±1.59 whiles that of the vendors was 69.21 µg/m^3. The mean total for $PM_{2.5}$ along the arterial roads was significantly higher than the WHO standard for 24 hours of 25 µg/m^3 as well as the Ghana EPA standard of 35 µg/m^3 ($p<0.000$) (Kleiman, 2021; WHO, 2006). Even though the P.$M_{2.5}$ levels measured were higher than the WHO and the Ghana EPA standards, they are quite lower than the levels recorded in some major cities Accra and Kumasi which recorded levels above 70µg/m^3 (Kleiman, 2021). The levels of $PM_{2.5}$ along the arterial roads suggest that vendors could have some respiratory health impacts such as respiratory tract infection, chronic obstructive pulmonary disease and asthma (Chen et al., 2023a, 2023b).

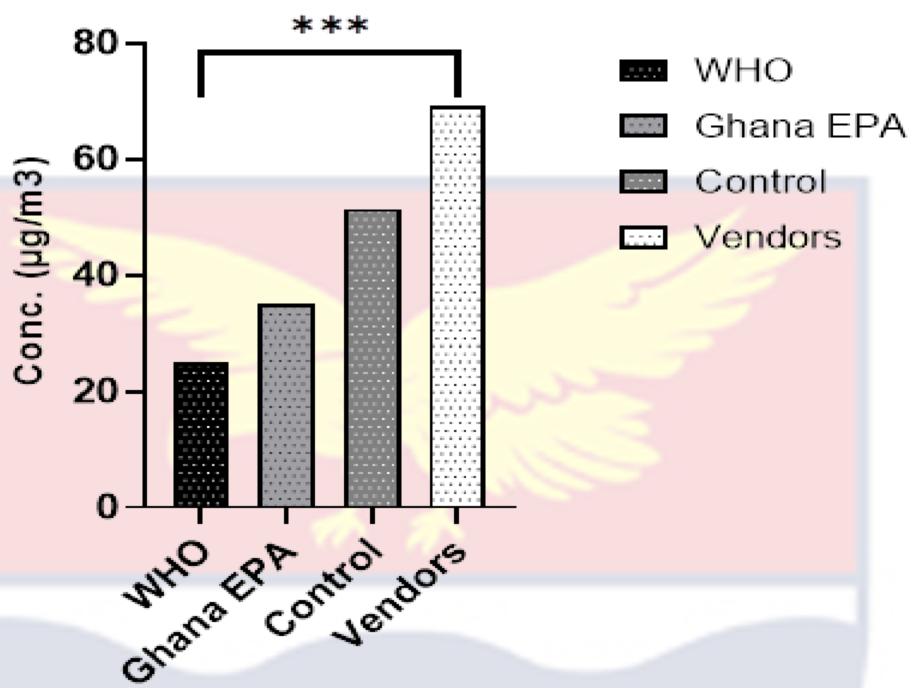

Figure 8: Comparison of mean $PM_{2.5}$ among WHO, EPA, Controls and Vendors

Results show that the mean $PM_{2.5}$ was higher for controls and vendors as compared to WHO and Ghana EPA standards.

4.4 Carbon Monoxide (CO)

The level of CO recorded at the surrounding of vendors in this study ranged from 2.61 ppm to 44.00 ppm with a mean total of 20.89±1.53 ppm while that of the controls was between 4.87 ppm and 12.14 ppm with a mean total of 8.12 ppm. The CO concentration at the roadside far exceeds that of the control sites. Comparing the roadside CO concentration with similar studies in some major cities in the country, the mean concentration of this study exceeds the CO concentration in Kumasi (5.26 ppm – 7.96 ppm) but it is lower than that of Accra which ranged from 7 ppm to 55 ppm, (Dionisio et al., 2010; Uka et al., 2019). Internationally, the mean CO concentration is higher than that of Lahore, Pakistan

(4ppm) but lower than Rumuola junction, Nigeria (150ppm), Osisioma-Aba, Abia State, Nigeria (6.18 ppm – 94.30ppm) (Agbozu et al., 2015; Kho et al., 2007; Otuu & Shu, 2018).

With regards to international recommended level, different organizations including American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), National Institute for Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration (OSHA), have set different limits but the agreement is that, over an 8-hour period, the permitted indoor safe level of carbon monoxide is 9 ppm. This is same as the WHO and USEPA recommended limits. In comparing the CO levels of this study with the 9 ppm, the mean concentrations of both vendors and the control site are lower. Meanwhile, the upper boundary CO concentration of the vendors (11.95 ppm) exceeded the 9ppm recommended by the WHO and the USEPA (Emmanuel, 2013; Levy, 2015; USEPA, 2000). CO is capable of combing with blood haemoglobin to form carboxy-haemoglobin in humans. Haemoglobin has a 200–250-fold greater affinity for carbon monoxide than for oxygen. This interferes with the oxygen-carrying capacity of blood and results in respiratory infections, chronic obstructive lung disease, asthma together with heart-related conditions such as high blood pressure. The levels of CO combined with $PM_{2.5}$ are likely to contribute to increased adverse respiratory health outcomes in vendors.

4.5 Topographical Ozone (O_3)

The levels of topographical ozone for both vendors and the controls are presented in Table 3. Mean concentrations of 93.95 ppb and 3.36 ppb were recorded at the roadside and control environment respectively. The mean ozone concentration was significantly higher at the roadside compared to the control environment ($p < 0.05$).

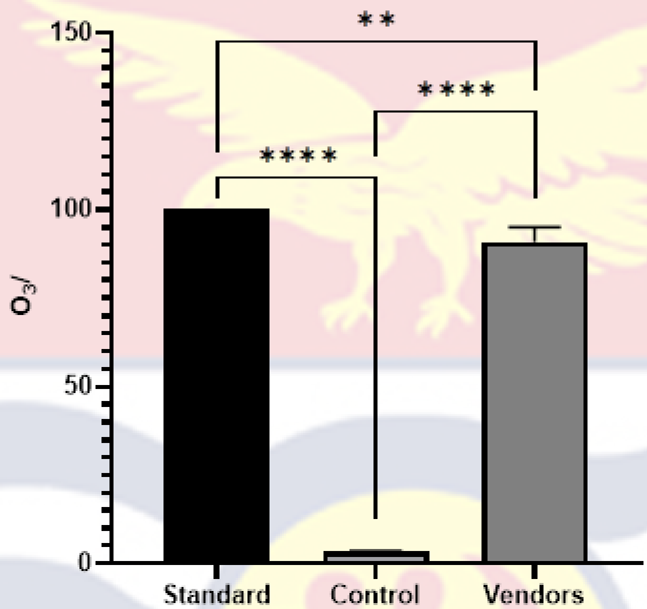

Figure 9: Comparison of mean ozone concentration of Vendors**** = p<0.0000

The significantly higher mean ozone (O_3) concentration at the roadside was suspected to be caused by the warm or hot temperature at the roadside which favours the formation of the ozone as well as the emission of precursor molecule NO_X from vehicles (Coates et al., 2016; Zhang & Stevenson, 2022). In comparison with recommended standards, the ozone concentration for vendors in this study far exceeded the WHO's threshold of 100 μgm^{-3} (50 ppb) and the USEPA threshold of 70 ppb (Kobza et al., 2021; WHO, 2006). The roadside ozone concentration in this study (12.25 ppb - 124.28 ppb) also exceeds that of Ranchi, (Jharkhand, India) 233. 23.45 μgm^{-3} to 126.66 μgm^{-3} (same as 11.94 ppb to 64.52 ppb). But lower than the National ozone concentration of China 124.1 ±

27.5 - 333.4 ± 13.0 ppm (Zhan et al., 2018). This indicates that roadside vendors are exposed to ozone concentrations that is capable of causing nausea to sensitive persons, shortness of breath, lung inflammation and reduced lung function (C. S. Kim et al., 2011).

Additionally, Air Quality Index value for all pollutants was calculated for the Metropolis using the USEPA's method. The worst sub-index was 180 with the critical pollutant being Particulate matter ($P.M_{2.5}$) (Emmanuel, 2013; USEPA, 2000). The air quality index (AQI) determined corresponds with the "Unhealthy category". The cautionary measures associated with the unhealthy category are that people with sensitive health conditions, the elderly, children, and people with lung or heart disease should avoid outdoor physical activities, move physical activities indoors or postpone to times when air quality is good. All other persons (especially vendors) should reduce protracted or heavy exertion (Great Britain. Committee on the Medical Effects of Air Pollutants. et al., 2011; Salvador & Salvador, 2012).

Table 4: Lung Function Before and After Shift of Controls and Vendors

Lung Function Parameters		Controls N = 45				Vendors N = 45				*p-value*
		Mean	SD	Min	Max	Mean	SD	Min	Max	
FVC	Before	3.216	0.71	2.1	4.8	3.131	0.91	1.1	5.2	0.634
	After	3.227	0.74	2.0	4.9	3.004	0.95	1.2	5.6	0.207
	Difference	-0.011	-0.03	0.1	-0.1	0.127	-0.04	-0.1	-0.4	
	p-value	0.848				0.032*				
FEV_1	Before	2.893	0.63	1.9	4.7	2.724	0.77	1.1	4.2	0.259
	After	2.842	0.61	1.8	4.5	2.614	0.76	1.2	4.2	0.123
	Difference	0.051	0.02	0.1	0.2	0.11	0.01	-0.1	0.0	
	p-value	0.185				0.011*				
FEV1/FVC Ratio (%)	Before	90.387	8.237	66.4	100.0	88.379	10.39	62.5	100.0	0.306
	After	89.040	11.017	50.3	100.0	88.245	12.15	58.0	100.0	0.747
	Difference	1.347	-2.78	16.1	0.0	0.134	-1.76	4.5	0.0	
	p-value	0.197				0.932				
PEF (l/s)	Before	6.880	1.583	3.8	10.3	5.562	1.94	2.6	9.5	0.001**
	After	6.499	1.842	3.0	10.2	5.130	1.93	1.7	9.1	0.001**
	Difference	0.381	-0.259	0.8	0.1	0.432	0.01	0.9	0.4	
	p-value	0.046*				0.000*				

Across the two groups (controls and vendors) there was no significant difference in the lung function parameters except the PEF where the controls performed significantly better than the vendors ($p<0.01$). Source: Field survey, Ofori (2023)

4.6 Forced vital capacity (FVC)

Force vital capacity refers to the total volume of air a participant can exhale for the entire duration of the test during maximal effort or the volume of air exhaled rapidly and vigorously following a deep inhalation. Lower FVC values may be a sign of more severe stages of Chronic Obstructive Pulmonary Disease (COPD).

From Table 4, the mean pre-shift value of the vendors was significantly higher than the mean post-shift value ($p < 0.05$) suggesting that lung performance of the vendors has been compromised during their shift period at the roadside. However, there was no significant difference between the pre-shift and post-shift values for the control group ($p > 0.050$). Also, there was no significant differences between the pre and post shift FVC values for both vendors and the control group.

4.7 Forced Expiratory Volume in one second (FEV_1)

This is the total volume of air a participant is able to exhale in the first second during maximal effort. FEV_1 values that are lower than average, suggest the presence of Chronic Obstructive Pulmonary Disease (COPD) or another condition that is causing breathing difficulties.

Table 4 presents the FEV_1 values for the vendors and the controls in the study. No significant difference was observed in the mean FEV_1 values before and after shift for vendors and controls ($p > 0.05$). Again, no significant difference is observed in the pre-shift and post-shift values for the control group ($p < 0,005$). However, there is a significant reduction in vendors' FEV_1 values before and after-shift and reduced FEV1 values among the vendors is an indication that they are experiencing a breathing obstruction or developing Chronic Obstructive Pulmonary Disease (COPD).

4.8 FEV_1/FVC Ratio

The FEV_1/FVC ratio indicates the percentage of an individual's vital capacity that they can exhale in the first second of forced expiration (FEV_1) to the entire forced vital capacity (FVC). The FEV_1/FVC ratio is used in predicting Chronic airflow limitation (CAL) i.e. obstructive or restrictive defects. The normal range for the FEV_1/FVC ratio is 0.7(70%) to 0.8(80%). Values below 0.7(70%) indicate airway obstruction, except in older adults where values 0.65 (65%) – 0.7(70%) may be normal.

The mean FEV_1/FVC ratio presented in Table 4 shows no significant difference in pre-shift and post-shift ratios for both vendors and the control group ($p>0.05$). However, the mean FEV_1/FVC ratios of the vendors was lower than that of the control group. This suggests that higher levels of air pollutants at the roadside is causing obstructive lung conditions to the vendors. Comparing the range of FEV_1/FVC values for vendors (62.5 – 100) and the controls (66.4 – 100), reveals that some of the vendor as well as the controls have ratios that are lower than the standard lower threshold value of 70%.

4.9 Peak Expiration Flow (PEF)

Peak expiratory flow (PEF) is the amount of air that is quickly and forcibly ejected from the lungs or it is the highest flow rate produced during a vigorous breath out. It is an effective indicator of airflow obstruction and ventilation adequacy of an individual. Low PEF values may mean respiratory airways are narrowing.

From Table 4, both vendors and controls recorded significantly lower post-shift mean PEF values than the pre-shift values ($p<0.05$). However, the mean PEF value (pre-and post-shift) for the control group is significantly higher than that of the vendors ($p<0.05$). Vendors also recorded lower range of PEF values than the control group. This again points to the likelihood of more vendors developing obstructive lung defects than the controls or vendor experiencing more severe obstructive lung diseases than the controls.

4.10 Normal and Abnormal Lung Function

The result of the spirometry test (FVC, FEV1 and FEV1/FVC ratio) were fit onto Timothy and Irene's algorithm for interpreting spirometry test results (see Appendix B) and the outcome is presented in the Figure 10.

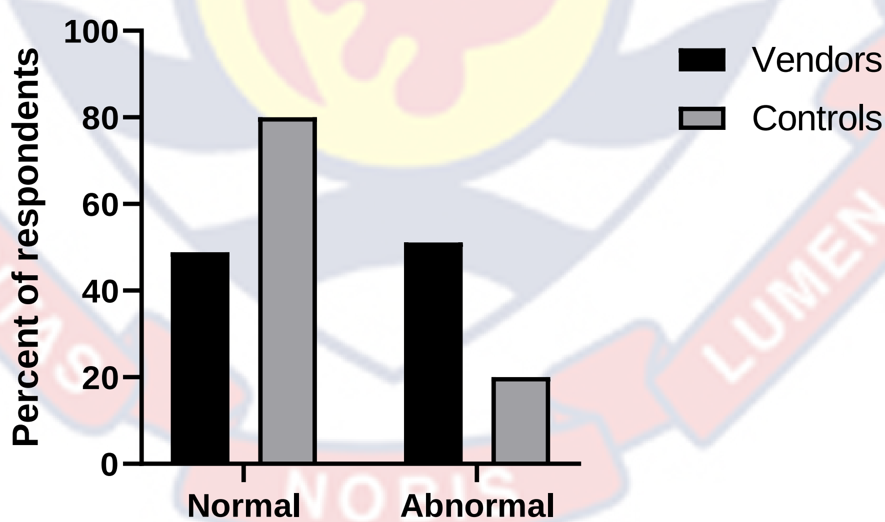

Figure 10: Percentage of respondents having normal and abnormal spirometry

The result show that after shift, there was a 3-fold increase in the percentage of participants that recorded abnormal lung function among the vendors than the controls. The Chi-square test was used to determine whether the association between the variables is statistically significant. The outcome of the lung function was dependent on the category of the (chi-square test of independence, x^2 =8.316, df = 1, p = 0.0039). The p – value was < the significance level. Therefore, at a significance level of 0.05, there is a statistically significant association between the variables.

4.11 Vendors' perception of exposure to air pollution along the road

Table 5 shows the result of vendors' awareness of exposure to air pollutant by the roadside.

Most of the vendors (91.10%) reported that they are exposed to air pollutants by the arterial roadside as against 24.4% of the control participants. The commonly reported pollutants were vehicular emissions (82.1%), dust (55.4%) and bad odour from nearby gutters (26.6%). Consequently, about 66.7% of the vendors rated the air quality along the arterial roads as being worse than the air quality at their residence (Much worse: 28.9 % and a little worse: 37.8%). On the other hand, 91.1% of the control participants rated the air quality at their workplace (offices) as better than the air quality along the arterial roads.

Table 5: Vendor's awareness of air pollution compared with Controls

Variables	Controls		Vendors	
	No	%	No	%
How long have you been working along the roadside?				
<6 months	45	100.0	0	0.0
6 – 11 months	0	0.0	15	33.3
1 – 2 years	0	0.0	12	26.7
3 – 4 years	0	0.0	18	40.0
5 – 6 years	0	0.0	0	0.0
7 – 8 years	0	0.0	0	0.0
9 years and above	0	0.0	0	0.0
Are you exposed to any air pollutants?				
Yes	11	24.4	41	91.1
No	34	75.6	4	8.9
What kind of air pollutants are you exposed to?				
Dust	4	8.9	2	4.4
Vehicular emissions	1	2.2	13	28.9
Smoke	4	8.9	0	0.0
Dust and Vehicular emissions	2	4.4	11	24.4
Dust, vehicular emissions and gutter scent	0	0.0	11	24.4
Dust, vehicular emissions & cigarette smoke	0	0.0	1	2.2
Vehicular emissions & gutter scent	0	0.0	1	2.2
No pollutant	34	75.6	6	13.3

Source: Field survey, Ofori (2023)

Table 5 Continue

Variable	Control		Vendors	
	No	%	No	%
How would you rate the overall air quality?				
Much better	30	66.7	4	8.9
A little better	11	24.4	7	15.9
Much worse	1	2.2	13	28.9
About the same	0	0.0	4	8.9
A little worse	3	6.7	17	37.8
Which of these factors do you think contributes the greatest amount of air pollution?				
Vehicle exhaust	43	95.6	43	95.6
Charcoal burning	1	2.2	1	2.2
Biomass burning	1	2.2	0	0.0
Household cooking	0	0.0	1	2.2
Construction sites dust	0	0.0	0	0.0
Industrial emissions	0	0.0	0	0.0
Smoking of cigarettes	0	0.0	0	0.0
Do you think heavy-emission vehicles should be prohibited from plying the Cape Coast roads?				
Yes	32	71.1	32	71.1
No	13	28.9	13	28.9

Table shows that both vendors and controls are aware of high levels of air pollution at the roadside. Source: Field survey, Ofori (2023)

About 95 3% of both vendors and control participants perceived that Vehicular emission as the major source of air pollution in the metropolis. 71.1%

each of vendors and control participants think that heavy emission vehicles should be prohibited from plying the Cape Coast roads.

4.12 Vendors' Perception of Effect of Air Pollution along the Road

Table 6 displays vendors' awareness of the effect(s) that air pollution at the roadside has on their respiratory health. A lot of the vendors (68.9%) indicated that air pollution has affected them or their colleagues on one or more occasions as against 15.6% of the control participants. Again, most of the vendors (82.2%) as well as the control participants (93.3%) perceived that respiratory diseases are related to air pollution. The first reason given to support the above assertion was that air pollutants especially vehicular emissions have a bad or unnatural or irritating smell. A good number of the vendors (20.0%) and some control participants (15.6%) are of the view that the bad or unnatural smell which irritates the nostrils, is not wholesome for the human body and is likely to have negative effect(s) on the respiratory system. This is just an assumption and is not backed by any literature. The second reason was that air pollutants block the respiratory tract. Lots of the control participants (40.0%) as against 17.8% of vendors gave this reason to explain the effect of air pollution. Few of the respondents (Controls 6.7%; Vendors 2.2%) also stated that air pollutants can cause lung cancer. This reason is also supported by some literature.

However, a greater percentage of both control (35.6%) and vendors (48.9%) did not answer this question. On the whole, it is evident that the control participants are much aware of the effect of air pollutants than the vendors. This is because a greater percentage of the controls gave answers that are backed by literature (Block respiratory tract 40.0%, carcinogenic 6.7%, total 46.7%) than vendors (Block respiratory tract 17.8% carcinogenic 2.2%; total 20.0%) who either had no idea or gave answers that were not backed by literature. Also, a lot both vendors and the controls stated that they do not do or put on anything to protect themselves from any harm that may be associated with air pollution. This also confirms that generally, people do not perceive air pollution to be harmful.

Table 6: Vendors' awareness of the effect of air pollution along the road

Variables	Controls		Vendors	
	No	%	No	%
Has air pollution affected you/ a colleague's health?				
Yes	7	15.6	31	68.9
No	38	84.4	14	31.1
Do you think respiratory diseases may be related to air pollution?				
Yes	42	93.3	37	82.2
No	3	6.7	8	17.8
Reason				
Has bad/irritating/unnatural smell	7	15.6	9	20.0
Block respiratory tract	18	40.0	8	17.8
Weakens immune system	0	0.0	3	6.7
Can cause lung cancer	3	6.7	1	2.2
Major pollutant activity	1	2.2	2	4.4
No idea	16	35.6	22	48.9
Do you put on anything to protect yourself from any harm that may be associated with air pollution?				
Yes	0.0	0.0	0	0.0
No	45	100.0	45	100.0
During a hazy condition, do you build up your immunity with foods rich in vitamin C or other supplements?				
Yes	23	51.1	0	0.0
No	22	48.9	45	100.0

Air pollution affect vendors more than the controls but controls have better knowledge of the impacts of air pollution than vendor.
Source: Field survey: (2023).

4.13 Effects of Pollution

The effects of air pollution were put into two categories. Namely physical or respiratory health effects and Behavioral or Psychological effects.

4.13.1 Physical/Respiratory health effects

These include the change in health conditions that participants observed upon exposure to air pollutants.

Table 7 shows the prevalence of respiratory symptoms experienced by the vendors and control within the last few months prior to the interview.

The respiratory health symptoms vendors reported significantly higher prevalence of than the control group. A significant number (82%) of vendors reported that they experienced sneezing, runny nose, dry throat and eye irritation (i.e. Always-33%; Often-11.1%; Sometimes-37.8%) as against 40% of the control. Approximately half (45%) of the vendors stated that they experienced shortness of breath or reduced lung function whiles only (20%) of the controls reported same. Vendors who reported of coughing or wheezing totaled (66.6%) as against 53.3% of the control group who reported coughing or wheezing. None of the vendors as well as the control group reported that they experience sleep deprivation or reduced energy level. Again, none of the vendors or control group reported that they have been diagnosed of asthma during the last three months.

Table 7: Physical/ Health effects of Air Pollution

Variables	Controls		Vendors	
	No	%	No	%
What are some air pollution effects that you experience?				
Breathlessness	24	53.3	33	73.3
Feeling depressed	1	2.2	2	4.4
Irritation to eyes/nose/throat	9	20.0	8	17.8
Skin problems	1	2.2	0	0.0
The urge to move to less polluted areas	10	22.2	2	4.4
Asthma indices	0	0.0	0	0.0
Poor visibility	0	0.0	0	0.0
How often do you experience sneezing, runny nose, dry throat and eye irritation?				
Always	0	0.0	15	33.3
Often	0	0.0	5	11.1
Sometimes	18	40.0	17	37.8
Rarely	22	48.9	6	13.3
Never	5	11.1	2	4.4
How often do you experience shortness of breath/reduced lung function?				
Always	0	0.0	15	33.3
Often	0	0.0	3	6.7
Sometimes	9	20.0	5	11.1
Rarely	17	37.8	17	37.8
Never	19	42.2	8	17.8
How often do you cough or wheeze?				
Always	0	0.0	1	2.2
Often	1	2.2	18	40.0
Sometimes	23	51.1	11	24.4
Rarely	19	42.2	11	24.4
Never	2	4.4	4	8.9
Is your cough accompanied with sputum?				
Yes	12	26.7	7	15.5
No	33	73.4	38	84.4

Source: Field survey, Ofori (2023).

Table 7: Continues

Variables	Controls No	%	Vendors No	%
How often do you get headaches and dizziness?				
Always	0	0.0	2	4.4
Often	6	13.3	5	11.1
Sometimes	20	44.4	18	40.0
Rarely	18	40.0	16	35.6
Never	1	2.2	4	8.9
How often do you experience reduced energy levels?				
Always	0	0.0	2	4.4
Often	0	6.7	4	8.9
Sometimes	0	37.8	8	17.8
Rarely	42	48.9	24	53.3
Never	3	6.7	7	15.6
How often do you experience sleep deprivation/ insomnia				
Always	1	2.2	15	33.3
Often	3	6.7	5	11.1
Sometimes	10	22.2	2	4.4
Rarely	18	40.0	12	26.7
Never	13	28.9	11	24.4
Have you been diagnosed of asthma?				
Yes	0	0.0	0	0.0
No	45	100.0	45	100.0

Table shows vendors reporting higher frequency of respiratory symptoms than the control group. Always: at all times or Daily Often: Weekly
Sometimes: Monthly Rarely: Not regular Never: Not observed
Source: Field survey, Ofori (2023).

4.13.2 Behavioural/Psychological Effects.

Behavioural effects include temporary or permanent change in an individual's behaviour when compared to previous behavior especially pertaining to the function of awareness, feeling or motivation. Examples are depression, frustration, aggression changes in mood, cognition, and behavior etc.

Table 8: Behavioural effects of Air pollution

Variables	Controls		Vendors	
	No	%	No	%
Do you feel depressed/ unpleasant at certain times/seasons such as during hazy weather?				
Yes	11	24.4	4	8.9
No	34	75.6	41	91.1
Does haze affect your routine exercise (running/jogging faster for a short time)				
Yes	14	31.1	16	35.6
No	31	68.9	29	64.4
Does haze affect your routine walking speed?				
Yes	13	28.9	15	33.3
No	32	71.1	30	66.7
Do you feel anxiety or frustration?				
Yes	10	22.2	26	57.8
No	35	77.8	19	42.2

Result indicates that vendor experienced more behavioural symptoms than the controls
Source: Field survey, Ofori (2023).

From the result (Table 8), most of the vendors (>50%) as well as the controls (>50%) did not report any symptom of behavioural effect. Among those who reported symptoms of behavioural effects, the vendors were slightly more than the control group, except for those who experienced depression/unpleasant feeling where the control group exceeded the vendors. The percentage of those vendors experienced depression/unpleasant feeling are 8.9% as against 24.4% of control group. In contrast to the above, more vendors experienced anxiety/frustration (57.8%) than the control group (22.2%). Again, more vendors reported that haze affect their routine exercise or walking than the control group.

This suggest that though vendors may be experiencing behavioural changes, the aggressive nature of their work prevent them from feeling depressed/unpleasant feeling.

4.14 Correlation between Air Pollutants and Lung Function Parameters among Controls and Vendors

Table 9 displays the correlation between air pollutants and lung function parameters. It shows that among the controls there was no significant correlation between $PM_{2.5}$ and the four lung function parameters (FVC, FEV_1,). However, among the vendors, significant weak negative correlation was observed between $PM_{2.5}$ and the lung function parameters (FVC, FEV_1 and PEF) i.e. ($p<0.05$) Implications: There was no correlation between the $PM_{2.5}$ and FEV_1/FVC ratio. No significant correlation was observed between CO and the lung function parameters in both controls and vendors. However, a significant weak positive correlation was observed between CO and PEF among the controls. A significant weak positive correlation was observed between O_3 and the lung function parameters (FVC, FEV_1, and PEF) among the controls. No significant correlation was observed between O_3 and FEV_1/FVC ratio in the controls. Among the vendors, there was no significant correlation between O_3 and the lung function parameters (FVC, FEV_1, FEV_1/FVC, and PEF).

Table 9: Correlation between Air Pollutants and Lung Function Parameters among Controls and Vendors

	FVC (L) (n=45)		FEV_1 (L) (n=45)		FEV_1/FVC (%) (n=45)		PEF(L/min) (n=45)	
	R	*P*value	R	*P*value	R	*P*value	R	*P*value
$PM_{2.5}$								
Control	-0.150	0.325	-0.173	0.257	-0.013	0.929	-0.109	0.475
Vendor	-0.332	0.026*	-0.349	0.019*	-0.121	0.428	-0.360	0.015*
CO								
Control	0.166	0.277	0.211	0.165	0.066	0.666	0.341	0.022*
Vendor	0.045	0.777	0.081	0.598	0.081	0.596	0.016	0.919
O_3								
Control	0.387	0.009**	0.375	0.011*	-0.073	0.632	0.345	0.021*
Vendor	0.104	0.497	0.069	0.655	-0.069	0.649	-0.137	0.369

r: Correlation coefficient, *significant at $P<0.05$, **significant at $P<0.01$

A weak negative correlation was observed between $PM_{2.5}$ and the lung function parameters. With respect to CO a weak correlation was seen for CO and PEF only. O_3 displayed significant positive correlation with lung function parameters except for FEV1/FVC ration which was negative. Source: Field survey, Ofori (2023).

$PM_{2.5}$ in both control and vendor environment significantly higher than the WHO and Ghana EPA standard $PM_{2.5}$. However measured $PM_{2.5}$ was higher in the vendors than the controls.

4.15 PAHs in roadside dust

The concentration of 18 roadside dust-bound PAHs were examined because vendors reported daily exposure to high levels of dust. Seven (7) of these PAHs were not detected at any of the sample site. These were Phenanthrene, Benzo(a)anthracene, Dibenz[a,h]anthracene, Chrysene, Benzo[b]fluoranthene, Pyrelene, and Indeno(1,2,3,c,d)pyrene. Acenaphthene and Acenaphthylene were present at one site only (Abura and Siwdo respectively). PAHs determined in the samples were in the µg/Kg levels. The mean concentration of PAHs detected in roadside dust at the various sample sites are displayed in the table below:

Table 10: Mean Concentration of PAHs

PAH	Abura	Adisadel	Kotokoraba	Pedu	Siwdo	∑PAH	%PAH
Naphthalene	55.70±9.39	48.95±16.26	27.94±12.25	11.74±3.91	89.08±23.60	233.41	6.10
Acenaphthylene	ND	ND	ND	ND	1.35±0.48	1.35	0.04
Acenaphthene	1.90± 0.15	ND	ND	ND	ND	1.90	0.05
Fluorene	49.48±9.58	37.79±7.77	38.38±15.46	133.33±55.92	162.84±59.44	411.82	10.76
Phenanthrene	ND	ND	ND	ND	ND	0.00	0.00
Anthracene	ND	0.86±0.43	ND	12.13±2.38	ND	12.99	0.34
Fluoranthene	93.92±24.33	125.23±6.62	25.92±3.13	86.02±8.64	35.13±4.62	366.22	9.57
Pyrene	89.77±4.05	120.99 ±5.57	38.68±13.54	108.85±50.22	43.73±58.57	402.02	10.51
Benzo(a)anthracene	ND	ND	ND	ND	ND	0.00	0.00
Chrysene	ND	ND	ND	ND	ND	0.00	0.00
Benzo(a)pyrene	6.07±2.28	4.11±1.33	11.51±1.62	28.15±8.09	33.21±14.43	83.05	2.17
Benzo(e)pyrene	20.02±5.29	32.18±6.28	32.96±3.56	60.11±36.04	108.93±25.83	254.20	6.64
Benzo[k]fluoranthene	249.40±14.16	139.38±2.35	91.62±8.44	116.19±13.24	416.12±17.89	1012.70	26.46

Table displays mean ± standard deviation of the concentration of PAHs at the various sites

Table 10 Continue

PAH	Abura	Adisaddel	Kotokoraba	Pedu	Siwdu	∑ PAH	% PAH
Benzo[b]fluoranthene	ND	ND	ND	ND	ND	0.00	0.00
Pyrelene	ND	ND	ND	ND	ND	0.00	0.00
Dibenz[a,h]anthracene	ND	ND	ND	ND	ND	0.00	0.00
Benzo[g,h,i]perylene	79.83±4.58	58.39	116.89±21.49	224.37±74.79	567.68±4.58	1047.20	27.36
Indeno(1,2,3,c,d)pyrene	ND	ND	ND	ND	ND	0.00	0.00
∑PAH	646.08	557.88	383.90	780.89	1458.07	3826.80	100.00
%PAH	16.88	14.58	10.03	20.41	38.10	100	
∑LMW PAH	107.08	76.74	66.32	145.07	253.27	661.48	
%LMW PAH	2.80	2.01	1.73	3.79	6.62	16.95	
∑HMWPAH	539.00	481.14	317.58	635.82	1204.80	3144.40	
%HMW PAH	14.08	12.57	8.30	16.61	31.48	83.05	
∑C7PAH	255.47	143.49	103.13	144.34	449.33	1095.76	
%∑C7PAH	6.68	3.75	2.69	3.77	11.74	28.63	

ND: Not Detected. HMW PAH; PAH: total PAH; %LMW: Percentage levels of low molecular weight PAH; %HMW PAH: Percentage levels of high molecular weight PAH.
Source: Field survey, Ofori (2023).

The mean PAH at all sites ranged from 0.86 µg/kg for Anthracene to 567.68 µg/kg for Benzo [g,h,I]perylene. Comparatively, almost the same kind of PAHs were detected at all the areas. Also, the proportional contribution of the individual PAH compounds to the total PAHs concentrations in roadside dust of the various areas were nearly similar. This similarity in contribution of the individual PAH compounds indicates that the study areas do share similar emission source(s). The dominant PAHs detected were the high molecular weight PAHs with Benzo[k]fluoranthene recording the highest concentration among all PAHs detected. The total concentration of high molecular weight PAHs and low molecular weight PAHs were 82.62% and 17.38% respectively. This is comparable to similar research in Jeddah, Saudi Arabia where high molecular weight PAHs in street dust constituted 83.38% of total PAHs (Ali et al., 2016). The dominance of the high molecular weight PAHs may be due to the fact that lower molecular PAHs which are more volatile, existed more in the gaseous state than being adsorbed to dust particles. It may also be due to the process producing the PAH as Wolska *et al*, 2012 observed that combustion of fossil fuels and its products, produces four or more-rings PAHs (High molecular weight PAHs) than the two or three-rings PAH (lower molecular weight PAHs) (Wolska et al., 2012). Pyrene was detected at all sample sites in this study with relatively high concentration. The total mean concentration of pyrene was 381.02 (10.01%) and this is in agreement with McClean's postulate that the percentage concentration of pyrene is usually between 2-10 % of total PAHs in all PAH mixture (McClean et al., 2012).

The mean concentration of Benzo[a]pyrene, a well-known carcinogenic PAHs in this study ranged between 4.11 µg/kg at Adisadel and 33.21 µg/kg at Siwdo. The total concentration of the seven (7) leading carcinogenic PAHs in the mixture was 1095.76µg/kg (28.63 %) which is quite significant.

The mean concentration of total PAH at the different areas ranged from 376.90 µg/kg at Kotokoraba to 1458.07 µg/kg at Siwdo. The differences in PAHs concentrations in the roadside dust among the different areas of the Cape Coast Metropolis may be due to difference in traffic density, and type of activities carried out on the land (i.e., Commercial or residential) (Anh et al., 2019; Cao et al., 2017). The PAHs concentrations are comparable to similar reported studies such as the concentration of dust-bound PAHs in Bushehr, Iran (1116 µg/kg), Mahshahr, Iran (769.60 µg/kg), Bangalore, India (1100 µg/kg), New Delhi, India (1100 µg/kg), Bangkok, Thailand (1100 µg/kg), Niteroi, Brazil (434–1247 µg/kg) and Lahore, Pakistan (120–1000 µg/kg) (Najmeddin et al., 2018; Shabbaj et al., 2018).

However, the levels are lower than those found in roadside dust of Hanoi, Vietnam (1900 µg/kg), Jeddah (3320 µg/kg), Beijing, China (3700 µg/kg), Guangzhou, China (4800 µg/kg), Xuzhou, China (6616 µg/kg), Xi'an, China (15767 µg/kg), Dalian, China (7460 µg/kg), Birmingham, UK (12,560–93,700 µg/kg) and Pasadena, USA (58,680 µg/kg) (Shabbaj et al., 2018). These are developed cities, thus variation in PAH concentration may be due to differences in traffic congestion, scope of human activities associated with development and local meteorological conditions such as rains which can remove the contaminants from roadside dust.

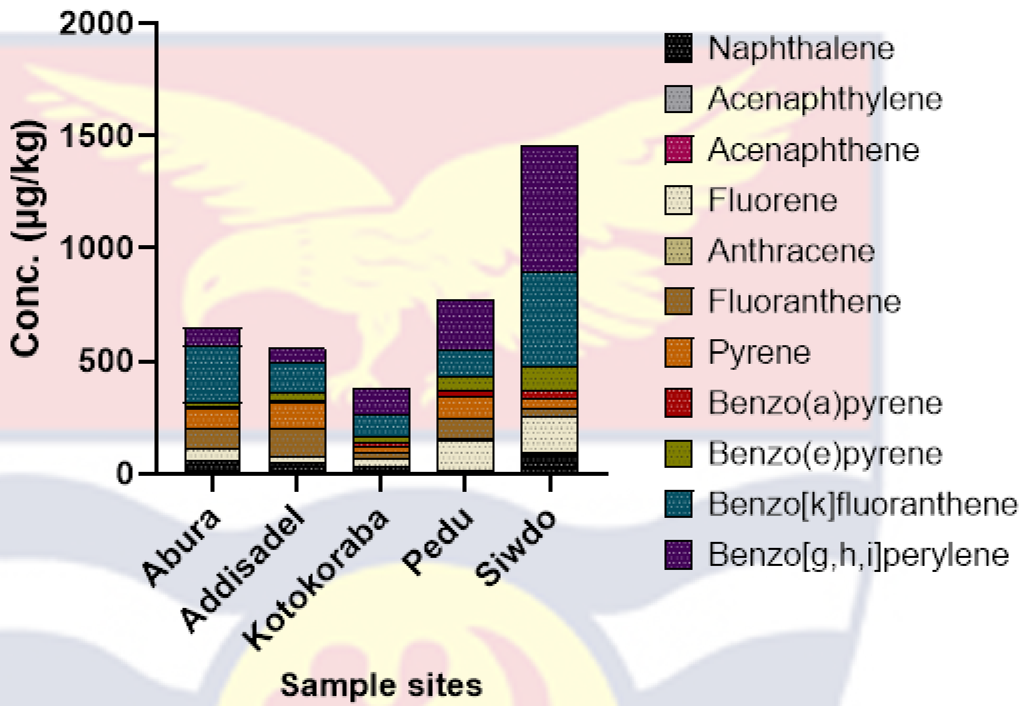

Figure 11: Distribution of PAHs at the various sample site

Comparing PAH pollution levels at the various suburbs of the Metropolis, Siwdo recorded the highest mean concentration of total PAHs (1458.07 µg/kg) while Kotokoraba had the lowest (376.90 µg/kg). The highest mean concentration of individual PAHs (567.68 µg/kg) was as well recorded at Siwdo but the lowest (0.86 µg/kg) was recorded at Adisadel. The descending order of mean concentration of total PAH was Siwdo > Pedu > Abura > Adisadel > Kotokoraba. The high PAHs pollution levels at Siwdo may be jointly due to PAHs from vehicular emission and leaks of petroleum products adsorbed to dust particles from the Siwdo mechanical Shop (the biggest and the most patronized mechanical shop in the Cape Coast Metropolis). Pedu which recorded the second highest

PAH pollution level is where the biggest traffic light in the Metropolis is situated. Abura and Kotokoraba which recorded the next highest level of PAH pollution, host the two busiest markets in the Metropolis. These markets enjoy an average level of regular traffic jam during the day resulting increased levels of vehicular emissions but Kotokoraba seem to be less dusty than Abura hence Abura recorded higher level of dust-bound PAHs than Kotokoraba. Adisadel which had the least level of PAHs is more of a residential area. It links Siwdo and Pedu (the biggest traffic light) and has virtually low or no traffic light jams even though the road is somewhat busy.

4.16 Incremental Lifetime Cancer Risk

The total cancer risk for vendors exposed to PAHs in roadside dust evaluated as the sum of ILCR values through the inhalation, ingestion and dermal pathways i.e. (Total cancer risk = $\sum$ [ILCR (inhalation) + ILCR (ingestion) + ILCR (dermal)]

Table 11: Cancer Risk Factor.

PAH	TEF	Abura	Adisadel	Kotokoraba	Pedu	Siwdo
Naphthalene	0.001	0.06	0.05	0.03	0.01	0.09
Acenaphthylene	0.001	0.00	0.00	0.00	0.00	0.00
Acenaphthene	0.001	0.00	0.00	0.00	0.00	0.00
Fluorene	0.001	0.05	0.03	0.04	0.13	0.16
Phenanthrene	0.001	0.00	0.00	0.00	0.00	0.00
Anthracene	0.01	0.00	0.01	0.00	0.12	0.00
Fluoranthene	0.001	0.09	0.13	0.03	0.09	0.04
Pyrene	0.001	0.09	0.12	0.03	0.10	0.04
Benzo(a)anthracene	0.1	0.00	0.00	0.00	0.00	0.00
Chrysene	0.01	0.00	0.00	0.00	0.00	0.00
Benzo(a)pyrene	1	6.07	4.11	11.51	28.15	33.21
Benzo[k]fluoranthene	0.1	24.94	13.94	9.16	11.62	41.61
Benzo[b]fluoranthene	0.1	0.00	0.00	0.00	0.00	0.00
Dibenz[a,h]anthracene	1	0.00	0.00	0.00	0.00	0.00
Benzo[g,h,i]perylene	0.01	3.68	0.58	1.17	2.24	2.80
Indeno(1,2,3,c,d)pyrene	0.01	0.00	0.00	0.00	0.00	0.00
	CSF	34.98	18.96	21.96	42.46	77.95

Source: Field survey, Ofori (2023)

Table 12: Estimated Total Cancer Risk

Adults	Inhalation	Dermal	Ingestion	Cancer risk
Abura	9.70E-12	2.22E-07	1.25E-07	3.47E-07
Adisadel	5.26E-12	1.20E-07	6.78E-08	1.88E-07
Kotokoraba	6.09E-12	1.39E-07	7.85E-08	2.18E-07
Pedu	1.18E-11	2.69E-07	1.52E-07	4.21E-07
Siwdo	2.16E-11	4.95E-07	2.79E-07	7.74E-07

Source: Field survey, Ofori (2023).

The total cancer risk for the five suburbs of the Metropolis ranged between 1.88×10^{-07} at Adisadel and 7.74×10^{-07} at Siwdo. The sequential order of the cancer risk, in decreasing order was Siwdo > Pedu > Abura > Kotokoraba > Adisadel. The evaluated Incremental Lifetime Cancer Risk (ILCR) based on exposure to PAHs concentration in the roadside dusts were below 10^{-6} indicating a virtual safety situation from cancer. The low carcinogenicity of PAHs in the roadside dust may be linked to the low concentration (28.63%) of the major carcinogenic PAHs (Table 10). The result also revealed that both dermal contact and oral ingestion pathways contributed significantly to the total cancer risk for the vendors. The BaP-equivalence values (Table 13) indicate that Benzo[k]fluoranthene contributed the highest risk followed by Benzo[a]pyrene.

Table 13: Toxicity Equivalence Factor

PAH	TEF	Abura	Adisadel	Kotokoraba	Pedu	Siwdo	∑BaPeq	%BaPeq
Benzo(a)anthracene	0.1	0	0	0	0	0	0.00	0.00
Benzo(a)pyrene	1	6.07	4.11	11.51	28.15	33.21	83.05	89.13
Benzo[k]fluoranthene	0.01	2.494	1.3938	0.9162	1.1619	4.1612	10.13	10.87
Benzo[b]fluoranthene	0.1	0	0	0	0	0	0.00	0.00
Dibenz[a,h]anthracene	1	0	0	0	0	0	0.00	0.00
Indeno(1,2,3,c,d)pyrene	0.1	0	0	0	0	0	0.00	0.00
Chrysene	0.001	0	0	0	0	0	0.00	0.00
	TEQ	8.564	5.5038	12.4262	29.3119	37.3712		
	BaPeq Dose	0.00268	0.00172	0.00389	0.00918	0.01170		
	Cancer risk	8.3E-06	5.3E-06	1.2E-05	2.8E-05	3.6E-05		

Source: Field survey, Ofori, (2023).

This model estimates the number of persons among a sample who are likely to develop cancer from exposure to PAHs during their lifetime of seventy (70) years. The calculated cancer risk by this model ranged from $5.3x10^{-6}$ at Adisadel to $3.6x10^{-5}$ at Siwdo. This suggest that, based on the mean PAH concentration at the various sites, five out of one million vendors at Adisadel, eight out of one million vendors at Abura, one out of hundred thousand vendors at Kotokoraba, two out of one hundred thousand vendors at Pedu and three out of one hundred thousand vendors at Siwdo are likely to suffer from cancer in their lifetime. The cancer risk of Abura, Adisadel and Kotokoraba fall below the upper boundary unit risk guideline of $1x10^{-5}$ and are in agreement with the ILCR values of the USEPA. However, the risk levels of Pedu and Siwdo are slightly higher than the upper boundary unit risk guideline.

4.17 Diagnostic Ratio

Ratios of specific PAHs such as Anth/(Anth+Phen), BaA/(BaA+Chr), IP/(IP+BghiP) and Flu/(Flu+Pyr) are usually used to identify the source of PAHs (Stogiannidis & Laane, 2015).

The use of Ant/(Ant+Phen) ratio as a marker for source identification was not possible because Phenanthrene was not detected in any of the samples in this study. Both IP and BghiP were not detected in the samples, likewise BaA and CHR. Thus, the application of BaA/(BaA+Chr) and IP/(IP+BghiP) ratios were also not feasible.

The FLu/(Flu+Pyr) ratio which is robust to changes during haze transfer and degradation in the environment was the only reliable ratio suitable to assess the emission sources. This ratio often appreciated very well because it covers the gaseous as well as the particle transported PAHs. For this ratio, values less than 0.4 implies a petroleum source, values between 0.4 and 0.5 indicates a liquid fossil fuel combustion source, whiles values above 0.5 represent biomass and coal combustion. The low molecular weight PAHs/high molecular weight PAHs ratio was also used to confirm the above.

Table 14: PAH Diagnostic ratio

Sample site	Flu	Pyr	Flu/(Flu+Pyr)	LMW	HMW	LMW/HMW
Abura	93.92	89.77	0.51	107.08	539.00	0.20
Adisadel	125.23	120.99	0.51	76.74	481.14	0.16
Kotokoraba	25.92	38.68	0.40	66.32	317.58	0.21
Pedu	86.02	108.85	0.44	145.07	635.82	0.23
Siwdo	35.13	43.73	0.45	253.27	1204.48	0.21

Table shows combustion of liquid fossil fuel as the major source of PAHs at Kotokoraba, Pedu and Siwdo. Flu: Fluoranthene, Pyr: Pyrene LMW: Low Molecular weight PAHs; HMW: High Molecular weight PAHs
Source: Field survey, Ofori (2023).

The results for the LMW/HMW ratio for the sample sites range from 0.16 for Adisadel to 0.23 for Pedu. and 0.21 indicating pyrogenic sources for all sites (LMW/HMW ratio < 1). The application of the Flu / (Flu + Pyr) ratio to PAH concentrations gave results which ranged between 0.40 and 0.51. The ratios obtained at Kotokoraba, Pedu and Siwdo were 0.40, 0.44 and 0.45 respectively. These indicate the presence of liquid fossil fuel combustion (Vehicular emission sources). The ratios at Abura and Adisadel were both 0.51 which characterizes the production of PAHs form biomass burning. Adisadel is somewhat a residential area with less commercial or industrial activities, unlike Siwdo, Pedu and Kotokoraba. The major road there is not very busy compared to major roads at Abura, Pedu and Kotokoraba. On the other Abura faces a regular traffic jam at the market but the market is still surrounded by residential houses where PAHs may be produced through cooking with firewood and similar sources of fire. There is also a palm kennel-production site situated about 1 km form the market where lot of biomasses burning occurs. It therefore implies that even though Abura and Adisadel experience some vehicular traffic, there are also significant emissions of PAHs from biomass burning or long-range transfer of PAHs (Lammel et al., 2015; Samburova et al., 2019).

4.18 Chapter summary

The data on the level of roadside air pollutants, spirometry and questionnaires completed by vendors and controls have been presented and discussed. The comparison of the environmental data of vendors and controls showed that the control group had a cleaner environment than roadside vendors. The relationship between air pollution levels and respiratory health characteristics of vendors, vendors perception on air pollution, Finally, the levels of PAH congeners adsorbed to dust particles at the roadside and the associated cancer risk in addition to source characterization of the PAHs have all been presented and discussed.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.0 Overview

This research titled impacts of vehicular emissions and dust on the respiratory health of roadside vendors sought investigated the effect(s) of vehicular emissions and roadside dust on the lung performance of vendors who sell their wares along selected arterial roads in the Cape Coast metropolis and in addition, determined vendor's perception of vehicular emissions and the associated health conditions. This issue arose because vendors, in order to meet more customers and maximize profit, set up stalls along the roadsides which exposes them.

The introductory chapter (Chapter one) gave a concise description of the issue of Air Quality along the roadside, and associated health effects as well as the research questions, purpose, significance and scope of the study. Chapter two presented the review of relevant literature on air pollution around the world and in Ghana as well as the related health effects, Chapter three provides the research design and describes how the data essential to addressing the research objectives and questions were collected, presented and analyzed. Chapter four focuses on the presentation and discussion of the result.

Whiles the chapter five of the thesis presents the conclusions made from the analysis of the result, the recommendations and suggestions for further research.

5.1 Summary

The findings of this study are summarized in line with the research questions as follows:

- The mean temperature and relative humidity at the roadside were found to be 30.98 ºC and 44.60% respectively.
- With regards to the pollutants, mean $PM_{2.5}$ concentration was 69.21 µg/m^3, mean CO was 8.52 ppm and mean topographical ozone concentration was 93.95 ppb.
- Also, $PM_{2.5}$-bound PAHs were determined and the mean concentration for the various PAHs ranged from 0.86 µg/kg for anthracene to 567.68 µg/kg for benzo[g,h,i]perylene.
- The result of PAH diagnostic ratios ranged between 0.40 and 0.51. These indicate that liquid fossil fuel combustion (Vehicular emission sources) and biomass burning are the major sources of PAHs along the road.
- The pollutant levels at the roadside were significantly higher than that of the environment. $PM_{2.5}$ and CO levels exceeded WHO-recommended levels.
- The result revealed that vendor's lung function parameters (FVC, FEV_1, and PEF) before were significantly higher ($p<0.05$) than after-shift. There was however, no observable significant difference in lung function parameters of the control group.
- Vendors also reported a high (82%) prevalence of respiratory symptoms such as sneezing, runny nose, dry throat and eye irritation.

- Most vendors indicated their awareness of air pollution along the roadside. The commonly reported pollutants were vehicular emissions, dust, and scent from nearby gutters.
- A greater percentage of the vendors regarded the air along the arterial roads as being worse than the air quality at their residence, thus, suggesting that heavy-emission vehicles should be prohibited from plying the Cape Coast roads.
- Vendors' knowledge of the impacts of the air pollutants on human health were mostly mere speculations, thus most vendors did not do anything to protect themselves.
- The data revealed that there was no significant correlation between $PM_{2.5}$ and the four lung function parameters (FVC, FEV_1, FEV_1/FVC, and PEF) for the control group. However, among the vendors, a significant weak positive correlation was observed.
- No significant correlation was observed between CO and the lung function parameters in both controls and vendors.
- However, a significant weak positive correlation was observed between CO and PEF among the controls. A significant weak positive correlation was observed between O_3 and the lung function parameters (FVC, FEV_1, and PEF) among the controls. No significant correlation was observed between O_3 and FEV_1/FVC ratio in the controls. Among the vendors, there was no significant correlation between O_3 and the lung function parameters (FVC, FEV_1, FEV_1/FVC, and PEF).

5.2 Conclusions

From the study, it can be concluded that:

Roadside vendors were exposed to high levels of air pollutants which exceeded the WHO and USEPA recommended limits. It was observed that the mean lung function parameters of vendors were lower than that of the control. The difference in pre-shift and post-shift spirometry values for the vendors were also high indicating that the lung function parameters of the vendor reduced more during the period at the roadside. There was a weak positive correlation between particulate pollutants levels at the roadside and the lung function parameters. The vendors reported quite significant higher prevalence of respiratory symptoms, probably due to $PM_{2.5}$ exposure. However, the vendors were aware of the exposure to air pollutants at the roadside but have very little knowledge of the health impact hence they do not make any efforts to protect themselves from the pollutants. Again, source characterization of $PM_{2.5}$-bound PAHs revealed that vehicular emission contributed significantly to the presence of these pollutants at the roadside followed by biomass burning. The evaluated Incremental Lifetime Cancer Risk (ILCR) associated with exposure to PAHs in the roadside dust were below 10^{-6} indicating a virtual safety condition The carcinogenic risk decreased in the order of; Siwdo > Pedu > Abura > Kotokoraba > Adisadel.

5.3 Recommendations

Based on the findings of this study, it is recommended that:

- Government should increase its surveillance and law enforcement activities on the importation and use of over aged vehicles which pose human health and environmental hazards.
- The Environmental Protection Agency should establish a unit for atmospheric research where trends in the emission of air pollutants into the atmosphere and other atmospheric studies could be monitored.
- There should be sensitization programmes and Health promotion campaigns for street vendors to increase their knowledge of work-related illness, risk behaviors as well as the necessity of wearing personal protective equipment (PPE).
- There is the need to adopt a modernized town planning system that reduces the generation of excess dust to help minimized exposure levels in our communities.
- Again, vendors should be educated on the hazards and risks associated with regular exposures to vehicular emission and harmful roadside particulate.

5.4 Suggestion for further research

There should be further research on the impact of roadside air pollution on children in schools that are closely situated on arterial roads in the Cape Coast Metropolis.

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APPENDICES

Appendix A

Sample Questionnaire

UNIVERSITY OF CAPE COAST

DEPARTMENT OF CHEMISTRY

QUESTIONNAIRE

This study is purely for academic purposes and it is aimed at **Investigating the Perception and Health Effects of Vehicular Emission on Roadside Retailers in the Cape Coast Metropolis.**

Instructions

Please tick the box ☑ appropriate response.

If make a mistake, circle the wrong response ☑ and tick the right response ☑

A. Biodata

Date: ___________________________

Respondent's ID: ____________________

Age: ___________________________

Suburb/Area: _______________________

Sex (M/F): ______________________

Weight/ Height: _____________________

B. Retailer's awareness and perceptions of air pollution

1. How long have you been working along the roadside?

Less than six months ☐

3 to 4 years ☐

9 years and above ☐

5. to 11 months ☐

6. 5 to 6 years ☐

1 to 2years ☐

7 to 8 years ☐

2. Are you exposed to any air pollutant?

Yes ☐ No ☐

3. What kind of air pollutant are you exposed to?

____

4. How would you rate the overall air quality along the road as compared to other places far away from the road?

Much better ☐ A little better ☐

Much worse ☐ About the same ☐

A little worse ☐

5. In your view, has air pollution (or vehicular emissions) along the road ever affected you or colleague retailer's health?

Always ☐ Often ☐ Sometimes ☐

Rarely ☐ Never ☐

6. To what extent is the air pollution affecting you?

Very much affected ☐

A little Affected ☐

Not affected at all ☐

7. What are some of the effects of air pollution that you experience?

Breathlessness/having more difficulty in breathing ☐

Feeling depressed ☐

Irritation to eyes/nose/throat ☐

Skin problems ☐

Wanting to move to other less polluted place ☐

Asthma incidences ☐

Poor visibility ☐

Other (please specify) ______________________________________

8. Do you think respiratory diseases (such as lung cancer, bronchitis/asthma) and heart diseases may be related to air pollution in Ghana?

Yes ☐ No ☐

Reason:____

____

____

____

9. Do you or colleague vendors put on anything (such as nose mask, eye-glasses or goggles) to protect yourselves from any harm that may be associated with air pollution?

   Yes ☐ No ☐

10. Do you think heavy emission vehicles should be prohibited from plying the Cape Coast roads?

   Yes ☐ No ☐

C. <u>Effects of Air Pollution</u>

Physical/Health effects		***Always***	***Often***	***Sometimes***	***Rarely***	***Never***
11.	Do you find yourself inhaling the air pollutant(s)?					
12.	How often do you experience sneezing, runny nose, dry throat and eye irritation?					
13.	How often do you experience shortness of breath/reduced lung function?					
14.	How often do you cough or wheeze?					
15.	Is your cough accompanied with sputum?					
16.	How often do you get headaches and dizziness?					
17.	How often do you experience reduced energy levels?					
18.	How often do you experience sleep deprivation or sleeping disorders such as insomnia?					
Behavioral and psychological effects		***Yes:***		***No:***		
19.	Do you feel depressed or unpleasant at certain times or seasons such as during hazy					

	climate?		
20.	Does haze affect your routine exercise i.e.: running or jogging faster and for a short time?		
21.	Does haze affect your routine walking speed, i.e. walking faster?		
22.	Do you feel anxiety or frustration?		
Others		***Yes:***	***No:***
23.	During haze, do you build up your immunity with foods rich in vitamin C (oranges, guava, strawberries), vitamin E (nuts and seeds) and omega-3 fatty acids (oily fish) or other supplements?		
24.	Have you been diagnosed of asthma?		
25.	Which of these factors do you think contributes the greatest amount of haze pollution? Circle the three issues that concern you the most. Please only circle three issues from the list: (a) Vehicles exhaust (b) Coal burning (c) Biomass burning (d) Household cooking and heating (e) Construction sites dust (f) Industrial emission (g) Smoking of cigarettes (h) Other …………………		

D. Lifestyle

26. Do you smoke?

Yes ☐ No ☐

27. If yes, for how long? ____________________

28. Do you drink alcohol?

Yes ☐ No ☐

29. If yes, for how long? ____________________

Appendix B

Timothy and Irene's Algorithm for Interpreting Spirometry Result